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Christopher Schlick
Stefan Trzcieliński *Editors*

Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future

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Preface

Contemporary manufacturing enterprises aim to deliver a great number of consumer products and systems through friendly and satisfying working environments for people who are involved in manufacturing services. Human-centered design factors, which strongly affect manufacturing processes, as well as the potential end-users are crucial for achieving continuous progress in this respect. Researchers around the world attempt to improve the quality of consumer products and working environments. This book presents the results of their work. We believe that such findings can either inspire or support others in the field of manufacturing to advance their designs and implement them into practice. Therefore, this book is addressed to both researchers and practitioners.

The papers presented in this book have been arranged into four sections. The first section covers a variety of topics that refer to human-centered organizations. This section starts with a general viewpoint of socio-technical systems, including organizational innovativeness and enterprise agility, followed by issues related to designing human-centered production systems. Such systems take into consideration workforce diversity, high-wage countries, work-related occupational safety, work environment factors, ICT, and demographic features. The last thematic part of this section is focused on assembly planning and production inventories management. The second section of the book presents the effects of applied ergonomics in manufacturing and work studies concerning the improvement of human skills, as well as the quality and effectiveness of workforce. The presented chapters depict the influence of worker experience and the technology used to improve work effectiveness. Next, the comparison of non-expert and expert work is studied to find patterns that can be used to improve the technique of performing different tasks by less skilled employees. The third section deals with outcomes ergonomics have on industrial quality and safety, while the fourth and final section of this book is focused on ergonomic design of future production systems.

The contents of this book required the dedicated effort of many people. We would like to thank the authors, whose research and development efforts are published here. Finally, we also wish to thank the following Editorial Board members for their diligence and expertise in selecting and reviewing the presented papers:

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Part I
Human Aspects in Composite Manufacturing and Product Evaluation

Study on Light Diffusion of Creped Silk Inserted GFRP

Erika Suzuki, Tetsuo Kikuchi, Kiyoshi Fujiwara, Mamoru Saito,
Yuka Takai and Yuqiu Yang

Abstract This research put the focus on fabricating the GFRP that inserted silk cloth (silk inserted GFRP) and developing the GFRP lighting materials. Now, the luminance diffusion of silk inserted GFRP is better than that of only GFRP have been reported. However, the light diffusion is not clear. In this study, the aim is to clear the light diffusion property of silk inserted GFRP by measuring haze. Furthermore, silk inserted GFRP's surface structure was measured to investigate relationship between the light diffusion and surface shape.

Keywords Haze measurement · Light diffusion · Silk insert molded · GFRP · Hand lay-up

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1 Introduction

Use of glass fiber reinforced plastics (GFRP) as lighting materials has spread. For example, exterior as the roof material of the housing terrace or the carport, interior material as the bathroom door and the indoor partition window. GFRP lighting materials has been said for appearance—a glass pattern appears—to be bad although physical properties, such as mechanical strength, are good. This problem was solved in pattern printing to the surface of the GFRP board with transcriptional molding technique. The ratio of the parallel light/diffusion light of the transmitted light of the GFRP board was shifted to the diffusion light side. From this technique, the glass pattern disappeared by the difference in the refractive index of resin and glass. As a result, the panel which does not have visibility at the same time it lets light pass was realized.

On the other hand, LED lighting has the high directivity of light and it is difficult to illuminate all the directions like a filament lamp. As one of the solution for this problem, it is thought that GFRP lighting materials with high light diffusion can be diverted to the housing of LED lighting.

In this research, the hand lay-up method was focused as one of the decoration molding techniques for the GFRP lighting materials. The hand lay-up method can be more developed in the market of the GFRP lighting material because type of form and reinforced material are free to be selected in this method. Therefore, this research aimed to clearly the light transmission property of the GFRP inserted the *Kyo Yu-zen* fabric with crape. The cross section structure and haze of silk inserted FRP samples were analyzed.

Previous researches on the embossed or grained GFRP can be referred for GFRP inserted the *Kyo Yu-zen* fabric with crape [1, 2]. Light transmission property and luminance of the FRP have been analyzed [3–5], there are less researches aimed to develop the GFRP lighting materials. Whereat, this research is significant for the development of the GFRP lighting materials.

2 Experimental Methods

2.1 Materials

An unsaturated polyester resin with no additives was used as the matrix resin. Glass mats (#230, #450) were used as reinforcing material. Inserted silk cloth in GFRP layer is the cloth which generally used for *Kimono*. In this research, we used the cloth which has crape. This cloth is called *Yo-ryu*. Crape is an irregularity to emerge on the surface of the textile by twisting yarn. Inserted silk cloth is not dyed and solid white color. Figure 1 shows silk cloth which we used.

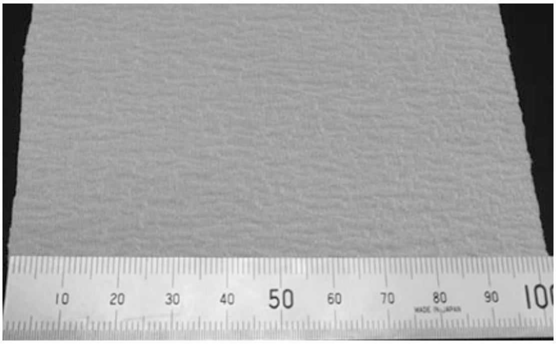


Fig. 1 Silk cloth

2.2 Fabrication

GFRP and Silk inserted GFRP samples were manufactured by skillful craftsman. The samples were molded by hand lay-up method. The size of the sample was 300 mm × 300 mm. GFRP samples which have three types thickness and silk inserted GFRP which have each one, two, three sheet are molded. Samples were cured at room temperature for an hour.

Table 1 shows GFRP layer thickness and the number of insert silk cloth of samples, Fig. 2 shows laminated configuration of samples and Fig. 3 shows picture of samples. Two types GFRP 1 mm samples were fabricated, one is laminated two #230 glass mat layers, the other is laminated a #450 glass mat layer. GFRP 4 mm sample is laminated four #450 glass mat layers, and GFRP 7 mm samples are laminated seven #450 glass mat layers. All silk inserted GFRP is laminated two #230 glass mat layers. Silk inserted GFRP which have a silk cloth laminated silk cloth in the third layer. Silk inserted GFRP which have two silk cloths laminated silk cloth in the first and fourth layer. Silk inserted FRP which have three silk cloths laminated silk cloth in the first, third and fifth layer.

Table 1 Thickness of FRP and the number of insert silk

Sample	FRP thickness [mm]	Number of insert silk cloth [sheet]
GFRP 1 mm (use #230 × 2)	1	0
GFRP 1 mm (use #450 × 1)	1	0
GFRP 4 mm (use #450)	4	0
GFRP 7 mm (use #450)	7	0
GFRP 1 mm + silk 1 sheet (use #230)	1	1
GFRP 1 mm + silk 2 sheets (use #230)	1	2
GFRP 1 mm + silk 3 sheets (use #230)	1	3

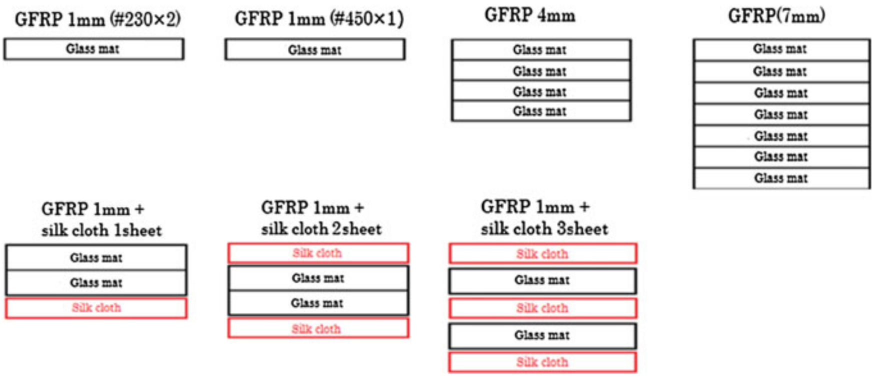


Fig. 2 Laminated configuration

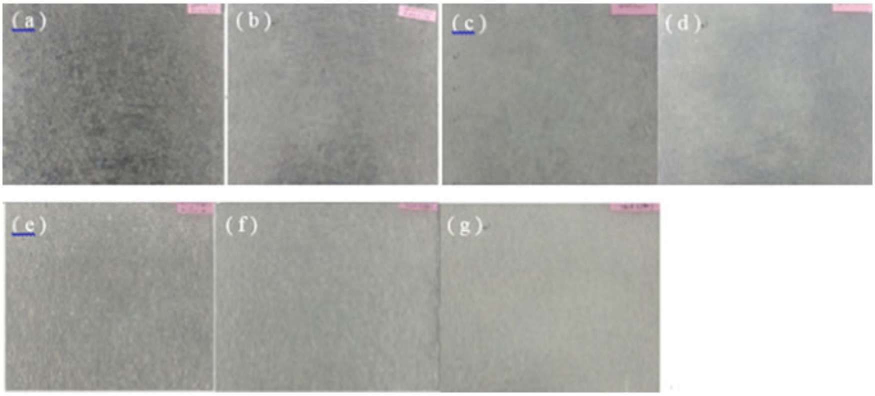


Fig. 3 Photo of samples. **a** GFRP 1 mm (#230 × 2), **b** FRP 1 mm (#450 × 1), **c** FRP 4 mm, **d** FRP 7 mm, **e** GFRP 1 mm +silk 1 sheet, **f** GFRP 1 mm + silk 2 sheets, **g** GFRP 1 mm + silk sheets

2.3 Measurements

Haze Measurement. In order to reveal light diffusion property of GFRP and silk inserted FRP, haze was measured. Haze measurement carried out according to JIS K 7136 and 7361-1. NDH400 (Nippon Denshoku Industries Co., LTD.) was used. From haze meter, parallel light transmittance and light diffusion can measure. By measuring these properties, total light transmittance and haze ware calculated by the following formula.

$$\text{Total light transmittance} = \text{parallel light transmittance} + \text{scattering transmittance} \tag{1}$$

$$\text{Haze} = \text{scattering transmittance/total light transmittance} \times 100 \quad (2)$$

Surface Structure. The surface structure of silk cloth was measured by using non-contact three-dimensional measuring device (VR-3100, KEYENCE Corporation). The surface structure of GFRP and silk inserted GFRP were measured by using contact three-dimensional measuring device (Form Talysurf PGI 1200, Taylor Hobson Ltd).

3 Results

3.1 Haze Measurements

Total light transmittance of GFRP is shown in Fig. 4. Total light transmittance of GFRP 4 and 7 mm is lower than GFRP 1 mm. The haze of GFRP is shown in Fig. 5. The haze of GFRP increases in order of GFRP 1, 4 and 7 mm, GFRP 4 and 7 mm show almost the same values. Furthermore total light transmittance and the haze of GFRP 1 mm change by laminating configuration.

Fig. 4 Total light transmittance of GFRP

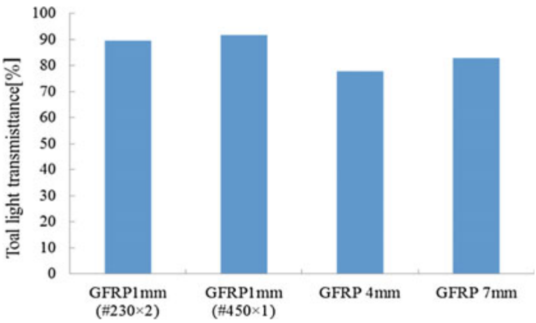
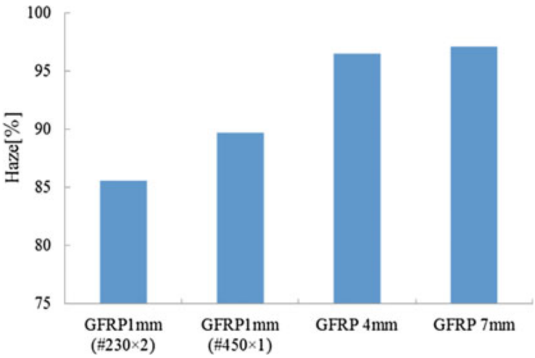


Fig. 5 Haze of GFRP



Total light transmittance of silk inserted GFRP is shown in Fig. 6. Total light transmittance of silk inserted GFRP decreases with the increase of the silk sheets. The haze of silk inserted GFRP is shown in Fig. 7. The haze of silk inserted GFRP which have 1 sheet have high haze value than GFRP. By increasing the number of silk cloth, the haze of silk inserted GFRP increase. However, in case of the number of inserting silk cloth is 2, and 3 sheets, the increment of the haze is small.

3.2 Surface Structure

Arithmetic average roughness (Pa) of samples are shown in Fig. 8. Arithmetic average roughness is the depth of mean value of the unevenness. Arithmetic average roughness of silk inserted GFRP is three times larger than that of GFRP. In addition, the number of insert silk cloth of silk inserted GFRP and surface irregularity structure do not have the association.

Fig. 6 Total light transmittance of silk inserted GFRP

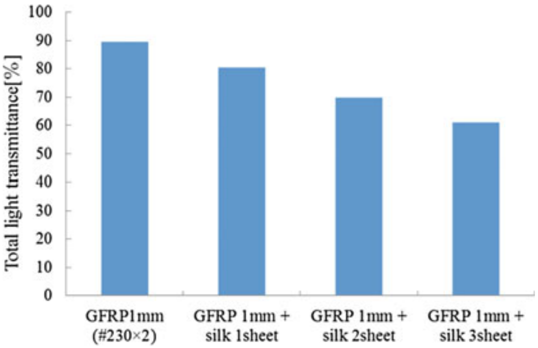
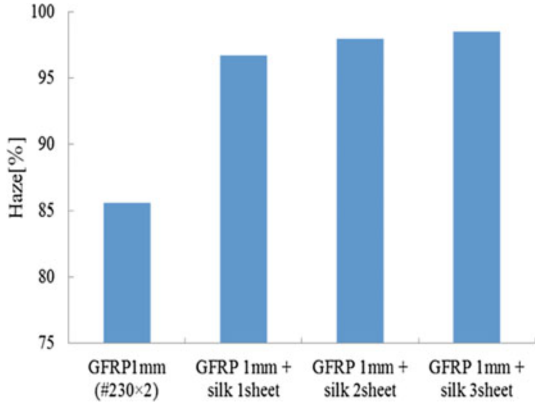


Fig. 7 Haze of silk inserted GFRP



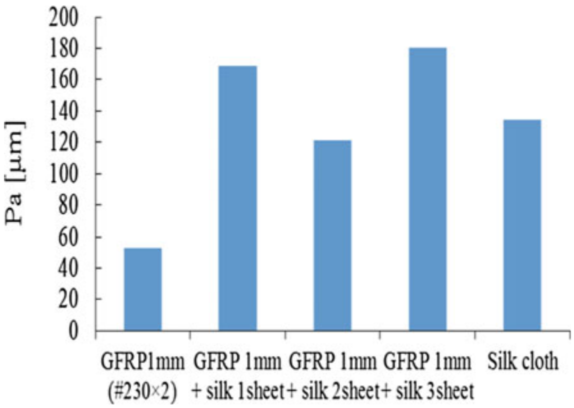


Fig. 8 Results of structure measurement (Pa)

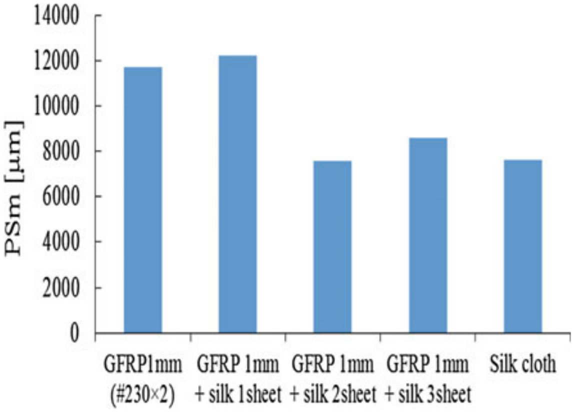


Fig. 9 Results of structure measurement (PSm)

Average length (PSm) of samples are shown in Fig. 9. Average length is an average value of the unevenness of the intervals. GFRP and silk inserted GFRP which have a silk sheet show the biggest average length of all. Silk inserted GFRP which have two and three silk sheets and silk cloth of average length is almost the same value.

4 Discussion

It is desirable that total light transmittance and haze have high value, because it is intended to creation of materials that produces soft light without reducing the amount of light in this research.

The relationship between total light transmittance and haze of GFRP and silk inserted GFRP are shown in Figs. 10 and 11.

Fig. 10 Relationship between total light transmittance and haze (GFRP)

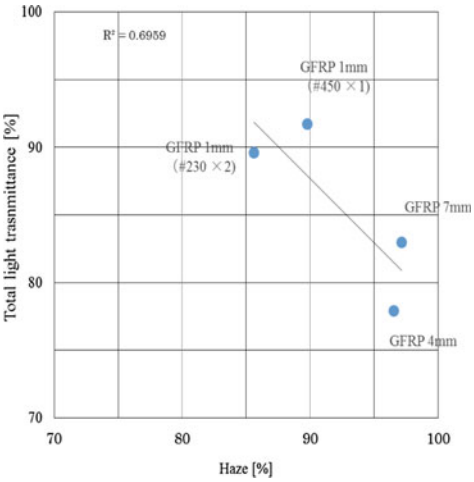
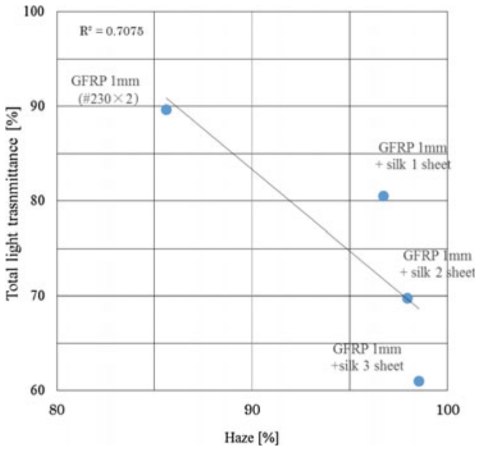


Fig. 11 Relationship between total light transmittance and haze (GFRP and GFRP + Silk)



From Fig. 10, Comparing GFRP 1 and 4 mm, GFRP thickness increase, it is seems that the total light transmittance is significantly reduced, and haze is increases greatly.

However, comparing GFRP 4 and 7 mm, GFRP thickness decrease, haze is almost no change. This is due to increase the thickness of the GFRP layer, the amount of glass fiber increases, therefore the percentage of incident light is reflected or absorbed increase by glass fiber. As a result, it is thought that total light transmittance decreased because transmittance light reduces by diffused reflection.

From Fig. 11, total light transmittance of silk inserted GFRP decreases with increasing the number of insert silk, haze increases. However, it is seemed that increase width of haze is small.

In addition, for increasing the number of insert silk, decline of total light transmittance is greater than the range of decrease of the total light transmittance for the thickness increase of the GFRP, therefore it is considered that silk fabric have an effect of reflecting or absorbing the source light than glass fiber.

From the above contents, factors relating to the transmittance and haze of the light include the following three points.

1. The number of insert silk cloth and increase the number of silk cloth.
2. Increase the number of glass mat layer.
3. Surface structure.

In addition, it is thought that there three points give an impact the light transmittance and haze, the influence degree is 1, 2, and 3 in descending order.

5 Conclusion

This research put the focus on light diffusion property of silk inserted GFRP, and measure haze and surface structure. Because the haze of silk inserted GFRP is higher than GFRP, it is clear that silk inserted GFRP have an effect of light diffusion. In addition, it is considered that factors relating to the transmittance and haze of the light are the number of insert silk cloth and increase the number of silk cloth, increase the number of glass mat layer, and surface structure in descending order of effect.

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Research and Development of Robots with Advanced Skills in Hand Lay-Up

Tetsuo Kikuchi and Erika Suzuki

Abstract Hand lay-up fabrication is a form of craftsmanship and an implicit skill supported by individual sense, and subjective implicit values deep-rooted in expertise and judgment by touch and from appearance based on “instinct” and “know-how” skills inherited from past generations for the evaluation of thickness and impregnation, removal of voids, etc. Typically, more than 20 years of experience is required for a person to become a skilled craftsman in hand lay-up fabrication. Challenges the need to be addressed are how to pass their skills onto future generations, foster artisans, and construct a sustainable manufacturing process. In this study, the development of HLU molding robots input with the knowledge of skilled engineers as an achievement of this research will help overcome the lack of skilled workers during the stage of training young personnel to replace their predecessors as generations change.

Keywords Hand lay-up · Tacit knowledge · Compressive pressure · Dimensional stability · Robotization

1 Introduction

Expectations on robot technology have been growing as a means to solve the lack of manpower due to the ageing population and declining birthrate, improve the labor environment, and enhance productivity. Within this context, this study aims to develop robots with advanced skills in hand lay-up (HLU) molding of composite materials and utilize them in the production of composite materials, to build a system for continuous supply of high quality composite material products.

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The HLU method has been used since long to fabricate composite materials. A simple mold, the skills, and raw materials are all you need in hand lay-up molding. The molds used for hand lay-up process is inexpensive and this method requires little equipment investment, allowing the manufacturer to flexibly respond to wide-ranging requirements in terms of production volume, size, and changes in product shapes. Meanwhile, there are disadvantages: as the HLU method depends on human skills, product quality differs by the worker who fabricated the product and even between different parts of the same product. For these reason, highly sophisticated control techniques and the succession of molding skills are required to constantly provide products with stable quality. In other words, HLU molding requires craftsmanship. The skills for removing air bubbles and smoothening material surface are based on “instinct” and “knack” passed down from predecessors, which are all tacit knowledge rooted in subjective senses such as touch, vision and bodily feelings obtained from repeated motions, supported by experience and individual sensitivity. Typically, an HLU molding worker would need more than 20 years to become fully experienced. Process analysis results suggest that the work time in the deaeration process and the method of using a roller characterize the HLU method. We therefore themed this study on the comparative review of the skills applied in the deaeration process and investigation on methods for converting tacit human skills to explicit knowledge and incorporating such knowledge into robots as explicit values.

While growing demand for housing and hotels is expected with Tokyo hosting the 2020 Olympics and Paralympic Games, the serious lack of labor skills and front-line workers is increasingly standing out.

Considering such circumstances, the development of HLU molding robots input with the knowledge of skilled engineers as an achievement of this research will help overcome the lack of skilled workers during the stage of training young personnel to replace their predecessors as generations change. In addition, it will enable a flexible response to the need for small lot production of diverse products, the reduction of manufacturing costs, high productivity, and other advantages of the HLU molding technique leveraging the low facility and operation costs involved. While applying such strengths, it should also realize the continuous and stable supply of high precision, high quality products originally expected of robots. Consequently, this may promote the further evolution of composite materials design and rapidly increase the opportunities of fabricating composite materials using HLU robots.

2 Methodology

2.1 Subjects

The subjects were four craftsmen consisting of an expert in HLU with 27 years of experience, and craftsmen with experience of 13, 3, and 0.5 years, respectively. Table 1 shows the biological data of the subjects.

Table 1 Biological data of subjects

Subject person	Age	Years of experience (year)	Height (cm)	Weight (kg)	Dominant-hand
Expert	50	27	171	52	Right
Intermediate-1	35	13	179	66	Right
Intermediate-2	31	3	164	52	Right
Non-expert	31	0.5	182	77	Right

2.2 Experimental Protocol

The subjects carried out FRP forming by HLU on the measuring device (Fig. 1). The roller used in this study was that used in normal work. Attached with 3 mm hog bristles throughout the whole circumference, the roller measured 14 mm in diameter and 70 mm in width (Fig. 2). Video was taken using one video camera. Figure 1 shows the measurements using a reaction force measuring device. As for the coordinates, the front-back direction in respect to the subject was taken to be the x axis, the left-right direction the y axis, and the up-down direction the z axis. Without specifying the roller work time, the subjects were asked to carry out finishing work using the roller until they were satisfied.

Fig. 1 Measurement environment of this study

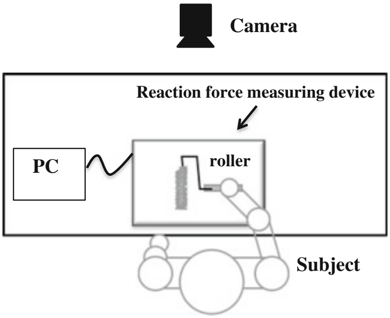


Fig. 2 Defoaming roller

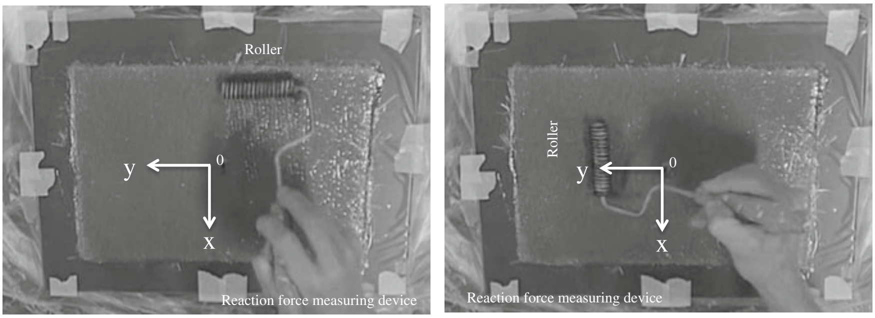


Fig. 3 Photo of reaction force measurement (*left* x-direction, *right* y-direction)

The requirements of the finishing roller work were the elimination of voids inside the FRP laminated layers and smoothness of the finished surface. Finishing is an important step in HLU fabrication and the step where difference in the level of experience appears most conspicuously. The unsaturated polyester resin used in this study changes to gel in 30 min because it is a photocurable resin, which means that the work time is restricted (Fig. 3).

2.3 Materials

Glass fiber chopped strand mat (450 g/m^2) was used as the reinforced substrate. For the matrix, unsaturated polyester resin made with isophthalic acid was used. A curing agent (MEKPO) was added to the resin at a ratio of 100:1.0. Three glass fiber chopped strand mats were laminated in the forming work. The size of the fabricated FRP sheet was horizontally 300 mm and vertically 200 mm (Fig. 4).

2.4 Measurement of Dimensional Stability

To compare the dimensional stability of the obtained samples, the thickness of the FRP sheets was measured every 20 mm using a micrometer (Fig. 4).

2.5 Measurement of Reaction Force

To measure the reaction force imposed by the finishing roller on the laminated layers using the HLU method, the reaction force measuring device was used

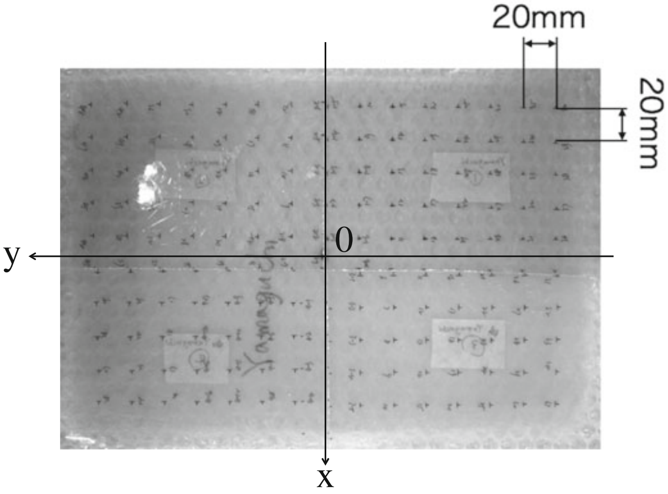


Fig. 4 Thickness measurement range

Fig. 5 Reaction force measuring device

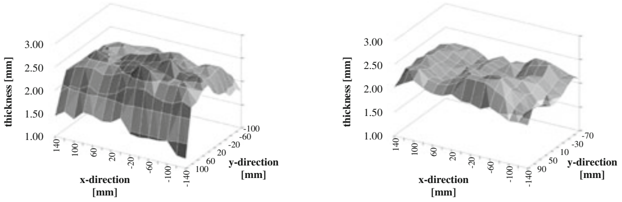
(TF-3040-A, 400 mm × 300 mm, Tec-Gihan) (Fig. 5). At a sampling frequency of 100 Hz, the reaction force of all operations from start to end was measured. At the same time, the trajectory of the x-y plane was also measured. The center of gravity of the reaction force is shown for the trajectory. The origin means the center of the reaction force measuring device.

3 Results and Consideration

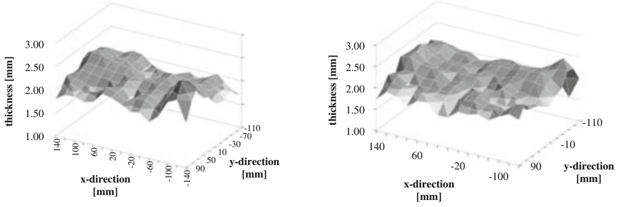
3.1 Dimensional Stability

Figure 6 shows the distribution of the thickness of the fabricated FRP sheet. The FRP sheet fabricated by the expert had stable thickness in both the X and Y directions, whereas it should be especially noted that the thickness of the FRP sheets fabricated by the non-experts was conspicuously inconsistent at the turning points of the stroke. (The edge of the flat FRP sheet is thin.) Figure 7 compares the average thickness of the FRP sheets fabricated by each subject. It can be clearly seen that the thickness of the sheet fabricated by the expert is stable around 2.1 mm in both the x and y directions. Inconsistency in the thickness was also small and the finished surface was smooth. On the other hand, the finished surface by the non-experts appears rough and undulated even to the naked eye, and the inconsistency of the thickness is large. The average thickness and number of years of experience were found to be closely correlated among the three subjects excluding the subject with experience of 0.5 years (simple correlation coefficient: 0.97).

These results suggest that how the roller is used clearly affects the thickness of the planar, elevation, and R convex sections, in other words the stability of the shape. In addition, it is evident that how the roller is used is closely related to operations that define “career,” as shown in Fig. 7.



Non-expert Intermediate-2



Intermediate-1 expert

Fig. 6 Comparison of dimensional stability

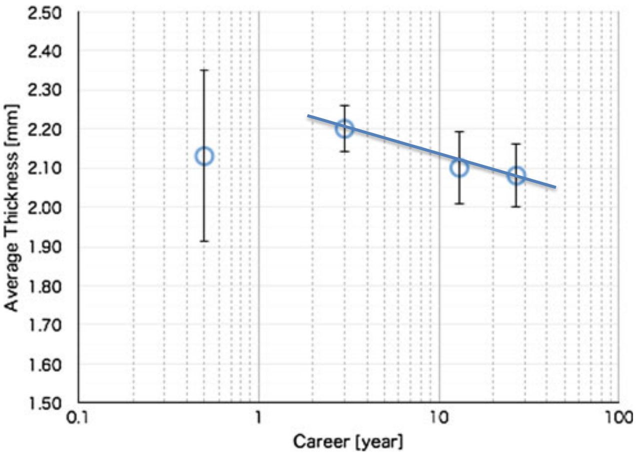


Fig. 7 Relation between average thickness and years of experience

3.2 *Compressive Pressure of Roller*

The effects of years of experience on compressive pressure of roller were investigated. Figures 8 and 9 show the trajectory of roller.

Next a relation between compressive pressure of a roller and working hours is indicated. Each chart indicates working hours in a transverse and indicates

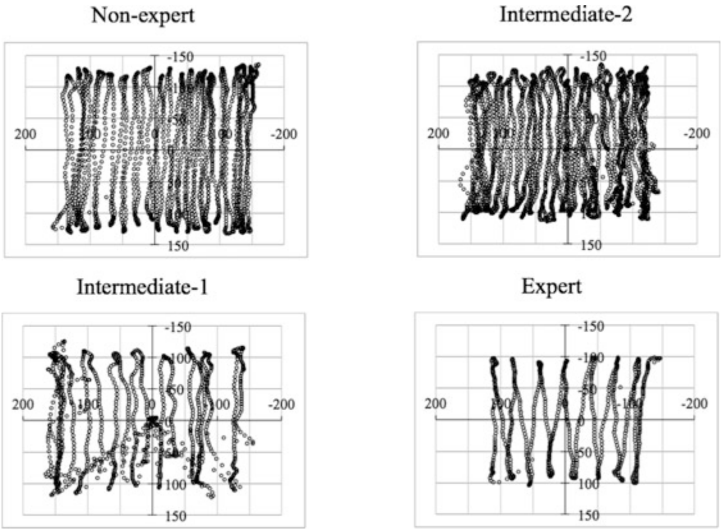


Fig. 8 Comparison of trajectory on x-y plane (x-direction)

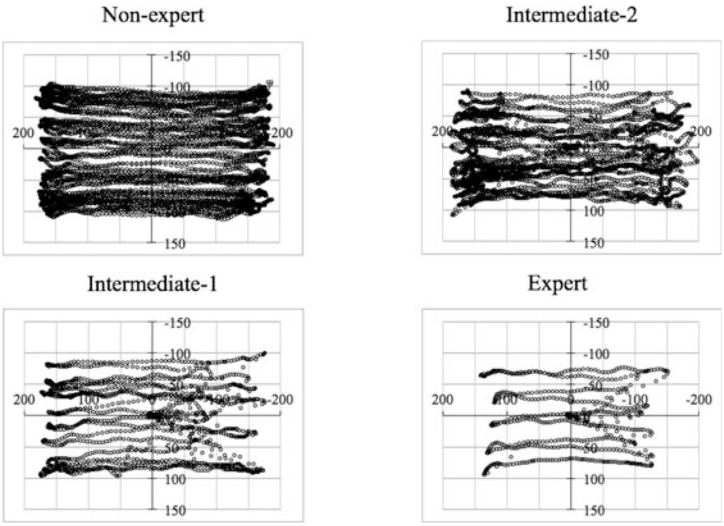


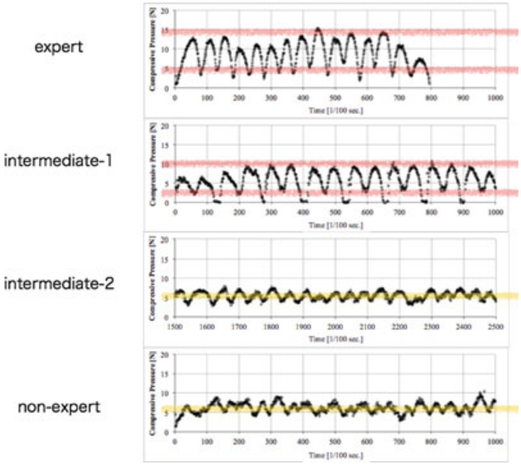
Fig. 9 Comparison of trajectory on x-y plane (y-direction)

compression pressure in vertical axis. There are no changes in compression pressure of a roller of intermediate 2 and an non-expert person (Fig. 10).

On the other hand, a change is big in compression pressure of a roller of expert and intermediate-1.

Figure 11 indicates the location of the x axis in a transverse, and vertical axis indicates compressive pressure of a roller. Roller compressive pressure of intermediate-2 and non-expert person doesn't depend on the location and is stable.

Fig. 10 A relation between compressive pressure of a roller and working hours



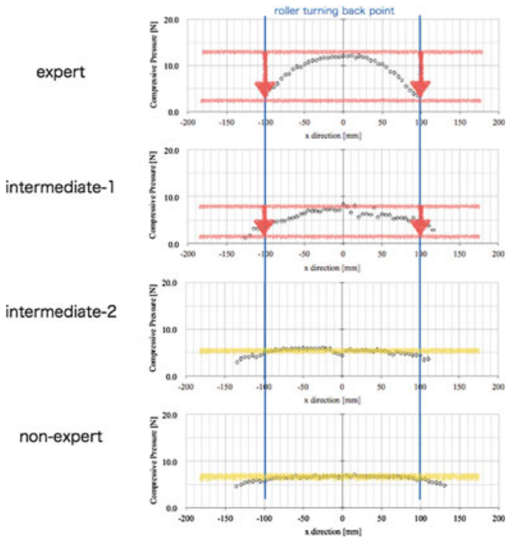


Fig. 11 A relation between x-axis and roller compressive pressure

On the other hand, expert and intermediate-1 are making compressive pressure fall at a roller turning back point. In particular, expert's compressive pressure falls to at most 1/3 at a roller turning back point.

3.3 *Robotization*

Aim of this research is to develop HLU molding robots input with the knowledge of skilled engineers. These quantified data is installed in a program of a robot. An efficient finishing process becomes possible by roller compressive pressure control. It can also be utilized as a tool of skill succession (Fig. 12).

Fig. 12 Robots with advanced skills in hand lay-up

4 Conclusions

The findings suggest a close relationship between how the roller is used (e.g., direction, frequency, and load), which is a measure of career, and mechanical property. Characteristics of the expert can be summarized as follows:

1. Compressive pressure of roller is evenly distributed. Then the coefficient of variation of the thickness and mechanical strength is estimated to be small.
2. Sample thickness that expert finished is uniform; this has been suggested to be responsible for the mechanical properties improved.
3. The defoaming work which is practician's tacit knowledge was quantified by compressive pressure of a roller.

Furthermore, it was found that the above three points can be incorporated into the educational tools of non-experts and intermediates, sharply reducing the skill acquirement time. And the national technical skills test is a national certification program to test and certify the skills of workers based on certain criteria. It is designed to motivate workers, including monodzukuri workers, to acquire skills, and it has contributed to improving the social status of workers. Robots with advanced skills in hand lay-up will be tested and certified by the national technical skills test in the near future.

Expert's Common Factor of Painting Motion in Auto Repair Painting Process

Shigeru Ikemoto, Hiroyuki Hamada and Yuka Takai

Abstract This study aimed to develop a learning system for studying the coating and painting tasks performed in automobile repair. This study analyzed and compared the characteristics of skilled spray gun handling for automobile repair painting with those with little experience. The spray gun movements and postures of 10 participants were measured using a motion capture system. The results showed the distance between the door and the experts' body to be approximately 1 m. The experts kept their axillae closed, bent an elbow, and set the distance between the door and the spray gun to approximately 0.22 m. The experts' spray gun running speed was faster than that of non-experts, and the speed reduced at the door panel edge. The experts' body movement realized a uniform thickness coating.

Keywords Auto repair · Painting · Spray gun handling · Posture · 3D motion capture

1 Introduction

Earlier, tasks in the automobile industry, from prototype development to mass production to repairs, as well as painting and coating of auto-mobiles, were done manually. These tasks have now become automated. Prototypes are produced by computer graphics, and robots carry out mass production. However, repair work

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must be tailored to customers' requirements; therefore, maintaining a skill base in some tasks is essential. This has become difficult because of the decrease in the number of engineers engaged in painting and coating and the declining quality of the workmanship.

Generally, engineers involved in painting and coating acquire the necessary skills in colleges or vocational schools; however, most schools do not allocate sufficient time for painting and coating practice. Thus, most new workers have no choice but to "watch and copy" the techniques of senior skilled engineers. However, it is not easy to acquire the optimal skills corresponding to each customer's request because the required skills are different every time.

In Japan, a significant proportion of the population is of retiring age, which includes many skilled engineers. Therefore, it is necessary to develop a method to help unskilled engineers acquire the relevant skills quickly and effectively.

Currently, unskilled coating engineers learn coating skills through training provided by corporate entities, paint manufacturers, or practical guidebooks. This situation has not changed for decades. However, the recent remarkable advancements in information technology have made it feasible to develop a new method for learning coating techniques. We propose a method using three-dimensional (3D) digital motion analysis equipment as a solution.

Behavior analysis has been incorporated into methods for technique acquisition in many fields [1]. This method is effective in learning new techniques. For instance, Murata et al. analyzed the pitching motion in baseball and proposed a better throwing motion. Marco et al. analyzed the different postures of athletes in the jump phase in a downhill race and clarified the characteristic motions of a skilled skier [2]. In the succession of skills, the characteristic motions of skilled technicians in the fields of cooking, sewing, nailing, glass forming, and chest compressions, used in cardiopulmonary resuscitation, have been analyzed.

This study developed learning materials for unskilled workers to acquire necessary techniques for automobile painting and coating. As a first step, this paper intends to clarify the characteristic motions of experts. We measured the motions of skilled and unskilled workers during a spray-gun operation by using 3D digital motion analysis equipment, and analyzed the results.

2 Methodology

2.1 Outline of Experiment

We used 3D motion analysis equipment to record workers' movement when they painted car door panels, then analyzed the results.

2.2 Experimental Facility

The experiment was carried out in March 2015 at the Nara Auto Body Repair Association Training Facility. At the training facility, automobiles were painted in a booth, in which all measurements were carried out for this study.

2.3 Participants

The participants included 10 craftspeople involved in automobile repair in the Kinki region. Five of the participants had 10 or more years of experience and were classified as experts, whereas the other five had less than 10 years of experience and were classified as non-experts. Table 1 presents the relevant details of the participants. All the participants were informed that their work would be recorded and the analysis results would immediately be made available to the public. The non-experts had no work experience but possessed relevant background knowledge, gained by working daily in the field of automotive sheet metal repair.

2.4 Materials and Tools

White solid paint made by Nippon Paint Co. (REAL MONO) was used. We adjusted 100 % paint for use in a spray gun by adding 25 % curing agent and 30 % solvent (paint urethane thinner). The spray gun was a Kiwami (W-101-136NPGC) made by Anest Iwata Corp. The input pressure of the spray gun was 2 kg, and the other conditions were adjusted such that the discharge amount and spread pattern were the same for all participants. The object to be painted was the left-front door panel of a Legacy (Fuji Heavy Industries Ltd.)

Table 1 Participant information

Participants	Career (years)	Height (cm)	Weight (kg)	Dominant hand
Expert 1	48	168	64.5	Right
Expert 2	40	161	65.0	Right
Expert 3	30	165	67.0	Right
Expert 4	23	168	62.0	Right
Expert 5	20	173	64.0	Right
Non-expert 1	3	172	65.0	Right
Non-expert 2	2.5	165	75.0	Right
Non-expert 3	0.5	170	80.0	Right
Non-expert 4	0.17	165	65.0	Right
Non-expert 5	0	170	78.0	Right

2.5 Experimental Motion

The participants were told to paint the door panels by using a spray gun. They were instructed to apply three coats and avoid painting the panel edges; otherwise, they were asked to paint as they did routinely.

2.6 Recording Procedure

Infrared responsive markers were placed at 20 locations on each participant's body, four on the spray gun, and eight on the door panel, and then these markers were set as targets. Coordinate collection was performed using a MAC 3D System (Motion Analysis Corporation) equipped with an optical, 3D, and automated analysis device. The sampling frequency was set at 120 Hz. Figure 1 illustrates the recording setup. The frame of reference was set to the left–right movement of the participant on the *x*-axis, forward–backward movement on the *y*-axis, and up–down movement on the *z*-axis. Three video cameras were used to concurrently record the movements of the participant.

2.7 Film Thickness Measurement

The condition of the finished coat was evaluated using a film thickness gauge (LE-300C, Kett Electric Laboratory). Measurements were taken at nine points on the door panel (Fig. 2). In addition, measurements were taken at five spots in the vicinity of each of these points.

Fig. 1 Recording setup

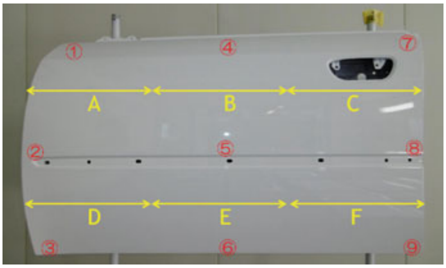


Fig. 2 Measurement area of the film thickness and spray gun handling speed

2.8 Analysis

Normal spray gun movements cover the entire width of the object being painted, going back and forth horizontally over the surface. We analyzed these movements in detail by using 3D motion analysis equipment. The paint operation used in this study is called wet-on-wet, in which a second coat of paint is applied before the first coat dries completely, and the same is done for a third coat. We did not analyze the motions during surface drying (flash-off time).

We calculated the mean values of time, distance, and speed of the spray gun from when it started to move to when it finished. These values were then compared between the groups. The spray gun movement speed was examined in detail in six areas created by dividing the upper and lower halves of the door into three areas (Fig. 2).

The three coats applied by the experts and non-experts were compared using a 2-way analysis of variance with a 5 % significance level. The spray gun motions and job history were correlated on the basis of a cross-correlation function with a 5 % significance level.

3 Results

3.1 Posture

Figures showing the painting postures were created by plotting the x and z positions of the right wrist, right elbow, right and left shoulders, right and left greater trochanters, right and left knees, and right and left ankles from the 3D motion analysis. The start, middle, and end positions show the beginning, midpoint, and end, respectively, when painting a door from the right to left edge. The postures of expert 3 and non-expert 4 who were of the same height were compared (Fig. 3). Among the expert 3, the angle of the shoulder to the upper body tilted to the left, going from 17.7° at the start position, to 22.9° at the middle position, and to 32.1° at the end position. The non-expert 4 showed a larger tilt to the left, going from 19.0° at the start position, to 27.9° at the middle position, and to 32.5° at the end position.

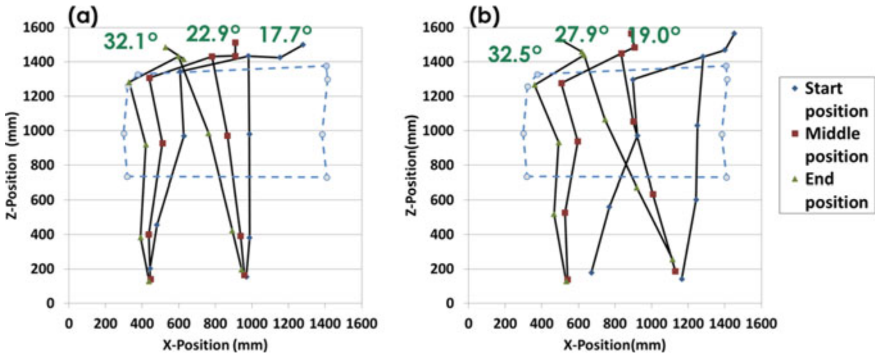


Fig. 3 Posture during spraying from the right to left of **a** expert 3 and **b** non-experts 4

When observing the lower body, non-expert 4 was found to have changed his standing positions, with the start position of the left ankle being to the right of its middle and end positions.

3.2 Angle of Elbow

We calculated the angle of the right elbow by connecting the right shoulder to the right elbow to the right wrist (Fig. 4). The experts' elbow angles tended to be smaller than those of the non-experts. Further, the elbow angles of the experts and non-experts decreased as the job progressed, showing their tendency to bend the elbow. The differences between the experts and non-experts were not significant.

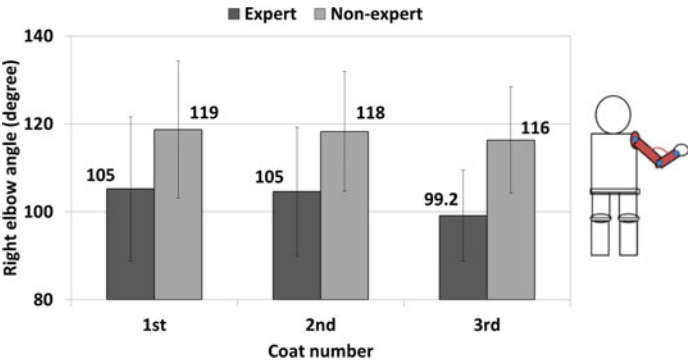


Fig. 4 Right elbow angle

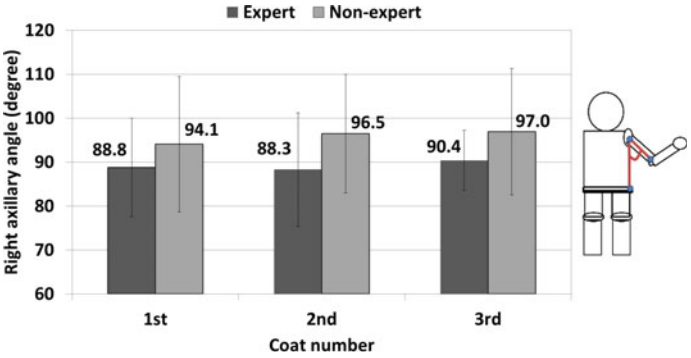


Fig. 5 Right axillary angle

3.3 Axillary Angle

We calculated the axillary angle by connecting the right elbow to the right shoulder to the right waist (Fig. 5). The axillary angles of the experts were smaller than those of the non-experts, and a tendency to close the axilla was observed. Further, the angles did not change much as the job progressed. The differences between the axillary angles of the experts and non-experts were not significant.

3.4 Distance Between the Spray Gun and Door Panel

We calculated the distance between the spray gun discharge port and door panel. The results are shown in Fig. 6. This distance was smaller among the experts than

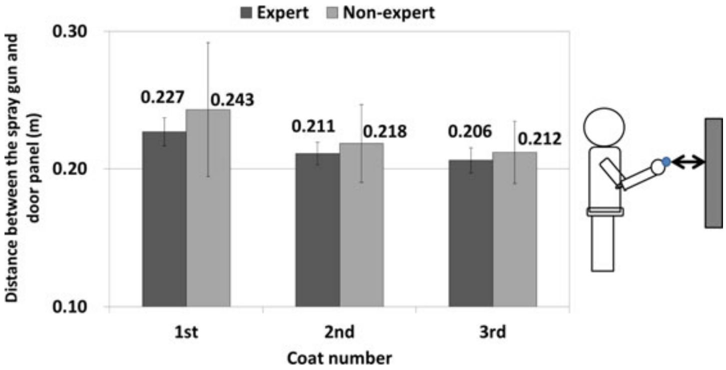


Fig. 6 Distance between the spray gun and door panel

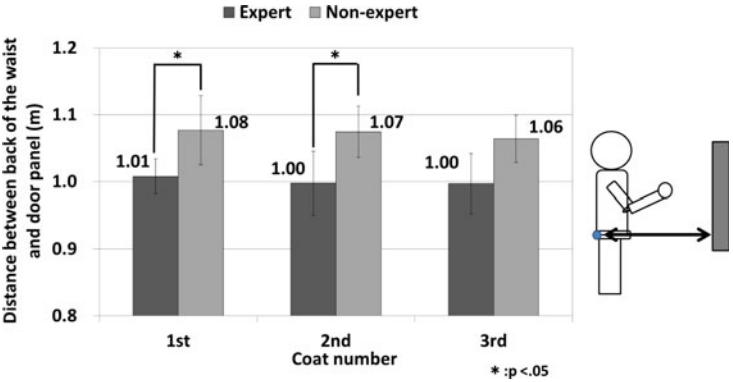


Fig. 7 Distance between back of the waist and door panel

the non-experts. Among both groups, the distance between the spray gun and door tended to reduce as the job progressed. Further, there was less variance among the experts, indicating that they moved the spray gun at an optimal distance for painting. The differences between the experts and non-experts were not significant.

3.5 Distance Between Back of the Waist and Door Panel

We calculated the distance between the back of the waist and door panel. The results are shown in Fig. 7. Among the experts, the distance between the waist and door was 0.07 m shorter than among the non-experts. As the job progressed, this distance tended to reduce for both the experts and non-experts, indicating that they were standing closer to the door. The differences between the experts and non-experts were significant for the first and second coats.

3.6 Spray Gun Running Length

Figure 8 shows the mean spray gun running lengths. The spray gun running length tended to increase as the job progressed for both the experts and non-experts, with the distance for the third coat being significantly longer than for the first coat ($F(1, 30) = 5.46$, $p < 0.011$). The running length tended to be shorter among the experts compared with the non-experts.

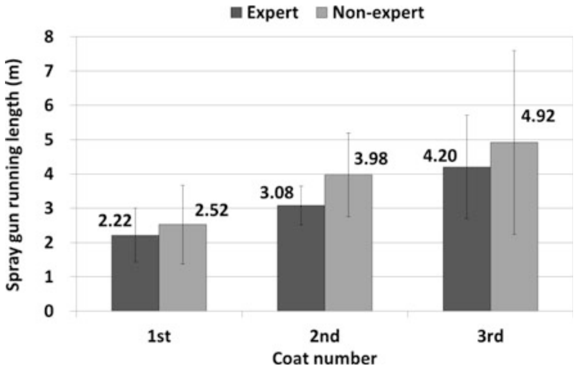


Fig. 8 Spray gun running length

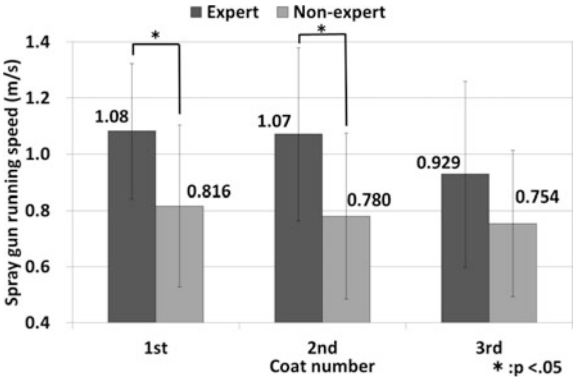


Fig. 9 Spray gun running length at all door panels

3.7 *Spray Gun Running Speed*

Figure 9 shows the spray gun running speeds. Speeds were higher among the experts compared with the non-experts, with the differences between the first and second coats being significant. Figure 10 shows the relationship between the speed and position of expert 2 while painting in one direction at second coat, that is, from the right to left edge of the door. The right and left edges of the door were at 1.47 and 0.34 m, respectively. The speed changed depending on the location to be painted on the door. Therefore, we calculated spray gun speeds for six regions, as shown in Fig. 2. In all these regions, the speed was greater among the experts compared with non-experts (Table 2). Further, speeds in the B and E regions in the middle of the door were approximately 0.35 m/s faster than on the edges of the door. Comparison of the speed of the experts and non-experts showed significant differences for the A, B, and C regions for the first and second coats. A significant difference in speed was observed for region D on the second coat, and for region E on the second and third coats. Region F did not show any significant differences.

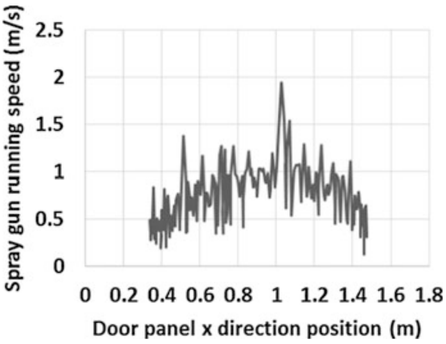
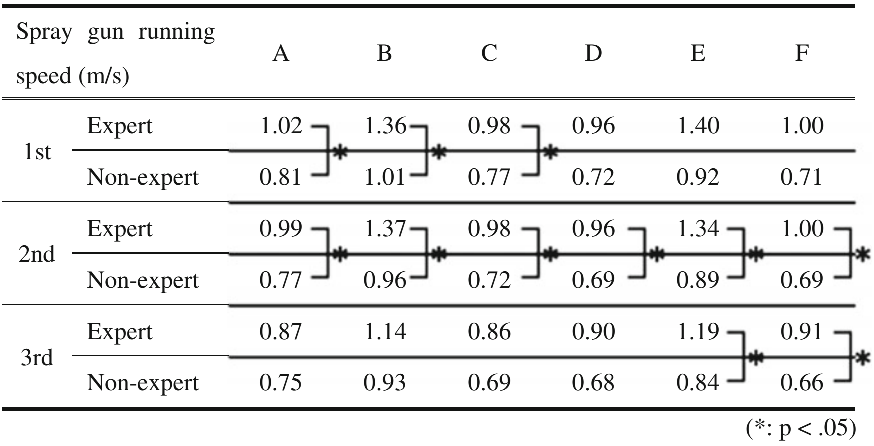


Fig. 10 Relationship between spray gun running speed and door panel x direction position of expert 2

Table 2 Spray gun running speed at each area



Spray gun running speed (m/s)		A		B		C		D		E		F	
1st	Expert	1.02	*	1.36	*	0.98	*	0.96		1.40		1.00	
	Non-expert	0.81		1.01		0.77		0.72		0.92		0.71	
2nd	Expert	0.99	*	1.37	*	0.98	*	0.96	*	1.34	*	1.00	*
	Non-expert	0.77		0.96		0.72		0.69		0.89		0.69	
3rd	Expert	0.87		1.14		0.86		0.90		1.19	*	0.91	*
	Non-expert	0.75		0.93		0.69		0.68		0.84		0.66	

(*: $p < .05$)

*$p < 0.05$

3.8 Coating Paint Thickness

Table 3 shows the mean film thickness values and mean differences between maximum and minimum thicknesses. The films painted by the non-experts were thicker compared with those by the experts. The difference between the maximum and minimum thicknesses was smaller among the experts.

Table 3 Coating paint thicknesses

	Expert		Non-expert	
	Avg.	S.D.	Avg.	S.D.
Film thickness (μm)	104.3	8.42	107.6	9.95
Difference of Max. and Min. (μm)	5.92	1.57	9.67	4.26

4 Discussion

Individual differences in the distances between the door and spray gun were small among the experts. Under the painting conditions in this experiment, 0.22 m seemed to be the optimal distance between the door and spray gun. To attain this distance, experts kept their bodies approximately 1 m from the door and painted, keeping their axillae closed and elbows bent. It appears that they were able to maintain their posture by not extending their arms much. Further, the experts tended to slow the spray gun near the edges of the door. When asked about this, the experts said that since the edges of the door are where connections with other parts were located, they were careful to paint in a manner that would minimize color differences. Thus, while the experts tended to paint the door faster, they slowed down near the door edges to work carefully on these areas. By moving their bodies in this manner, they maintained a small difference between the maximum and minimum film thickness, and were able to apply paint at a uniform thickness over the entire door panel.

5 Conclusions

We analyzed the motions used in painting doors and clarified the characteristics of technicians with expertise in applying paint for automotive repair. The results showed that the experts maintained a distance of approximately 1 m from the door, closed their axillae, bent their elbows, and held the spray gun at approximately 0.22 m from the doors. Moreover, while the experts tended to paint faster, they slowed down near the door edges to work carefully on these areas. By employing such motions, the experts were able to apply paint to the door panels at a more uniform thickness than the non-experts.

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Effect of Expert and Non-expert Workers' Skill Level on the Quality of Glass Fiber Reinforced Composites by Hand Lay-Up Method

Xi Xie, Lili Chen, Yuqiu Yang, Erika Suzuki, Tetsuo Kikuchi and Hiroyuki Hamada

Abstract Glass fiber is well known as a reinforced material with low costs and excellent mechanical properties advantages and it has been extensively exploited over the past few years. In this paper, glass fiber was selected and used to fabricate composite with unsaturated polyester resin by hand lay-up method. However, the issue that it is difficulty for quality of product to control was caused by this method. At recent research, the effect of the worker's skill levels on the quality of product has hardly been investigated. Therefore, it mainly focuses on worker's skill level influence on the mechanical performance of molded product in this paper. To achieve this purpose, Subjects (Subject A, B, C, D, E had 25, 18, 15, 4, 1 year of experience, respectively.) were allowed to choose their familiar molding tools to produce product which were made of the same materials and met the requirements of volume friction. The thickness of laminates was measured especially in the corner before the test. In addition, bending properties and low cycle bending fatigue (LCBF) were also discussed and investigated. After the test, the fracture cross

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sectional observations was implemented on the selected test specimens by using a scanning electron microscope (SEM), with a focus on the fracture morphologies.

Keywords Quality control · Hand lay-up · Low cycle fatigue

1 Introduction

Composite materials produce combinative properties of two or more materials which cannot be achieved by either matrix or fiber when they are acting alone [1]. Fiber-reinforced composites were successfully applied to many engineering applications for many decades [2]. In addition, composite materials have wide range of industrial applications and laminated GF reinforced composite materials are used in industries because of better damage tolerance for impact force, good environmental resistance, and higher specific strength and stiffness [3–5]. The preparation of laminated GF-reinforced composite materials usually use hand lay-up method. The mechanical performance of laminated GF-reinforced composite materials which made by hand lay-up method is related to worker's skill level. However, up to now, the effect of the worker's skill levels on the quality of product has hardly been investigated. Therefore, this paper mainly focuses on the influence of worker's skill level on the mechanical properties of molded product.

In this paper, subjects with the different working years were employed to use the same experimental materials to fabricate the same fiber volume fraction of the molded laminates, in addition, subjects can use their own molding tools and molding process. In order to compare the quality of laminates made by the subjects with different skill level, the molded laminates were marked as shown in Table 1. Before the experiment test, every laminate was divided into 8 smaller parts as showed in Fig. 1a for measuring corner thickness, and the bottom of every laminate was divided into 20 smaller parts as showed in Fig. 1b for measuring bending properties. After the bending test, sample's cross-section of fracture surface was observed by SEM.

Table 1 Molded laminates marked

Index laminates	Subjects	Experience of year
A-4#	Expert	25
E-5#	Non-expert	1
B-6#	Intermediate-1	18
A-7#	Expert	25
E-8#	Non-expert	1
B-9#	Intermediate-1	18
B-10#	Intermediate-1	18
D-11#	Intermediate-3	4
C-13#	Intermediate-2	15

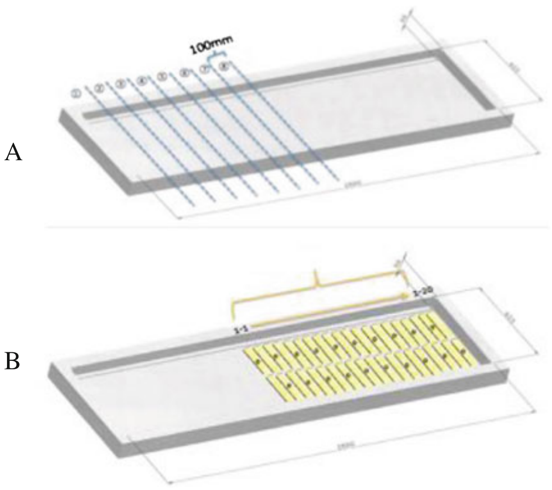


Fig. 1 Schematic diagram of sample preparation **a** thickness measurement, **b** bending test

2 Experiment and Materials

2.1 Specimen

As shown in Fig. 1b, the hand lay-up molded plates were cut into rectangular specimens of $l * w * t$ mm ($l = 150$ mm, $w = 30$ mm). "t" delegated the thickness of specimens which varied a bit as different thickness corresponding to different working experience of the workers. Then all specimens of 150 * 30 * t mm were cut into 4 pieces (①, ②, ③, ④) as a predetermined size of $h * b * t$ mm ($h = 50$ mm, $b = 1.28$ mm) according to the standard as shown in Fig. 2. Piece ① was conducted with bending test and others with low cycle bending fatigue (LCBF) test. In order to know whether the quality of the products related to the experience of workers, additional experiments as measuring the thickness of corners shown in Fig. 3 were conducted.

2.2 Corner Measurement

During the course of material processing and using, the most easily broken part was the corner. Therefore, as shown in Fig. 3, there were four parts to be measured in total and the lower right corner included three sections as corner-1, corner-2 and corner-3 which were contained in the measuring range. In the process of experiment, a ruler was placed near the corner to be taken a photo which was processed by ImageJ2x so as to know the thickness of corners.

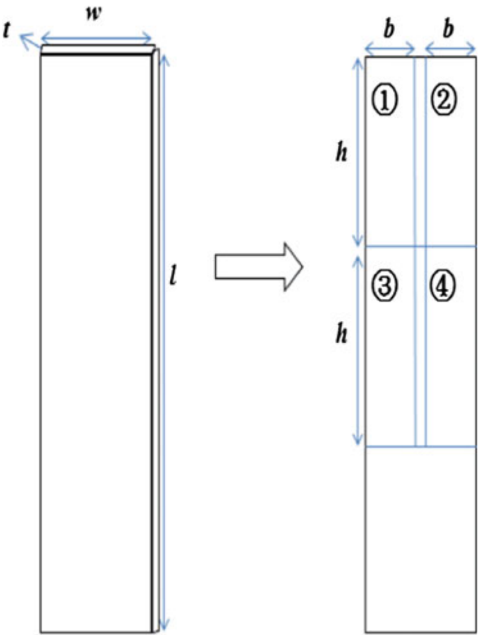


Fig. 2 Sample preparation of bending property

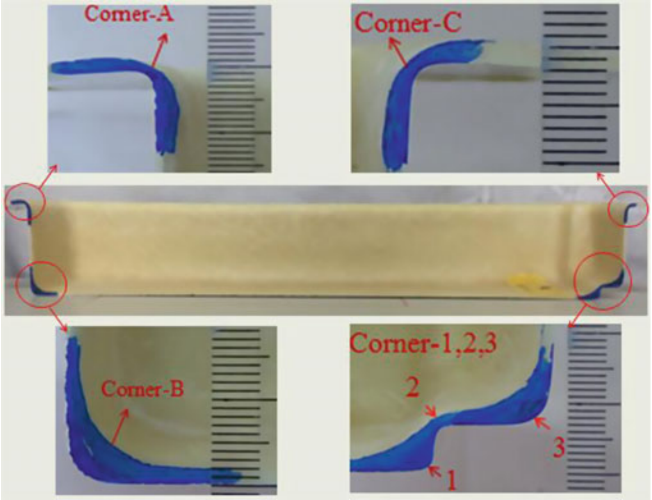


Fig. 3 Thickness measurement of corners

2.3 Experimental Method

Three-Point Bending. Flexural properties of specimens were conducted by QJ-212C at a cross-head speed of 5 mm/min under the condition of standard laboratory atmosphere according to ASTM D 790-2003. As Fig. 4 indicated, the span length was 38 mm, at the same time, a camera was placed straight ahead to record the whole fracture process. The outward side of the specimen was painted blue for the reason that it could take on a clearer image in the camera. The three enlarged pictures were intercepted under the condition of different time.

Low Cycle Bending Fatigue (**LCBF**). LCBF test was conducted in the same machine shown in Fig. 4 with the same cross head speed. Then the cycle load was calculated and determined by the maximum value of load obtained from the three point bending test. During the experimental process, once it reached the pre-set load, which is 55 and 85 % of the corresponding max load, respectively, it would repeat the process again until 30 cycles. LCF test was implemented to verify the result of three-point bending test by comparing the final flexural properties after 30 cycles with the condition of non-cycle.

SEM Test. The fracture surface of the bending tested specimens and LCBF tested specimens were observed by scanning electron microscope (SEM) whose type is S-3400N.

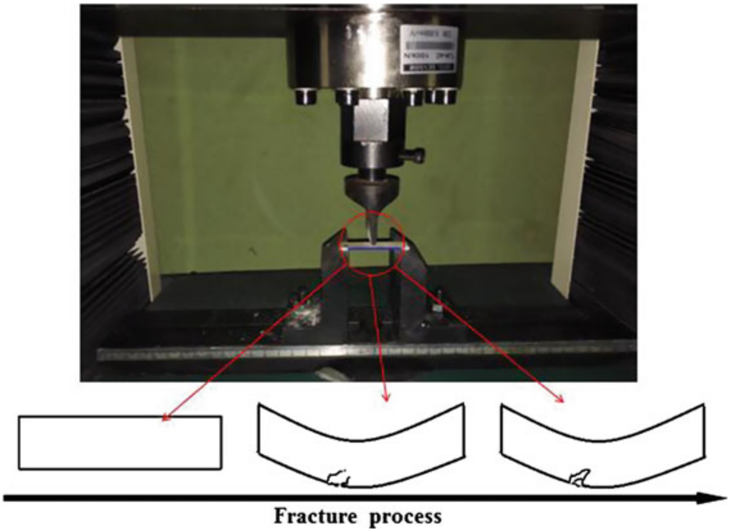


Fig. 4 Bending test

3 Experimental Results and Discussion

3.1 Results of the Corner Thickness Measure

Figure 5 showed the measured thickness in terms of the different corners in Fig. 3. The figure clearly showed that the thickness of the laminate was also increased with the increasing working years at the corner-C and the corner-1. However, the thickness of the laminate which was made by intermediate had significant variations. In terms of corner-A, corner-B and corner-2, the thickness of the laminate which was made by intermediate was lower than Non-experts'. In addition, at the corner-3, it can be seen that the thickness of laminate which was made by intermediate was higher than Experts'. In general, the corner thickness of laminate made by expert was higher than the corner thickness of laminate made by non-expert.

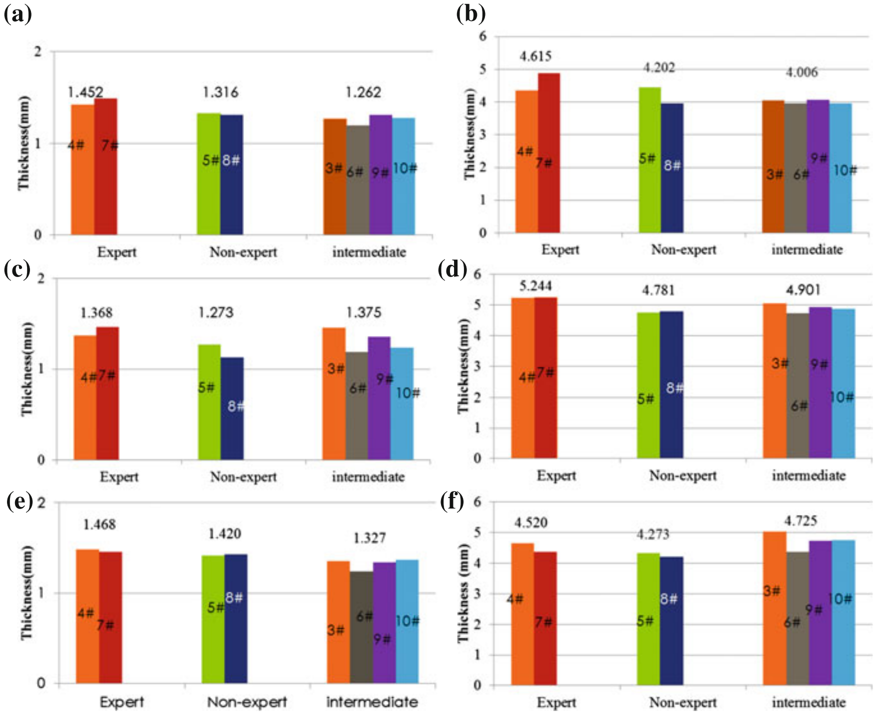


Fig. 5 Comparison of corner thickness **a** corner-A, **b** corner-B, **c** corner-C, **d** corner-1, **e** corner-2, **f** corner-3

3.2 Results of Bending Test

Figure 6 showed that bending damage process of specimens made by expert, intermediate and non-expert. From Fig. 6, it can be seen that all the specimens were under similar damage process.

Flexural modulus and Flexural strength were shown in Figs. 7 and 8, respectively. In the figure, different colors represent the same position of laminates which was made by workers with the different skill levels. And different symbols represent

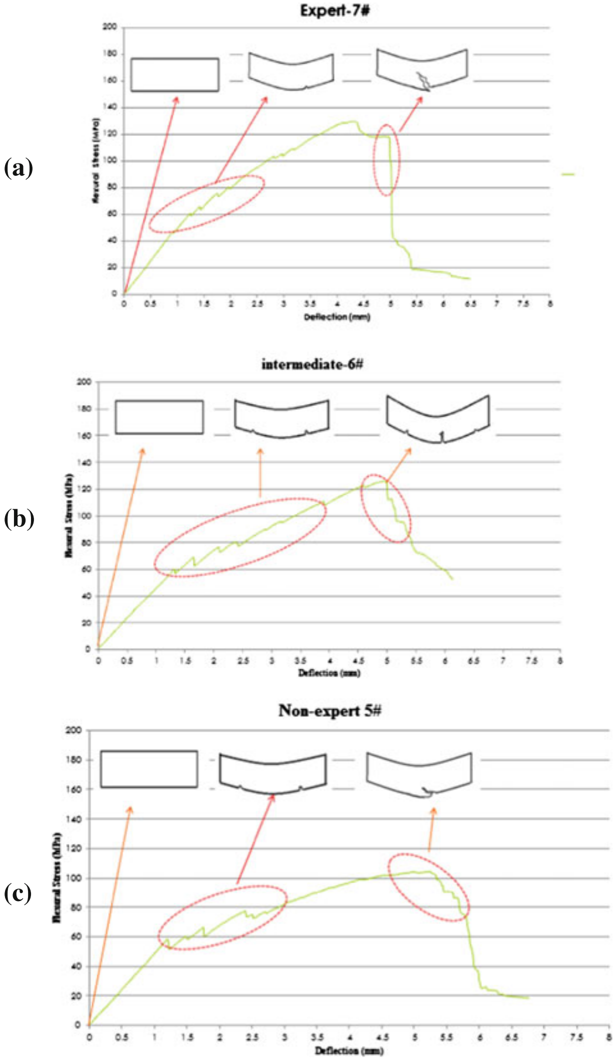


Fig. 6 Damage process of specimens **a** expert; **b** intermediate; **c** non-expert

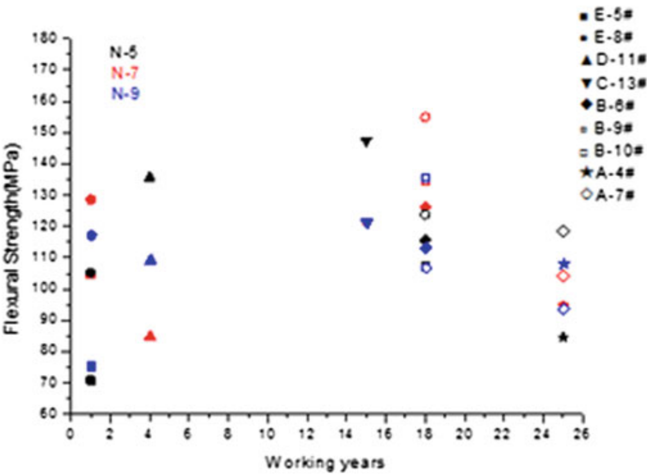


Fig. 7 Comparison of flexural modulus

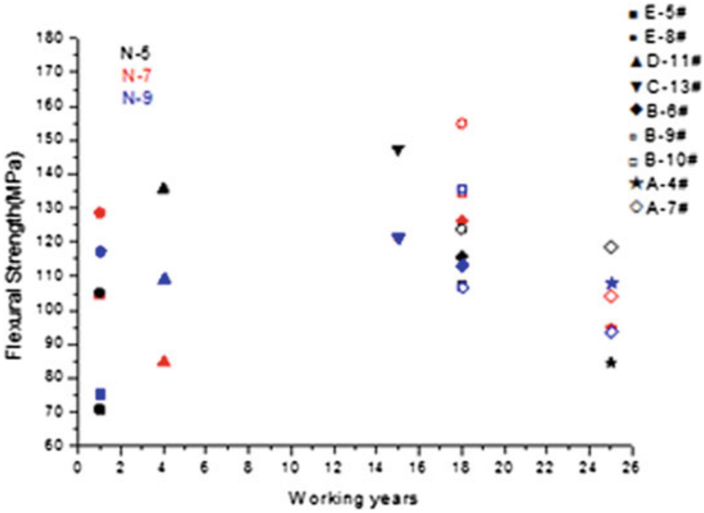


Fig. 8 Comparison of flexural strength

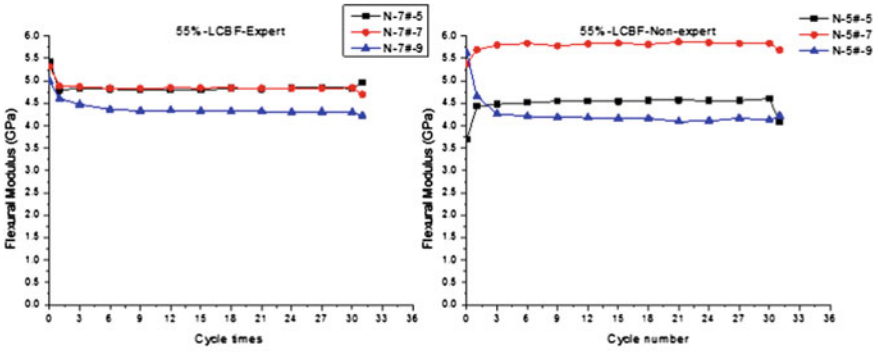
different laminate. Figure 7 showed the flexural modulus of different laminates. Comparing the flexural modulus of specimen from the same position of different laminates, it can be seen that the dispersion degree of the laminate made by subject E was larger than subject B and subject A. In addition, it can be also seen that flexural modulus was not increased with the increasing of working years. However, with the increasing of working years, variance of the flexural modulus decreased.

From Fig. 8, it can be seen that there was no obvious relationship between the flexural strength and the workers skill levels, because the dispersion of the reinforced glass fiber was uneven. In order to find the reason why bending property of the laminate made by expert is better than non-expert', the degree of dispersion was investigated. It can be seen clearly that with the increasing of working years, variance of the bending strength decreased.

3.3 *Results of LCBF Test*

The pre-set load for the LCBF test was predetermined with 55 and 85 % of the maximum bending load. To achieve this purpose that seeing the tendency of the bending performance during the LCBF test, the flexural modulus was recorded every three cycles. In order to evaluate the effect of the LCBF test, the final flexural modulus after 30 low cycle bending fatigue test was compared with normal flexural modulus.

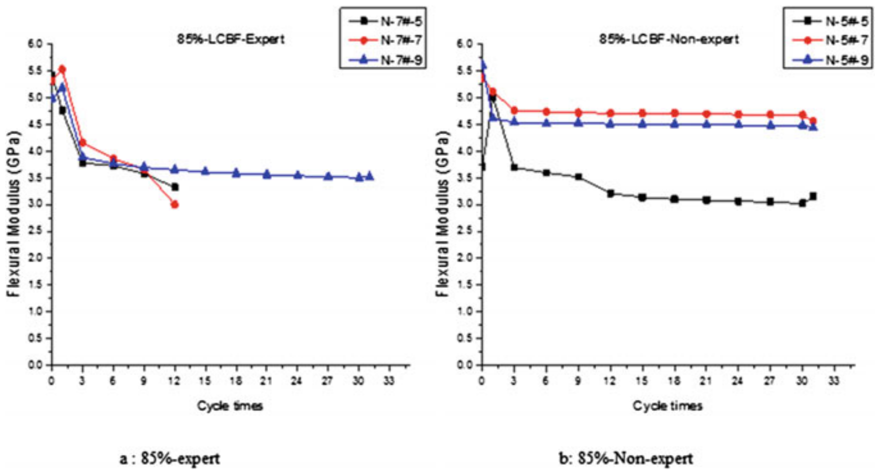
Figures 9 and 10 showed the flexural modulus summary during the 55 and 85 % LCBF test, which was calculated every three times, and includes flexural modulus from the final bending test. Take Fig. 9 as an example, when the cycle time was zero, it represented the modulus of the normal bending test. And when the cycle time was 31, it represented the flexural modulus after the LCBF test. Figure 9a revealed that the flexural modulus of specimens from expert during the 55 % LCBF test have a smaller different. The three specimens (N-7#-5, N-7#-7, N-7#-9) had also a lower variation with CV value of 1.4, 1.1 and 6.6 %, respectively. However, the different with Fig. 9b was that the three specimens had the similar trend. The changing rage of flexural modulus from the three specimens was decreasing 8.7, 11.8 and 15.3 %, respectively. From Fig. 9b, it can be seen that the flexural modulus during the 55 % LCBF test had a lager difference. The three specimens



a : 55%-Expert

b : 55%-Non-expert

Fig. 9 Flexural modulus during the 55 %-LCBF test. **a** 55 % expert, **b** 55 % non-expert



a : 85%-expert

b: 85%-Non-expert

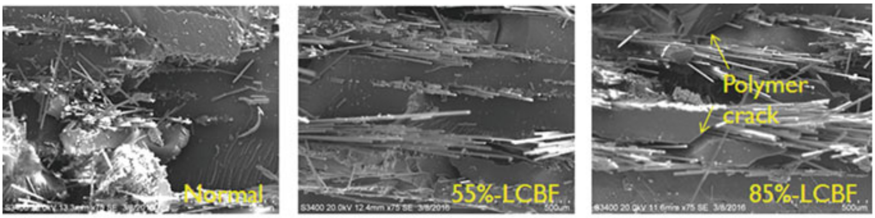
Fig. 10 Flexural modulus during the 85 %-LCBF test. **a** 85 % expert, **b** 85 % non-expert

(N-5#-5, N-5#-7, N-5#-9) showed lower variation with CV (coefficient of variation) value of 3.8, 3.1 and 4 %, respectively. Additionally, comparing the normal flexural modulus and the final flexural modulus after 30 cycle LCBF test, it can be seen that changing rage of flexural modulus from this three specimens was decreasing 4.7 %, increasing 5.8 % and decreasing 24.9 %, respectively. Therefore, with respect to CV of flexural modulus before and after 55 % LCBF test, expert performed better than non-expert.

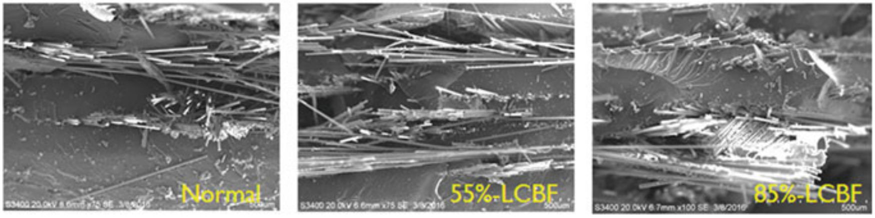
Figure 10 showed the flexural modulus during the 85 %-LCBF test. From Fig. 10b, the similar trend can be seen with Fig. 9b. However, in Fig. 10a, it can be seen clearly that flexural modulus had a high decreasing speed, and the specimens (N-7#-5, N-7#-7) was fractured when the cycle times was 12. It indicted that fatigue resistance of specimen made by expert performed worse during the 85 % LCBF test. This phenomenon need to be further studied.

3.4 Results of SEM Test

Figure 11 showed the fracture characteristics of cross-section. According to Fig. 11a, b, it is deserved to find that fiber pulled-out phenomenon was obvious after fatigue bending loading than normal bending, especially when underwent larger pre-loading value during the LCBF test. Additionally, in Fig. 11a, not only fiber pulled-out behavior, but also the matrix crack could be detected during the 85 %-LCBF test. In terms of the different on the micrograph of cross-section between expert and non-expert, which need to be further studied.



A: Expert



B: Non-expert

Fig. 11 Micrograph of cross-section **a** Expert; **b** Non-expert

4 Conclusions

This study explored the effect of expert and non-expert workers' skill level on the quality of glass fiber reinforced composites by hand lay-up method. It is found that the corner thickness of laminate made by expert is obviously higher than that made by non-expert. Additionally, with respect to the bending test, it can be seen that with the increasing of working years, the variance of flexural modulus and flexural strength decreased. Referring to the LCBF test, conclusion can be also drawn that expert performed better than non-expert with respect to CV of flexural modulus before and after LCBF test. In addition, on the micrograph of cross-section observation, the conclusion can be drawn that fiber pulled-out phenomenon was obvious after fatigue bending loading than normal bending, especially when underwent larger pre-loading value during the LCBF test.

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Analysis of Blowing in Quartz Glass Fire Process

Masamichi Suda, Toru Takahashi, Akio Hattori, Akihiko Goto and Hiroyuki Hamada

Abstract Quartz glass has a superior performance than other glasses. Especially it has been used as a key component of high-performance analytical instruments and scientific instruments and special manufacturing equipment. But now we have to manufacture these products by engineer's human hand, the most important reason is a very small lot production of many products. And engineer expend the long time to study about process technology. So we have to analyze these processing technology from expert and non-expert engineers and have to make a standard model of the fire process technology.

Keywords Ergonomics and sustainability · Quartz glass · Process analysis · Fire process · Jointing · Bending · Blowing

1 Introduction

Quartz glass has a very high purity of silicon, and has heat resistance, chemical resistance, and excellent optical transparency. Therefore, it has been called the king of the glass.

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Quartz glass has a superior performance than other glasses. Especially it has been used as a key component of high-performance analytical instruments and scientific instruments and special manufacturing equipment.

Because of its high heat resistance, it is difficult to the processing in a variety of shapes. General borosilicate glass can be mass produced by a hot press processing with precision mold. Quartz glass is difficult to mass-produced by mold because of its high melting point. Therefore, many of the quartz glass product is manufactured by engineer's hand processing for each product.

Therefore, in order to produce high-precision quartz glass product efficiently, engineers training is the most important. Also, engineers with a high processing technology has been aging in recent years. There are situations in which the tradition of technology is not going well. To keep stable supply of high-precision products, to analyze the processing technology of highly skilled engineers, it requires efforts to help education and training.

There are several types of the processing of quartz glass. Especially, products used in such analysis equipment, special and complicated shapes are required. Therefore, the heating processing by flame called "Fire-process" is needed.

"Fire-process" is a processing technology that uses a mixed flame of oxygen and hydrogen by heating the quartz glass material to the softening point, to form the softened glass by hand of the engineer. Therefore, to produce high-precision products efficiently it is believed to require special processing technology by many years of experience.

In this study, we focused on "Blowing" in the bending process of Fire-process. Blowing in the craft field of common glass, are using to be shaped inflatable glass tube. It's because it can be relatively processed at low temperature. However, there is a high softening point in the case of quartz glass, and therefore Blowing conditions are different. Blowing is confirmed as the motion, it is not really clear what effect is given.

We think that Blowing motion has a significant impact on the control of quality. We conducted a process analysis of bending process and a basic experiment to reproduce the processing status of the Engineer, and analyzed whether out what kind of effect on the quality by Blowing in bending process of Fire-process.

2 Experimental Method

First, in the process using a blowing it took up the bending process. The bending process is one of basic process of the quartz glass fire process, It is susceptible to process the effects of the engineers of the technology.

This section describes the experimental method of bending.

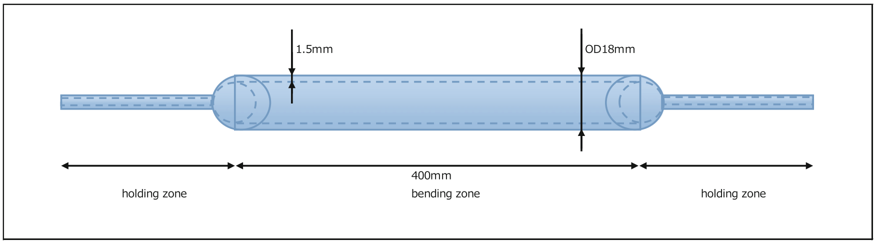

Fig. 1 Quartz glass tube for test, after jointing of hold glass tubes

We chose the engineers of two people with different years of experience as a subject.

Two of the engineers did a bending under the same conditions, and analyzed the process by the video shooting.

The experiment material was normal quartz glass tube with outside diameter: 18 mm, inside diameter: 15 mm, length: 400 mm.

Before bending process, engineers join the glass tube for holding to two ends of quartz glass tube (Fig. 1).

The status of operator and burner and blowing tube are shown in Fig. 2.

The flame with about 3000 °C which can soften the quartz glass was generated by the combination of hydrogen and oxygen. Operator sat behind the burner and kept sitting posture for processing.

Engineers were directed to perform bending process on quartz glass tube to 90° without any other instruction. Meanwhile, each subjects processed one piece of tube

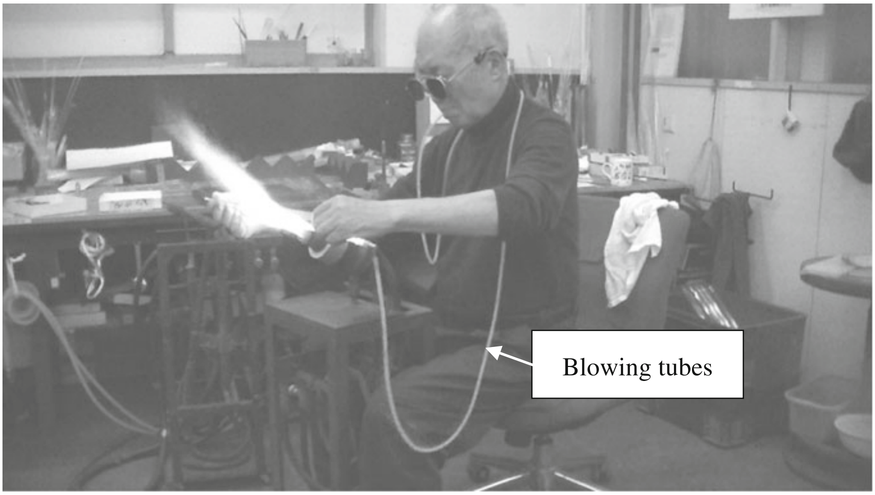

Fig. 2 Processing position of engineer with flame burner and blowing tube

at a time and totally 3 times. During process, every experimental subject was controlled in same process environment without distraction. This is so that the subject is not affected by watching the processing techniques of the other subjects. In order to analyze the detail, the whole process was recorded by digital camera.

3 Engineer’s Information

In this study, two different experience engineers were invited as subjects who “Engineer-A” has 54 years of experience, “Engineer-B” has 5 years of experience. Two were selected from engineers who works on fire process every day and their experiment of processing was continuous for many years.

4 Motion Analysis

Firstly, we have analyzed the processing recorded video, were compared for time from start to finish (Fig. 3).

Firstly, subjects were heated while rotating the quartz glass tube in the axial direction by hand. And After heating, engineer A was bent 90° by one of the bending motion. Engineer B was bent 90° by the number of times of bending motion. The number of the bending motion is shown in Fig. 4.

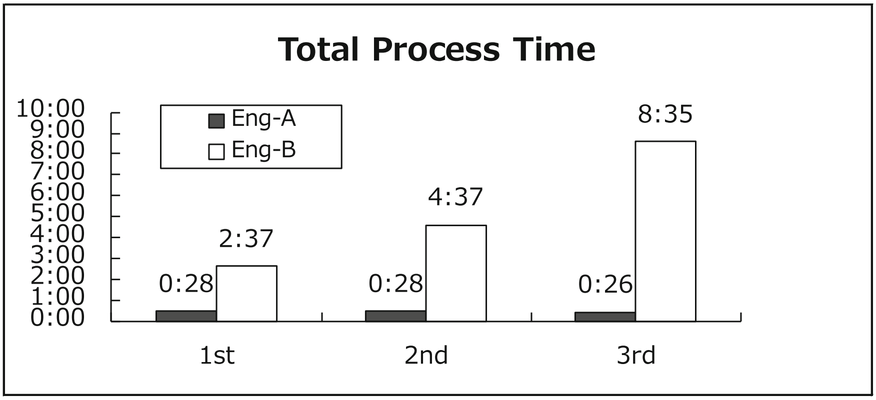

Fig. 3 Total process time

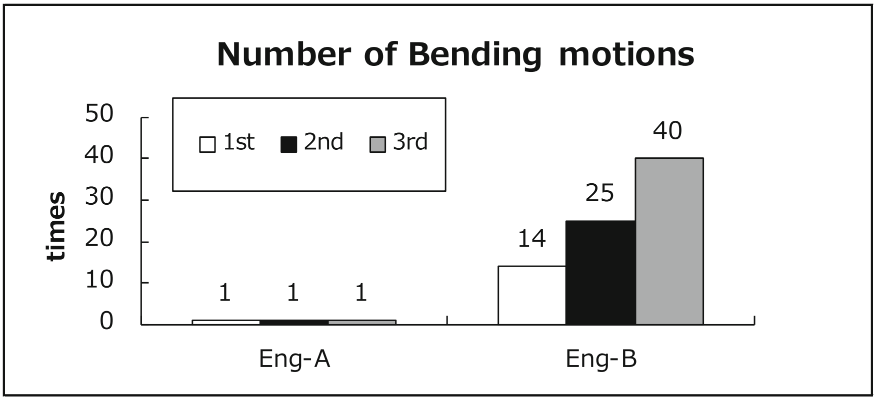

Fig. 4 Number of bending motions

Next, we investigated the difference of heating points and heating time of the glass tube in each subject. The glass tube is divided in four areas (Fig. 5), and measures the heating time by the burners in each area (Fig. 6).

In the case of Engineer-A, it was processed in a single bending motion. In that case, the glass tube before bending motion had been evenly heated.

In the Engineer-B case, it had been processed in several times of bending motion. In that case, the processing time becomes relatively longer. Addition, it was found that the glass tube is not evenly heated before bending motion.

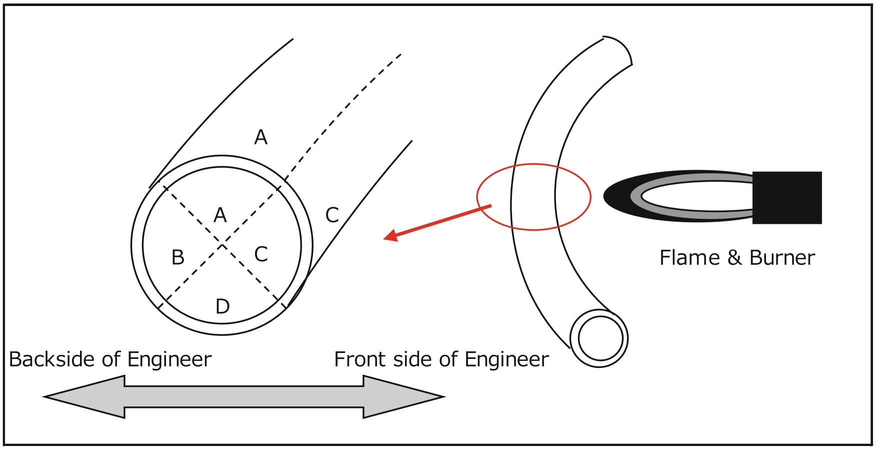

Fig. 5 Area of heating

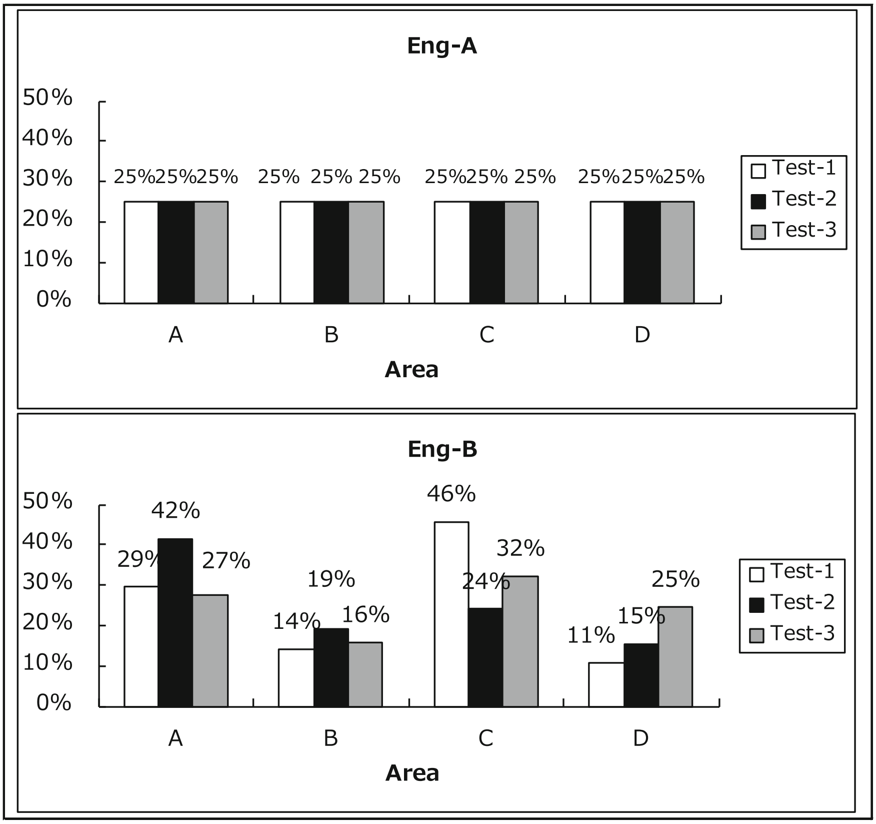

Fig. 6 Ratio of process time by heating area

5 Measurement of Bending Part

Next, we investigated the quality of the quartz glass tube after bending. There are several quality standards for Glass products needs the bending processing. In this study, we measured the outer diameter and wall thickness of the glass tube.

The amount of change before and after processing is the basis for the evaluation of the processing quality.

The image of the quartz glass tube after bending is shown in Fig. 7. Also it shows the measurement points of the outer diameter in Figs. 8 and 9 show the change in the outer diameter before and after processing.

In the case of Engineer-A, the diameter of the glass tube was reduced in the X direction. In the Engineer-B cases, the diameter was expanded. Y direction of the

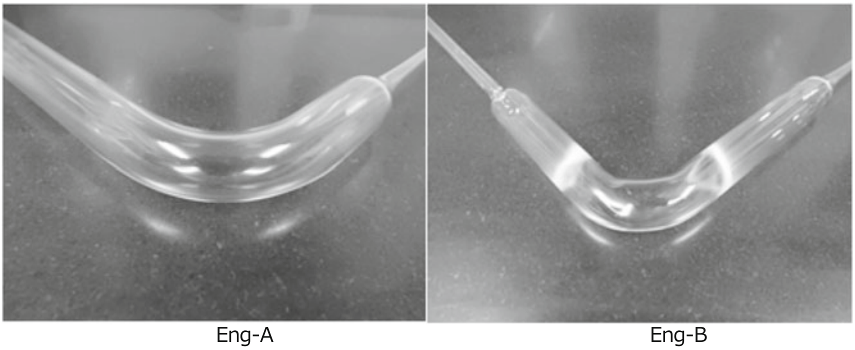

Fig. 7 Sample after bending

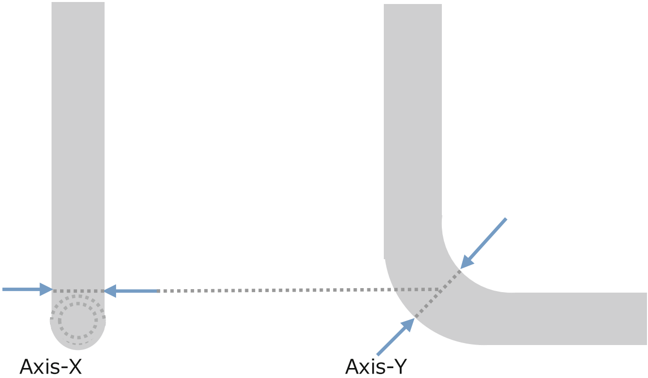

Fig. 8 Measuring point of out diameter

trend was the same as the X direction. In the case of Engineer-A, reduced diameter of the glass tube, in the Engineer-B case, the diameter of the glass tube is expanded (Fig. 10).

The following were the measurement of wall thickness. Figure 11 shows the measurement point. We cut the glass tube, and measured wall thickness with a digital caliper (Fig. 12).

In both cases the Engineer-A and -B, the thickness of the C section is thinned in comparison with the wall thickness of the Original. C section had been stretched

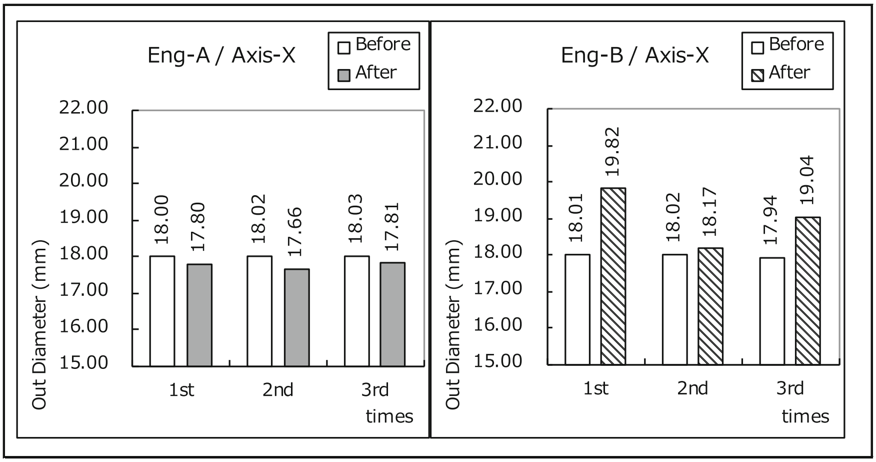

Fig. 9 Changes of Axis-X

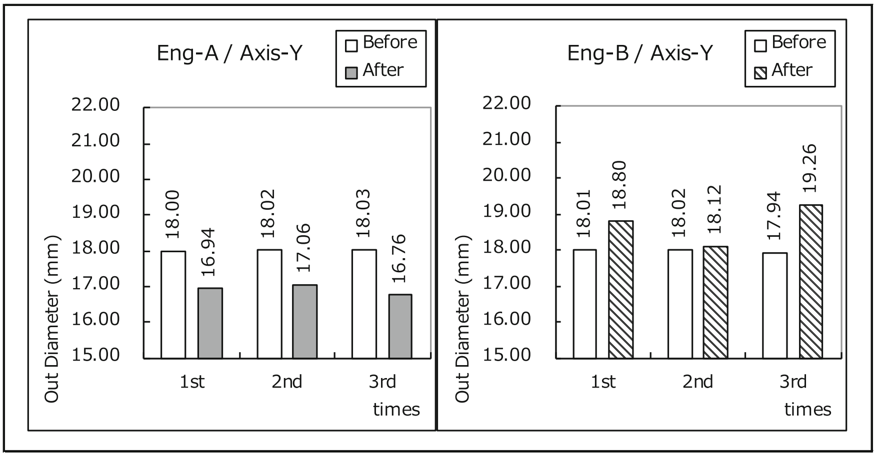

Fig. 10 Changes of Axis-Y

most at the time of bending. Engineer-A’s C section reduction of wall thickness was less.

Addition, Eng-B cross section of the bending is deformed (Fig. 13). On the other hand, Eng-A’s cross-section deformation is small. Eng-A was able to bending with a high roundness.

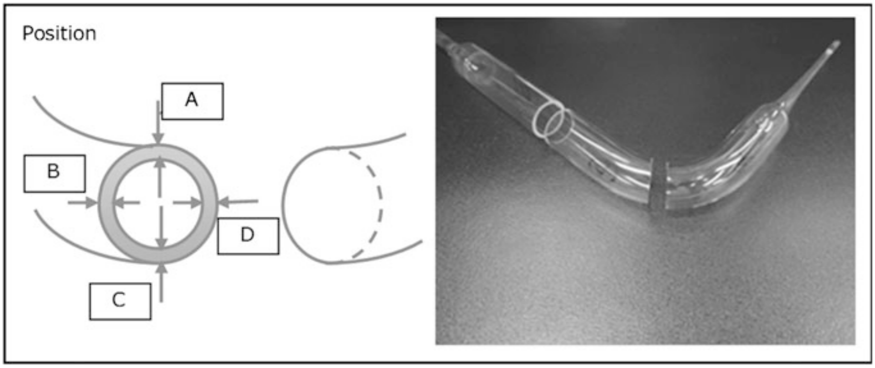

Fig. 11 Measurement point of wall thickness

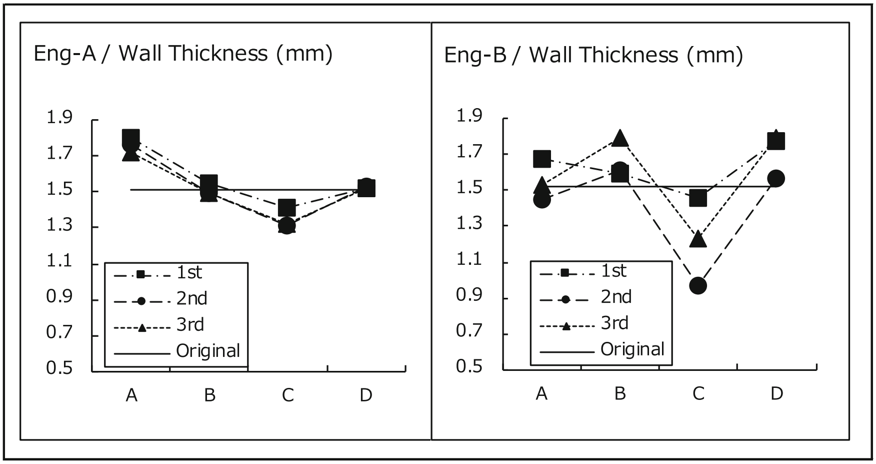

Fig. 12 Changes of wall thickness

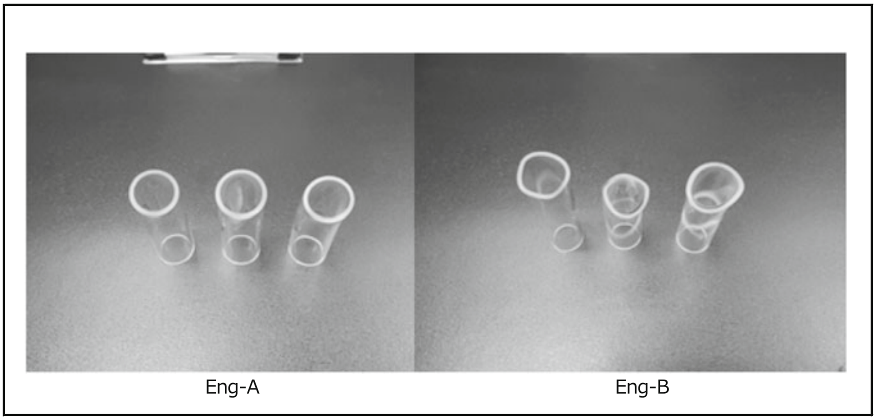

Fig. 13 Cross-section shape of bending part

6 Blowing Experiment

Then, to examine the change in the glass tube and blowing the relationship in a heated state, were performed additional experiments. As shown in Fig. 14, one was heated in a state of opening the both ends of the quartz glass tube. Another was heated in a state of being sealed with a silicone stopper. Both were video recording.

When bending, engineers a silicon tube was held at the mouth, has been blowing during processing. Closed state and an open state is to reproduce the extreme operation.

Further, and heated for 1 min by rotating using automated glass lathe to the constant rotation. Also, it was used quartz glass tube material of the same size used in Bending Test.

Figure 15 is a state of the glass with glass lathe and glass tube after heating. First, in the state in which sealed, heated part at 12 s from the start of heating melts, and the glass tube is burst, and heating was discontinued. By thermal expansion of air inside the glass tube by heating, it is considered to have burst from the heated

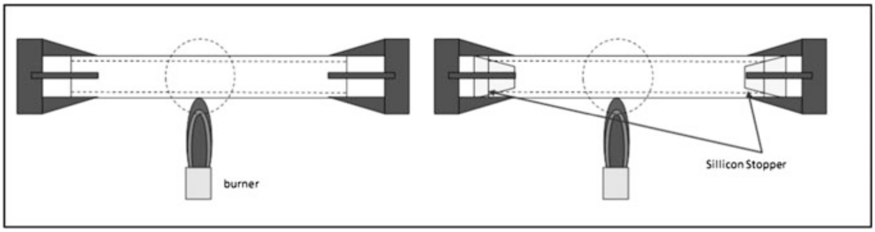

Fig. 14 Open state and close state of glass tube with glass lathe machine

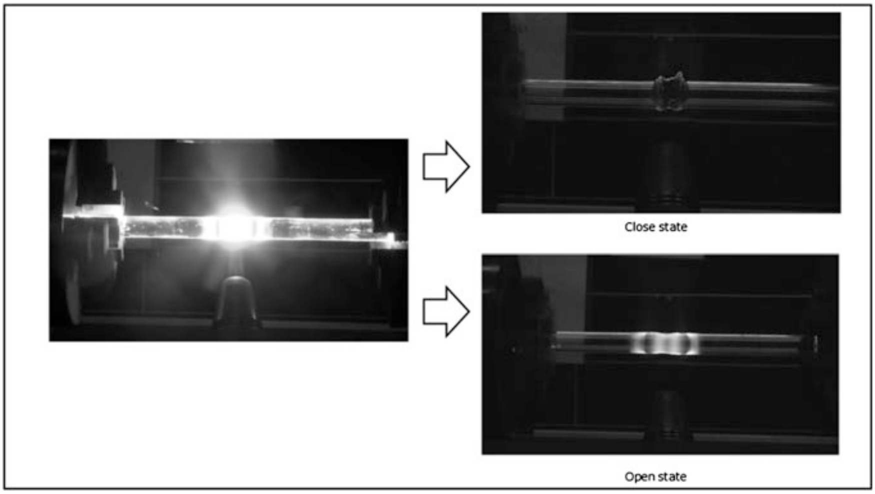

Fig. 15 Heating of open and close state glass tube and result view

softening the glass walls. Further, when heated in an open state, the outside diameter at the smallest part is reduced to 15.9 mm, after 1 min. If the internal pressure rise in the Open state does not occur, the glass tube was Softening by heating was found to diameter reduction.

7 Consideration of Bending Process

In this study, the differences in the working process and the product quality between engineers with different years of experience during the ‘fire-process’ of quartz glass material were analyzed.

As for product quality, the researches and engineers watched the records after experiment, and engineer-A dictated that the wall thickness, outside diameter of quartz glass tube determined the product quality. Engineer-A told, outside diameter of heated tube will shrink at the beginning of the process. If the tube was heated the outside diameter would shrink and the tube wall would be thicker. Above phenomenon is called collect the thickness’. If the tube was stretched the outside diameter would shrink and the tube wall would be thinner, on the contrary, if the tube was compressed to center the outside diameter would expand and the tube wall would be thicker.

In bending process, bending inside part is compressed which cause tube wall thicker, and bending outside part is stretched which cause tube wall thinner. When Eng-A rotate and heat the tube, consciously conducting ‘collect the thickness’. Eng-A was able to make a bending products of stable quality because the thickness was conscious control.

In addition, the change in outer diameter of the horizontal (Axis-X of Fig. 8) is generated (see Fig. 9). Expansion of Axis-X direction, could be confirmed by the glass tube after processing of Eng-B.

By interview, Eng-A had assumed the change. When tube was heated and the outside diameter became smaller, Eng-A promptly bended the tube which can prevent Axis-A&B from expanding and can get approximate circle cross section products.

And researchers also interviewed the Eng-B. Eng-B mainly focused on bending procedure and hardly cared about the collect thickness of tube wall which is very different from Eng-A’s operation.

This interview, among engineers, clear differences were found in the knowledge of each process.

8 Consideration of the Blowing Influence

About the role of blowing, one of the roles it has been suggested from the basic experiment. Important role of one is working as a adjustment valve of the internal pressure at the time of heating. It is to avoid damage due to the rapid increase in the internal pressure of the sealed glass tube. The blowing has a function for releasing the inside the air during the heating.

In addition, in the case of fully open too reduced outer diameter. Engineers control the “Collect the wall thickness” while adjusting the internal pressure, had to achieve a stable thickness.

9 Conclusion

In order to perform bending with stable quality is to understand that the glass tube is changed by bending motion and blowing, and it is important to control the heating of the glass tube. Superficially, it may be seemed that the main difference between two engineers is that the Eng-A just conduct one bending movement to process required effect. But it is just suitable for the quartz glass tubes which were used in this study. It’s possible that Eng-A conduct more bending-motion for other different size of tube. In this case also, Eng-A told that the most important factor should be concerned is the status of tube during heated and processed. Meanwhile, ‘collecting the thickness’ is of great concern during bending process, which is useful for determining the process method for specific type of tube and improving product quality.

In this study, the differences in the working process and the product quality between engineers with different years of experience during the fire-process of quartz glass material were analyzed.

The result shows that there was a clear difference in the product quality based on skill maturity about bending and blowing.

Eng-A can use ‘collecting the thickness’ method to control the status of quartz glass tube and expend much less time than Eng-B, which not only improves product quality but also enhance productivity.

In future research, do some additional experiments on the effect of Blowing, we will continue to analyze the engineers of the technology.

Process Study of Hand Lay-Up Method to Clarify Implicit Knowledge of Professionals

Toshihiro Motochika, Masakazu Migaki, Erika Suzuki and Akio Ohtani

Abstract Hand-lay-up method is superior as the molding method for FRP in terms of small lot production of many products. However, there is potentially the problem that mechanical property of molding products depend on technique of workers. Therefore, if tacit knowledge those experts have, early growing of that non-experts and automation of hand-lay-up method are hoped. The purpose of this study is to clarify the tacit knowledge and to change it explicit knowledge. In order to this purpose, process analysis, measurement of thickness and pressure of molding production and many subjects were examined to clarify correlation to mechanical properties. As a result, it was established that the guide of technique for hand-lay-up enabled non-expert to mold the FRP which has similar mechanical property to expert by clarifying the explicit knowledge of experts.

Keywords Processing analysis · RP · Hand lay-up

1 Introduction

FRP is the abbreviation of Fiber Reinforced Plastics. Using fiber and resin significantly improves the strength to reinforce the plastic. Including the aerospace industry bike, automobile, railway, construction industry, and is used in the medical field such as a variety of fields.

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Hand lay-up method is a general FRP molding method which can flexibly respond to various shapes. As the advantages, and the like “it is suitable for high-mix low-volume production,” “capital investment is small,” “it is possible to molding of complex products.” On the other hand, since all work is done by hand, there are also disadvantages such as “dependent on the skill of the quality of the molded article is an operator.” In this study, we aimed to explicit knowledge of the know-how of hand lay-up method expert who is a tacit knowledge. To that end, process analysis in the hand lay-up method, we tried moldings of thickness, pressure at the time of molding, the format underground from the point of view of mechanical properties.

2 Experimental Methods

2.1 Hand Lay-Up Method

Hand lay-up method of the present study and GFPR plate of 300 mm × 300 mm by using a roller on the smooth metal plate and molded CFRP plate of 200 mm × 200 mm. Reinforcing material was stacked three layers.

2.2 Subjects

Hand lay-up method expert (11 years, 167 cm, 105 kg, right), middle (13 years, 182 cm, 80 kg, right), non-expert (0 years, 184 cm, 70 kg, right) experiments were performed in the subjects of each one person a total of three people.

2.3 Process Analysis

It was taken from directly above so that the entire plate is captured area to carry out the work by using video camera. The expert in the working process, “the influx of resin”, “degassing”, “stretched resin of a roller”, “laminated reinforcements”, are classified into five “resin-impregnated waiting”, and investigate the working time did.

In addition, both the subjects of the three in this experiment work time of “waiting impregnation of resin” we were fixed to 3 min per layer.

2.4 Eye Movement Measurement

The experimental apparatus for the analysis of eye movement with using a hat-type eye mark recorder (nac Image Technology). Detection method in the pupil/corneal reflection method formula, the sampling frequency is set to 60 Hz.

2.5 Materials

Unsaturated polyester (RIGOLAC150HRBQTNW) was used as matrix. M137 chopped strand mat (Owens Corning® Co.) was used as a glass reinforced material and used Carbon roving cloth (the Tsudakoma Corporation, Ltd.) as a carbon reinforced material. The amount of resin was 500 ml prepared in each molding.

2.6 Thickness Measurement

Each subject has performed the thickness measurement of a molded article was produced. Thickness measurement was performed for each 10 mm spacing.

2.7 Pressure Measurement

Three-dimensional force plate installation type was used for pressure analysis. Measurement items have 3 component force (X, Y, Z-axis), the moment (Mx, My, Mz) and the acting point COP.

2.8 Tensile Test

The tensile test was carried out by universal testing machine (INSTRON type 55R4206). The speed of tensile test was 1 mm/min, The capacity of load cell was 10 t. Glass fiber-reinforced molded article was cut in width 20 mm, length 200 mm and the score distance is set to 100 mm, Carbon fiber-reinforced molded article was cut in width 10 mm, length 100 mm, scores between the distance I was 50 mm.

2.9 Cross-Sectional Observation (Optical Microscope, SEM)

The fracture surface after tensile test was observed by the SEM, the cross section of molding products made by each subject were observed by an optical microscope.

3 Results

3.1 Process Analysis

The working time rate of each GFRP making process was shown in Fig. 1. The working time of each CFRP making process was shown in Fig. 2. The total working time of glass fiber, expert is the shortest, 947.5 s, middle is 1086.7 s, non-expert 1138.0 s. On the other hand, unlike glass fiber in the case of carbon fiber, the working time of the non-expert is the shortest, 754.3 s, middle is 760.9 s, and expert was 794.3 s.

Among the classified process, it was the most difference came out process “degassing”. Expert had finished the degassing time of about half of the non-expert. The expert whereas the percentage of “degassing” of the total was 30 %, middle is 40 %, non-expert was 5 %.

As a feature of each subject in this “degassing” First non-expert, the stroke of when you make a roller is always short, wore roller mainly in the center. In contrast middle the stroke when applying the rollers always long, were impregnated with vertically and horizontally and the whole fibers. Meanwhile, the stroke at the time of applying a skilled rollers longer central end is taken short, it was found that it had varied the bets roller by site. This glass fiber, was the same result in both the carbon fiber.

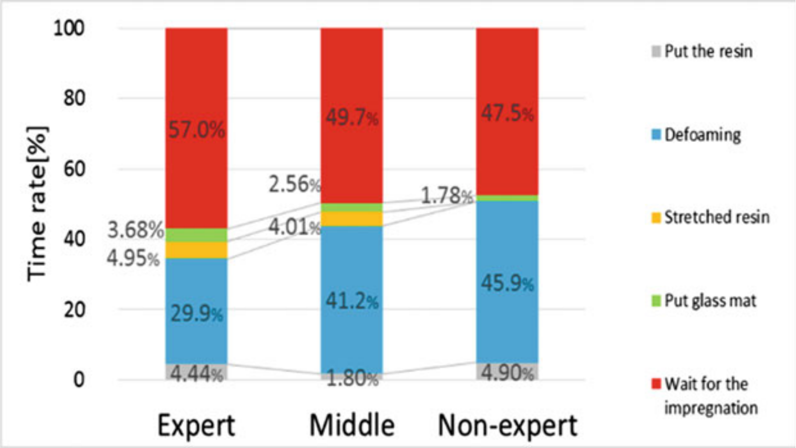

Fig. 1 The working time of each GFRP making process

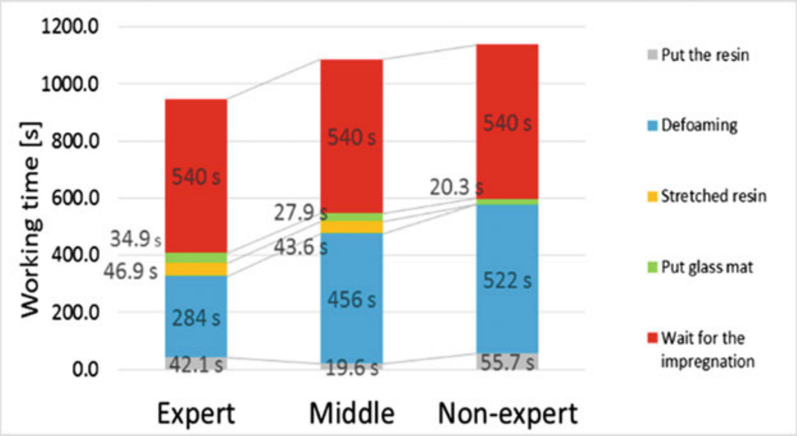

Fig. 2 The work time of another CFRP making process

3.2 Eye Movement Measurement

According to results of process analysis, it was clarified that the most difference exits among the three people were degassing operations, so eye movement was examined during the degassing operations. The results of GFRP were shown in Fig. 3, the results of CFRP were shown in Fig. 4. First, the line of sight of the non-expert had been gazing at the near work sites that are multiplied by the roller. In contrast intermediate's line of sight was watching a little bit ahead of the work site. It is assumed that predicts the next site to put the rollers. Meanwhile, in the person of ordinary skill in the line of sight, we have seen a little ahead of the same work site and the middle, after rub the whole was doing the confirmation finish

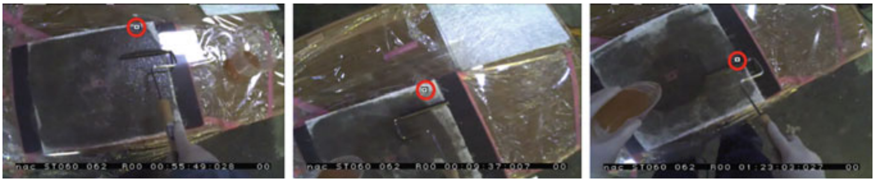

Fig. 3 Appearance of eye movement (GFRP)

Fig. 4 Appearance of eye movement (CFRP)

condition. It is considered that it was going to check the impregnated state. Expert non-expert in order to molding in this way, has a clear objective comparison with middle, was found to have more ingenuity.

3.3 Thickness Measurement

The average values and coefficient of variation of the thickness were shown in Table 1. Expert and middle in glass fiber thickness average value was about the same. Variations in the thickness direction of a skilled person was small. In addition, non-skilled person has a large variation in thickness, and the average thickness was found that high compared to expert and middle. In the carbon fiber, only intermediate, the thickness average, showed a high number in both the coefficient of variation.

The results of the thickness measurement it is shown in Figs. 5 and 6. Thus, expert in the glass fiber is constant thickness, middle although there is a thin part thickness portion of the end was nearly uniform thickness. On the other hand, non-expert became the result that the thickness of the end portion in the non-uniformity is the thickness of the mountain is thin center thickness. Although the carbon fiber was not especially seen in the center, intermediate of the molded article thickness has been a high value at the ends.

Table 1 The thickness of average and variable

	Glass fiber			Carbon fiber		
	Expert	Middle	Non-expert	Expert	Middle	Non-expert
Tickness Ave	2.40	2.32	2.83	0.88	1.05	0.95
Variation coefficient	5.08	8.23	16.36	5.59	11.45	5.88

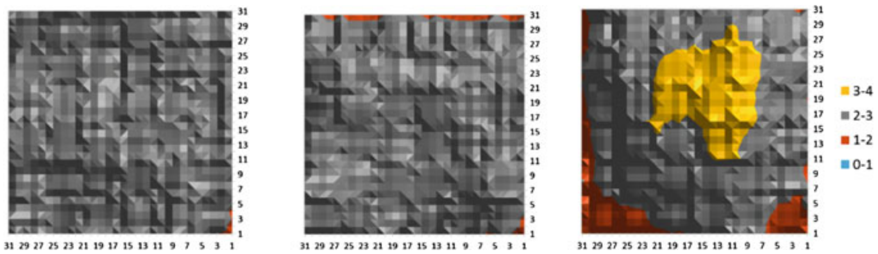

Fig. 5 Thickness distribution (GFRP)

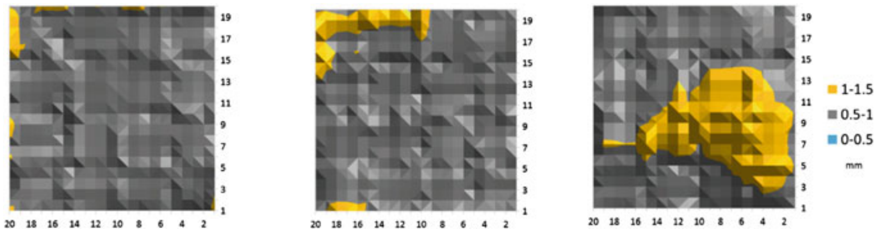

Fig. 6 Thickness distribution (CFRP)

3.4 Pressure Measurement

The results of process analysis, for the most different between the three people were out it was deformed work was investigated the pressure is focused at the time of degassing operation. The pressure in the Z direction of each subject was shown in Fig. 7. Middle continues giving a constant force, but expert had a variation in the force. But the point of application of the maximum pressure at this time, showed an end. Therefore, the skilled person rice forces the end, center I found that are shaped light. It is considered that prevents the backflow of voids extruded out from the center.

3.5 Tensile Test

Glass-reinforced molded article Fig. 8, indicating the mechanical and elastic properties of the carbon fiber-reinforced molded article Fig. 9. Glass fibers the tensile strength, in the tensile modulus in both, and shows the lowest number is that of the non-expert, and shows the highest values those expert in the contrary, it was confirmed similar tendency also in carbon fibers.

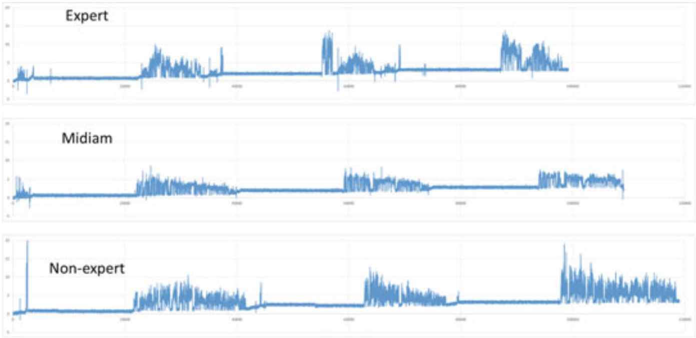

Fig. 7 The pressure in the Z direction

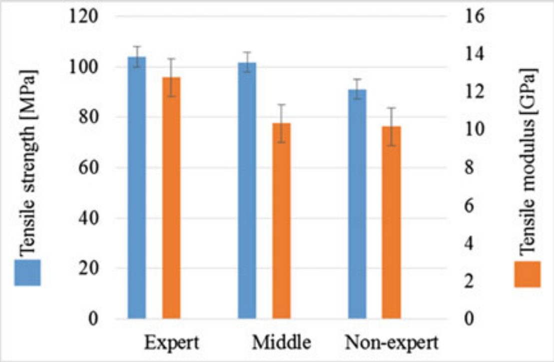

Fig. 8 Mechanical properties of GFRP

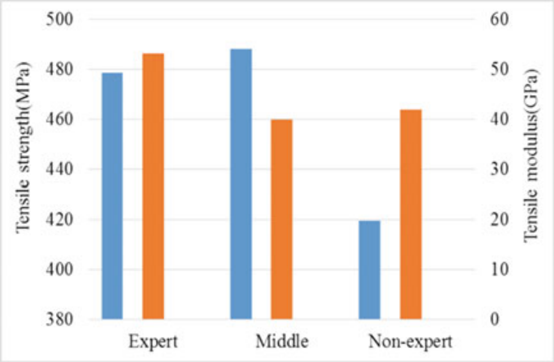

Fig. 9 Mechanical properties of CFRP

3.6 Cross-Sectional Observation

Cross sections of GFRP and CFRP with an optical microscope were shown in Figs. 10 and 11. Fracture surfaces of GFRP and CFRP observation by SEM were shown in Figs. 12 and 13. The glass void, it is understood by cross-sectional observation with an optical microscope that are eliminated according to the area skill only resin carbon. Also, it is understood that the resin adhering to the fibers according to the well skilled in the fracture surface is increased.

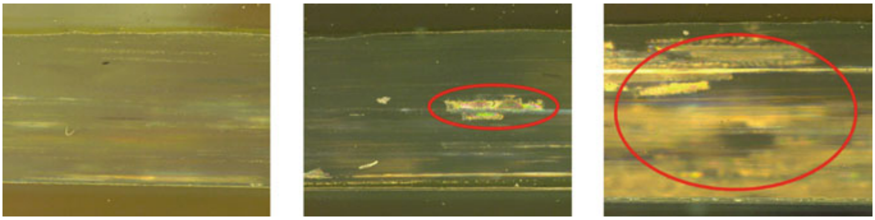

Fig. 10 Cross-sections GFRP

Fig. 11 Cross-sections of CFRP

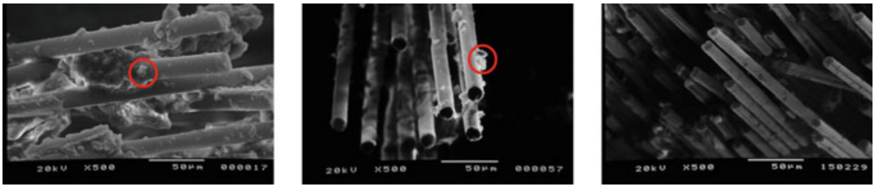

Fig. 12 The fracture surface observation by SEM (GFRP)

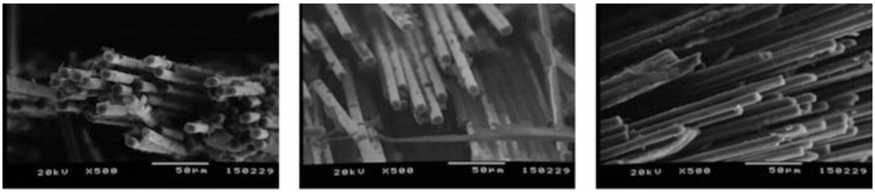

Fig. 13 The fracture surface observation by SEM (CFRP)

4 Conclusion

First, as a summary of GFRP, mechanical properties are increased in proportion to the skill of the void as this factor, Vf, was found to be the interface. When the explicit knowledge of the tacit knowledge of the order to these optimizations, impregnation confirmation at the time of molding. It was revealed that pressure applying roller corresponding to the reverse flow of the void is important.

Next, as summarized in the CFRP, Mechanical properties are increased in proportion to the skill level, the interlayer as the factor, Vf, was found to be the interface. When the explicit knowledge of the tacit knowledge that these optimization, It was revealed that the molding method that imparts a higher pressure to eliminate the space only between the layers of the resin not only the impregnation is important.

Part II

Human Aspects in Textile Manufacturing and Product Evaluation

Interval Timing Analysis of Behavior Patterns on "Kana-Ami" Making Process

Zelong Wang, Ken-ichi Tsuji, Toru Tsuji, Yuka Takai, Akihiko Goto and Hiroyuki Hamada

Abstract In this paper, the motion making technique of Japanese traditional handicraft was analyzed by motion analysis system. Two experts were employed as expert and non-expert for comparison. The feature of interval time for each main work process was paid attention. The interval timing during the weaving process was clarified to investigate the proficiency of weaving technique quantitatively. It is found that expert was able to go into working state easily.

Keywords Kana-ami · Interval time · Motion analysis · Expert · Non-expert

1 Introduction

"Kana-ami" is a kind of Japanese traditional handicraft. The "Kana-ami" products in Kyoto dish were played an important role from generation to generation. "Kana-ami" structure has been popular in Japan since the "Kana-ami" kitchen tool was invented one thousand years ago. "Kana-ami"—a kind of metal wire network based on hexagon structure. As same with other traditional handicraft industry, "Kana-ami" is not only shedding handicrafts every year, but losing its future workforce too, as the traditions of family succession dwindle. It has already decreased dramatic year by year due to mechanization production's difficulty and lacking heritage consciousness of handicraft technique. Many young people shy

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away from this career because it has to take a long time training to become an expert. Therefore, it is the urgent time to pay attention to this severe reality and do something to shorten the training time.

Referring to our previous study, “Kana-ami” was all made by hand work, so the processing motion technique makes a big effect on final products’ quality and craft-man’s long-term working efficiency. There was a short pause before each weaving motion during expert’s making process, which was considered as a regular pattern of motion changing, called interval timing, enhances the fingers the coordinated ability, control the muscle the strength and present a kind of weaving rhythm feeling.

The weaving process of crossed rotation was a short movement, which can considered as the unlimited repetitive movement, the craftsman had to repeat time and time again during “Kana-ami” product weaving process. It is required that the craftsman needs to have the strong fingers strength with endurance. However, even if for a craftsman, who has several experience years, has to takes a large of physical strength and finger power. Therefore, a good craftsman understood to apply finger power concentrated in the process of “Main task1”. According to previous research, the “Main task1” was most important process, which must be control speed and power very well in order to ensure product’s aesthetics and durability. Additionally, the weave the rhythm was also deemed to an important element for crossed rotation process, which can help craftsman to better control of the speed and strength of making “Main task1”.

In this study, the expert and non-expert’s interval timing during “Kana-ami” making process was focused and measured by motion analysis system. More importantly, this characteristic interval timing was expected to explain expert’s long-time stable product making. In other words, specific interval timing of experts made themselves feel more relax and obtain enough rest to burden long-time fatigue of making “Kana-ami” process, which let them keep the stable good quality of products. Therefore, it is very interesting to analyze and compare the motion gesture between expert and non-expert during interval time.

2 Experiments

2.1 Participants and Subject

In this study, the subjects were two males who had experienced wire netting technique for 48 years and 12 years respectively, which called expert and the non-expert. The expert and non-expert not only have parent child relationships but also have mentoring relationship. And both of them would be committed to heritage this Japanese handicraft technique of ‘Kana-ami’.

The participants were required to make one “Kana-ami” product of Tofu scoop. Figure 1a shows a photo of a completed sample. The Tofu scoop was

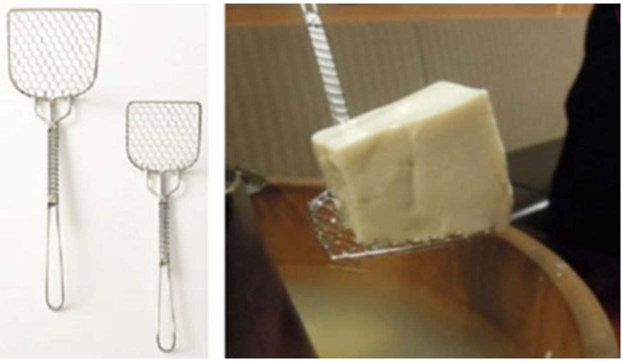
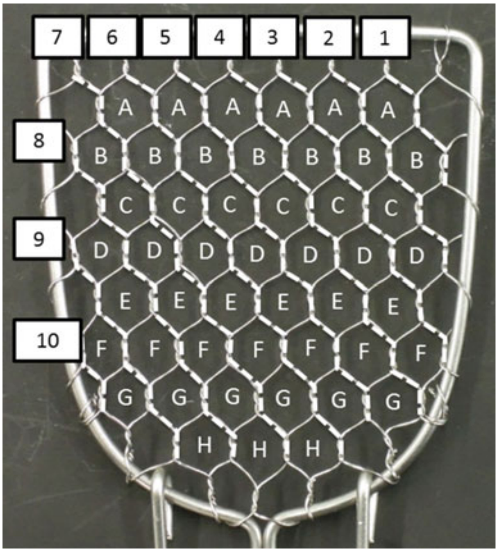


Fig. 1 “Kana-ami” of Tofu scoop

Fig. 2 The oblique row of “Kana-ami” structure



applied to scoop Tofu in Japanese cuisine of YuTofu as shown in Fig. 1b. The hexagonal pattern was started and twisted from 1st oblique row to 10th oblique row according to weaving order. Figure 2 was illustrated a schematic detailing the making process of a hexagonal pattern of wire network.

The detail weaving method was displayed in Fig. 3. According to Fig. 3, the “Kana-ami” product was consisted of Hexagonal structure, which was weaving by two metal wire crossed by two times in double side. The metal wires were weaved into oblique row from upper right to lower left. Each oblique row was weaved from upper left to lower right. Therefore, the crossed rotation process was considered as most important program during “Kana-ami” weaving process. The weaving process of first crossed rotation was called as “Maintask-1”, and the second crossed was

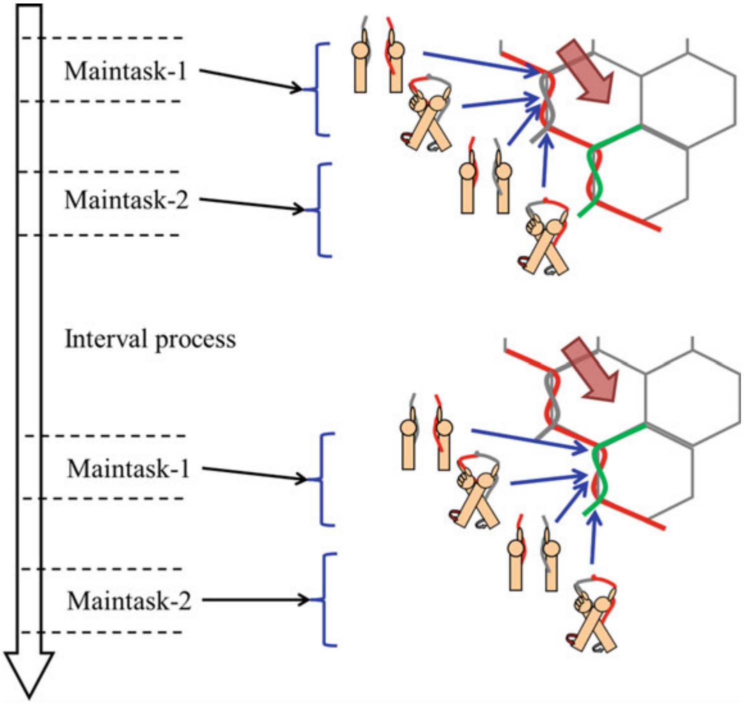


Fig. 3 The weaving method of "Kana-ami" hexagonal structure

called as "Maintask-2". There was some working time between weaving the up and down two hexagons as shown in Fig. 3, which was called "Interval process" in this research.

2.2 *Motion Analysis*

The three-dimensional motion capture system was used for evaluating the motion of making wire nets. (Hawk-I; Motion Analysis Co. Ltd.) The infrared reflection markers were affixed at 21 points on the body of the subject to analyze motion during the wire netting as shown in figure. And six cameras captured the position of each marker in the X, Y and Z directions with 100 Hz sampling rate. All markers position data were synchronized and entered into a computer. Both expert and non-expert's final products were recorded under the former predetermined condition as shown in Fig. 4.

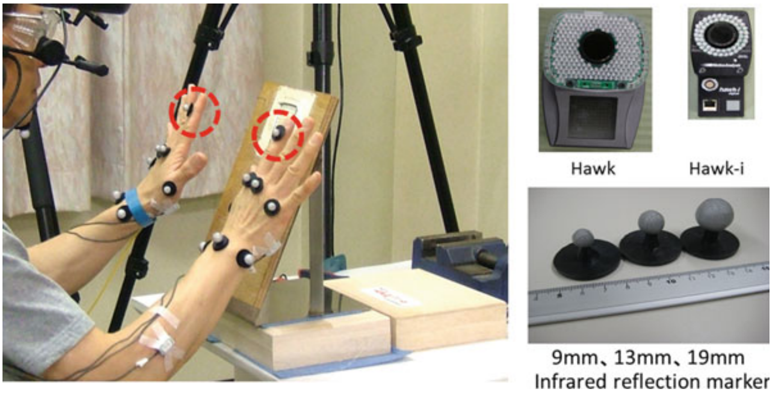


Fig. 4 Motion analysis experiment

2.3 *Interval Timing Analysis*

The index fingers of left hand and right hand were paid attention in this research as shown in Fig. 4. The expert and non-expert's weaving process of "Main task1" and "Main task-2" were extracted one by one. The velocity of first three hexagons of row7 made by expert and non-expert were illustrated in Fig. 5. The "Main task1" and "Main task2" were marked by red lines. The "Interval process" also was illustrated in Fig. 5.

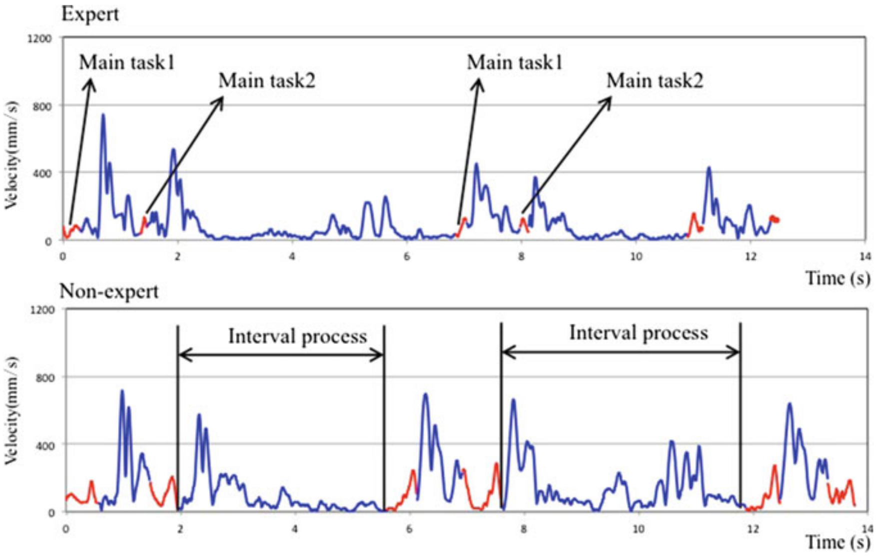


Fig. 5 The schematic diagram of velocity graph for expert and non-expert

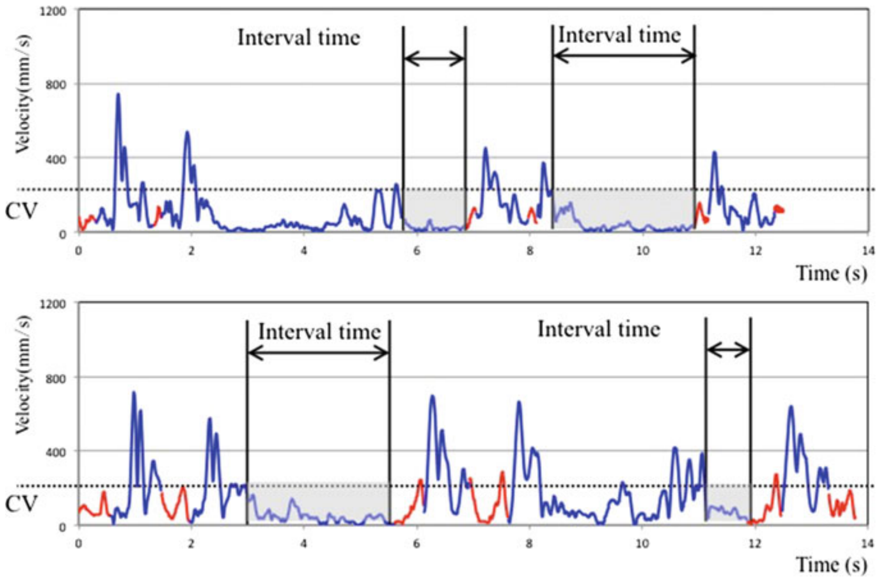


Fig. 6 The schematic diagram of interval time

As mentioned above, the short time before "Main task1" was focused corresponding to critical velocity (CV). As shown in Fig. 6, the interval time was defined as the short time from the last moment that velocity less than the CV to before "Main task1". It was regarded as a preparation state of working process to adjust the working status, which can reflect the working condition. Interval time will change according to the critical velocity. In this research, the velocities of 25, 50, 100, 150, 200, 250, 300, 400 and 500 mm/s, were employed as CV to investigate the interval time in order to compare the different between expert and non-expert.

3 Result and Discussion

The expert and non-expert's average interval times of left hand and right hand corresponding to each row were presented in Figs. 7 and 8. In case of Left hand, the interval times of expert and non-expert were shown small value when CV was 25 and 50 mm/s. The non-expert's interval time presented significant increasing when CV was larger than or equal to 100 mm/s. Comparing with non-expert, expert appeared obvious dividing velocity when CV was 200 mm/s. The interval times of non-expert's left hand were presented concentration trend when CV was larger than 150 mm/s. In other case of right hand, the expert's interval time shown the lower value when CV was less then 150 mm/s, and displayed obviously change when CV larger than 200 mm/s. The non-expert's interval time shown lower value when CV

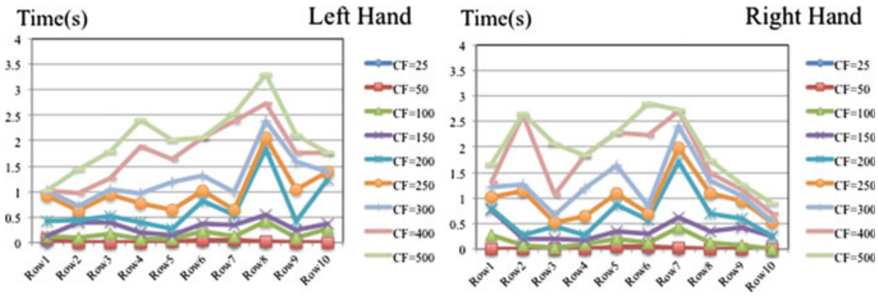


Fig. 7 Average interval time left hand and right hand of expert corresponding to each row

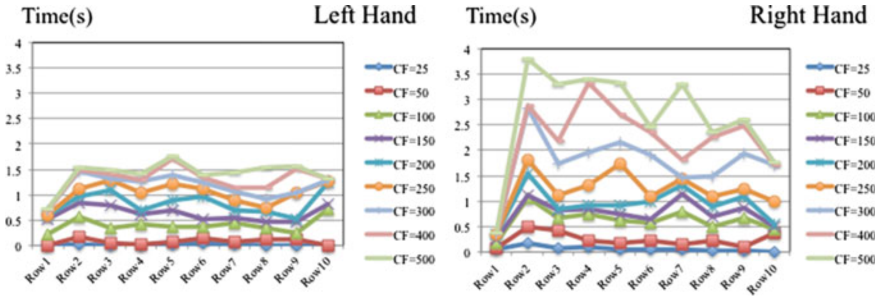


Fig. 8 Average interval time left hand and right hand of non-expert corresponding to each row

small then 50 mm/s. Compared between expert and non-expert, non-expert shown larger interval time when CV was larger than 300 mm/s. It was considered that the expert shown the stability of preparation with current speed of finger movement. The expert's index finger of left hand and right hand was stable at the velocity of 100 mm/s during the preparation period before making "Main task1". The non-expert's index finger of left hand was stable at the velocity of 50 mm/s, but the interval time did not have obviously change when CV was larger than 100 mm/s, which can deem that the non-expert shown high velocity of left index finger before "Main task1" making. And shown very slow velocity of right index.

The total interval time of left hand and right hand of expert and non-expert were summarized in Figs. 9 and 10. Both expert and non-expert's interval time of left hand were larger than right hand. Expert's interval times of left hand and right hand were larger than non-expert. The total interval time of expert's left hand and righ hand shown steadily increasing with similar trend when CV was increasing, which left hand was larger than non-expert, and right hand was small than non-expert. The interval time showed obviously increasing between 150 and 200 mm/s. According to Figs. 9 and 10, the expert presented lower value of total interval time when CV was small, and presented larger value when CV was large. It was deemed that expert could maintain a prepared readiness with current speed of index fingers.

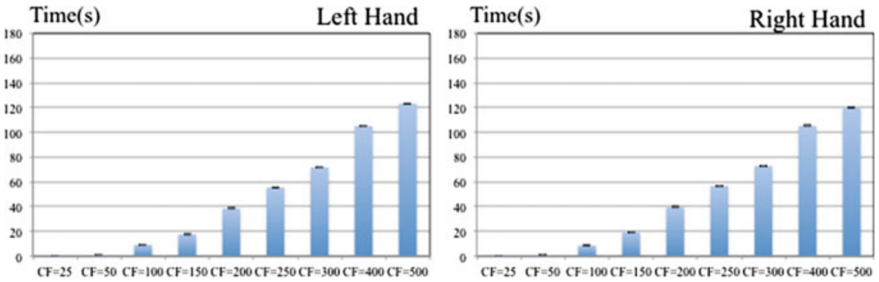


Fig. 9 Total interval time of left hand and right hand of expert corresponding to nine CV

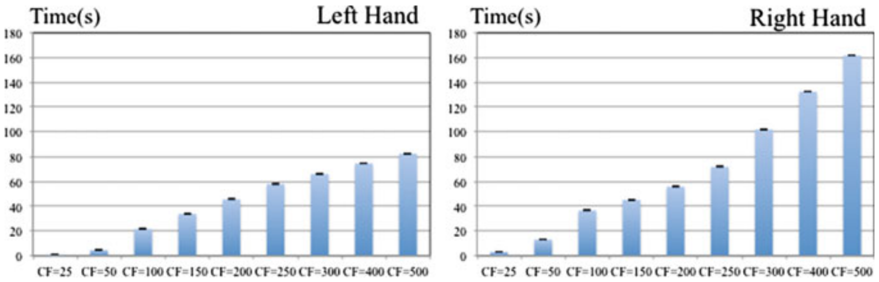


Fig. 10 Total interval time of left hand and right hand of expert corresponding to nine CV

4 Conclusion

In a word, expert shown similar trends of interval time between left hand and right hand, which were presented very small values when CV was 25 and 40 mm/s. Left hand of Non-expert was shown smaller value then expert, and right hand of Non-expert shown larger value then expert. The expert could maintain a prepared state with a current speed of double hand, which was considered to be a working rhythm made the energy to focus on key weaving process.

Study on Braiding Skills of Experts with Eye Movement Measurement and Operating Analysis

**Kontawat Chottikampon, Shuhei Yasuda,
Suchalinee Mathurosemontri, Akihiko Goto and Tadashi Uozumi**

Abstract A braiding rope is the Japanese traditional rope that a quality and beauty of them have depended on the skill and experience of a braider. In this research, the skill of the expert and two non-experts who practice the braiding everyday and every week, respectively were measured and compared through the eye's movement measurement and observed the braiding rope quality. The measurement was carried out every month for three times. It was found that the expert showed the constant of eye's focus at the center of a marudai plate and revealed a complete pattern of braiding rope. For two non-experts, their eye's movement wobbled around the marudai plate for all trials. However, the braiding speed and quality were developed by the regular training. There are no defects in the ropes in the trial number 2 and 3.

Keywords Braiding · Kumihimo · Eye's movement measurement · Braiding skill

1 Introduction

Kumihimo can be defined as a braided cord. The word has come to represent, in a larger sense, one of the least has been known on the traditional arts and crafts of Japan. Due to a cord's small, inconspicuous presence, it is often overlooked, even

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in discussions related to kimono dress. The obi, a wide 5 m long sash, is a substantial component. An 'obijime' is required to hold the obi, and everything underneath it, in place, Obijime are usually narrow braided belts, 2.5 m in length (three examples in photos at lower as show in Fig. 1.

In Japan, in Fig. 2 braided cords are also used for religious ceremonies, ornament on festival carts, tea ceremony containers, ribbons for mirrors, fans and inro, and most recently for attaching cell phones to belts, purses, etc.

For braiding method, marudai (Round stand) is the most common stand that can produce braids by either round, square, or flat. While being worked, the finished braid is pulled downward by a counterweight as shown in Fig. 3.

To investigate the effect of braiding skill on braiding rope quality the expert and non-experts were studied their eye movement and rope position during braided process.

Fig. 1 Example of Obijime [1]

Fig. 2 Kumihimo or braided cord styles [1]

Fig. 3 Marudai [1]

2 Braiding Method

The working arrangement for braiding requires threads that are held under tension. In Fig. 4, eight fine silk threads are bundled and wound around wooden bobbins that are weighted with lead to reach 85 or 100 g. The braiding on the marudai balance is achieved by the addition of a counterweight that weighs roughly half of the combined weight of all the bobbins used. The bobbins are lifted across the top of the marudai in pairs [2].

The braiding method is shown in Fig. 5. The strands were crossed each other by start from moving the strand A across strand B and strand E across strand F. After that move strand C across strand D and strand G across strand H. Next the strands are braided anticlockwise. To start by moving the strand F across strand C and strand B across strand G. Finally move strand D across strand A and strand H across strand E. Continue the braiding from first step until finish.

Fig. 4 Threads are tied to bobbins

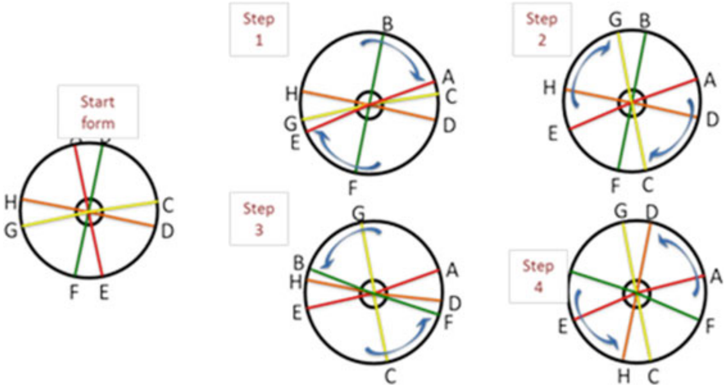

Fig. 5 Braiding method

3 Experimental

In this research, there were three subjects of the expert and two non-experts. The expert taught both of the non-experts how to fabricate kumihimo. By the first non-expert has to practice the braiding every day but the second non-expert practices only one time per week. The time period was operated for 2 months. For eye movement analysis [3, 4], the subjects were measured their eye movement for three times as tabulated in Table 1.

The first started after the expert taught two non-experts how to braid kumihimo. The second and the third were measured after 1 and 2 month later.

4 Comparison of Braiding Rope Quality

A quality and a beauty of the braiding rope of the expert and non-experts were observed. Figure 6 shows photographs of braiding ropes. The braiding rope of the expert revealed the complete braiding pattern along the rope. The quality of braiding ropes that were fabricated by both of non-experts at the first trial showed

Table 1 Summary of the experimental

Sample	Braiding practiced time	Eyes movement testing
Expert	X	1st
Non-expert 1	Everyday	1st, 2nd and 3rd
Non-expert 2	1 time/week	
1st	2nd	3rd
First day	After 1 month	After 2 month

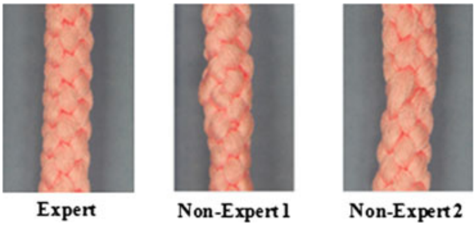

Fig. 6 Photographs of kumihimo ropes from the expert and two non-experts

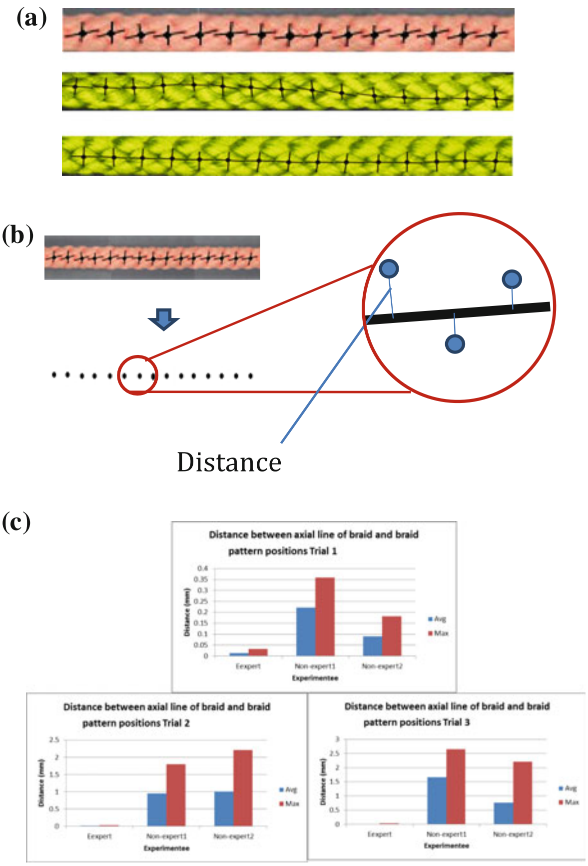

Fig. 7 Observation of distance between axial line of braid and braid pattern positions. **a** Photographs of braiding ropes **b** Distance between axial line of braid and braid pattern positions measurement **c** Distance between axial line of braid and braid pattern positions

the defects due to the incorrect pattern. However, the everyday practice of braiding for one month of the non-expert 1 led to the development of braiding speed and the beauty of the braiding rope. There was no the defects of the incorrect pattern both of trial 2 and 3. For the braiding rope quality of the non-expert 2, they were also no defect in the braiding ropes in trial 2 and 3.

Because expert is always process at the middle of the marudai, she can control the angle of the braided rope, which was better than both non-experts. Figure 7 shows photographs of the ropes with distance between axial lines of the braid and braid pattern positions. The expert rope line showed a straight line over the non-experts. Figure 7c presents the distance from the center to the rope that the expert has less distance for making the straight line, which looks beautiful when compared to the non-experts.

5 Eye Movement Analysis

Figures 8 and 9 shows the eye's movement position of 1st, 2nd, 3rd and 4th process. These figures present the position of eyes in 4 braiding process. In trial 1, 2, 3 the expert revealed the position in the middle of the marudai from starting to ended process. On the contrary, both of non-experts are more distribution when compared with expert.

6 Braiding Rope Position

Figure 10 depicts the position of the braided rope during braiding process. The position of the rope was directly influenced by the tension of each thread. The braided rope positions of an expert scatter around the center of the marudai while the non-experts show the unsymmetrical scattering of the rope positions. The unsymmetrical distribution of the rope position is caused by the instability of the tension of the thread during braiding process.

7 Angle Rope During Braiding Process

Figure 11 illustrates the angle of rope. The angle rope of the expert has in the range of 170°–180°. On the othe hand, the non-expert has the range from 160°–180°. As a result, the expert can control the position of the rope while braiding process.

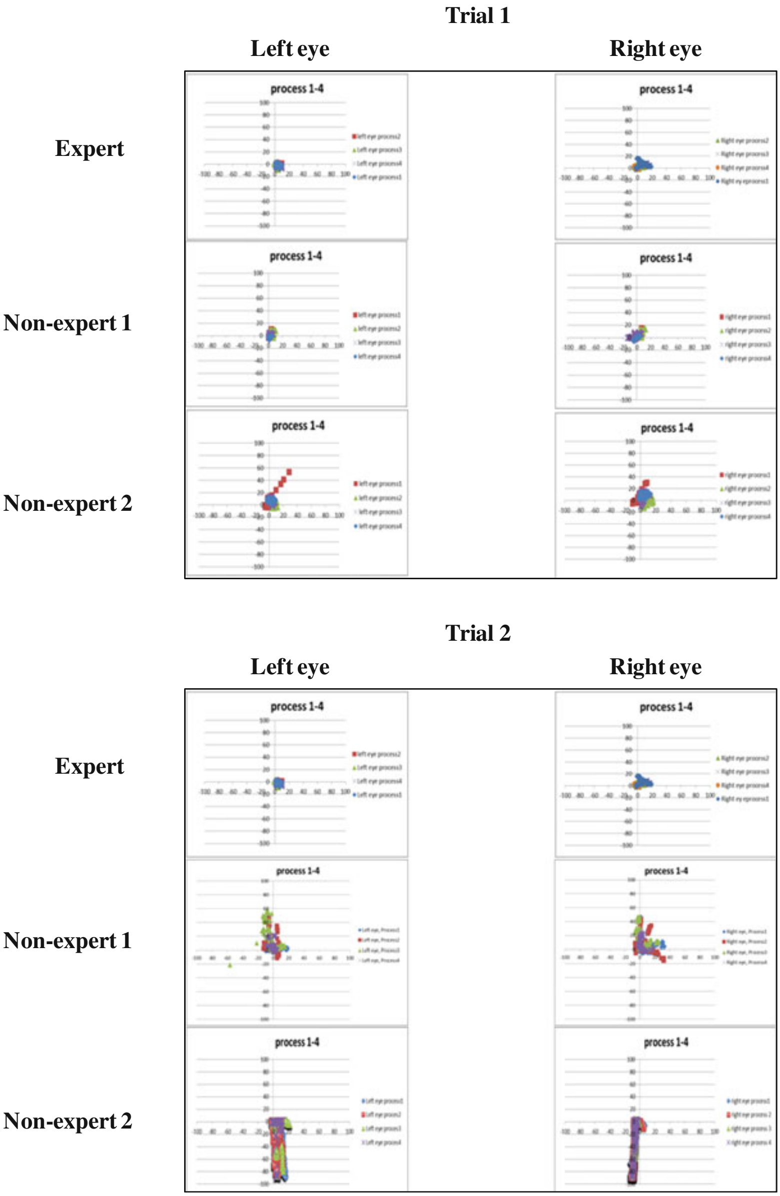

Fig. 8 Eye's movement of the expert and non-experts during the braiding process trial 1–2, respectively

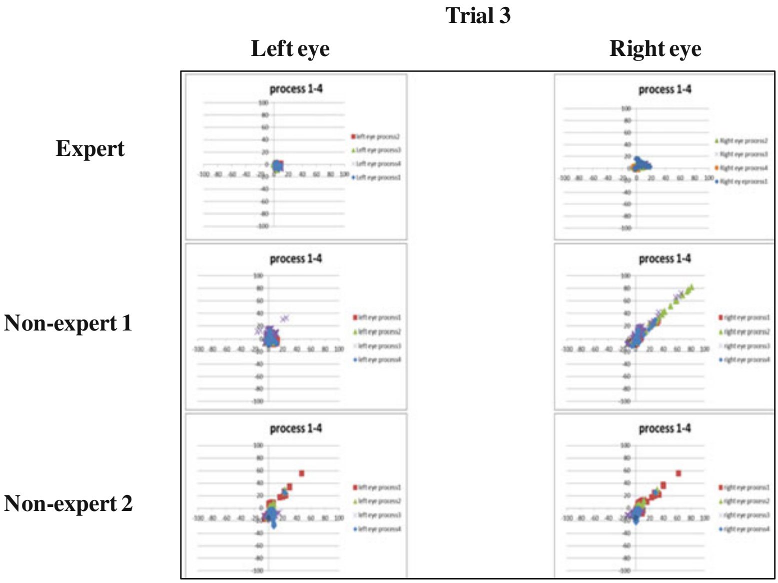

Fig. 9 Eye's movement of the expert and non-experts during the braiding process trial 3

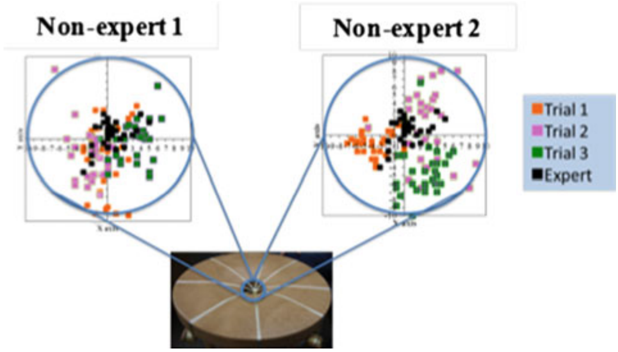

Fig. 10 Braiding position of the expert and non-experts around the marudai

8 Distance Raising Rope During Braiding Process

Figure 12 presents the distance of rasing rope during the braiding process. As the comparison, it can be seen that the rasing of rope of the expert exhibited constantly while both of non-experts rose up the rope uncertainty during the braiding process. Therefore, the skill of braiding led the beneficial on the quality and the beauty of the

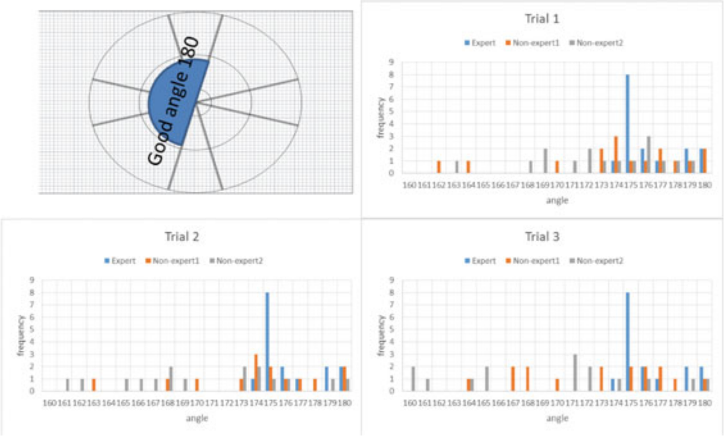

Fig. 11 Measurement of the angle of the rope around the marudai

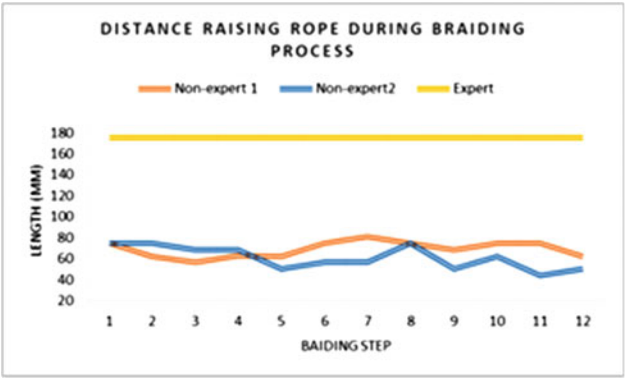

Fig. 12 The distance of raising rope during the braiding process

braiding. For the expert, she raised ropes higher than marudai around 17 cm whereas non-experts show the results around 4–8 cm. It can say that this difference affected the softness and beauty of products.

9 Conclusion

The expert showed the high performance and constant of braiding skill. Her eye's movement focused at the center of the marudai plate that according with the braiding rope position. The expert can balance the rope tension during the braiding process well. On the other hand, the eye's movement of non-experts did not relate with the braiding rope position. However, the braiding experience of non-experts revealed the improvement on their braiding speed and the quality of braiding ropes.

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Study on the Effect of Arm Movement in Knitting Process on Knitting Quality

Kontawat Chottikampon, Suchalinee Mathurosemontri, Tadashi Uozumi, Akihiko Goto, Tiemi Funatsuki, Miyako Inoda and Hiroyuki Hamada

Abstract This research interested on the developing the ability of knitting skill. The comparison of skill between the experts with non-experts was studied. The movement of arms was measured to examine the effect of arm movement on quality of knitting fabric. The experiment was carried out with a video camera to record and analyze the differences of the knitting speed and manner in knitting. The quality of the fabric was measured by a loop of fabric to see the consistency of the loop fabric, which is important for beautiful fabrics. The results revealed the procedure used to crochet knitting machines were very different in appearance, knitting and speed. The quality of the fabric was beautiful, similar to the use of the knitting as machine knitting. The main difference between them was only part of the seams.

Keywords Knitting · Arm movement measurement · Knitting skill · Plain pattern

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1 Introduction

Knitting is the second most important method of fabric formation. Knitting is a process of manufacturing a fabric by interlooping of yarns. It can be defined as a needle technique of fabric formation, in which, with the help of knitting needles loops are formed to make a fabric or garment. Fabric can be formed by hand or machine knitting but the basic principle remains exactly the same i.e. pulling a new loop through the old loop. A wale is a vertical column of loops produced by the same needle knitting at successive knitting cycles. The number of Wales determine the width of the fabric and they are measured in units of Wales per centimeter. Courses are rows of loops across the width of the fabric produced by adjacent needles during the same knitting cycle and are measured in units of courses per centimeter. The courses determine the length of the fabrics [1].

Manual knitting machines require the knitter to move the specific needles, based on a chart, into pattern position [2, 3]. In this research I study the knitting structure is plain and rib. Plain knit, the basic form of knitting can be produced in flat knit or in tubular (or circular) form. It is also called jersey stitch or balbriggan stitch. A row of latch or beard needles is arranged in a linear position on a needle plate or in a circular position on a cylinder. Rib stitch produces alternate lengthwise rows of plain and purl stitches and as such the face and back of the fabrics are a lookalike. Rib stitch can be produced on a flat rib machine as well as circular rib machine [4].

2 Experimental

One expert and six non-experts were recorded their movement during knitting process. By all of them used the same material and the similar pattern in this experiment. Figure 1 shows the knitting process and the pattern in this study. The process is left to right and right to left.

3 Results and Discussion

3.1 Knitted Fabrics

Figure 2 shows photographs of the final knitting fabrics from the expert and the non-experts. It is difficult to inform which one is poor or good quality by eyes. Therefore, we informed a way to measure the quality of the fabrics in the next section.

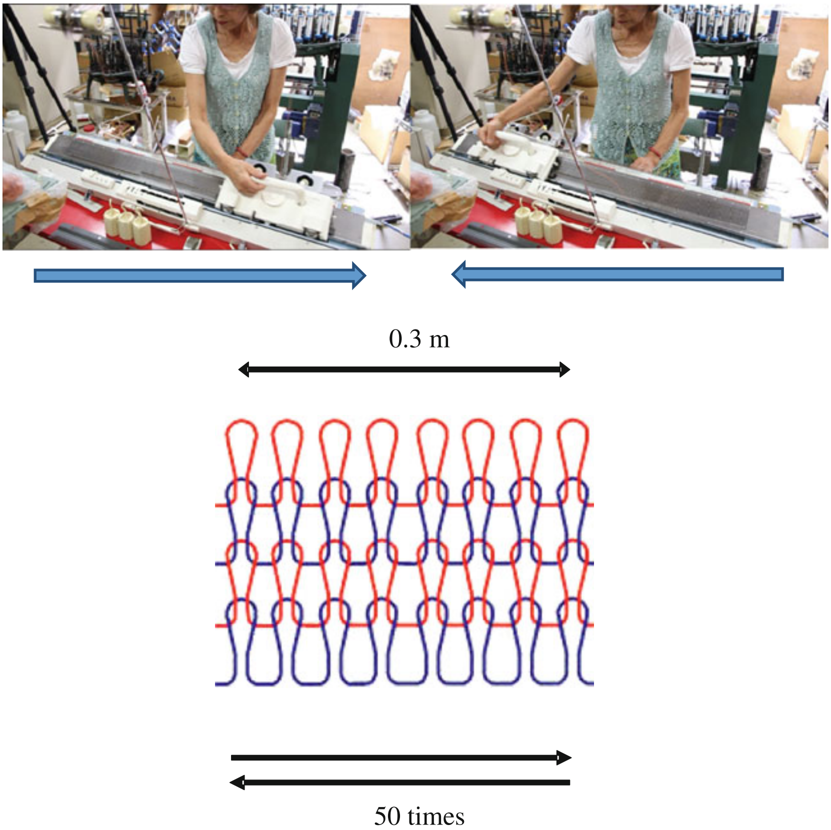


Fig. 1 Knitting process

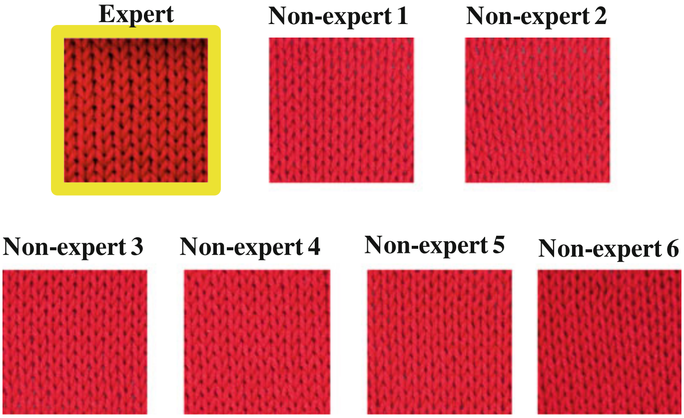


Fig. 2 Photographs of knitting fabrics from the expert and the non-experts

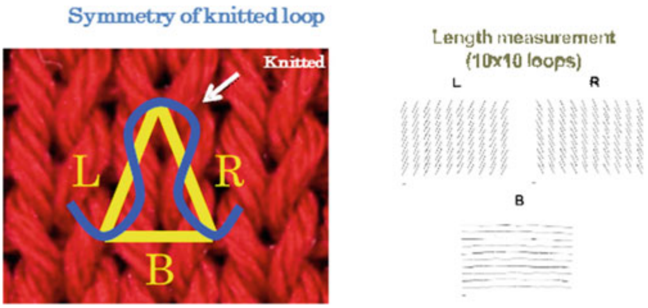


Fig. 3 Observation for the quality of knitted fabrics

3.2 Quality of Knitted Fabrics

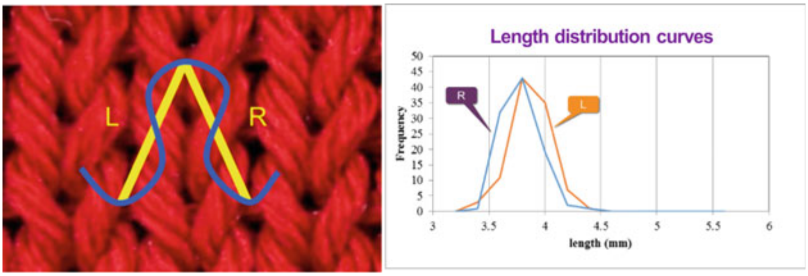
The quality of the knitted fabric has been validated by the symmetry of the knitted loop. The blue line represents the loop knitting patterns. The length from the center of the curve to the left side of the curve, as measured on the right. In addition, the length from the center of the curve, it is also a right-left curve as shown in Fig. 3.

3.3 Symmetry of Knitted Loop of the Expert and Non-experts

Figure 4a presents the length of the loop at left and right of the expert performance in a relatively symmetrical distribution curve length. Figure 4b–4g shows the results from non-experts. It can be seen that both non-experts 2 and 4 exhibited the symmetry of the band, while others revealed asymmetry between the sides and lateral L R.

3.4 Relatively Handle Moving Distance and Times of the Expert and Non-experts

Figure 5 shows the relative handle moving distance and times of expert. The moving distance is in range of −0.3 to 0.3. When compare with non-experts, it was found that the non-experts took longer time for moving the handle from left to right. However, their distances were in the same range as shown in Fig. 6.



(a) Expert

Symmetry of knitted loop of Non-expert (L-R)

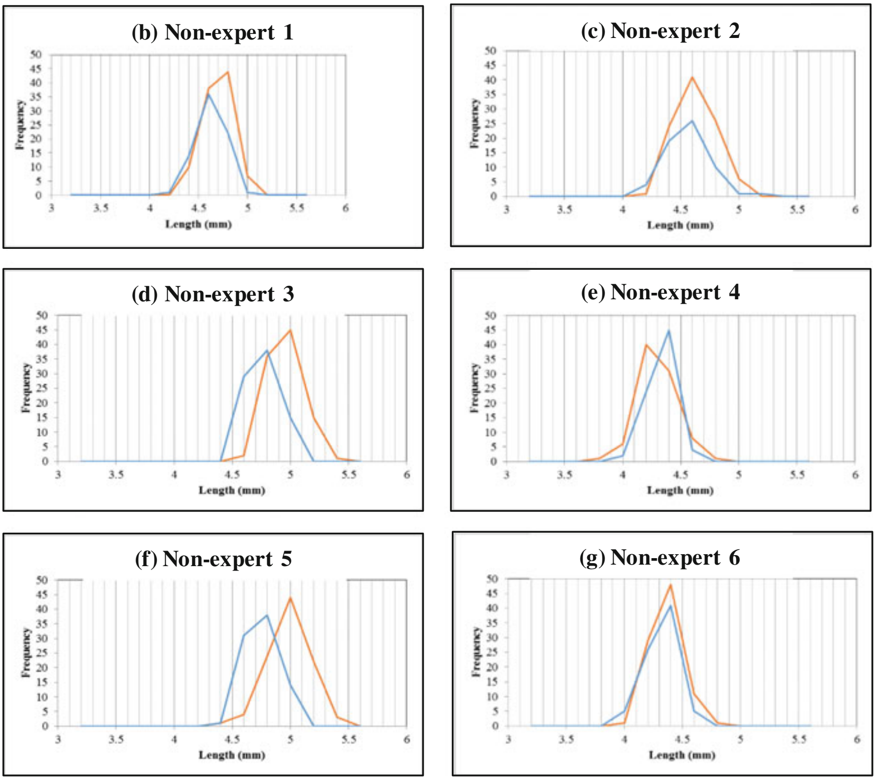


Fig. 4 Symmetry of knitting loop from the expert and the non-experts

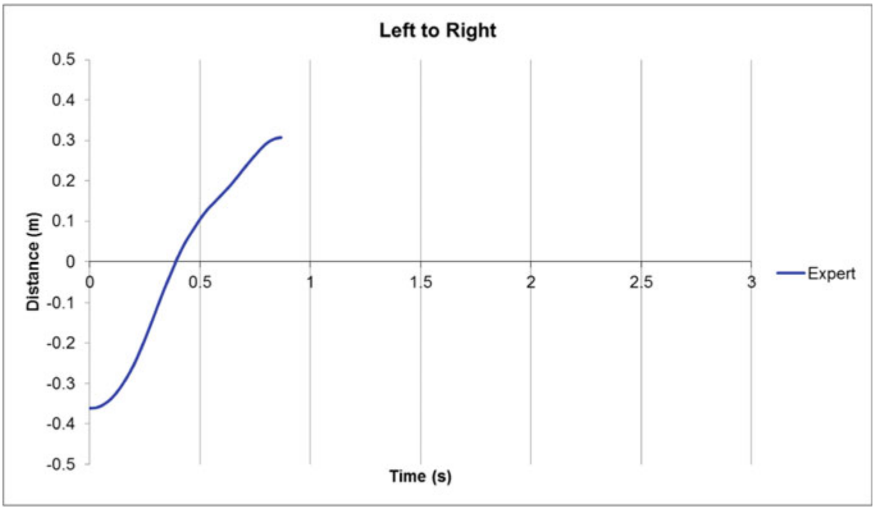


Fig. 5 Relatively handle moving distance and times of the expert and non-experts

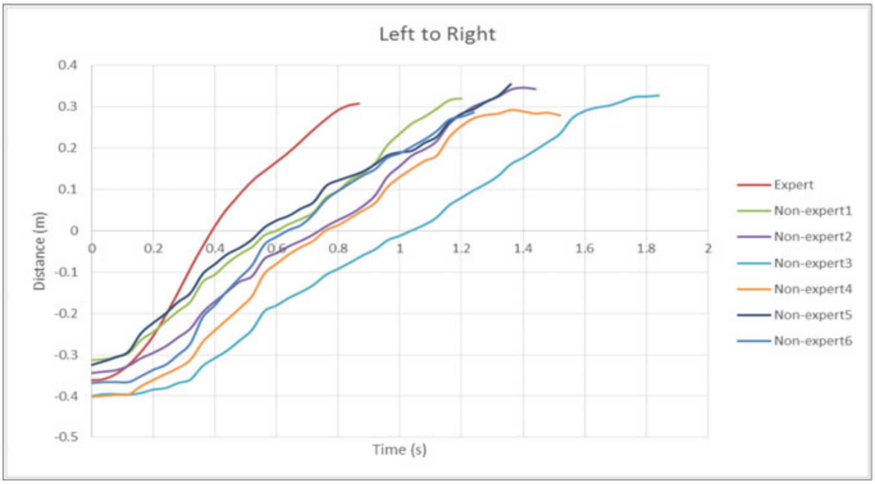


Fig. 6 Movement of the handle from left to right at the knitting of the expert and non-experts

3.5 *Relatively Velocity and Times of the Expert and Non-experts*

Figure 7 presents the relative of velocity and times of the expert. The velocity rapidly increased and dropped obviously. The velocity decreased due to high fiction when handle slided pass the fabric as a circle shown in Figs. 7 and 8.

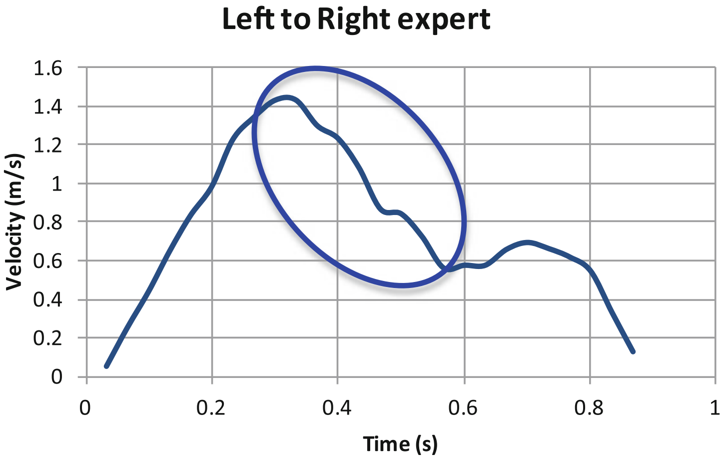


Fig. 7 Relatively velocity and times of the expert

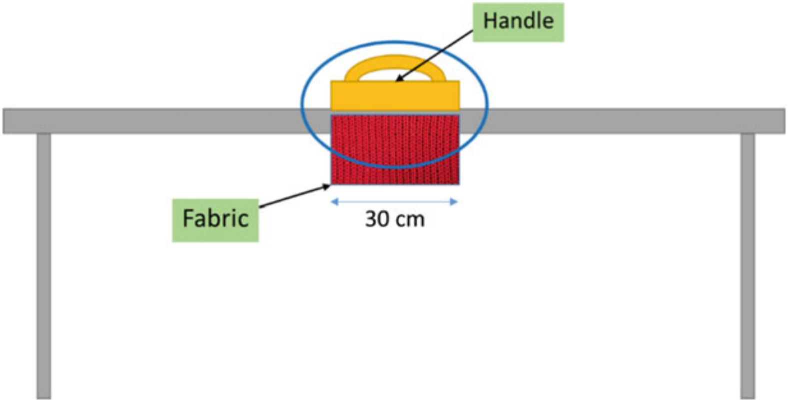


Fig. 8 Position of knitting fabric

Figure 9 depicts the comparison of the velocity between the expert and non-experts. The range of velocity that the handle slided along the fabric of the non-expert was lower than the expert.

For the expert, the acceleration rapidly increased and dropped obviously. Because the high fiction occurred when handle moved pass the fabric, the results of the non-experts are quite different from the expert as presented in Fig. 10. Although the tendency of them were quite similar, their curves of relationship between time and acceleration did not smooth when compare the expert. When the handle were

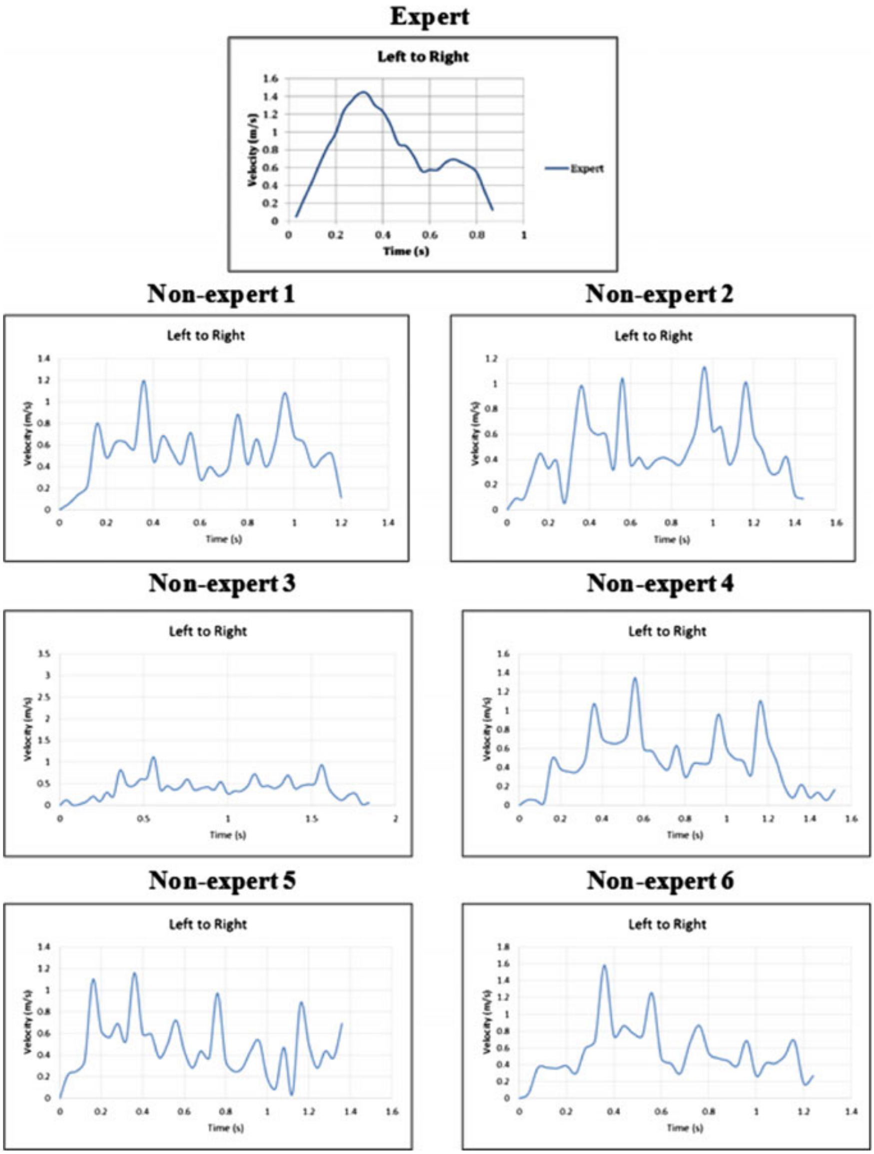


Fig. 9 Relative velocity and times of the expert and non-experts

moved pass the fabric, there was high variability of acceleration. This may cause the less familiarity of the non-experts. The action of arm movement is also important for forced that propel the handle.

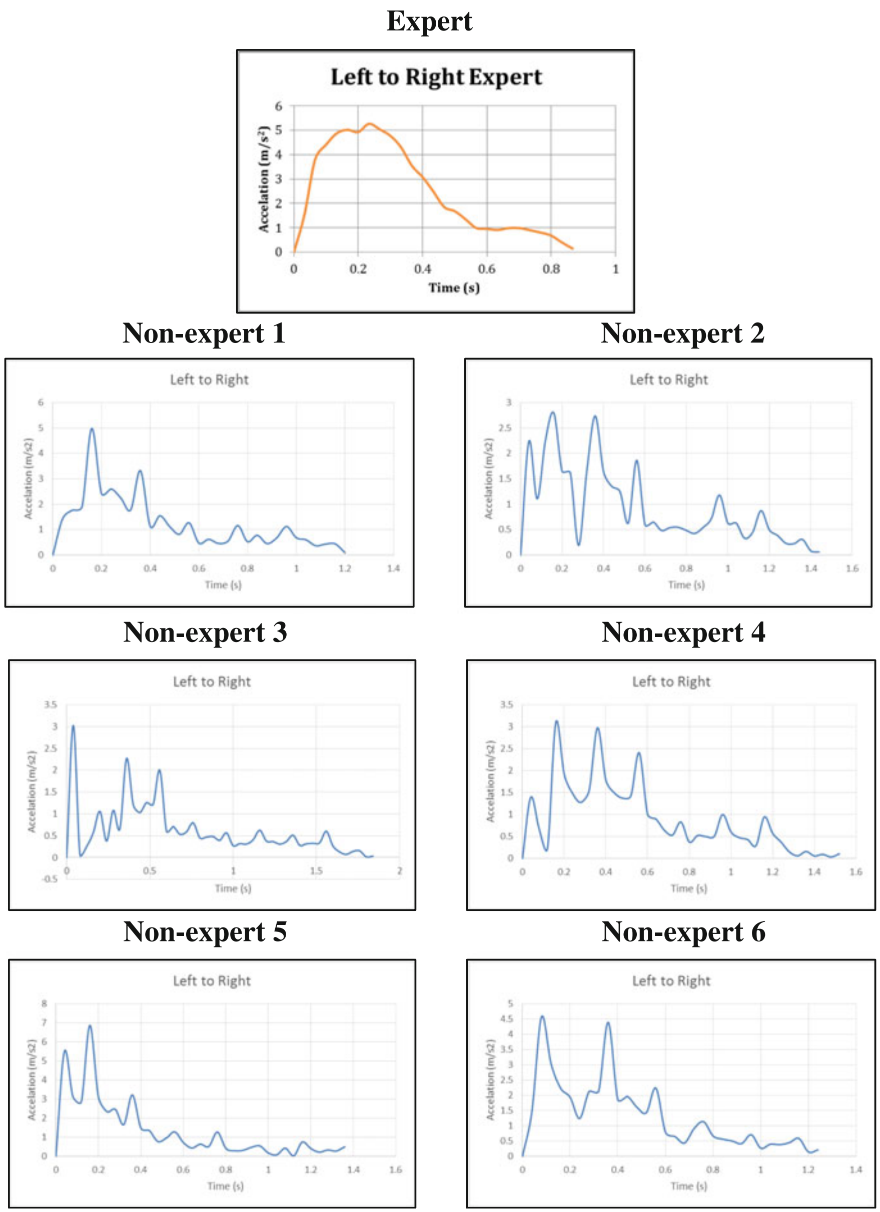


Fig. 10 Relative acceleration and times of the expert and non-experts

4 Conclusion

Comparative analysis of the movement of the arm between the expert and non-expert knitting has been reported. Experts have shown that the speed of knitted up using only the arms move. While experts are not using the rotation of the body, and some experts are not moving their bodies together a deal to move to support the movement of the arms, because they hold the catch invalid. That led to the knitting speed is slower compared to the experts. Speed Knitting higher impact on large areas of the loop knit. The next test for non-experts to IMI-Tate behavior knitting expert, especially the arms and hold the position and measuring the working of muscle. Then compare the quality of their fabrics and speed knitting.

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Part III
Ergonomic Design of Future Production Systems

Model-Based Evaluation of Cooperative Assembly Processes in Human-Robot Collaboration

Marco Faber, Sinem Kuz, Alexander Mertens and Christopher M. Schlick

Abstract The increasing variety in product range demand high flexibility of the production technologies and assembly systems of producing companies. Integrating the human into the assembly process by establishing collaboration between the human and robotized assembly systems seems to be a promising approach to achieve this flexibility even for very small lot sizes. This paper presents a model for assessing the ergonomic risk in such collaboration scenarios. Criteria for assigning assembly steps to the human or the robot are introduced as well as for describing the physical and cognitive ergonomic risk of an individual assembly step. The presented risk model is finally applied to the process of assembly sequence planning, in order to find the optimal assembly sequence in situations of human-robot collaboration.

Keywords Human-robot collaboration · Ergonomic work conditions · Risk modeling

1 Introduction

Individualized and customized products get increasingly important. Otherwise, companies cannot satisfy sufficiently the specific customer demands or lose their position in the global markets. These demands result simultaneously in a large

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variety in product range and consequently in smaller lot sizes. Traditionally automated production systems fail to cope with such a variety, because their automation is not flexible enough to produce all variants of a product efficiently [1]. This is one of the reasons why products of small lot sizes are usually assembled manually by highly qualified and skilled workers [2]. The automated assembly would instead require manual adjustments of robotic control programs or redevelopment of parts of these programs for each new product variant. For flexibility and economical purposes, the amount of these non-value adding production processes should be reduced to a minimum.

One approach to achieve the desired flexibility of an assembly system is to combine an appropriate level of automation with human skills [3, 4]. Considering the human operator as an integral part of the production system combines the power of machines with extensive human skills. Due to the unique cognitive and sensorimotor skills of the human, the operator is able to take over assembly steps that cannot be automated by today's assembly systems such as handling limp components. Experience and creative thinking let the operator find solutions even to unstructured, not well-defined problems. In contrast, the robot can relieve the operator, for instance, by carrying heavy weights or taking over monotonous actions. Therefore, an effective function allocation between human and robot relieves the operator from too high mental and muscular stress and strain and reduces the risks and hazards for the human as well as the production costs [5–7]. Collaborative assembly cells are highly flexible and adaptive and are able to switch between different products, product variants, and lot sizes [4].

However, in order to establish safe and effective human-robot collaboration, dangerous situations for the human operator have to be avoided at all time of the cooperative assembly process. On the one hand, safety restrictions have to be satisfied, but, on the other hand, also the behavior of the robotic system must be understandable and clearly recognizable for the collaborating person. In addition, the robot has to adapt to the human dynamically, as the operator's behavior may be unpredictable for the automated system. Otherwise, the human operator will not be able to trust the system and will not accept the robot as a collaboration partner (e.g. [8, 9]). Due to their unpredictability in movements and actions robots have a higher probability to evoke injuries [3]. Though, the algorithms for assessing the risk of traditional machines are not sufficient for robots. Hence, it is important to appraise situations of human-robot collaboration with respect to the ergonomic risks for the human operator. This paper presents an approach of modelling this risk mathematically and applies it using a graph-based assembly sequence planner.

2 Assembly Sequence Planning in Human-Robot Collaboration

2.1 Influencing Factors on Human-Robot Collaboration

The interaction between human and robot is influenced by multiple factors. According to Rahimi and Karwowski [10] human-robot interaction systems can be decomposed in different influencing factors. The authors define this kind of interaction system as a tuple of

$$HRIS = (T, U, R, E, I). \tag{1}$$

Hereby, T represents the task requirements, U and R the user and robot characteristics, respectively, E describes the environment and I the set of interactions. Both task requirements and user characteristics can further be divided into cognitive and physical properties, whereas robot characteristics consist of software and hardware aspects. Hence, the interaction between human and robot can be influenced by many different factors, although this depends on the kind of interaction. Especially in cases of direct and indirect interaction or temporally and spatially shared interaction, their importance may vary significantly [11].

Against the background of examining trust in human-robot teams, Billings et al. [9] conducted a meta-analysis of empirical studies in the field of human-robot interaction and identified similar influencing factors. The most significant influence was found in the robot characteristics such as performance, appearance or proximity. A moderate effect could be found in the environmental characteristics including the task and the team. Human-related factors such as the abilities or the personality only revealed a small effect. However, these characteristics have indeed an influence in the context of direct human-robot collaboration during an assembly task. Considering human-robot team trust Billings et al. conclude that manipulating design and behavior aspects of the robot is the most effective instrument to calibrate trust, in order to achieve a successful interaction. Figure 1 summarizes the influencing factors on human-robot collaboration.

2.2 Derivation of Optimization Criteria for Assembly Sequence Planning

Depending on the influencing factors human, robot, and environment different optimization criteria for planning and evaluating situations of human-robot collaboration can be derived. Thereby, assembly sequence planning and function allocation between the human operator and the robot is focused. The optimization criteria have a different impact on the resulting assembly sequence, especially if the assembly system comprises multiple assembly robots or cells. Table 1 gives an overview about all optimization criteria within the context of this work separated

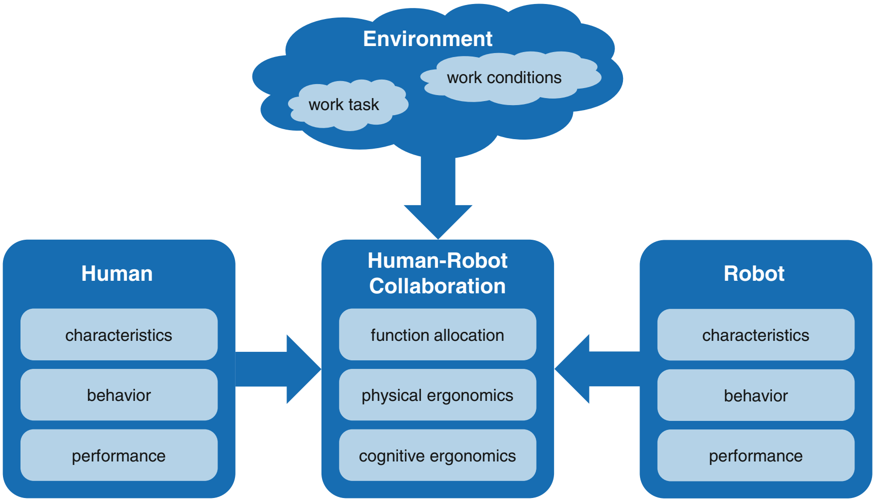

Fig. 1 Influencing factors on human-robot collaboration

Table 1 Optimization criteria for planning and evaluating human-robot collaboration

Category	Human	Robot
Function allocation	Availability Feasibility Execution time	Availability Feasibility Mountability Execution time
Physical ergonomics	Ergonomic risk Human-robot change	
Cognitive ergonomics		Transparency of assembly sequence Transparency of robot behavior
Environmental ergonomics	Work conditions (e.g. noise, lightning, temperature)	
Technical		Tool change

into criteria with respect to the human and the robot, respectively. The optimization criteria comprise the function allocation, i.e. whether the assembly step is performed by the human or the robot, ergonomic, and technical aspects.

The fundamental requirements for the function allocation and for being able to perform the assembly step are the availability of the corresponding resources and their capability to perform the assembly. The availability of the human operator may vary due to concepts such as job rotation, i.e. a systematic change of the workplaces over time. Hereby, the operator supervises multiple work stations or performs actions at these stations and is consequently available at only one station at the same time. The order of rotation can be considered as cyclic, but may also be random or at least irregular, which may be caused by a necessary human intervention in the production process. The availability of technical resources such as the robot or single robotic tools can be influenced by the so-called shared resource principle or simply by a technical outage. Thereby, multiple work stations share a single robot or, alternatively, multiple robots share a set of (possibly expensive) tools, in order to reduce the overall investment. The unavailability of both human operator and technical resources impacts the assembly sequence in a way, in which the corresponding assembly steps should be delayed while preferring others instead of waiting for the blocked resource or the human.

Besides the availability the fundamental feasibility of the assembly steps by either the human or the robot is an essential optimization criterion. If the assembly of a component can only be performed by one of them, this results in less flexibility to plan the assembly sequence, especially in case of multiple parallel assembly cells. Relating to the human the feasibility is essentially based on the skills and capabilities [12, 13]. They primarily decide about the suitability of the operator for the task due to, for example, heavy weights or forces that are necessary. In addition, there may occur situational criteria for exclusion caused by, for instance, non-reachability of the join patch due to other parts that have been assembled previously. The feasibility by the robot mainly depends on its technical properties and the capabilities of the robotic tools such as the kind of gripper. The gripper can also induce situational exclusions, as it may require two freely accessible parallel sides, describing the mountability of the component.

The last influencing factor for the function allocation is the execution time of the assembly step. From an economic point of view it seems to be advantageous to assign the assembly to that resource that performs fastest. Thereby, the assembly time of the total product can be optimized. However, these economic criteria may contradict other (e.g. ergonomic) criteria such as the number of changes of the workflow between the human and the robot. If the workflow changes too frequently, this would not be beneficial for the work conditions of the human operator, as the mental workload raises or ambiguous situation may occur leading to hazards for the human. Therefore, the chosen assembly sequence should also take these criteria into account.

In order to assess the stress and strain of the individual assembly steps for the human operator, the ergonomic work conditions have to be gathered including physical, cognitive, and environmental ergonomics. Physical ergonomics comprise the evaluation of the ergonomic risk as well as the number of changes of the workflow between the human and the robot. Regarding the ergonomic risk those assembly steps that are linked with poor ergonomic work conditions should totally be avoided or their number should be at least minimized, respectively. In addition, assembly steps with different ergonomic assessments within the "acceptable" range may lay the foundations to prefer one step to the other. Similar to poor ergonomic work conditions the number of human-robot changes in the workflow should be minimized as mentioned above. They provide a strong potential to introduce dangerous situations or misunderstandings between the human and the robot. Furthermore, with regard to a complete and efficient work process the manual assembly steps should be grouped into only few clusters rather than decomposed into multiple segments each containing only few steps.

However, human-robot interaction involves not only physical interaction. Against the background of self-optimizing production systems [14] the role of the human operator have changed more and more towards supervisory tasks [7]. Though, the capability of anticipating the behavior and actions of the robot crucially depends on their transparency and familiarity with respect to the mental model of the operator. Unpredictable and counterintuitive actions will keep the operator from trusting the robot, so that an effective interaction cannot be established. Besides an understandable behavior of the robot, also the assembly sequence should be chosen in a meaningful way. Being able to anticipate the past assembly steps is useful, if an intervention is necessary in case of any error, whereas being able to predict the future assembly steps helps to estimate the next actions of the robot.

Further influencing factors for human-robot collaboration can be founded in the environmental conditions. Noise exposure or temperature stress, for example, influences the human performance significantly. In addition, an insufficient lightning of the workplace prevents a stress-free work. However, considering only the assembly process itself and the involved human and robot, the environmental factors can be considered as externally given. They cannot be changed using the presented planning strategies and are usually related to the exposition duration at the workday. Therefore, they will be excluded here from the further examination.

As already mentioned above, multiple tools such as different grippers or power screw drivers can be provided for a single robot or tools can be shared between several work stations. As a consequence, effort (generally in terms of time) is necessary to switch between those tools dependent on the pending assembly task. In order to avoid unnecessary set-up processes, assembly steps requiring the same tool should be clustered similar to those of the human operator.

3 Risk Model for Assessing One Assembly Step

In the previous section, optimization criteria for the assembly sequence planning and for situations of human-robot collaboration were introduced. Using these criteria a risk model is built, in order to mathematically model the ergonomic risk of a single assembly step. The first part of the risk model considers the assignment of the assembly step to the human operator or the robot. The second part assigns an ergonomic risk factor to the assembly step, in order to be able to compare multiple assembly steps with each other.

3.1 Allocation Costs

As described above, the allocation decision depends on the availability of the resources as well as the feasibility of and execution time for the task. As the values of these factors differ for the human and the robot, the allocation costs have to be gathered separately. The costs for the human operator are calculated according to

$$c_{resAlloc,H} = c_{avail,H} + c_{feasibility,H} + c_{execTime,H}. \tag{2}$$

Similar to this definition, the costs for the robot are calculated as

$$c_{resAlloc,R} = c_{avail,R} + c_{feasibility,R} + c_{mountability,R} + c_{execTime,R}. \tag{3}$$

Thereby, the availability c_{avail} of the human operator and the robot, respectively, is modeled with 0, if one or the other is ready to perform the assembly step. In contrast, it is rated with ∞, if the human or the robot is not available. In a similar way, a feasibility value $c_{feasibility,H}$ of 0 indicates that the operator is skilled enough to perform the assembly step, whereas ∞ represents a step that cannot be performed by the human. Likewise, in case of the robot, ∞ indicates that the current component cannot be assembled by the robot and 0 that the assembly is generally possible. For the robot there is an additional term $c_{mountability}$ describing whether the assembly is even in the current situation possible, while $c_{feasibility,R}$ describes only the basic ability regardless if, for instance, the join path is blocked by other parts.

In order to compare the execution time of the human and the robot for the assembly step, the assembly is evaluated using the predetermined motion time system Methods-Time Measurement (MTM). Using MTM the assembly time $t_{exec,H}$ for the human can be estimated by analyzing the motion elements of the assembly. The execution time $t_{exec,R}$ of the robot can be determined by simulating the robot movements. To compare the time values of both human and robot they are set into relation by

$$c_{execTime,H} = \frac{t_{exec,H}}{t_{exec,R}} \tag{4}$$

and

$$c_{execTime,R} = \frac{t_{exec,R}}{t_{exec,H}}, \tag{5}$$

respectively. The final assignment of the assembly step can then be made by determining the minimum of $c_{resAlloc,H}$ and $c_{resAlloc,R}$.

3.2 Ergonomic Evaluation

Beyond the function allocation, all alternative assembly steps have to be evaluated, in order to be able to compare them with each other. Provided that only valid assembly steps are considered, the main influencing factor is the ergonomic evaluation c_{ergo} comprising aspects of physical as well as cognitive ergonomics:

$$c_{ergo} = \underbrace{c_{ergoRisk} + c_{resChange}}_{c_{physErgo}} + \underbrace{c_{transAssSeq} + c_{transRobot}}_{c_{cognErgo}} . \quad (6)$$

One main aspect for evaluating physical ergonomics is to gather the stress and strain of the human operator. This can be done by standardized methods such as DIN EN 1005-2 or Ovako Working Posture Analysing Systems (OWAS). In case the robot performs the assembly step, $c_{ergoRisk}$ equals to 0, because there is not any concrete risk for the human assuming that all safety requirements are satisfied. Furthermore, the number of changes in the workflow between the human and the robot as well as between the robotic tools is considered to estimate the physical ergonomics. For the sake of simplicity of the presented model, the tool changes that actually belong to the technical influences are combined with the number of human-robot changes. This results in an evaluation of $c_{resChange} = v_{i,j}$, if for the current assembly step the resource has to be changed from i to j. Hence, the fundamentals of this calculation lay in the $n_{res} \times n_{res}$ square matrix v, where n_{res} denotes the number of resources, i.e. human operators and robotic tools, in the considered assembly cell. This matrix does not need to be symmetric, because the change of the workflow from the robot to the human may, for instance, induce higher mental workload than the other way around due to the dependency on the unambiguousness of the robotic behavior.

The cognitive ergonomics consists of the transparency of the assembly sequence and the robot behavior and is influenced by the mental workload and the predictability. The assembly sequence is chosen with respect to three conditions [15]:

1. Components that are assembled in direct vicinity of components already positioned are preferred.
2. The product is assembled in layers parallel to the mounting surface.
3. The product is assembled in assembly groups.

The more conditions are considered in the planning procedure, the lower the mental workload for the human operator who is interacting with the robot [15]. The robot behavior itself can be varied in terms of the velocity and trajectory of its movements. Thereby, anthropomorphic velocity profiles and trajectories significantly increase the predictability of the robotic actions [16, 17]. On contrary, in situations, where no interaction is necessary, traditional velocity profiles and trajectories such as Point-to-Point or Linear may be used, as they are slightly more efficient. Consequently, depending on the kind of assembly step the kind of robot behavior has to be assessed differently.

Each of the aforementioned factors of the risk model may be of different importance for the assembly planning process. This also depends on the policy of the company and the particular choice of optimization criteria. Therefore, each of the influencing factors may be weighted or even deactivated before summing them up.

4 Application to Assembly Sequence Planning in Human-Robot Collaboration

The risk model introduced in the previous section can be used to evaluate assembly processes with respect to the ergonomic work conditions for the human operator. On that account, the product to be assembled is mapped to a graph-based structure representing all valid assembly sequences [18]. In particular, the product is decomposed recursively, such that each edge of the graph can be considered as one independent assembly step and each node as a valid semi-finished product. An exemplary assembly graph of a product consisting of four cubic parts is depicted in Fig. 2.

Considering each of the resulting assembly paths, the individual steps should be assigned to the human or the robot, respectively, and assessed by the risk model. Therefore, $G = (S, A)$ represents the assembly graph for a product consisting of n parts and the set of states, i.e. semi-finished products, S and the set of assembly steps A. The path

$$\mathcal{P}(s_i, t) = \left(e_{0,1}, e_{0,1}, \ldots, e_{n-1,n}\right) \in A^n \tag{7}$$

describes an arbitrary assembly sequence with $e_{u,v} = (s_u, s_v) \in A \ (0 \leq u, v \leq n)$, where s_i denotes any intermediate state and $t = s_n$ the final state, i.e. the final product. The optimization criteria $c_{resAlloc}$ and c_{ergo} of the risk model can be adjusted to this notation by defining the assessments for the assembly step $e_{u,v}$ as

$$c_{resAlloc}\left(e_{u,v}\right) = \min\left\{c_{resAlloc,H}\left(e_{u,v}\right), c_{resAlloc,R}\left(e_{u,v}\right)\right\} \tag{8}$$

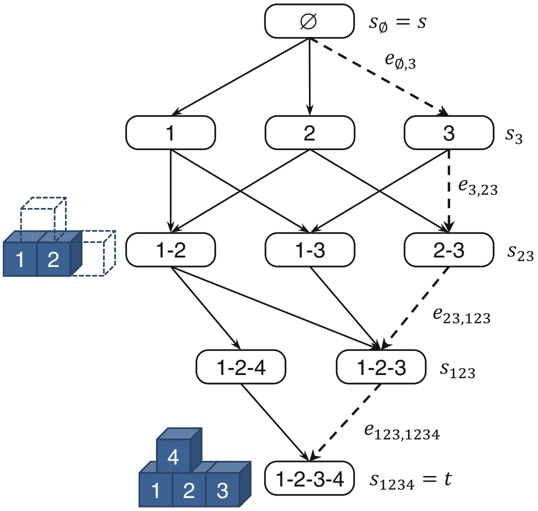

Fig. 2 Exemplary assembly graph of a product consisting of four cubic parts. The numbers indicate the assembled parts and the dashed path represents one possible assemble sequence

and

$$c_{ergo}\left(e_{u,v}\right) = \left(c_{ergoRisk}\left(e_{u,v}\right), c_{resChange}\left(e_{u,v}\right), c_{transAssSeq}\left(e_{u,v}\right), c_{transRobot}\left(e_{u,v}\right)\right)^T, \quad (9)$$

respectively. They can further be extended to the considered assembly sequence by summing up the values for each assembly step lying on that path:

$$c\left(\mathcal{P}(s_i, s_j)\right) = \sum_{k=0}^{n-1} \left(c_{ergo}\left(e_{k,k+1}\right) \circ w\right) \cdot r^T \quad (10)$$

for $0 \leq i,j \leq n$. Thereby, $w \in [0,1]^4$ denotes a weight vector that is multiplied componentwise with the four summands of c_{ergo}. By defining $r \in \{0,1\}^4$ the individual criteria can additionally be activated or deactivated independently from their weight. Finally, the problem of finding the optimal assembly sequence from the initial, i.e. empty, state s to the final state t can be reduced to the optimization problem

$$c_{min}(s,t) = \min_{\mathcal{P}(s,t) \in G} c(\mathcal{P}(s,t)) \quad (11)$$

that can be solved by graph search algorithms such as Dijkstra or A* [19].

However, the process of assembly sequence planning strongly depends on the number and kind of available parts for the assembly system [18]. Assuming only few parts to be available at the same time, the optimal assembly path might not be feasible due to missing parts. Hence, the sequence planner has to be able to react dynamically to the available parts. This is realized by using the heuristic algorithm A*Prune [20], a k-shortest path algorithm. The resulting set of k best paths describes the possibilities to continue the assembly progress of the product. The possibilities are compared to each other and ranked using a cognitive control unit (see [18, 21] for detailed information).

5 Summary and Outlook

The increasing variety in product range demands more flexibility from the assembly systems of producing companies. As a consequence, the human operator should collaborate with robotized assembly systems in order to combine the advantages of both human and robot and to reach the highest flexibility. The human contributes extensive cognitive and sensorimotor skills, whereas the robot accounts for force, accuracy and endurance. However, in order to establish safe and effective human-robot collaboration, the assembly process should be designed such that neither occupational safety nor efficiency is endangered. The present paper introduces a risk model for evaluating assembly steps with respect to their ergonomic risk for the human operator. Therefore, evaluation criteria for assessing the suitability of the human and the robot, respectively, are deviated. Furthermore, optimization criteria for evaluating the ergonomic risk of an individual assembly step are presented. Afterwards, the mathematically formulated model is applied to the process of assembly sequence planning. Therefore, a graph-based approach is chosen, where each edge represent an assembly step and each path from the start node to the end node represent a valid assembly sequence. Using this assembly graph, the optimal assembly sequence can be determined by applying graph search algorithms.

In the following steps, the presented risk model has to be finalized and validated. Not all influencing factors could be quantified yet. In addition, it would be beneficial to have a personalized model, so that personal characteristics and skills can be taken into account for the assessment and planning of the assembly process. However, this is also closely related to ethical and legal questions as well as privacy concerns.

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Lightweight Robots and Human Interaction in Assembly Systems

Wilhelm Bauer, Manfred Bender, Peter Rally, Oliver Scholtz and Moritz Hämmerle

Abstract Automation of certain processes in assembly systems used to be too expensive for SMEs, but thanks to small, lightweight robots, there is now a new cost-effective option. The new robots make it possible to work without security barriers, thereby opening up new approaches for work design, especially in manual assembly systems.

Keywords Human factors · Human-Systems integration · Systems engineering

1 Introduction

The manual assembly is changing: small, economical lightweight robots allow new automation solutions for small and medium sized companies, which are not economically today. The new robots allow working with employees without a protective fence. This opens new approaches to work design, especially in today mainly manual assembly areas.

Working with robots for collaborative operation without safety fence also has cost advantages. However, the other benefits are also important such as simple integration of robots in one-piece-flow systems for example. From the perspective

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Fig. 1 Adaptable assembly workstation (on the *left* single- and on the *right* triple- workplace)

of work design the main advantage is the potential for a completely new design of the work flow in previously manual systems [1].

As part of the research project PLAWAMO [2, 3] an adaptable assembly workstation was developed. With this it is possible, to triple the manual assembly capacity within a few minutes (see Fig. 1). By a simple opening of the material preparation shelves and through an enlargement of the table surface, by a lateral plug-in module, a triple-workstation (see Fig. 1 right part) can be formed from the single-workstation (see Fig. 1 left part).

According to the recent developments in the assembly technology, the adaptable engine assembly workstation is combined with a lightweight robot. After the transformation of the workstation from the single to the triple workplace, a lightweight robot can perform some of the installation work of the assembly worker or it can support him, enter parts, position parts and do similar work.

Figure 2 shows how a lightweight robot that can be integrated into the engine-assembly workstation. In doing so, a manual-hybrid system is created. With this new concept, a design gap can be closed, which was not currently available for the automation because of cost reasons.

Fig. 2 Engine assembly workstation with LBR support

2 Design Dimensions for Accepted Collaborative Workplaces

Below the design dimensions of collaborative human-robot cooperation should be described. This differs significantly from those during the planning of today's manual assembly systems. Figure 3 shows the design dimensions that have to be considered, to create accepted and productive collaborative workplaces.

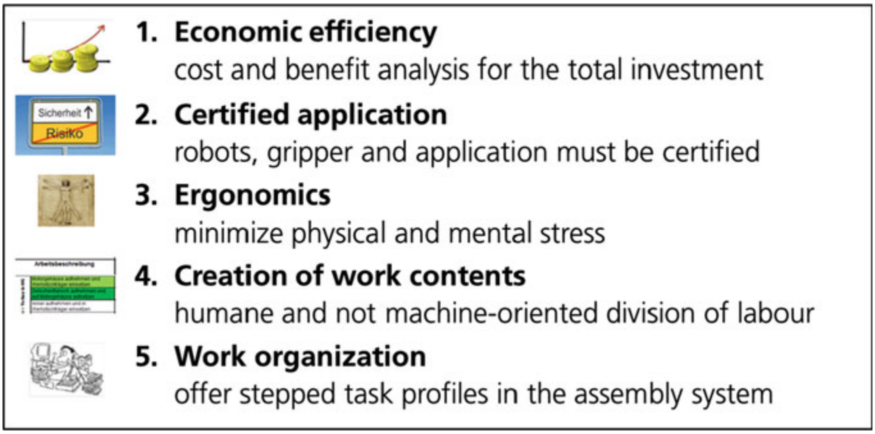
Subsequently these design dimensions are described more detailed.

2.1 Economic Efficiency

In the serial assembly with long operating hours (3 shift-work), high levels of system availability and manageable maintenance costs automation solutions redeem relatively quickly compared to pure personnel costs (at comparable time structures).

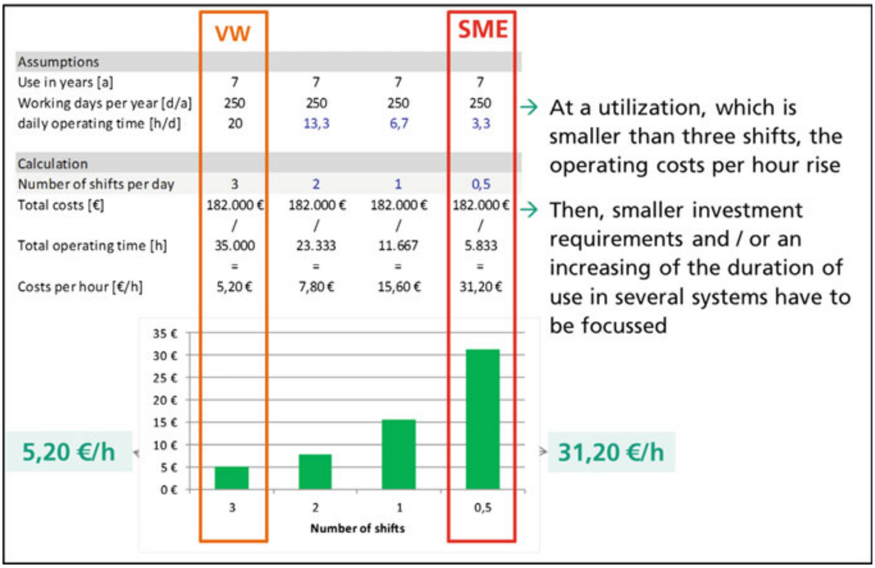
Typically, assembly systems in automotive companies are designed for a three shift-work organisation. Therefore, they can realize hourly robot costs of 5.20€ [1]. The same robot application with the same investment volume is typically operated in a one shift-work organisation with fluctuation quantities at a SME. Hence the hourly robot exceed 30€ easily (Fig. 4). In this example is the total investment with robot, end effector, sensor/controller, software, programming and maintenance and costs of electricity for 7 years is already included [4].

There is a great interest in a mobile and flexible application of the lightweight robot, so that the operating hours of the robot are increased or the robot is installed at current bottlenecks. Bottlenecks can be capacity peaks (e.g. peaks of quantities)



1. **Economic efficiency**
   cost and benefit analysis for the total investment
2. **Certified application**
   robots, gripper and application must be certified
3. **Ergonomics**
   minimize physical and mental stress
4. **Creation of work contents**
   humane and not machine-oriented division of labour
5. **Work organization**
   offer stepped task profiles in the assembly system

Fig. 3 The five design dimensions complete designed and accepted collaborative assembly workstations



	VW			SME
Assumptions				
Use in years [a]	7	7	7	7
Working days per year [d/a]	250	250	250	250
daily operating time [h/d]	20	13,3	6,7	3,3
Calculation				
Number of shifts per day	3	2	1	0,5
Total costs [€]	182.000 €	182.000 €	182.000 €	182.000 €
	/	/	/	/
Total operating time [h]	35.000	23.333	11.667	5.833
	=	=	=	=
Costs per hour [€/h]	5,20 €	7,80 €	15,60 €	31,20 €

→ At a utilization, which is smaller than three shifts, the operating costs per hour rise

→ Then, smaller investment requirements and / or an increasing of the duration of use in several systems have to be focussed

Fig. 4 Hourly Rate of a lightweight robot, depending on the hours of operation [4]

or also workers efficiency differences, as described in Chap. 2.5. The mobile application of lightweight robots in several systems and for the manufacturing of different products means, that in the calculation of the profitability, of the costs and of the cost potentials must be done with the influence of different products and different maturities of the different assembly systems.

2.2 *Certified Applications—Example Collision Case*

For safe human-robot collaboration (HRC) the following standards and guidelines are relevant in Germany:

- Machinery Directive 2006/42/EG
- ISO 12100, Parts 1/2 (Safety of machinery: Basics)
- EN ISO 10218 Part 1/Part 2: 2011 (safety requirements Industrial Robots)
- ISO/TS 15066 (Collaborative robots: Publication in early 2016)
- ISO 13849/IEC 62061 (safety of machine: control)
- ISO 13855 (Safety of machinery: safety devices)
- IEC 60204-1 (Electrical equipment of machines).

Due to this context, the robot itself cannot obtain a CE-Identification, but only a declaration of incorporation, because it is an incomplete machine without associated application, sensors and effectors. The individual system with a collaborative robot application must be subjected to a comprehensive risk analysis [5].

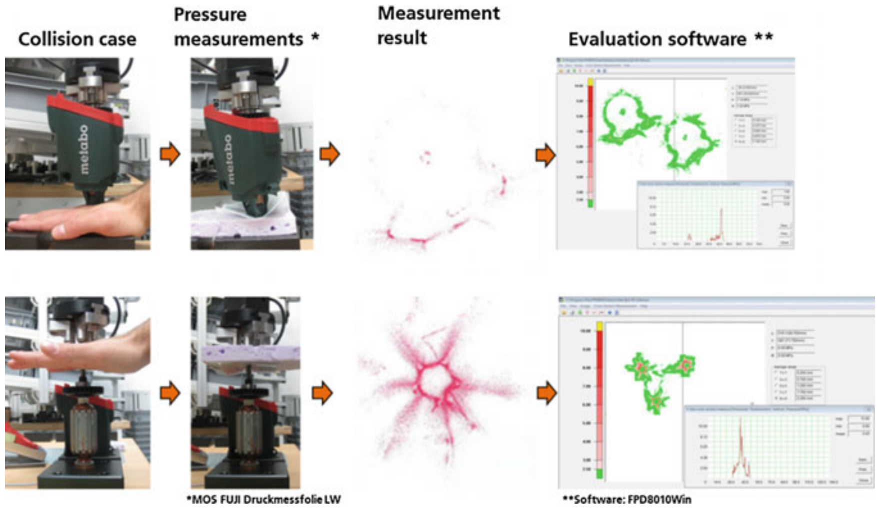


Fig. 5 Pressure measurements in case of collision with the drill assembly

The certification of an application can be supported with power-, velocity- and pressure- measurements [6]. Figure 5 shows, in the left part, the case of two possible bruise patterns of a human hand between the robot and the workpiece or the workpiece and the table surface. In the middle part of the picture, the pressure profiles show a collision case on a pressure-sensitive film (MOS FUJI pressure measuring film LW). The analyses done with the evaluation software are diagrammed in the right section. The red areas in the right section are considered critical (see also Fig. 6).

Figure 6 shows further tests of the lower collision case above. To reach acceptable evaluations, different variations are performed on the experiment setting. On the one hand the velocity of the robot is reduced and on the other hand the stop triggering force. The result is a picture of the influence of force and velocity to the collision pressure. If the maximum allowable pressure values [7] cannot be reached, additional safety devices must be installed for the robot application.

2.3 *Ergonomics*

Essentially, the application of robots will also contribute to the physical discharge of employees that are working under unfavourable ergonomic working conditions. These are primarily:

- Assumption of activities, which are outside the human space of action or ergonomic handling area
- Support in working situation of unfavourable posture

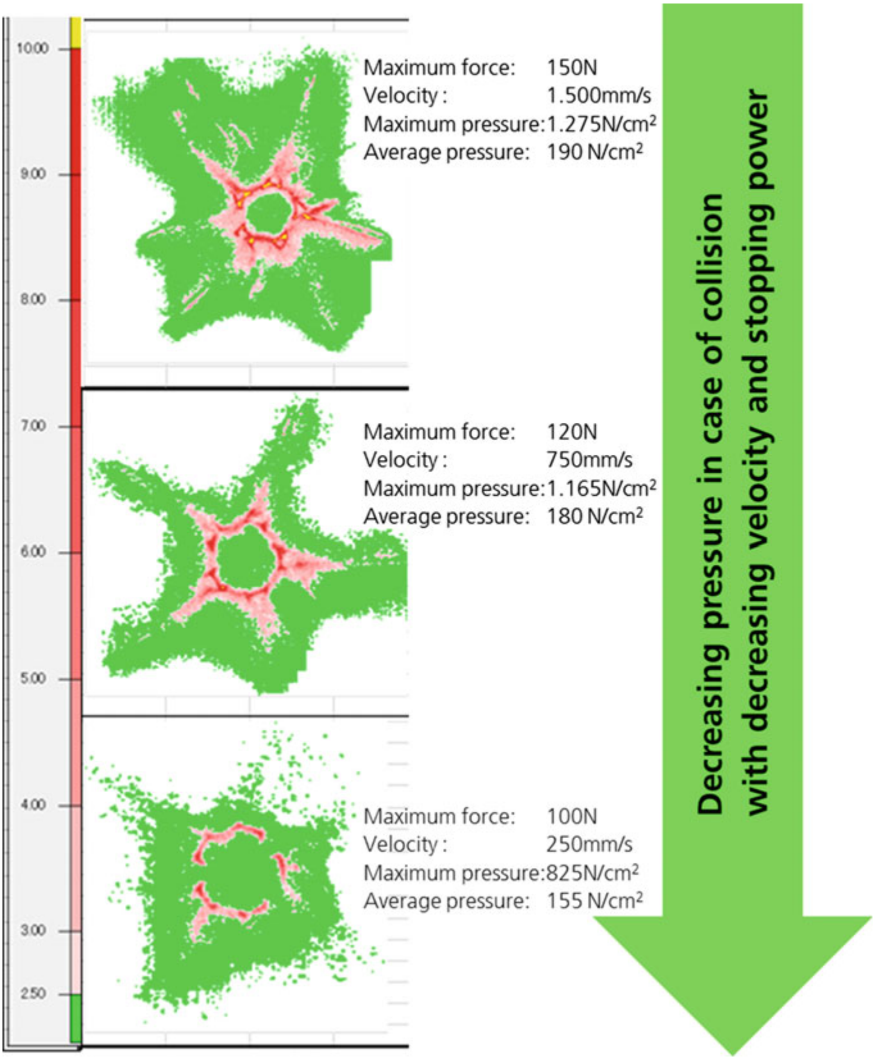


Fig. 6 Influence of force and velocity on the pressure-evaluation

- Assumption of overhead work
- Relief in difficult physical and chemical work environments (noise, light, climate, pollutants)

If the concept of ergonomics is extended beyond the physical stress, the results of other studies show that e.g. a shorter distance to the robot, higher robot velocities and unpredictable trajectories have unfavourable effects on the stress, performance and well-being level of the employees [8, 9].

In addition to the physical and ergonomic stress above, which can be avoided or reduced by a robot, an HRC application can also lead to negative effects:

- more monotony—because of shorter cycle times
- work situation is perceived that the robot is a dominant feature by defining the working tact
- closeness/distance/location/position of the robot is perceived as unpleasant
- actions of the robot are not predictable
- limiting the space of action for human worker

In contrast the positive effects of HRC applications can be a reduction of:

- time pressure
- complexity in working processes
- monotony
- working situations with need of permanent attention

For the evaluation of these effects, the assembly processes must be analysed systematically based on the labour situation and possible mental stress. This also includes questions about meaningful work content, the design of work organization, to promote learning and personality through the work task and the acceptance by the employees.

2.4 Creation of Work Content

If a completely new system has to be planned is the division of work contents is more complex as in the example above, when tasks and work contents have to be redefined in the existing assembly system. For a systematic definition of the tasks of the robot the cost drivers for a lightweight robot application are essential. These are primarily the additional cost of a robot suitable material availability, for any additional handling and the technology for the certain assembly process. Safety considerations have to be focused in addition as they also can be cost drivers.

These considerations must be made for each part of the product and each assembly step including the robot trajectories. The analysis of each part is fundamental especially in the safety consideration for the process and systems design. The contours of the assembly parts set the maximum velocities and the maximum force (see Chap. 2.2) and therefore they have a great impact on the economics of the system.

Considerations for defining the division of work between humans and robots finally lead to a consideration of the remaining total task. Leading questions can be: Does the employee have a reasonable complete work task? How is the situation of the worker in the new HRC environment? In order to evaluate the entire situation it is also necessary to look at the selected work organization.

2.5 Work Organization

In the area of work organization human-robot-collaborations have a very large design potential. The possibilities to design a new form of organization start with the direct activities. With the robot is a new opportunity to give performance impaired employees or employees in the reintegration phase after illness, a tact conform workplace through the support of a robot.

The flexible, temporary and mobile HRC application can also counteract the effects of demographic change. On the one hand in terms of the support of older employees, who are performance limited. On the other hand there can be a stepped support provided during learning phases in a HRC-area for new employees.

The possibilities mentioned above aim at new work organization possibilities for direct assembly activities. Furthermore in the previously manual assembly systems new indirect activities will be generated in the assembly system through the robot. These offer new opportunities for the design of work organization. If the range of tasks should be completed, then tasks for planning, evaluation and implementation of HRC applications are added.

The range of tasks, which offers new design options in the field of work organization, can be described in stepped task profiles. Here a 7-level model of the tasks in HRC environments is described:

- direct assembly tasks (in tiered HRC scenarios)
- set, equip robots and eliminate (simple) disorders
- training and education at the robot
- plan and organize the HRC-use dispositive
- program and maintain the robot
- planning and assessment of new HRC applications
- establish HRC applications

3 With Cooperative Design to Accepted HRC-Workstations

If the design dimensions, described in Chap. 2, will be adequately considered, then the conditions are created for an employee-oriented HRC workstation. It is advantageous to make the planning and implementation process cooperatively, in order to ensure the necessary level of acceptance for the new technology among employees.

Cooperative design means the integration of all involved employees and includes the following elements:

- Participation:
  Detailed planning of the implementation of the HRC solution is decentralized with the involved employees.

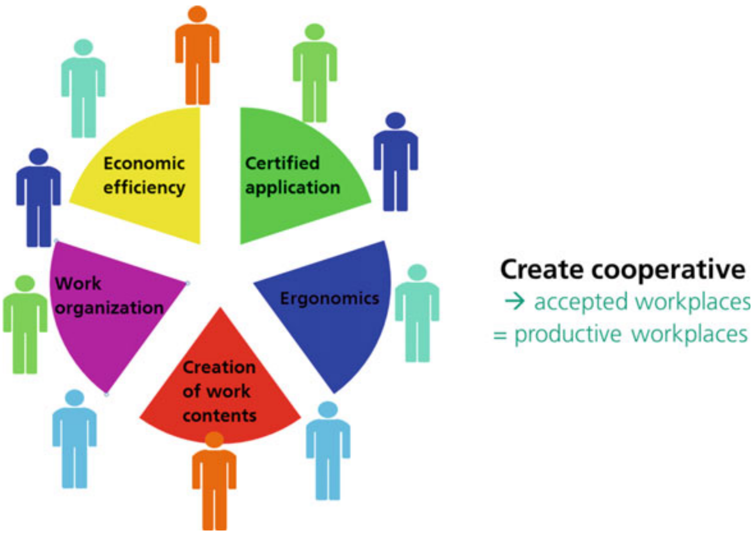


Fig. 7 Cooperative design for accepted HRC-workplaces

With respect to the tasks responsibility is delegated down to the shop floor level. Where available: Early information and involvement of the works council.

- Communication:
  Start with the communications at an early stage and provide current information on the whole process constantly.
  Create transparency to the goals of HRC and establish a clear link with the goals of the company.
- Personnel development:
  Basic qualification for all employees and start with specific qualifications early (see task profiles Chap 2.5). Even managers have to be qualified to be prepared for any potential conflicts.
- Creating a culture of trust:
  Interact with each other openly and honestly and gain the trust of its employees.

Methodical approaches to participation are described in [1]. If the cooperative HRC design is succeeded, then accepted and productive workplaces arise (Fig. 7).

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Digital Control of Flexible Labor Hours to Support Agile Enterprises and Employees' Concerns

Wilhelm Bauer, Stefan Gerlach and Moritz Hämmerle

Abstract In globalized and digital connected markets enterprises have to respond immediately to customer demands. Therefore flexible utilization of labor hours is a significant key element of an agile enterprise. At the same time in a digitalized society private concerns of employees are expected to get more important. Therefore work assignments and employment contracts have to offer flexible regulations and means of control for the staff also. On the other hand, digital interaction and communication offers new ways to organize work flexible. Within this paper a new mobile application for the support of self-organized and highly flexible labor utilization will be presented. The approach is to involve employees in the personnel planning and scheduling processes by means of a matching and voting process with mobile communication devices and a rule base with a comprehensive set of priority rules which limit the possible work assignments within a legal and economical justified corridor for flexible working hours. Used Criteria are the qualification of employees, the legal restrictions on maximum working hours, the flextime wage records and the personal preferences of the employees.

Keywords Personnel planning · Human-resource-allocation · Rule based planning

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1 Introduction

The digitalization of the business and the society is both, a driver and an enabler of new concepts for the organization of work. A “smart” and self-organized control of flexible working hours are an concept to meet the demands of volatile businesses, employee concerns and job markets, as shortly introduced in this chapter.

Companies businesses are more and more forced to offer tailored and customized products to fulfil customer demands. The product life cycles are shortened and the number of product types and variants are extremely increased and the products of high quality have to be delivered quickly and reliably [1]. Nevertheless they have to meet high requirements in terms of short delivery times, low stock quantities and competitive costs [2, 3]. Additional influences results from the world-wide economic activities [4], seasonal demands, marketing campaigns, or overlaid, very large, singular orders. Therefore it is difficult to estimate the actual workload for a specific period of time [5]. As a consequence manufacturing companies cannot predict and plan their production quantity and workload in advance. The still used approach of a centralized planning and scheduling of production demands and orders [6] is too slow and to inefficient to meet new requirements of dynamic and volatile markets. Nowadays companies are forced to utilize flexible forms of production activities, schedules, and labor [7]. In a current survey of the Fraunhofer IAO 72 % of the participating companies agreed, that they need to increase their possibilities of flexible labor utilization within the next five years [8] (Fig. 1a).

The utilization of flexible labor not only has to ensure the short-time fulfilment of individualized customer demands in real-time and the fluctuations of volatile markets. The employees also expect to be involved in the process of the personnel planning and scheduling. More and more they call for a transparent personnel planning which better combines the business demands with their private concerns and leisure interests. The upcoming demographic change of the job market, with aging workforces on the one side and the Generation Y at the beginning of their business careers additionally stress this trend.

The personnel planning therefore have to meet divergent targets in terms of business demands, reliability and productivity. As constraints it has to reflect the individual requirements and personal concerns of the employees. Obviously the personnel planning and scheduling is a complex task of several stakeholders with divergent targets, as depicted in Fig. 2. In the survey mentioned above, 62 % of the

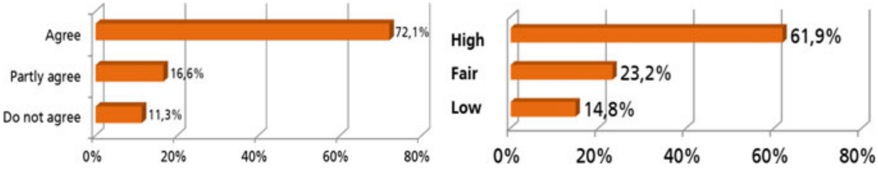


Fig. 1 **a** Demand for flexibility (Spath); **b** effort for short-time production control [8]

Fig. 2 Forces on the organization of flexible working hours

participating companies stated, that their effort for short-time production control is high [8] (Fig. 1b).

The approach of the project “KapaflexCy” is to involve the employees in the personnel planning and scheduling of their work assignments. Groups of employees use mobile communication devices together with social media functions to agree upon their work assignments. The approach of the project will increase the degree of flexibility of labor utilization in production. The companies will be able to react efficiently, immediately and in short times to unbalanced and fluctuating workloads. At the same time they can reduce the effort for their capacity management and they will be better prepared for volatile markets.

The core of the research approach of the project is a so called Cyber-Physical-System (CPS). A CPS connects the virtual cyber world with the real, physical world to an Internet of things, data and services [9]. They capture data of the real “physical” world via sensors, process them with software from embedded controllers, use the Internet and cloud computing for mutual communication between the connectors and interact with real world by means of mechatronic actuators [10, 11]. It is expected, that CPS will shift production technology, processes and equipment towards flexibility and self-control of the production facilities. The desired benefits are evident. Intelligent, networked objects and autonomous control systems are able to reflect customer demands in real-time. The flexible utilization of production facilities with short throughput-times and zero-stock are the answer to the increasing demand of customized products and the trend of more volatile markets. Therefore a paradigm shift is expected, from centralized production planning to a decentralized coordination of self-controlled and autonomous processes.

The impacts of the application of CPS in production environments are expected as so tremendous, that in Germany they will be designated as the ‘4th industrial revolution’ [12]. To stimulate this important future vision, the German government has started a large national research program in 2012. KapaflexCy is one of the first three projects started in Germany to explore the topic of “Industrie 4.0”. A description of the CPS to be developed within the project KapaflexCy is given in [13].

The paper will highlight in particular the application and the findings of a pilot study of the KapaflexCy-System.

2 Flexible Labor Planning

Labor utilization has to follow the facility utilization closely. Daily working hours must not longer be on fixed times and equally spread throughout the day. They still have to reflect the fulfilment of customer demands in real-time.

There are two principle ways for flexible labor utilization in general. First, the working time of a group of employees can be reduced or enlarged, perhaps day by day. Second, the group of employees can be reduced or enlarged [14]. Figure 3 gives an impression for the two ways by the example of a so called “U-Shape assembly system”. Within this system one worker can assemble a whole product by passing all work places in one walking circle. According to German law he is allowed to work at maximum ten hours a day in Germany. There is no law for the minimum working time. But usually there is a minimum amount for the daily working hours because of economically reasons. If a higher utilization is needed, an additional worker may be added to the assembly system. The two workers split the assembly tasks between them. Obviously the maximum amount for workers within the assembly system is given by the number of work places.

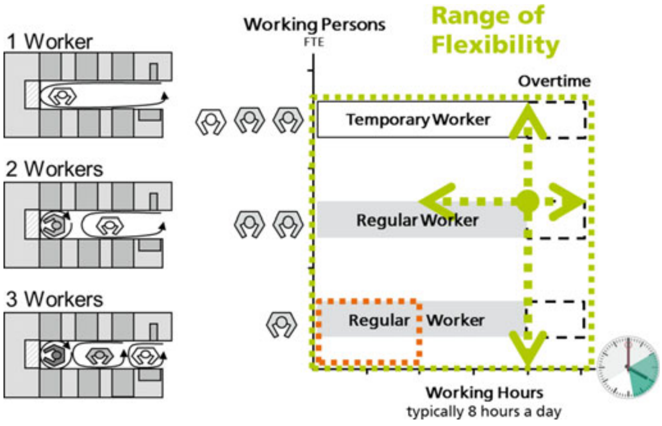


Fig. 3 Flexible working hours [14]

An overview and brief introduction of the common measures to implement a flexible labor utilization is given e.g. in [15]. These measures will often and throughout this paper be called ‘flexibility instruments’.

2.1 Manual Scheduling of Work Assignments

Flexible labor utilization requires a short-term control of flexibility instruments and the use of staff. In practice this is done always manually. Team leaders and shift managers coordinate the arrival and absence of staff, requesting support by part-timers and freelancers and plan the use of temporary workers. For this purpose they communicate daily with their workers, the human resources department, additional shift managers and temporary employment agencies—usually orally, rarely, and with sufficient time by E-Mail. This kind of short-term staff usage is also reactive. Occurring capacity gaps have to be closed by daily trouble shooting, in which usually established patterns will be used. That denotes, that always the same flexibility instruments are used and the same staff will be requested. A coordinated use of flexibility instruments in regard to volatile markets is hardly possible.

The manual and oral coordination of flexible capacity utilization and the use of short-term staff are therefore subject to serious drawbacks [16]. First a high coordination overhead due to oral communication, second short-term adjustments of capacity use does not succeed, third an uneven distribution of lucrative or unlikely activities, and fourth a false and cost-driving use of flexibility instruments.

2.2 Self-organized Labor Planning

In a self-organized labor planning, horizontal decisions within and between working groups will replace the conventional vertical directives ‘from top to bottom’. A central coordination instance and mobile devices provide a platform for employees to agree self-organized upon their work assignments. They have to decide, which persons take over the additional work assignments. The use of mobile devices accelerates the assignment process between employees who are more accessible in this manner. Moreover they ease the horizontal oral communication between the employees, which may be helpful in specific situations.

A self-organized labor planning depends from a sufficient range of flexibility instruments. A lot of flexibility instruments, i.e. possible forms for flexible labor utilization are known. For example increased demands for capacity can be covered by the core employees in additional shifts. Alternatively, the increased demands can also be handled through the use of temporary workers. Whereas both flexibility instruments can cover the additional demand, they are different in terms of cost, time to utilize and coverable amount of capacity. Usually a company provides a mix of different overlaid and sized flexibility instruments. The mix has to meet the unsteady demand for capacity. Further restrictions may result e.g. from long training periods or high qualifying requirements. Therefore the mix and size of the flexibility instruments has to be determined thoroughly based on a calculation of the total benefit and the financial budget needed [17].

In a particular case of capacity alignment, it has to be decided, which of the provided flexibility instruments should be used. Usually the production supervisor is in charge to align the working hours to the actual workload, see also Fig. 6. For this he plans and schedules additional shifts or he enlarges already planned shifts. In case of overcapacity he cancels already scheduled shifts or he reduces the duration of the shifts.

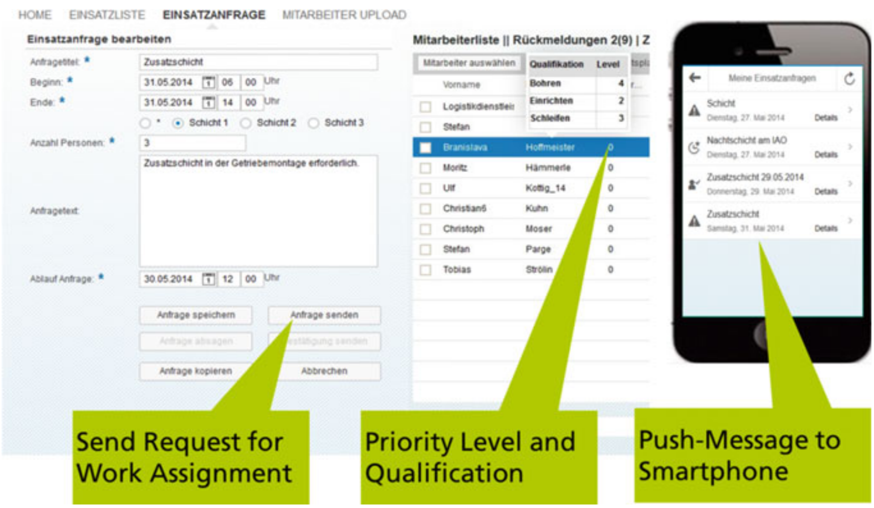
After the capacity is aligned to the actual workload, the employees have to take over the alignments. It has to be assigned, which persons work additionally, longer or shorter or which persons cancel an already planned work assignment. In self-organized labor planning this is the task of the employees. The process of agreement between the employees by means of a mobile matching and voting board is described in the following paragraph.

3 Mobile Matching and Voting Board

The mobile matching and voting board for the employees is the interactional part of the software developed in the project. It comprises two major components, a central planning instance for the supervisor and a mobile voting app for the employees.

The first component is a central planning instance for shift schedules and work assignments. The component is mainly operated by the production supervisor who is in charge for the alignment of the production capacity to the actual workload. He also monitors the matching and selection processes of work assignments to the employees. The component is therefore called “Supervisor Cockpit”. Figure 4 shows a screen-shot of the supervisor cockpit at the left side of the picture. At the left part of the screen, details of a possible work assignment can be specified. The list at the right part of the screen is to select the employees to be requested. The most important criteria and information for the supervisor for the selection of employees “eligible” for work assignments is their priority level and qualification. This information is displayed in the right column of the selection list for employees. For convenience of the supervisor the list is sorted according to the priority level. So usually he selects the top most employees to be requested for work assignments. To allow agreement between the employees typically twice as needed employees will be requested.

After the work assignment is entered and eligible employees are selected, the supervisor sends the request to the smartphones of the employees. A mobile push client will inform the user immediately about new possible work assignments he has to vote for. The push client may use typical means to attract attention. For example the telephone rings or the smartphone vibrates and the employee checks



Einsatzanfrage bearbeiten

Anfragetitel: * Zusatzschicht
Beginn: * 31.05.2014 06 00 Uhr
Ende: * 31.05.2014 14 00 Uhr
○ * ● Schicht 1 ○ Schicht 2 ○ Schicht 3
Anzahl Personen: * 3
Anfragetext: Zusatzschicht in der Getriebemontage erforderlich.
Ablauf Anfrage: * 30.05.2014 12 00 Uhr

Mitarbeiterliste || Rückmeldungen 2(9) | Z

	Vorname		
☐	Logistikdienstleis		
☐	Stefan		
☐	Branislava	Hoffmeister	0
☐	Moritz	Hämmerle	0
☐	Ulf	Kottig_14	0
☐	Christian6	Kuhn	0
☐	Christoph	Moser	0
☐	Stefan	Parge	0
☐	Tobias	Strölin	0

Qualifikation	Level
Bohren	4
Einrichten	2
Schleifen	3

Schicht
Dienstag, 27. Mai 2014

Nachtschicht am IAO
Dienstag, 27. Mai 2014

Zusatzschicht 29.05.2014
Donnerstag, 29. Mai 2014

Zusatzschicht
Samstag, 31. Mai 2014

Send Request for Work Assignment

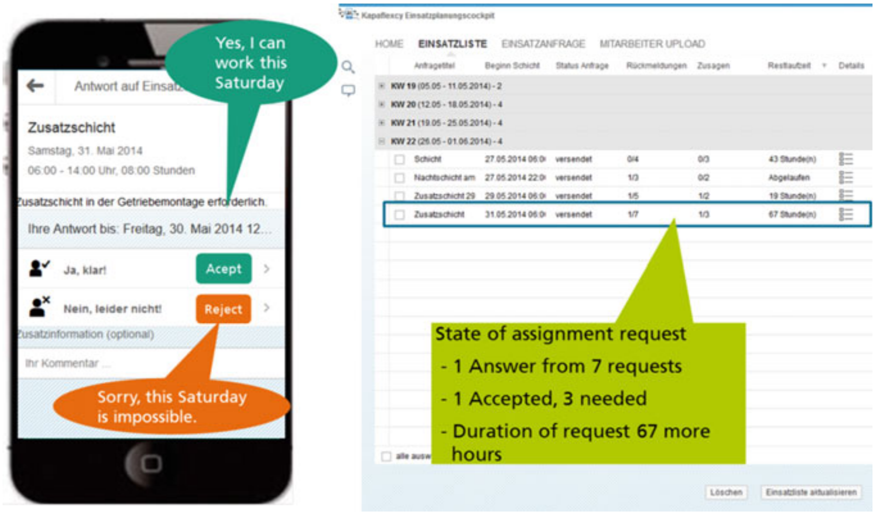
Priority Level and Qualification

Push-Message to Smartphone

Fig. 4 Supervising cockpit

the list of his possible work assignments as shown in the screen of the smartphone in the right section of Fig. 4.

Now the group of eligible employees has to agree upon the possible work assignments, which are scheduled from the supervisor. Therefore they can vote upon their work assignments directly over their mobile devices, as shown in Fig. 5. For example an additional shift is scheduled for Saturday and employees with



Yes, I can work this Saturday

Zusatzschicht
Samstag, 31. Mai 2014
06:00 - 14:00 Uhr, 08:00 Stunden
Zusatzschicht in der Getriebemontage erforderlich.
Ihre Antwort bis: Freitag, 30. Mai 2014 12…
Ja, klar!
Nein, leider nicht!
Zusatzinformation (optional)
Ihr Kommentar …

Sorry, this Saturday is impossible.

	Anfragetitel	Beginn Schicht	Status Anfrage	Rückmeldungen	Zusagen	Restlaufzeit	Details
KW 19 (05.05 - 11.05.2014) - 2							
KW 20 (12.05 - 18.05.2014) - 4							
KW 21 (19.05 - 25.05.2014) - 4							
KW 22 (26.05 - 01.06.2014) - 4							
☐	Schicht	27.05.2014 06:0	versendet	0/4	0/3	43 Stunde(n)	
☐	Nachtschicht am	27.05.2014 22:0	versendet	1/3	0/2	Abgelaufen	
☐	Zusatzschicht 29	29.05.2014 06:0	versendet	1/5	1/2	19 Stunde(n)	
☐	Zusatzschicht	31.05.2014 06:0	versendet	1/7	1/3	67 Stunde(n)	

State of assignment request
- 1 Answer from 7 requests
- 1 Accepted, 3 needed
- Duration of request 67 more hours

Fig. 5 Mobile voting app

qualification of adjusting and transporting are eligible. The employee can agree to the work assignment or he can reject it via the action buttons of the screen.

The voting is directly transmitted to the central planning instance and displayed in the supervisor cockpit as shown in the right part of Fig. 5. The most important information will be presented at a glance to him: How many employees have processed the request, how many of them have accepted and how long is the duration of the request.

After the request is closed, the supervisor has to fix the assignments and close the voting requests. The schedule of work assignments will be updated. An informational message about the fixed work assignment is sent to the employees to close the process formally.

4 User Participation

The process is called "self-organized labor planning" and the employees are directly involved in the process. Also the User Interface of the App is very easy to understand and "intuitively operable", the process has to be understand and it has to meet different targets of the business as well as of the employees. A key element and a success factor in the implementation of the process and the app is the participation of the users, the supervisors and the workers [18]. To foster the participation of the users a role playing game was developed. It consists of a process blue print, of sketches of the User Interfaces from the IT-Components and of realistic test data, to describe typical situations of the application of the process, see Fig. 6.

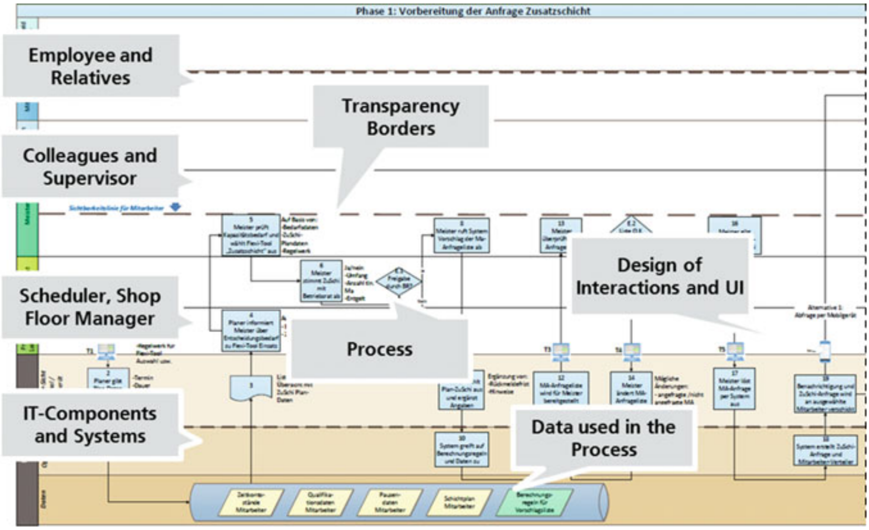


Fig. 6 Participation of the users by means of a role playing game

The role playing game can be used in two stages of the implementation. First it can be used to set up the process itself and to define the tasks and responsibility of the persons and components involved. The process will be inspected of possible target conflicts which may be solved by an alternative behavior and therefore branches in the process. The role playing game offers a structured medium to discuss the decisions behind the possible target conflicts. It clarifies the conditions and solutions of the target conflicts and the solutions to these conflicts.

After the process is defined, it has to be rolled out to all the persons involved. In this second stage of the implementation of the self-organized labor planning the role playing game becomes a training instrument. Typical situations and measures for the alignment of the production capacity will be presented based on the underlying test data of the role playing game. The User Interfaces of the IT-components will be introduced; the flow of the process with his possible branches shown, and the rationale behind the decisions explained.

Within the pilot studies and test cases of the project “KapaflexCy” the role playing game has successfully shown and proved its usefulness [18].

5 Findings of the Pilot Studies

A prototype of the IT-System was implemented. Three pilot applications of the system are still used by the industrial application partners in the project. The pilot applications have gained valuable insights about conditions, requirements, and acceptance of the developed tools.

The first partner started his test phase in April 2014 and has the application still running successfully. The company produces automotive parts for the ignition and combustion of Otto- and Diesel-Engines. The production process is highly automated and operated continuously in three shifts from Monday till Saturday morning. The company uses the KapaflexCy-System in two production units with round about 80 workers, which are distributes over three shift groups [19]. Figure 7 shows a few impressions from the pilot study.

The upper left picture shows the automated assembly system, called “PSG”, of one of the two production units involved in the pilot study. Most of the workers use their private smartphone for voting app and to sign into or to reject the work assignments, see the lower left photo in Fig. 7. At the start of the project “KapaflexCy” in September of 2012 round about 60 % of the employees of the two production units doesn’t own whether a smartphone neither a Home Computer and an private E-Mail-Account. For those employees it was decided in the project to offer them a special terminal in their production area as a public inquiry kiosk, as shown in the lower right photo of Fig. 7. At this kiosk those employees can check into the system with their electronic staff badge and check their work assignments and vote upon them. Moreover the fully functionality of the KapaflexCy-App is offered in the kiosk.

Production Unit	Additional Work Assignments
PSG	> 130
HTS	> 350
Total:	**> 480**

Fig. 7 Impressions from one pilot study of the KapaflexCy-system

In the 16 month between April 2014 and September 2015 the KapaflexCy-System was used for in total more than 480 alignments of the production capacity. At the end of the testing phase the user experiences are collected in interviews with the employees and the supervisors. The feedback is throughout encouraging:

- Faster planning and an immediate response of the workers.
- Easier decision and direct coordination with private matters for the employees.
- Better personal organisation since the work schedule and the private appointments are now accessible through the same device.
- Quick overview about work assignments at every place and any time.
- Modern tool and image.

Other findings are:

- An immediate and reliable response is only given from the smartphone users. Therefore the optional kiosk is as a „work around“ suitable, but will not offer all the advantages of the application.

- The share of smartphone users in the two production units has increased within the three years of the research project from round about 60 % of the employees to more than 80 %. In one production unit all of the user own a private smartphone.
- The users prefer the combination of private appointments and the work schedule in one device. Therefore "Bring Your Own Device" is a urgent suggestion for the success of those kind of business applications.

6 Conclusion

The main task of the German research project 'KapaflexCy' is the development of strategies, methods, and tools to implement, support, and operate a self-organized scheduling of labor times. The solution will use in particular mobile devices, to include persons acting as leading authorities in CPS control logic. The application is also designed as a scalable cloud solution. Therefore the implementation of the solution needs no investment and the effort and the time for the set-up is dramatically reduced. This is an example, how the new paradigm of the Industrie 4.0, Internet of Things and Software as a Service may contribute to the agility of enterprises through new applications and new IT paradigms.

KapaflexCy is one the first realized use cases for an "Industrie 4.0". It is implemented and still operative in two companies. The internal feedback as well as the extraordinary high public interest is exceptional encouraging. Therefore two partners of the KapaflexCy project has decided to start the development of a commercial IT-Solution, which will be available in the summer of 2016.

With this commercial solution it will be possible to do some long time evaluation of the application of the KapaflexCy approach. We expect, that a higher degree of self-organization will be possible than today is trusted by the supervisors. For example, today the alignment of the production capacity is task of the supervisor, who is in charge for the production due dates. The supervisor therefore creates and sends requests for work assignments to the operators. Why not to hand over this task to the group of operators? Why not to present in a next generation of the KapaflexY-App the group of operators the production orders, due date and the work assignments needed therefore? The group of operators now may agree upon their individual work assignments on their own responsibility. The supervisor only has to be informed if not all necessary work assignments can be occupied.

In January 2016 a new research project named "myCPS 4.0" is started, where among others use cases the KapaflexCy pilot study will be extended to a long term evaluation, especially of the changes of the behavior patterns for the capacity alignment.

Acknowledgments The research and development project 'KapaflexCy' is funded by the German Federal Ministry of Education and Research (BMBF) within the Framework Concept "Research for Tomorrow's Production" and managed by the Project Management Agency Karlsruhe (PTKA). More information about the ongoing research project is provided via [20]. Please apologize, that the website is in German language.

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Increasing Safety in Human-Robot Collaboration by Using Anthropomorphic Speed Profiles of Robot Movements

Henning Petruck, Sinem Kuz, Alexander Mertens and Christopher Schlick

Abstract The demand for flexible production systems in which the flexibility at assembly processes is increased by human-robot collaboration rises. In such systems the safety of the worker, transparency of the robot's actions and mental effort are of special importance. As acceptance of technical systems can be increased by anthropomorphism, an anthropomorphic speed profile of a simulated gantry robot is compared to conventional robotic trajectories. Results of a study with 20 male participants, in which the influence of these speed profiles for movements of the gantry robot on mental effort and prediction time was investigated, are presented in this paper. The results show a significant increase of accuracy for predicting target positions for the movements with an anthropomorphic speed profile. The speed profile does not have a significant effect on prediction times and mental effort. Hence, design recommendations for an ergonomic design of human-robot collaboration can be derived from these results.

Keywords Human factors · Anthropomorphism · Human-Robot collaboration · Occupational safety

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1 Introduction

Caused by multi variant products and ever shortening product life cycles there are usually assembly steps, which cannot be automated economically for small lot sizes. Additionally there are assembly steps, whose automation is either very difficult and time consuming or even not realizable. The handling of limp components, for instance, causes a lot of problems in automation [1], although it is intended to produce these products automatically as well. The automated production proceeds until an assembly step occurs that is not intended for automated execution. At this time, the partial product can be transferred out to a human-robot collaboration workplace, which is affiliated to the automated assembly cell. Here, the manual assembly of the next step can be performed. In this case, the robot passes required components and tools to the working person. A study by Faber et al. [2] focuses on the reduction of the number of human-robot changes by choosing the assembly sequence accordingly, since these changes are error prone and time consuming.

As robot and human become more and more involved with each other, acceptance of the robot and understanding its actions by the human rather than getting confused by its large repertoire of actions is very important. Hancock et al. [3] points out that trust is an essentially important factor in effective human-robot collaboration. One important design principle for increasing trust is anthropomorphism, i.e. the transmission of humanlike attributes to non-human entities. This concept is used to increase the familiarity and acceptance of those entities. A driving simulator experiment in automotive engineering revealed, that the trust in a vehicle can be increased by an anthropomorphic vehicle design achieved by giving the car name, gender, and voice for instance [4]. Other studies showed that an anthropomorphic design enhances the acceptance of a robot [5]. This can for instance be achieved by combining verbal communication of the robot with a human gesture [6].

Kuz and Schlick [7] analyzed the effect of anthropomorphic and trapezoidal speed profiles with constant speed on the prediction of the target position for placing movements with a human movement trajectory on a 4 × 5-grid, similar to a chessboard, by a gantry robot in a virtual simulation study. The use of anthropomorphic speed profiles led to significantly lower prediction times and error rates. In a further study conducted by Kuz et al. [8], human joint angles for placing movements were transferred to a robot simulation and compared to conventional Point-to-Point (PTP) robot movements. This was done with the same virtual simulation from the earlier study [7]. In another simulation a digital human model was used to investigate various levels of anthropomorphism. Here, an activation of the mirror neurons indicating a detection of intention could be measured during observation of the movements. Thereby a stronger activation of the mirror neurons could be proven for anthropomorphic movements than for PTP-movements.

Continuing these studies the effect of the speed profile for PTP movements on the prediction time, error rate, and mental effort was investigated in the presented study. The PTP movements were chosen, as the effect of speed profiles for these trajectories has not been investigated before. Similar to the previous study by Kuz and Schlick [7], this study also considered anthropomorphic and trapezoidal speed profiles. The methodology and results of this study are presented in the following.

2 Method

2.1 Transfer of Speed Profiles to PTP Movements

As the study presented here continues the study conducted by Kuz and Schlick [7], the movement trajectories used in the preceding study serve as a basis for this study. Nevertheless, the movement trajectories used for this study basically differ from the earlier used trajectories. Those trajectories were captured from a human placing movement using an infrared motion tracking system. The anthropomorphic speed profile was extracted from the trajectory. Within this study only PTP movements are considered. To generate a PTP movement from an anthropomorphic movement, start and target position from the PTP movement have to be applied. These positions define the start and target joint angles of the robot, which can be calculated by inverse kinematics. A PTP movement is performed by shifting the joints directly from start to target angles. The intermediate joint angles are calculated by interpolation. Both the PTP and anthropomorphic movement follow a parabolic course, whereas the parable of the PTP movement has a positive gradient. This leads to an approach to the target position by the robot from below the grid (see Fig. 1). Hence, in reality this movement is not realizable due to collisions with the grid. Lowering the grid so that no point of the resulting movement trajectory is below the target position (the target position is lowered likewise), prevents collisions with the grid and makes the movement realizable. For this reason the grid has been lowered by 200 cm in contrast to preceding study (see Fig. 1).

After defining the movement trajectories unambiguously, the speed profile was adjusted. The used speed profiles were also adopted from the preceding study (see

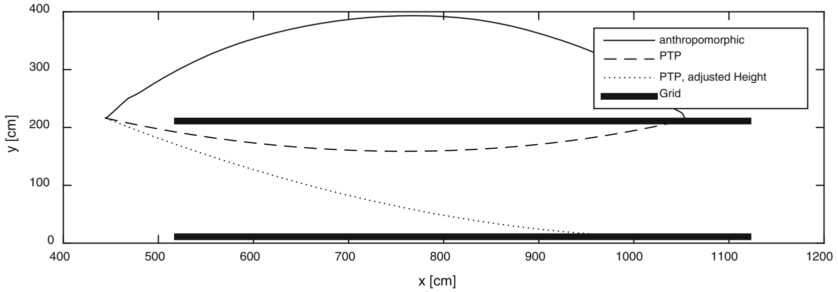

Fig. 1 Trajectory of the TCP for anthropomorphic and PTP-movements with original and adjusted height of grid

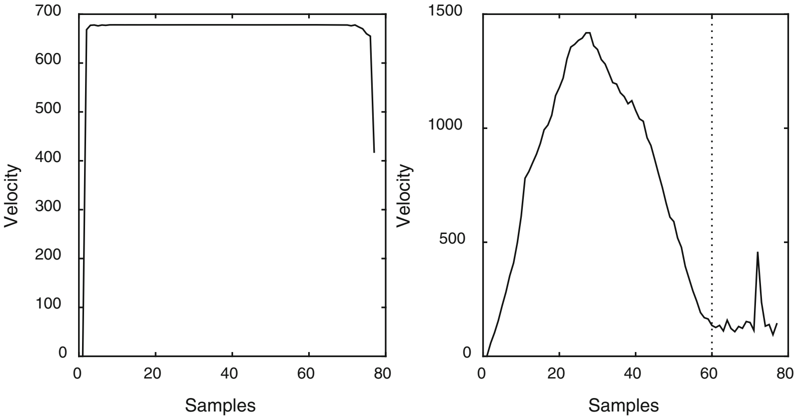

Fig. 2 Trapezoidal (*left*) and anthropomorphic (*right*) speed profiles of robot movement trajectories. The dotted line indicates the considered range of the anthropomorphic speed profile

Fig. 2). As they were calculated numerically by derivation from the discrete position data, they are only accessible in a discrete time series with a finite number of samples. For the anthropomorphic speed profile a noise can be recognized in the signal after 60 samples, where the speed increases significantly for a small time interval.

That noise can be explained by a jerking that was captured by the motion tracking system during the fine-positioning. Here, corrections are made in the sense that the hand is moved a little in one direction and then into another direction to precisely hit the target position. Since a PTP movement does not contain a fine-positioning element—this would be contradictory to a robot movement, as robots can precisely approach the target position without further corrections—the fine-positioning part of the speed profile is ignored for the PTP movement and only the first part up to the 60th sample is considered.

The PTP movement trajectories are defined by position data. That are available in the vectors $\boldsymbol{x} = (x_1\, x_2 \ldots x_n)$, $\boldsymbol{y} = (y_1\, y_2 \ldots y_n)$ and $\boldsymbol{z} = (z_1\, z_2 \ldots z_n)$ of length n. The speed profile is defined by the vector $\boldsymbol{v} = (v_1\, v_2 \ldots v_N)$ of length N. The path length of the movement trajectory up to the jth coordinate can be calculated by

$$r_{PTP,j} = \sum_{i=1}^{j-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2}, 1 \le j \le n. \quad (1)$$

The speed profile defines the speed in equidistant time steps. The duration of a single time step in the speed profile is denoted by

$$\Delta t = \frac{T}{N - 1}, \quad (2)$$

depending on the total movement duration T and the number of samples N in the speed profile. With the single time step duration Δt the covered distance of an arbitrary speed profile $\xi \in \mathbb{R}^{1 \times M}, M \in \mathbb{N}$ up to the jth sample can be calculated by numeric integration using the trapezoidal rule:

$$r_{profile,j}(\xi) = \Delta t \sum_{i=1}^{j-1} \frac{\xi_{i+1} + \xi_i}{2}, 1 \leq j \leq M. \tag{3}$$

By means of the scaling factor

$$\alpha = \frac{r_{PTP,n}}{r_{profile,N}(\boldsymbol{v})}, \tag{4}$$

which is the ratio of total length of the movement trajectory and speed profile, the scaled speed profile $\boldsymbol{w}$, whose covered distance is identical to $r_{PTP,n}$, can be calculated by:

$$\boldsymbol{w} = (w_1 w_2 \ldots w_N) = \alpha \cdot \boldsymbol{v}. \tag{5}$$

The movement trajectory with scaled speed profile is defined by targeted positions in equidistant time steps of the length $\delta t = 16\text{ms}$. The partition in time steps of length δt enables a judder free run of the movement in the virtual simulation. The first position $\boldsymbol{p}_1 = (x_1 y_1 z_1)^T$ is initialized with the start coordinates of the PTP trajectory. For all further time steps the following two steps are carried out iteratively:

I. Calculate the covered distance after j time steps by means of the speed profile. To obtain a preferably exact calculation of the distance the position is interpolated between the closest points of the speed profile in terms of time. The formula for this calculation is given by

$$r(t_j, \boldsymbol{w}) = r_{profile,k-1}(\boldsymbol{w}) + \left(r_{profile,k}(\boldsymbol{w}) - r_{profile,k-1}(\boldsymbol{w})\right) \cdot \beta \tag{6}$$

with $t_j = (j-1) \cdot \delta t,\ k = \min_{1 \leq k \leq N} \{k \cdot \Delta t > t_j\} \cdot$ and

$$\beta = \frac{t_j - (k-1) \cdot \Delta t}{\Delta t}. \tag{7}$$

II. Calculate the according position on the movement trajectory. This is also done by interpolating between the known positions of the movement trajectory. The formula for this calculation is given by

$$p_j = \begin{pmatrix} x_l \\ y_l \\ z_l \end{pmatrix} + \left(\begin{pmatrix} x_{l+1} \\ y_{l+1} \\ z_{l+1} \end{pmatrix} - \begin{pmatrix} x_l \\ y_l \\ z_l \end{pmatrix} \right) \cdot \frac{r(t_j, \mathbf{w}) - r_{PTP,l}}{r_{PTP,l+1} - r_{PTP,l}} \tag{8}$$

with $l = \min_{1 \le l \le n} \{ r_{PTP,l+1} > r(t_j) \}$

By means of this algorithm an arbitrary movement trajectory can be equipped with an arbitrary speed profile, both of which being available in discrete form, but not necessarily of the same length. This algorithm is applied to the discussed PTP trajectories and speed profiles in order to generate the movements for this study.

2.2 Task

The participant's task was to monitor the robotic movements and predict the target position on the 4 × 5 grid. As soon as they recognized the targeted position, they had to stop the movement by pressing a button. In total 20 different positions on the grid were approached by the robot. Considering the two speed profiles this results in 40 different prediction tasks. For all movements the duration was identical. By choosing identical durations the maximum speed is higher for the anthropomorphic speed profile, but the mean speeds are equal, so that the prediction times are comparable. The movements were displayed to the participants in real time in a virtual simulation. consisting of a KUKA KR30 Jet gantry robot and the grid in front of the robot (see Fig. 3). After stopping the movement, the participant named the recognized position to the supervisor of the experiment and rated the perceived

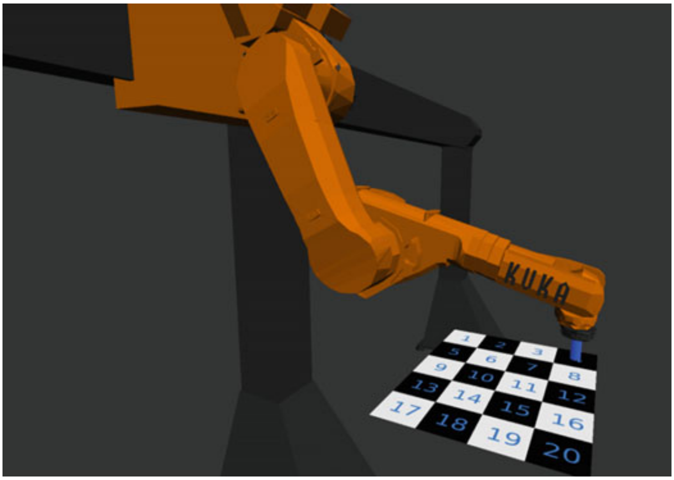

Fig. 3 Design of the virtual simulation of the gantry robot and the grid

mental effort on the Rating Scale of Mental Effort (RSME) [9], which evaluates the mental effort in a range of zero to 150. During the task the position of the participant's heads were fixed using a chin rest.

2.3 Experimental Variables

Independent variables of this experiment are the targeted position (20 positions) and the speed profile (trapezoidal & anthropomorphic). The dependent variables are the prediction time, the prediction accuracy, and the mental effort.

2.4 Procedure

The study started with a questionnaire that queried general information like age, educational level, and experience in robotics and production. Afterwards an eyesight test was conducted, followed by a cube assigning test that tests the spatial power of imagination. Afterwards, a preliminary test similar to the main task, with a reduced size of the grid and reduced number of movements was conducted, in order to let the participants familiarize with the test environment and the task. The main part consisted of observing the 40 movements and evaluating the perceived mental effort after each movement. The order of movements was permutated for each participant, in order to avoid possible sequence effects. The whole experimental procedure is sketched in Fig. 4.

2.5 Participants

The movements were displayed to 20 male participants at the age of 18 to 46 ($x = 24.15, sd = 6.44$), who were either following a Bachelor's or Master's program in engineering or have already graduated. All participants had a visual acuity

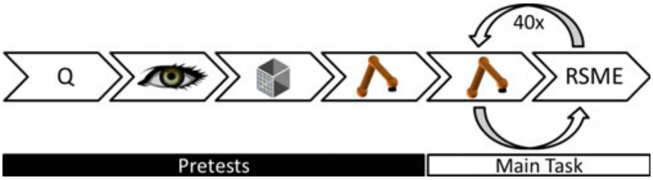

Fig. 4 Pretests and main tasks in experimental procedure

larger than 80 %, no limitations in color sense and only one participant had limitations in spatial vision. On average the participants assigned 64.25 % ($sd = 16.57$) of the cubes correctly within the cube test.

3 Results

The prediction times and the mental effort for correct predictions summarized over all fields of the grid are depicted in Fig. 5. For the anthropomorphic speed profile the prediction time ($\bar{x} = 1951\text{ms}$, $sd = 761.86\text{ms}$) is larger than for the trapezoidal speed profile ($\bar{x} = 1811\text{ms}, sd = 678.58\text{ms}$). The mental effort is larger for the anthropomorphic speed profile ($\bar{x} = 17.31, sd = 15.74$) than for the trapezoidal one ($\bar{x} = 14.47, sd = 11.78$) as well. However, the standard deviation is comparatively large and proven by an ANOVA with repeated measurements and a significance level of $\alpha = 0.05$ these effects are not significant neither for the prediction time ($p = 0.214$) nor for the mental effort ($p = 0.189$). A significant effect for the field position for the prediction times could be proven ($F(19; 361) = 99.836, p < 0.01$). However, these effects cannot be interpreted due to a disordinal interaction effect ($F(19; 361) = 9.977, p < 0.01$). The same applies to the field position ($F(19; 61) = 6.205, p < 0.01$) and interaction ($F(19; 361) = 1.730, p = 0.03$) for mental effort.

Because of the different speed profiles, the covered distance is not equal for given points in time. Considering this, the evaluation of the prediction time in not sufficient, so that the covered distance at the time of prediction is additionally evaluated. As the distances differ for the individual field positions, the covered distances at prediction time t_{pred} are normalized with their total length by evaluating:

$$d_{rel} = \frac{r(t_{pred}, \boldsymbol{w})}{r_{PTP,n}}. \tag{9}$$

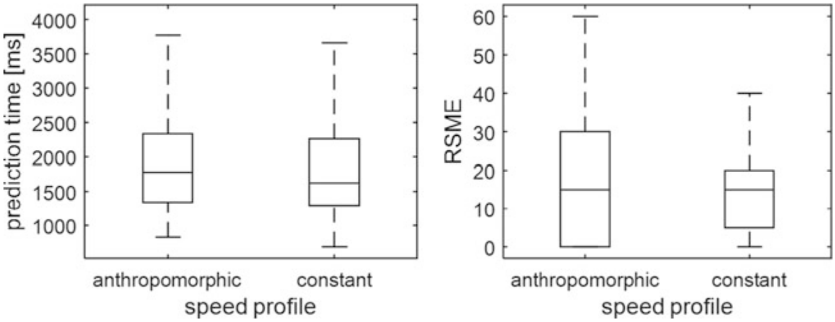

Fig. 5 Prediction times (*left*) and mental effort (*right*) for correct predictions for anthropomorphic and trapezoidal speed profiles

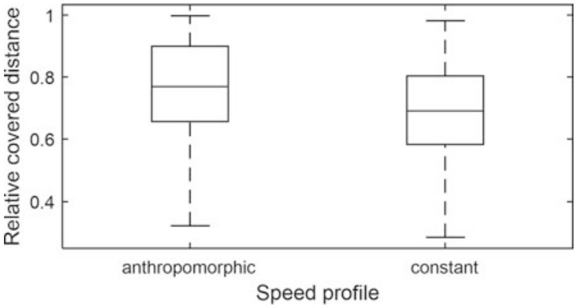

Fig. 6 Relative covered distance at prediction time for anthropomorphic and trapezoidal speed profile

The relative covered distance is depicted for both speed profiles in Fig. 6. The results show, that the relative covered distance is on average larger for the anthropomorphic speed profile ($\bar{x} = 0.7632, sd = 0.1577$) than for the trapezoidal speed profile ($\bar{x} = 0.6852, sd = 0.1643$). This difference is significant ($p < 0.01$) proven by an ANOVA with repeated measurements ($F(1, 19) = 44.295$). This can be explained by the particular covered distances at prediction.

Figure 7 shows the covered distance of both speed profiles over time. At first, the covered distance is smaller for the anthropomorphic speed profile, but at a distance of 326.9 cm (46.08 % of total distance) the two speed profiles intersect. After that, the covered distance is higher for the anthropomorphic speed profile until they intersect again at completion of the movement. For both speed profiles the mean relative covered distances at prediction time are larger than this intersection, so the covered distance is larger for the anthropomorphic speed profile at one point of time. So the covered distance would already be larger for the anthropomorphic speed profile for equal prediction times. If the prediction time for the anthropomorphic speed profile is longer than for the trapezoidal profile, which is the case on average, this difference gets even larger. An explanation for the surprising effect that the covered distance at prediction is larger for anthropomorphic speed profiles could be, that the measured prediction time contains the reaction time and with an earlier recognition time even the covered distance was shorter than for the constant speed profile.

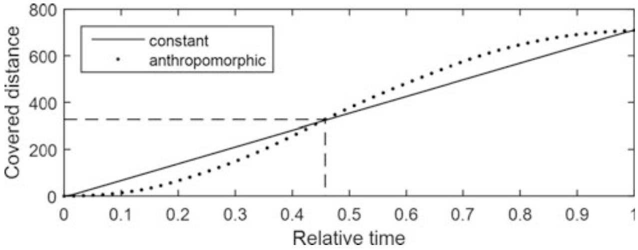

Fig. 7 Covered distance over time for anthropomorphic and trapezoidal speed profile

The evaluation of error rates for the anthropomorphic speed profile shows that the targeted fields are predicted correctly by a rate of 58.75 %, predicted incorrectly by a rate of 36 % and the spare 5.25 % are missing predictions. Missing predictions indicate those predictions that were made after completion of the movement and could therefore not be accepted or those that were not made at all. For the trapezoidal speed profile 42.5 % of the field positions were predicted correctly, 48 % incorrectly and 9.5 % were missing. These differences are significant, proven by a chi-square test at a level of significance of $\alpha = 0.05$.

4 Summary and Outlook

The results of the presented study show a significant effect of the speed profile on the prediction accuracy. Thereby, the usage of anthropomorphic speed profiles yields a higher accuracy. Because of the acceleration and deceleration within this movement the targeted position is more predictable, whereas the robot stops abruptly at the target position when using the trapezoidal speed profile. Prediction times and mental effort are on average smaller for movements with a trapezoidal speed profile, although this effect is not statistically significant. However, a significant effect of the speed profile could be proven on the covered distance until the prediction. The covered distance is longer, when using the anthropomorphic speed profile. Summarized with the results from Kuz and Schlick [7] and Kuz et al. [8] it could be shown, that the movement trajectory of the robot has the largest influence on prediction times and mental effort. The effect of significantly reducing the prediction times and mental effort, observed while using an anthropomorphic trajectory in combination with an anthropomorphic speed profile, could not be observed for a PTP trajectory. However the prediction accuracy and the covered distance until prediction could be increased doing the same with a PTP trajectory. This is only partly advantageous, since the robot's target should be recognized as early as possible and after the shortest covered distance possible. As the accuracy improvement can also achieved by using anthropomorphic trajectories, the use of PTP movements might not be the best choice, if a good recognition of actions is desired.

In this study, the human and robot collaborated only indirectly, because the human occupies the role of an observer and was separated from the robot. It would be interesting to investigate the effect of anthropomorphic trajectories and speed profiles in a direct human-robot collaboration scenario. Such studies should be performed in real world with a real robot, because a robot in a virtual simulation cannot directly collaborate with the human in a realistic manner.

Acknowledgments The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries".

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A Comparative Empirical Evaluation of the Accuracy of the Novel Process Language MTM-Human Work Design

Thomas Finsterbusch, Andreas Petz, Marco Faber, Jörg Härtel, Peter Kuhlang and Christopher M. Schlick

Abstract The paper presents the comparative evaluation of the building block system MTM-HWD® (Human Work Design). It aims at verifying the statistical accuracy of the method to predict motion times compared to the generic MTM-1 system. The MTM-HWD® system is for use in serial production and especially for cycle times between 30 and 120 s. The accuracy of the system as the mean difference between MTM-HWD® and MTM-1 cycle times at the 95 % confidence level are determined by using a sample of 43 real work place analyses summing up 12,499 MTM-1 process building blocks. The sample size is representative by comparing it to a similar study during the development of MTM-2 made by the Swedish MTM Association. The findings show a statistical significant difference between MTM-HWD® and MTM-1 ($\alpha = 0.05$). However, the cycle times analyzed with MTM-HWD® deviate on average not more than 5 % from those using MTM-1.

Keywords Method-Time measurement · Process language · Human work design · MTM-HWD®

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1 Introduction

The Methods-Time Measurement (MTM) process language is a standard method for productivity improvements of manual work, measurement and evaluation of the performance of work systems and workflow optimization as well. Manual assembly times are predicted prior to actual implementation of the working system. The required time to complete specific tasks is determined by assessing motions of the human limbs, the work conditions as well as specific influencing factors on the motion times.

The early beginning of motion studies goes back to Frank Bunker Gilbreth. Gilbreth was the first modelling human motions of the hand. He defined so called "therbligs" (his name spelled backwards) as elementary motions for describing and subsequently designing the actions performed by the worker [1]. This was the first approach in optimizing work process by reorganizing or reducing unnecessary motions. Therefore, no time-related evaluation was necessary or did exist.

Maynard, Stegemerten and Schwab developed the basic Methods-Time Measurement System MTM-1 in 1948 based, among others, on the research of Gilbreth [2]. They thoroughly analyzed the work performed on the shop floor of the Westinghouse Brake Corporation by filming and rating qualified workers. Thus, the newly developed method defines process building blocks and evaluates the workers motions by standard time values [3]. The major benefit lies in the model building ability of the method. Thus, target times are calculated before the work system is been set up. Therefore, the method is considered to belong to the predetermined times system measurement techniques.

The portfolio of MTM process building block systems family grew by development of additional specialized systems. This was only possible because of the building block principle. Further developments of the MTM system derive from and are fully compatible with MTM-1. This means that basic motions of MTM-1 are aggregated, in order to increase the speed of application or too adapt to a specific activity or working environment. In this respect, beyond generic systems like MTM-1 and MTM-2, also functional and specific systems were developed like MTM-UAS (Universal Analyzing System) for a particular type of activity like office work or for a particular industry or organization [4].

The further enhancements of the generic systems focuses only the determination of target times by aggregation of the process building blocks thus increasing application speed and reducing level of accuracy. The work process and consequently the work method are not considered in detail, although they represent a great potential for process and workplace optimization, especially from an ergonomic point of view.

In summary, existing procedures from the past decades focus on a paper-based evaluation of movements for minimizing the production time by avoiding waste. Thereby, they focus only target times neglecting potential integrative ergonomic evaluations and process optimizations. Thus, a comprehensive evaluation is not given but prerequisite for a holistic optimization of the production system. We propose going back to the roots by describing the process and the motions in a chronological order at an acceptable accuracy level for cycle times between 30 and 120 s. Therefore, a novel process building block system MTM-Human Work Design was developed by a research group consisting of industrial and scientific institutions.

The Institute of Industrial Engineering and Ergonomics at RWTH Aachen, as one of the research partners, evaluated the accuracy of MTM-HWD®. Therefore, two evaluation phases were defined. First, an internal verification based on 43 work places where statistically analyzed for determining relative accuracy to MTM-1 of the novel system. The results are presented as follows. In the second phase an external validation will be conducted, not presented in this paper.

The next section presents the modelling and assessment method. The method for evaluating the system's accuracy and the data sample are presented in Sect. 3. Finally, results and a brief conclusion are given.

2 Development of MTM-Human Work Design

The generic MTM and ergonomic assessment systems are collecting information of the work process and methods, determining time, and evaluating physical loads with different methods and in different steps. Therefore, the HWD® research group evolved a notation language based on pictograms and aggregated MTM-1 process building blocks. The notation language combines time-relevant influencing factors of the work method (e.g. distance classes, cases of grasp, weights) as well as influencing factors of the ergonomic assessment (e.g. rotate trunk, bend trunk, finger forces, case of grasp, positions of hand, arm, and shoulder joints). The novel MTM building block system MTM-HWD® facilitates the transformation of MTM towards a process language for modeling human work [5]. Based on motion elements and their graphical representation (pictograms, see Fig. 1), we are able to

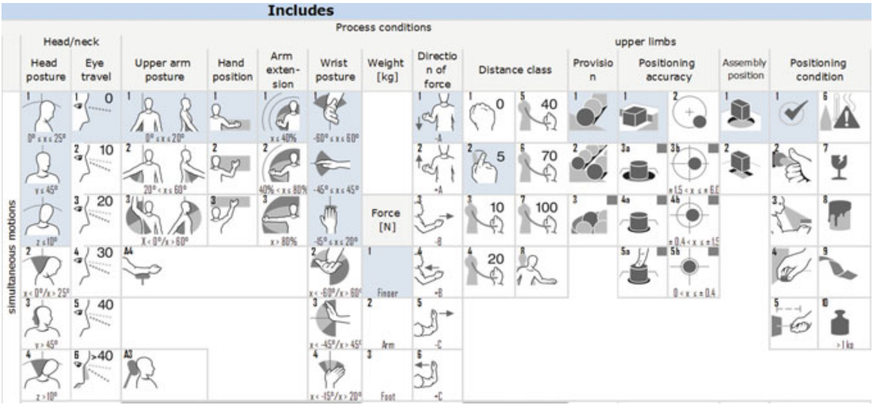

Fig. 1 Excerpt of the description form of the building block system MTM-HWD® [5]

model human movements simultaneously and as well as to asses it from an ergonomic point of view by prominent methodologies such as Ergonomic Assessment Worksheet (EAWS).

2.1 Modelling Human Work with MTM-HWD®

Based on the building block principle of the MTM family various influencing factors need to be considered for accurately modelling human work. The MTM-HWD® working group combined basic motions in a chronological order and clustered influencing factors in representative time blocks by specific principles of building block creation. Furthermore, specific influencing factors on the work system's ergonomics (e.g. head posture) are considered as well. By doing so, the user is able to create an exhaustive anthropological motion model of the human worker. Thus, the model holds information for time determination as well as for ergonomic assessment by describing individual body parts, such as lower limbs, trunk, head/neck, and upper limbs.

Whereas the traditional MTM application is characterized by the use of a data card and the filling-in of structured analyzing forms, in MTM-HWD® a description form is used in which the corresponding actions together with their influencing factors have to be marked. For optimization purpose, the lowest speed of the basic motion is highlighted as well. This value supports the user in designing productive and ergonomic work processes. Thus, MTM-HWD® enables the creation of a motion model of human work. MTM-HWD® always describes the complete motion. Therefore, a partial description (of, for example, only the time-related influencing factors) is not possible [6].

2.2 Assessing Human Work with MTM-HWD®

The assessment is performed in two steps. In the first step the individual HWD® influencing factors are assigned standard times from which, based on a (company-specific) time structure, target times can be derived. In the second step, a load analysis is performed by coupling an ergonomic assessment method (e.g. EAWS) to the HWD® description, in order to determine a load index (score value). In other words, the information from the description (such as actions, influencing factors, times, frequencies) is made available to the algorithm (sections and rules) of the assessment method.

3 Method

3.1 Procedure

For the verification of the MTM-HWD® cycle times 43 work places of different companies were analyzed using both the MTM-1 and MTM-HWD® system. Each of the resulting analyses was subdivided into multiple sections. In a first study, the total cycle times of the MTM-HWD® analyses were compared to those of the MTM-1 analyses. In order to find the relation between the time values, a regression analysis was performed.

For ensuring representativeness, the raised sample was compared by performing a X^2-test to similar studies conducted by the American and Swedish MTM Association. A paired *t*-Test investigates the relationship between MTM-1 and MTM-HWD®.

3.2 Sample

The sample comprises 43 MTM-1 analyses with a total of 12,499 process building blocks. The frequencies of the used process building blocks are depicted in Fig. 2. The MTM-1 process building blocks that were used most frequently in the data sets are: Move (29.5 %), Grasp (18.2 %), Reach (15.2 %), and Release (12.8 %). The present sample deviates significantly ($X^2(10) = 175.9183$) compared to the sample that was used to develop MTM-2 with over 22.000 process building blocks [2]. However, nearly 96.2 % of the test statistic is caused by the high deviation for the process building block (basic motions) "T". This might be explained by the fact,

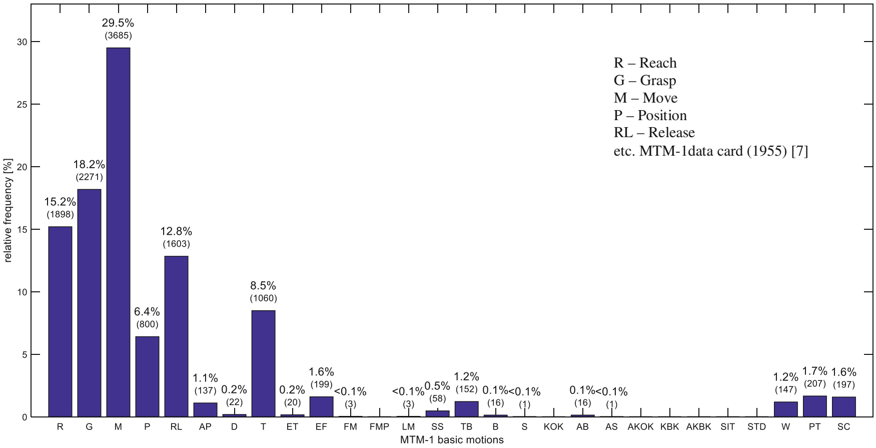

Fig. 2 Frequencies of the MTM-1 process building blocks

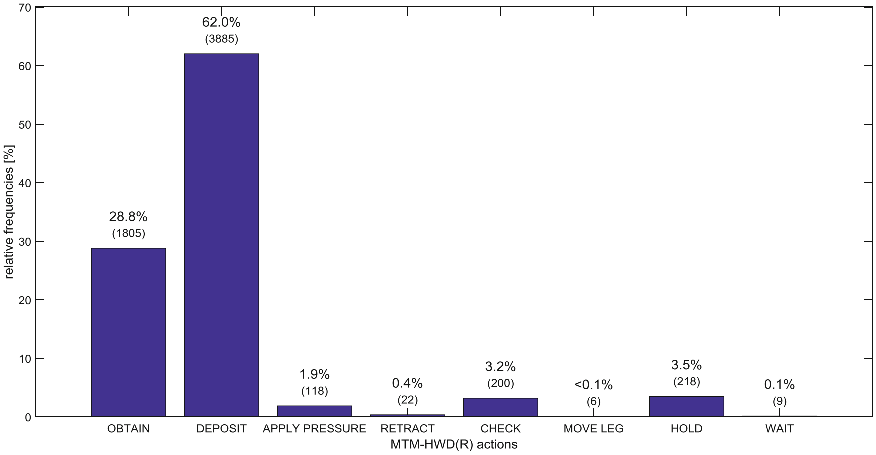

Fig. 3 Frequencies of the MTM-HWD® process building blocks

that in the MTM-2 sample motion sequences not contributing to the overall time were not analyzed. Regarding the basic motions of the finger, hand, and arm system (R, G, M, P, RL) there is no significant difference between both samples ($X^2(4) = 0.6984$). The average cycle time of the MTM-1 analyses is 1847.6 TMU (*SD* = 879.8).

The corresponding MTM-HWD® analyses comprise 6263 actions. The most frequent ones are Deposit (60.6 %) and Obtain (31.1 %) as depicted in Fig. 3. The average cycle time of the analyses is 1909.4 TMU (*SD* = 887.2).

3.3 Statistical Analyses

All statistical analyses were executed with MATLAB 2014b. The cycle times of MTM-1 and MTM-HWD® were compared by means of a paired *t*-Test. For all statistical analyses a level of significance of $\alpha = 0.05$ was chosen. The paired *t*-Test was chosen because of the dependency between the evaluated systems caused by the aggregation of building blocks.

The *t*-Test assumes that the measurement unit is an interval scale and the distribution of the differences between the two related groups should be normally distributed. Although the differences between the paired values of MTM-1 and MTM-HWD® are not normally distributed, the sample covers enough data (size $n > 30$) for a valid testing [7].

We expect to find a significant difference between MTM-1 and MTM-HWD®. Thus, we test the zero hypotheses of having no difference between the time values of MTM-1 and MTM-HWD® (H_0).

4 Results and Discussion

In order to verify the MTM-HWD® system, the deviations of the cycle times of all work place analyses were determined. The mean deviation amounts to +61.8 TMU (*SD* = 66.6), so that the relative deviation amounts to +3.8 % (*SD* = 3.7). The minimal deviation of a work place analysis is −57.7 TMU (−3.2 %) and the maximal deviation +258.0 TMU (+12.3 %). The distribution of the deviations is depicted in Fig. 4. Hence, in general the modelled cycle times according to MTM-HWD® are higher than those determined with MTM-1. This can be traced back to the aggregation principle used during the development of the building blocks of MTM-HWD® as well as to the fact that all time values are rounded up.

According to the paired *t*-Test, the cycle times of the MTM-HWD® analyses ($M = 1909.4$, $SE = 135.3$) are significantly higher than those of the MTM-1 analyses ($M = 1847.6$, $SE = 134.2$, $t(42) = 6.08$, $p < 0.001$, $r = 0.68$), see Fig. 5. The 95 % confidence interval of the deviation accounts for [41.3, 82.3]. Thus, the null hypothesis is rejected.

Pearson correlation coefficient $r = 0.997$ shows a strong, positive linear relation between the cycle times of MTM-HWD® and MTM-1 ($R^2 = 0.994$). For further investigation, a linear regression analysis with the basic linear model

$$y = b \cdot x + a \tag{1}$$

was conducted. Thereby, the slope *b* is of great importance, as it describes essentially the dependency of MTM-HWD® to MTM-1. For the current data basis, the linear model amounts to

$$t_{HWD} = 1.0056 \cdot t_{MTM1} + 51.5175, \tag{2}$$

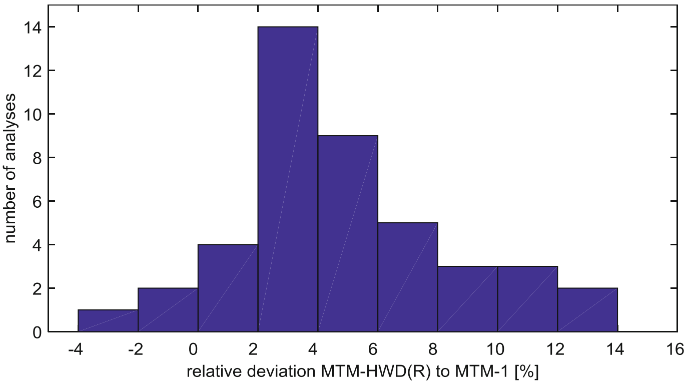

Fig. 4 Distribution of the relative deviation of the total cycle times of the work place analyses of MTM-HWD® to MTM-1

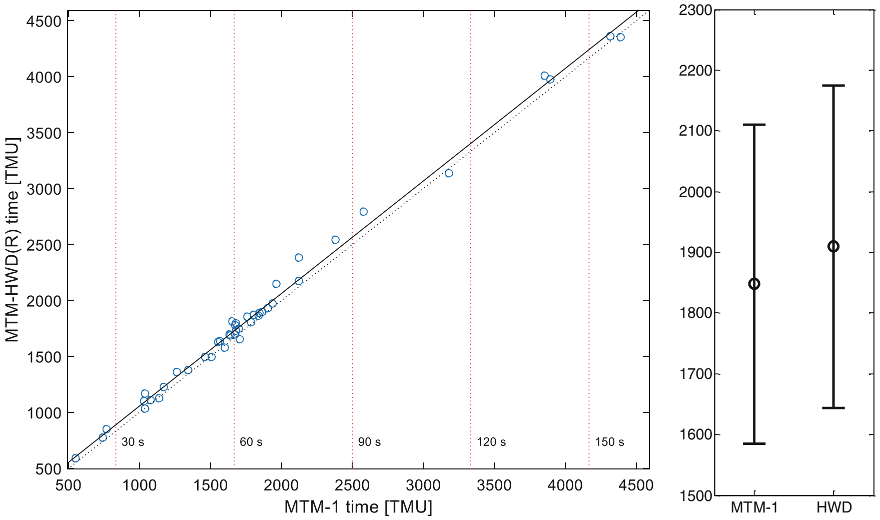

Fig. 5 Linear regression of the cycle times of MTM-1 and MTM-HWD® (*left*) and error bar chart (*right*)

whereas t_{MTM1} and t_{HWD} represents the cycle times for MTM-1 and MTM-HWD®, respectively. There is no significant difference from the optimal slope $b_{opt} = 1$ and the 95 % confidence interval for b amounts to [0.9817, 1.0294]. The coefficient a differs significantly from the optimal value $a_{opt} = 0$ resulting in a 95 % confidence interval of [2.7857, 100.2493]. The linear regression model is depicted in Fig. 5, where the dotted line represents the optimal relation $t_{HWD} = t_{MTM1}$.

5 Conclusion

Aided by the novel building block system MTM-HWD® novel motion patterns (HWD® actions) and the related process conditions as well as the work method is profoundly modelled. This results in an integrative assessment of the work process, the process time as well as an ergonomic assessment. We expect that the application speed is also significantly reduced a less error prone by the usage of pictograms instead of the so far common coding (e.g. R20A in MTM-1). This will be the topic of future investigation.

The findings show a statistical significant deviation of MTM-HWD® compared to MTM-1. However, the mean value of the analyzed cycle times deviate less than 5 % from those analyzed with MTM-1 (95 %-CI: [2.68 %, 4.89 %]). Thus, the relative accuracy places MTM-HWD® between MTM-1 and MTM-2. Considering the comprehensive character of the novel system it is a milestone towards an integrative ergonomic and productivity improvement.

Following research will investigate the application accuracy due to the variation in analyses time by different analysts using MTM-HWD® whilst analyzing a given work situation.

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Interaction Dialog Design for the Use of Mobile Devices While Walking

Jessica Conradi, Bjoern Nord and Thomas Alexander

Abstract A study was carried out to determine an optimal solution for presenting multiple interaction options on the limited space of a mobile device, e.g., a smartphone, taking into account the special situation of walking. We compared three different hierarchy models and a complex interaction editor which combines all the required interaction alternatives in one screen. Slow versus fast walking on a treadmill was introduced as an additional mobility condition. The results showed that menus with a hierarchy breadth of 4 or 8 to be suit best for walking. Flat hierarchies required longer time on task and led to fewer gaze changes per single interaction. The complex interaction editor triggered a high error count and a high task load level and therefore should be avoided while walking.

Keywords Mobile device · Interaction · Design · Menu hierarchy · Walking · Attention

1 Introduction

Size and weight of modern mobile devices are decreasing while their capabilities and relevance are increasing. They facilitate ubiquitous interaction in a broad application area, e.g., in industrial production systems for controlling and supervising automated machines and robots.

Furthermore, users usually perform additional activities while interacting with mobile devices. Smartphones are used in different environmental contexts, e.g.,

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while walking. This draws the user's attention to the device and away from the environment, and thus leads to distracted walking. 78 % of the adults in the U.S. believe that this is a "serious" issue, and 74 % say other people are almost always or sometimes distracted while walking. Just 29 % of the Americans admitted to do so themselves. Using a cell phone is a common means of distraction to walkers (e.g. 90 % talking on the phone; 85 % using a smartphone). Many pedestrians are aware of the danger of being distracted as they either witnessed a distracted walking incident (38 %) or have been involved in one themselves (26 %) [1].

This puts pedestrians at risk of accident, injury and even death. In the recent years, numbers of accidents due to smartphone usage have multiplied and are likely to continue rising [2].

Additionally, walking triggers movements of different parts of the body. Head as well as device-holding hand move independently from each other. This results in a relative movement which also affects interaction. It hampers interaction in different ways, e.g. by interfering with visual acuity as well as with input motions [3, 4].

This context calls for specially adapted interfaces, taking into account also the limited space on the displays. As mobile applications provide a vast amount of information they require sophisticated interaction. This includes the presentation and selection of multiple options. Due to the small interaction space, options have to be chosen deliberately. This can for example be done by arranging large numbers of items in hierarchical menus. They provide a given number of interaction options on each level (hierarchy breadth) resulting in a number of levels (hierarchy depth). Therefore, considering a given number of items, a large hierarchy breadth triggers a small hierarchy depth and vice versa. For example, 64 items could be arranged in 2, 3, or 6 equally sized levels. The broadest hierarchy of 2 levels depicts 8 options per level, resulting in 8^2 = 64 items. 3 levels demand 4 options per level (4^3 = 64) and 6 levels result in 2 option per level (2^6 = 64). Broad and shallow hierarchies can be learned easily, as they demand short operation paths. On the other hand, they provide a large number of options per level and therefore a higher searching effort [5].

Menu hierarchies in desktop applications have been a research topic for years. A study by [6] focused on the optimal relation of breadth and depth for 64 items. Experimental error rate as well as search time hinted an optimal menu breadth of 4–8 items per level. Other surveys showed broader hierarchies to be more effective as interaction time and accuracy decrease in deeper hierarchies and disorientation increases [7, 8].

For mobile devices, studies show mixed results. While [9] recommend broader hierarchies, [10] found slimmer hierarchies to be beneficial for small displays. The hierarchical structure affects navigational behavior and perception of users and therefore should be adapted to the display size [8]. According to [11] slim hierarchies should be used. These are to utilize the whole screen space; scrolling it to be avoided.

Besides hierarchical menus, other kinds of menus are frequently used in smartphones, e.g. fisheye-menus or 3D-menus. According to [11] in 3D-menus broader structures should be used to utilize the additionally presentable options. The kind of menu is to be selected according to the application. However, most of these menus include scrolling. This can be avoided by using an editor, which displays all the needed options in one screen, for a limited number of options. However, compared to a hierarchical menu, it results in intricate interaction.

In previous studies walking has been addressed scarcely. Therefore, in this study we focused on the influence of menu structures in hierarchic menus and of an editor which facilitated the interaction in one display in the special scenario of walking in an attention-demanding surrounding.

2 Method

We hypothesized that the menu structure influences the performance on a smartphone, especially while walking. Therefore, we carried out a study with 16 male volunteers aged 27 ± 6.7 years (MW ± SD). A design with repeated measures for all conditions was chosen, conditions were permutated according to Latin square [12].

Participant's task was interaction with a smartphone while walking on a treadmill. Additionally, a projection-wall (2.3 × 3.6 m) with a virtual environment was used (see Fig. 1 left). So, the participants walked through a rural virtual landscape. The landscape was realized by means of the gaming-engine CryEngine 2 (Crytec®, Frankfurt a.M., Germany). The treadmill was an H/P/Cosmos pulsar (h/p/cosmos sports & medical gmbh, Nussdorf, Germany). Interaction device was a Samsung Galaxy S2 (see Fig. 1 right). A head-mounted eye-tracking system (Dikablis®, Ergoneers GmbH, Germany) was used to estimate the number and duration of glances directed at the smartphone.

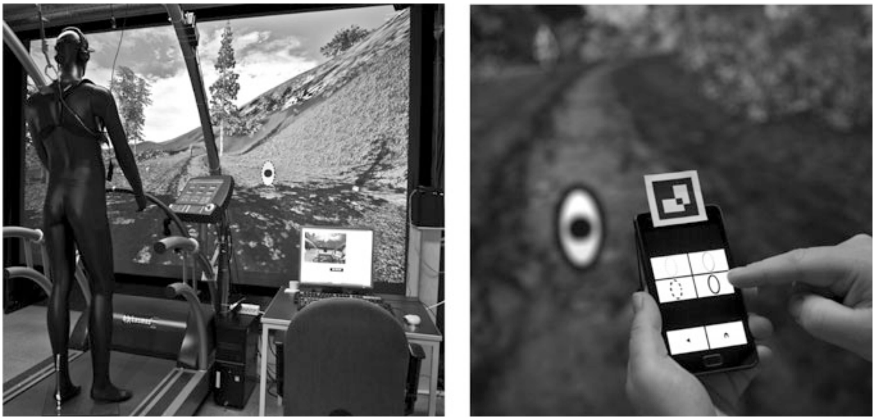

Fig. 1 Apparatus of the study, including powerwall and treadmill *(left)* and interaction device *(right)*

Additionally, an attention-demanding secondary task was administered. Distractors appeared randomly to draw the participant's attention to the environment. Participants had to observe the environment and react to the distractors.

In the main task, a set of 64 different symbols was used. These symbols differed in fringe, form, color and filling-element and were easily distinguishable. They were selected to be items of 2^6, 4^3 and 8^2 hierarchical menus as well as for a symbol editor. As soon as a symbol randomly showed up in the environment, input process started. The symbol was visible during the whole process until the participant quitted the interaction. The first 32 symbols were used for practice; data of the second set of 32 symbols was used in the analysis. Time to fulfill the task in one condition was about 15 min.

The independent variables were treadmill walking speed and kind of menu. Walking speed was 2.5 and 5 km/h respectively. Kind of menu was the second independent variable. It consisted of 4 conditions, i.e. three hierarchical menus and an intricate symbol editor. The hierarchical menus differed in depth and breadth. The slimmest hierarchy consisted of 2 options per level (see Fig. 2 left) which required 6 levels (2^6) to lead to 64 items. The medium hierarchy level is depicted in Fig. 2 second from left, it shows 4 options on one level in 3 levels (4^3). The broadest hierarchy is shown in the second from the right picture in Fig. 2, it has 8 items per level (8^2). The right-hand picture in Fig. 2 shows the symbol editor (SE). By touching one of the six buttons, the features of the symbol on the bottom were changed accordingly. To create a particular symbol, 0–6 interactions were needed, with a medium of 3 interactions. In all conditions it was possible to correct input by either using the "back"-button on the bottom (hierarchical menus) or by a second interaction with the accidentally used button (SE).

Walking induces a relative motion of the hand and therefore hampers interaction. To exclude any influence of this on the interaction, button size was chosen

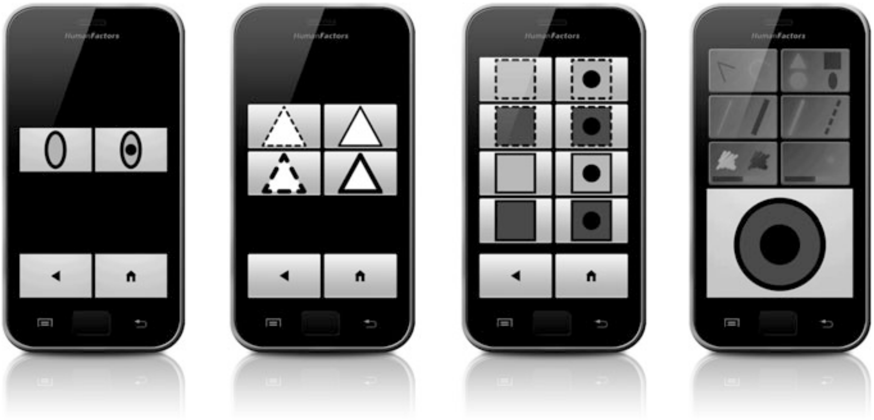

Fig. 2 Independent variable menu: 2 options in 6 levels (2^6, *left*), 4 options in 3 levels (3^4, second from *left*), 8 options in 2 levels (8^2, second from *right*) and symbol editor (SE, *right*)

deliberately. It meets the conditions of Fitts' law for a difficulty index for ballistic movements [13, 14]. Due to this, only 10 options were depicted on one screen. Two of them were necessary for the "back" and "home" buttons. Therefore, a maximum number of 8 options per level were applicable.

Dependent variables were performance in main task (time on task and error count) and reaction time in secondary task. Data used from the eye-tracking were number of glances, mean glance duration and glance time per single level. Glance time per level was calculated only for hierarchical menus as each input triggered the change of hierarchy level. So, glance time was assigned to specific levels or input actions respectively.

Additionally, NASA-TLX was used to estimate the workload induced by the different menus and walking speeds [15, 16].

Two-factored multivariate analysis of variance was used. In advance, all data were checked for normality and sphericity (Mauchly-Test). In case of significant results, pairwise comparisons using the Bonferroni-correction were administered. Significance level was 5 %. We used SPSS 20 to calculate the results.

3 Results

The dependent variable "mean time on task" (interaction time for a single symbol) was analyzed. We found a significant influence of menu ($p < 0.01$, $F(3, 45) = 105.8$, $\eta_p{}^\wedge 2 = 0.876$). Post-tests showed significant differences for all conditions ($p < 0.01$ for all conditions). Means were found to be $M_{2^\wedge 6} = 5.6$ s; $M_{4^\wedge 3} = 3.319$ s; $M_{8^\wedge 2} = 2.96$ s und $M_{SE} = 4.05$ s. Figure 3 (left) depicted these findings. 8^2 resulted in the shortest time on task, 2^6 in the longest.

Walking speed had no influence on time on task ($p = 0.38$; $F(1, 15) = 0.815$, $M_{2.5} = 4.02$ s und $M_5 = 3.97$ s).

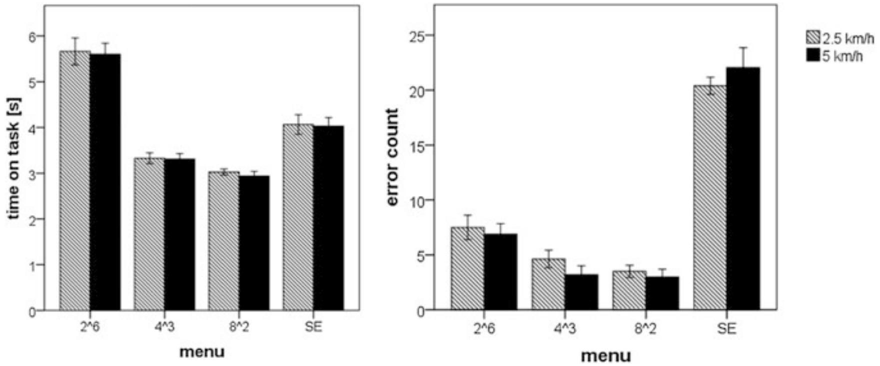

Fig. 3 Mean and ±1 standard error of time on task *(left)* and error count *(right)*

Figure 3 (right) shows the error count performed by the participants is given. We found a highly significant influence of menu ($p < 0.01$, $F(3, 45) = 216.7$, η_p^2 = 0.935). The post-test showed significant differences for all combinations (each $p < 0.01$) but 4^3 versus 8^2 ($p = 1$). Mean error count was $M_{2^\wedge 6} = 7.188$; $M_{4^\wedge 3} = 3.906$; $M_{8^\wedge 2} = 3.250$ und $M_{SE} = 21.234$. Least errors count demanded 4^3 and 8^2, while SE demanded a very high number.

Walking speed did not influence the error count ($p = 0.64$; $F(1, 15) = 0.224$, $M_{2.5} = 9.01$ und $M_5 = 8.78$).

Mean reaction time to detect a distractor was analyzed. A statistic trend was found for the factor menu ($p = 0.064$, $F(3, 45) = 2.59$, η_p^2 = 0.148). Means were $M_{2^\wedge 6} = 1.54$ s; $M_{4^\wedge 3} = 1.41$ s; $M_{8^\wedge 2} = 1.40$ s and $M_{SE} = 1.57$ s.

Walking speed showed a significant influence on reaction time ($p < 0.01$; $F(1, 15) = 39.388$, η_p^2 = 0.724, $M_{2.5} = 1.65$ s, $M_5 = 1.31$ s, see Fig. 1). Reaction time was lower in faster walking.

Number of glances on the smartphone were significantly influenced by menu ($p < 0.01$, $F(3, 45) = 11.49$, η_p^2 = 0.434). The post-test showed significant differences for 2^6 versus 4^3 and 2^6 und 8^2 (each $p < 0.01$), for the combination 4^3 und SE we found a trend ($p = 0.1$). Means were $M_{2^\wedge 6} = 134.8$; $M_{4^\wedge 3} = 90.9$; $M_{8^\wedge 2} = 82.8$ and $M_{SE} = 113.4$; so 4^3 and 8^2 demanded the lowest numbers of glances.

Number of glances proved to be independent of walking speed ($p = 0.696$; $F(1, 15) = 0.159$, $M_{2.5} = 106.30$ and $M_5 = 104.73$).

Mean glance duration was influenced neither by menu ($p = 0.629$; $F(3, 45) = 0.583$, $M_{2^\wedge 6} = 1.12$ s; $M_{4^\wedge 3} = 1.065$ s; $M_{8^\wedge 2} = 0.997$ s; $M_{SE} = 1.052$ s) nor by walking speed ($p = 0.814$; $F(1, 15) = 0.058$; $M_{2.5} = 1.061$ s; $M_5 = 1.054$ s).

Glance time per level was calculated only for hierarchical menus. We found a highly significant influence of the factor menu ($p < 0.01$, $F(2, 30) = 68.1$, η^2 = 0.819). Post-tests showed significant differences for all combinations (each $p < 0.01$, $M_{2^\wedge 6} = 0.71$ s; $M_{4^\wedge 3} = 0.92$ s; $M_{8^\wedge 2} = 1.19$ s., see Fig. 4)

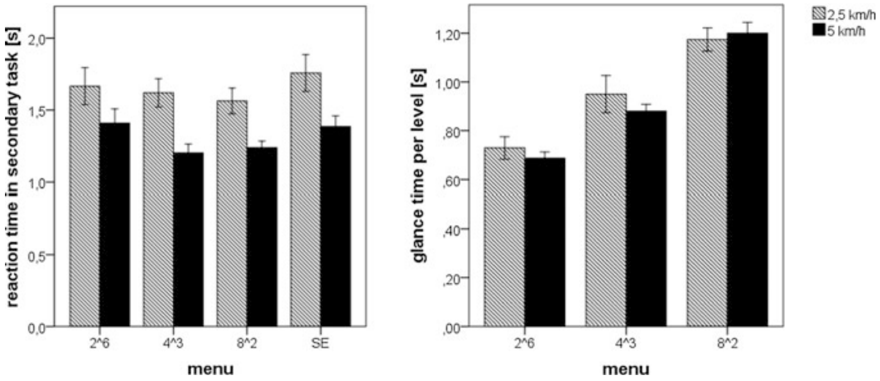

Fig. 4 Mean and ±1 standard error of reaction time in secondary task *(left)* and glance time per level *(right)*

Table 1 Results of MANOVA and means of the NASA-TLX Subscales for the factor menu

Subscale	P	F(3, 45)	η_p^2	$M_{2\text{^}6}$	$M_{4\text{^}3}$	$M_{8\text{^}2}$	M_{SE}
Mental demand	0.042	2.971	0.165	42.0	38.5	36.1	48.1
Physical demand	0.123	2.032	0.119	42.5	35.2	37.3	44.7
Temporal demand	0.334	1.164	0.072	47.5	43.7	41.6	50.8
Performance	0.427	0.945	0.059	38.9	40.0	34.5	41.6
Effort	0.049	3.016	0.167	50.6	41.3	38.1	48.4
Frustration	0.006	4.780	0.242	32.7	19.7	25.2	37.0

Table 2 Results of MANOVA and means of the NASA-TLX Subscales for the factor walking speed

Subscale	P	F(1, 15)	η_p^2	$M_{2.5}$	M_5
Mental demand	0.001	18.968	0.558	36.8	45.5
Physical demand	0.000	81.000	0.844	29.4	50.5
Temporal demand	0.000	47.980	0.762	39.8	52.0
Performance	1.000	0.000	0.000	38.7	38.7
Effort	0.000	62.086	0.805	36.8	52.4
Frustration	0.015	7.581	0.336	26.7	50.5

vel increased according to the number of options.

Walking speed showed no influence on glance time per level ($p = 0.268$; $F(1, 15) = 1.223$, $M_{2.5} = 0.5$ s und $M_5 = 0.92$ s).

Results of the MANOVA for the NASA-TLX-Subscales for the factor menu are given in Table 1.

Post tests were used for those subscales showing a significant influence for the factor menu, i.e. for mental demand significant differences showed up between 8^2 and SE ($p < 0.01$) and for frustration between 4^3 and SE ($p = 0.034$). Effort showed no significant differences in the post test.

Walking speed had a significant influence on most subscales of NASA-TLX (see Table 2), only frustration was not altered. Workload was higher in faster walking. Besides physical attributes, this is also true for mental and time demand.

4 Discussion

We carried out a study on the influence of smartphone menu structures on the interaction and distraction while walking. We found an influence of different hierarchical structures on performance and workload, especially on time on task and on error count, as well as on visual focus. This is in accordance to the work of [8].

Broad hierarchical structures with few levels and 4–8 options per level showed best results. While time on task differentiates between the conditions, there is no difference for error count. Performance in the secondary task, focusing on attention allocation also showed slight benefits of broad hierarchies. Number of glances on the smartphone as well as rate indicates a benefit of broader hierarchies. Attention focused longer on the environment than for deeper structures or more complex menus. Additionally, workload was estimated to be lower in broader hierarchies.

But we found no difference between hierarchies of 4–8 options per level. Also number on interactions per symbol is lower in the 8 option condition, glance number and time is not different, time on task and accuracy show only a small benefit. Seemingly, the advantage of a lower number of interactions in the 8 option condition is used up by the higher effort in searching the bigger number of options. The results are in accordance with earlier studies on interactions with menus on desktops [7, 8]. In those studies time on task and accuracy degraded with depth of menus, 8 options per level are recommended. These findings can be used for smartphones as well.

A hierarchy with 2 options per level in 6 levels showed longest time on task, error count was also higher than in the other hierarchical structures. This is probably due to the higher number on interactions, as well as the high number of glances on the smartphone. While glance time per symbol was high, glance time per interaction was lower than in all other conditions. Workload was lower than the complex menu and higher than broader menus. This confirms the recommendations of [10].

The intricate symbol editor which facilitated symbol creating in one frame led to high assessment of workload. While time on task was comparable to the slimmer menu hierarchies, error count was 3–7 times higher. Number of glances was also higher than in broader hierarchic menus. Workload, especially mental demand and frustration were high.

Walking speed had no influence on interaction of glances. Only reaction time on additional distractors was lower in fast walking than in slow. This is probably due to the higher activation level in faster than in slower walking. Workload differentiates clearly between slow and fast walking speed. Faster walking is perceived as more strenuous than slow walking. For objective measures no such effect was found. This may be due to the special situation in the lab. Walking speed was regulated by the treadmill and the motion was steady and not hampered by any external influences, e.g. irregularities of the surfaces or obstacles. So, adaption of walking on environmental issues was not necessary.

For a given number of items, broader menu hierarchies of 4–8 options are beneficial for smartphones used while walking. While 8 options show fastest interaction results, frustration is lowest for 4 options. Additionally, more time is left to focus visually on the surroundings than in slimmer hierarchies or intricate menus. Slim menus need too many interaction steps while more complex structures lead to errors and high workload.

Nevertheless, glance time per interaction frame is lowest for frames with a low number of options. For a bigger number of options visual focus is tied longer to the smartphone. Therefore, each presented option should be scrutinized for its importance to find the lowest number of possible options.

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A Customizable Digital Human Model for Assembly System Design

Jochen Deuse, Alexander Grötsch, Lukas Stankiewicz and Sascha Wischniewski

Abstract For a wholesome and comprehensive planning and design of future hybrid work systems and adaptive workplace assistance systems, several components of these systems are to be considered in detail. To ensure a human-centered and safe prospective planning and design process, these components need to be thoroughly investigated already in early stages of the simulation and virtual environment. In his context, especially the joint workplaces of humans and robots are of increasing importance for industrial assembly systems. For the planning process, existing software in Computer-Aided-Engineering (CAE) provides the possibility to incorporate the factor human by means of digital human models (DHMs) as well as robots by implementing e.g. robot trajectories, path planning and specific factory characteristics. Both partners show the potential to be incorporated in a simulation tool that accounts for the flexibility of robotic technology as well as the variability of the human body, anthropometrically and biomechanically. For an accurate description and simulation of a hybrid work system it is necessary to align the DHM individually to the employee's anthropometric data and physical performance parameters. These data can be recorded with motion capturing methods and systems and serve as a basis for the human-centered design and planning process of adaptive work assistance in assembly systems and technologies.

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Keywords Human-Robot collaboration · Customizable digital human model · Individual performance parameters · Human-Centered workplace design

1 Motivation

The ongoing demographic change in many industrial countries affects the working age population in a large extent. According to predicting calculations, the number of people in Germany, aged between 20 and 65 years, will decrease by 28.8 % until 2060 [1], while 34 % of the population will be aged 65 or above [2]. Related to this change the average age in various industrial companies rises and thus individual limitations of physical performance parameters and expressions of skills appear more frequently. In particular, the motoric skills, such as agility, endurance, coordination and skeletal muscle strength as well as the employee's physical work capacity show a pronounced age-related interindividual variance [3]. In addition, temporary or permanent physical impairments, e.g. injuries of the musculoskeletal system, also lead to restrictions in the performance of work tasks. Currently individual restrictions are not sufficiently taken into account in the prospective design of workplaces. By considering individual performance parameters, the planning process can consider person specific requirements in an early phase before real prototypes are developed. This fosters the design of individual and human-centered workplaces as well as competitive hybrid manufacturing systems [4]. Both partners, the human and the robot, show a high amount of flexibility that can contribute to the needs of current challenges in the field of industrial engineering and ergonomics. The aforementioned age-related increase of inter- and intraindividual variance of employee's parameters as well as the possibility of flexible applications of robotic technology demand the implementation of individual human-centered approaches already in the simulation process. In the future the utilization of synergetic effects in collaborative scenarios of humans and robots will strongly depend on enabling these aspects of an improved planning of hybrid assembly systems. In consequence it can help to design human-centered workplaces as well as to face challenges for industrial companies such as increasing product variants and smaller batch sizes.

Thus, the individual characteristics of the employee need to be considered for an optimal and human-centered design of workplaces. For this reason, highly customizable human models for the simulation and design of hybrid work systems are required to account for the person-specific parameters of the future employee in early phases of the design process. It therefore represents a huge step forward in comprehensive and wholesome consideration of the future work and production process.

2 Hybrid Assistance Systems and Human-Robot-Collaborations

The worldwide annual supply of industrial robots increased in the last decade and shows a tendency to grow further in the following years. In 2014 the amount of industrial robots sold worldwide exceeded the mark of 200,000 what corresponds to a growth of 17 %. Especially the automotive and electrical industry, which are characterized by a high percentage of assembly tasks, are decisively responsible for the increasing sales volume of industrial robots [5]. Economic reasons and triggers for this development are the productivity growth by an increase in output quantity, high product quality and a reduction of production costs. The high accuracy and fast handling even of heavy loads causes a high benefit particular in the high-volume production [6] with recurring work contents. Due to an industrial robot's given repeat accuracy the output quality is highly predictable.

On the other hand, humans show a significant superiority to robots by having a high flexibility with regard to altering environmental-, process- and product parameters. In addition, humans are capable to make decisions and widen their experience by learning from past events. Thus, manual workplaces have the advantage that employees can predict certain occurrences and react proactively. However, most assembly work places have physical minimum requirements for the accomplishment of tasks [4]. Because of that, employees may not be able to perform these tasks due to given physical performance restrictions, which in turn can be caused by the tasks themselves and resulting constant high stresses. Affected assembly employees often have extensive experience in the processes due to long-time experiences and therefore are valuable for the process stability [7]. To cope with the employee's requirements on the one hand and to implement the advantages of automated processes for assembly tasks on the other, there is a trend to implement hybrid solutions by a direct collaboration of employees and robots in a common work space without separating safety devices like fences.

The elimination of spatial boundaries between humans and robots leads to the consideration and analysis of potential dangers for the human health and integrity of equipment and operating material [8]. Additional sensors need to be implemented in the work system to ensure safety at work and a secure collaboration between a human and a supporting robot. Built-in sensors in robots and their ability to reduce movement speed rapidly ensure the force and power limitation enabling collaboration without separating safety devices. To monitor speed and distance, external sensors are necessary. For a comprehensive risk assessment, the whole workplace has to be taken into account including the robot itself, the effector, the workpiece, the operating material and the workplace layout. Optical sensors like light barriers or camera systems monitor 2D or 3D zones and detect objects entering the area. In interaction with the robot control, movement speeds are reduced depending on the defined task and different protection areas within the workspace [9].

All these approaches permit an intervention during operations. Accordingly, they are reactive and thus prone to errors due to slow reaction times or wrong interpretations of the current situation. To react to possible collisions predictively and to adjust the collaborative system these hardware based security technologies have to be expanded by a simulation of the assembly system.

3 Digital Human Models for the Simulation of Human-Robot Collaborations

A holistic CAD-based simulation of a hybrid work system needs to contain a digital mockup of the workspace and all included components in the work systems (e.g. the human employee, the robot, the work piece and operating material). The description of all components and their characteristics in a simulation environment allows precise statements about the system without creating a physical model such as for example used in cardboard engineering. Although cardboard engineering can be used to develop age-related work systems [10], it is on the one hand very time consuming as all adjustments in the system need to be newly designed and on the other hand it is hardly possible to evaluate human-robot collaborations as the human factor especially in terms of long time stresses can hardly be displayed. By transmitting predetermined process characteristics into a digital environment there will be less need to setup physical mockups for adjustment purposes. Thus, digital simulations generate a significant advantage over physical prototypes by identifying equally good or even better process parameters more economically.

3.1 Offline Programming and Simulation of Industrial Robots

Solutions for a digital mockup of work environments already exist. Furthermore, there are providers of 3D simulation software, which combine a CAD-based image of the workspace with the ability to simulate various types of robots and their trajectories. Common examples are EASY-ROB as a multi-vendor solution or KUKA.Sim which explicitly addresses KUKA robots. Extensions of these simulation environments integrate the possibility to use the generated trajectories to program the robots. A post processor translates the movements to the robot's individual program language to transfer the simulated trajectories into the robot cell. For this purpose, there are in addition common software solutions like Sim Pro for KUKA robots, RobotStudio for ABB robots or Robot expert as a full service solution for various robot manufacturers. These solutions offer an increased planning and investment security as the feasibility and efficiency of robot systems can be evaluated in advance. They provide information about the work system, making them valuable tools to examine the potentials of implementing automated processes in assembly environments. For a wholesome evaluation of collaborative systems, such simulation environments need to be extended by the use of digital human models. Some of the mentioned approaches provide the possibility to combine different parts of the simulation process subsequently in order to realize a wholesome representation of the future workplace. Nevertheless, the implementation of these kind of combined planning tools are still subject of thorough investigation, especially with respect to an easy-to-use approach that is supposed to be affordable also for small and medium sized enterprises (SMEs) and comprehensively applicable for a wide range of assembly systems.

3.2 Digital Human Models

Digital human models (DHMs) are used in industrial settings to represent the factor human and its person-specific characteristics in a work environment and to simulate specific requirements of the given work task. Integrated into a CAD-based simulation environment DHMs can contribute to analyze and improve the ergonomic situation at various work systems. For this purpose, DHMs are molded on the human's anatomy. They have a similar amount of joints and joint segments and offer various anthropometric adjustments, like preset percentiles, various nationalities, or the given sex [11]. For the use in simulations of work systems, industrial DHMs also offer several analysis functions, which are important to evaluate the feasibility and difficulty of assembly tasks. This includes inter alia vision analysis, reachability analysis and force analysis. Furthermore, the DHM can be used to perform ergonomic analyses of body postures. Thus, ergonomic insights can be integrated into the planning process of a work place at an early stage of planning. An exact ergonomic assessment of body postures requires a realistic illustration of human body movements. To ensure accurate movements DHMs have a skeleton structure trying to mimic the human body. The existing human models show a similar joint structure, anthropometric adaptability and degrees of freedom but differ in the preferential application area depending on their analysis functions. As an example, RAMSIS by Human Solutions targets the simulation of vehicle occupants and therefore is mainly used by automotive manufacturers [12]. The area of application of ema, a DHM from imk automotive, focuses on the ergonomic assessment of manual assembly tasks and therefore considers applied forces, handling of loads and body postures [12, 13]. The AnyBody Modeling System by AnyBody Technology in turn simulates the biomechanical processes of muscles and tendons and thus can give a detail insight in metabolism and predict fatigue [12, 14].

3.3 Customization of Digital Human Models

Approaches exist that try to integrate a DHM into a simulation with an integrated offline programming tool for robots [4, 15, 16]. This opens up new possibilities in the evaluation of direct human-robot collaborations in respect to the prediction of a relevant division of labor between humans and robots and required safety aspects. To ensure a safe collaboration a detection of collisions between the robot and its environment including the employee needs to be performed. Therefore, a safe prediction of motions is indispensable. As the robot's trajectories are programmed manually, the exact position of the robot at any time is given. The human motions instead depend on a variety of factors and vary interindividually. As a result, human movements are difficult to predict. An employee's movements mainly are determined by the employee's individual anthropometry and range of motion for each joint. By capturing and transferring these limitations and restrictions, an individually aligned DHM as a matching image of the employee can be created. Hence, the simulations can be empowered to estimate ergonomic deficiencies which allow reproducing the expected motions from the real system in the simulation automatically. Consequently adverse postures can be identified before the employee has worked at the workplace. In order to evaluate and display these postures an ergonomic screening method needs to be combined with the DHM (see Fig. 1).

The used ergonomic screening method must comply with the requirement to be adaptable to an automatic evaluation, which can be interpreted by the simulation software without a further assessment by an ergonomics expert. For the detection of body postures and their different gradation of ergonomic concerns, the ergonomic screening method needs to differentiate between angular ranges for certain body parts. To evaluate the ergonomics for human-robot collaborations comprehensively

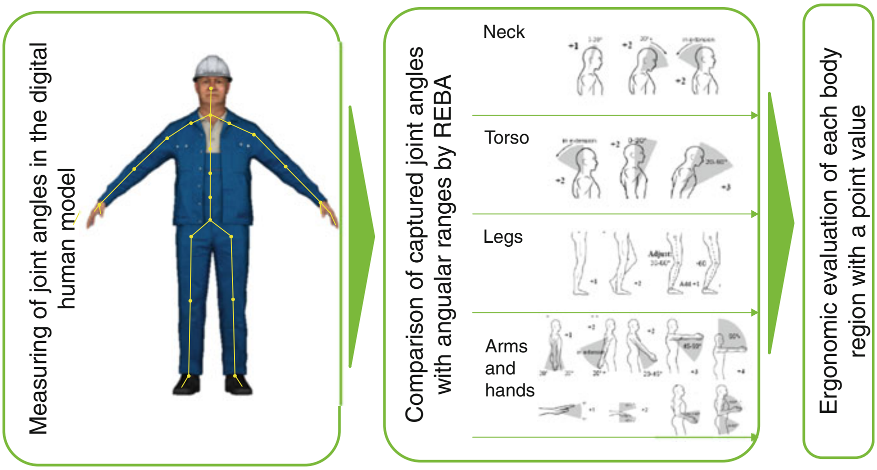

Fig. 1 Digital ergonomic screening by recognizing postures with a digital human model cf. [17]

and to implement decision support for an appropriate division of tasks between humans and robots, an additional screening process is needed, that also includes the assessment of loads and forces. A suitable quantitative ergonomic screening method that fits the mentioned requirements is the rapid entire body assessment (REBA) [17]. Within the simulation the given angular ranges by REBA for several body parts are compared to the actual joint angle of these specific body parts. A certain joint angle is calculated by the inner product of two according vectors that represent adjacent body segments. By permanently querying all joint angles the simulation evaluates the employee's body posture and assesses it with the parameters given by REBA as shown in Fig. 1.

In this manner, point values for certain body postures are calculated, which continually indicate the corresponding ergonomic risk level for each of the considered body regions. The accuracy of the ergonomic assessment of body postures dependents on the quality of the movements performed by the DHM. So there is an urgent need to consider individual restrictions of the employee's movements as closely as possible to customize the DHM accordingly. A best possible representation of the employee enables the simulation to predict individual movements within the simulation matching the actual movement possibilities und behavior of an employee.

4 Recording of Anthropometric Parameters and Physical Motion Limitations to Individualize DHMs

The prerequisite for the customizable DHM is the use of person specific parameters in terms of anthropometry and biomechanics (see Fig. 2, I).

In this research context, the latter is addressed by the recording of kinematic data of the employee, especially with respect to motion limits of specific joints of the upper and lower extremities as well as the head, trunk and torso. The selected joints and areas of interests are primarily important when taking predominant work-related musculoskeletal problems in workplaces into account [18]. The anthropometric data are comprised of the corresponding segment lengths of the

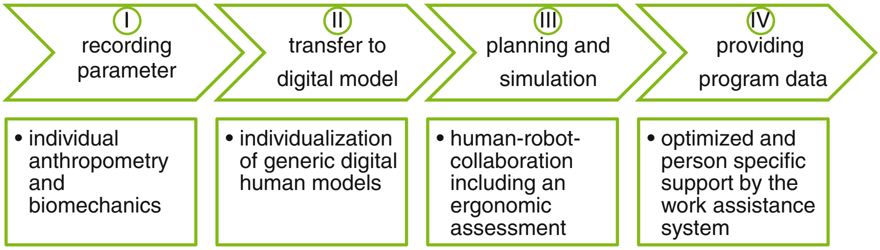

Fig. 2 Conceptual workflow for the individualization of DHMs

human skeleton of the employee. By including these parameters, the DHM can be scaled anthropometrically and parametrized biomechanically. It thus represents the actual worker in the context of human-robot-collaboration scenarios and ensures a human-centered design of the prospective workplace in the virtual planning environment.

The recording of anthropometrical and biomechanical data requires a tracking system that translates motion limits and segment lengths into processable data (see Fig. 3) As depicted in Fig. 4 the selected recording process of the required individual anthropometric and biomechanical parameters consists of the following hard- and software components as well as spatial requirements for the measurement setup:

(i) PC/Tablet equipped with a project specific graphical user interface for data recording, processing and export
(ii) Monitor (optional) to support the measurement and to give visual feedback for the measurement personnel and the employee
(iii) Time-of-Flight-sensor (Microsoft Kinect for Windows v2.0) for data recording
(iv) Measurement volume of 4 m × 4 m (optimal)

The use of a time-of-flight-sensor [19] of the Microsoft Kinect for Windows v2.0 [20] is motivated by several aspects regarding the usability and applicability for

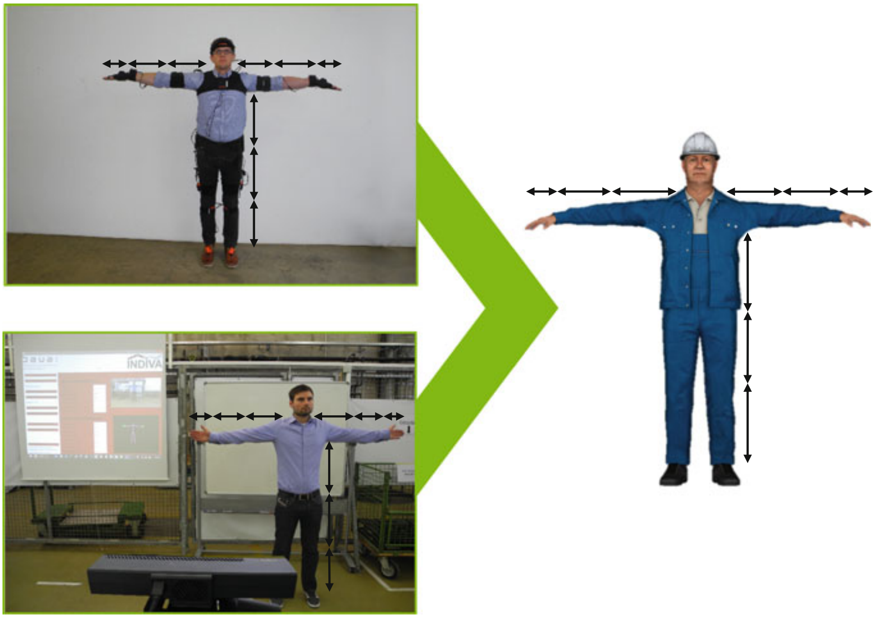

Fig. 3 Use of motion capturing systems (*top*: Xsens, *bottom*: Kinect) to record anthropometrical and biomechanical data to scale and parameterize the skeleton of the DHM

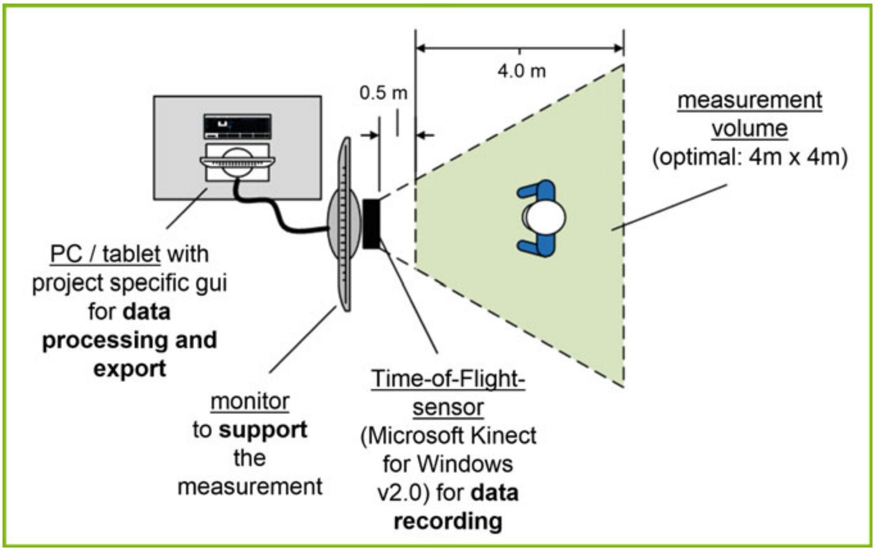

Fig. 4 Schematic setup of the measurement and its real use in an industrial setting (see text for further details)

different companies including SMEs. The markerless motion capturing approach serves as an advantage in terms of an effective workflow, the lack of using additional markers and sensors during the recording process as well as the financial costs of the complete measurement setup. Despite the lower accuracy compared to marker based motion capturing techniques, markerless motion capturing approaches are reported to be suitable for the estimation of human posture and the analysis of human movements [21–24].

The data processing and data export for the implementation into the virtual environment of the offline programming software including the parameterization of the DHM, is further realized with the help of a self-programmed (C#) extension of the body tracking algorithm of the Software Development Kit of the Microsoft Kinect v2.0 [20, 21]. It allows an effective workflow and the direct export of corresponding csv-files.

To create the person specific data via motion capturing and to integrate the recorded data into the digital human modeling and offline robotic programming software (Fig. 2, II, III), the recording procedure is divided into two separate measurement parts. At first the employee’s anthropometric data are taken in a predefined pose. Secondly this is followed by the subsequent recording of the joint limits (range of motions) of the upper extremity (shoulder, elbow), lower extremity (hip, knee) as well as the neck, trunk and the torso. The C#-code allows for the direct export of the minimum and maximum joint limits that makes an import into the aforementioned software feasible. To guarantee the usability of the proposed concept, a graphical user interface (GUI) was created to facilitate the use of the system and to design the necessary steps in the data recording, processing and export in a stringent manner. An instruction manual supports the measurement procedure, explains the different parts of the GUI and serves as an operator's guide for the one responsible for the measurement.

The recorded parameters are stored in a database to serve as the basis for the adaptable work assistance system in the joint workplace of humans and robots (Fig. 2, IV). The simulation of the collaborative workplace thus is centered towards the individual employee who is supported by the hybrid manufacturing system that is aware of the individual parameters and limitation of every employee stored in the system. In this proposed workflow, the system is designed recursively to account for changed anthropometric and biomechanical data of an employee and to add the data of new employees to the system's database. Obviously data privacy regulations need to be taken into account in the context of recording individual employee-specific parameters [25].

5 Conclusion

The proposed method of customizing DHMs represents an easy-to-use approach that is suitable to be used in SMEs as well as in larger industrial companies. It is motivated by the need to integrate individual anthropometric and biomechanical parameters into early stages of the design and planning process [26] of direct human-robot-collaboration scenarios [27]. Especially with respect to the increase of the employee's age-related inter- and intraindividual changes of physical parameters and the growing market of joint workplaces of humans and robots, assembly systems and technologies need to be adaptable to the prerequisites of the individual human.

The introduced procedure of recording individual parameters can be used in controlled environment and aside any security critical situations. The use of a time-of-flight sensor is suitable in the proposed context and lowers the bar for individualized DHM especially in SMEs. Nevertheless, the implementation of several sensors is subject of further investigations and can be added within the proposed workflow.

The overall concept for the individual and virtual planning of human-robot-collaborations combines several advantages with respect to collaborative assembly processes. Hybrid manufacturing systems benefit from the synergistic effect of an efficient human-robot-collaboration. Virtual planning is extended by the use of individualized and customizable DHM, scaling and parameterizing the digital representation of the employee with motion capturing data. The system thus has the potential to support older and physically disabled workers at their worksites, reduce physical stresses and prevent indirect work-related musculoskeletal health risks for a safe and human-centered workplace design in assembly systems and technologies.

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Management of Enterprise of the Future in the Ecosystem of the Internet of Things

Łukasz Sułkowski and Dominika Kaczorowska–Spychalska

Abstract The process of digitization in the surrounding business reality is constantly developing, which causes that every year a number of devices, including everyday devices that are incorporated into the network, is growing. The Internet of Things is a specific ecosystem in which devices that surround us communicate with each other while remaining in the interaction thanks to mobile solutions and applications. Due to that enterprises of the future have a chance to increase the level of competitiveness. All of these, however, require a holistic approach to market perception and understanding the essence of changes. Observed growth of interest in the Internet of Things will entail social and behavioral changes while changing the specificity of contemporary management.

Keywords Management · IT · Internet of things

1 Introduction

The observed dynamic development of mobile technologies and their evolution have led to significant transformations in a way their potential and possibilities of absorption in business are perceived. Mobile era in a considerable way has some impact on behaviour, strategies and decisions, both of enterprises as well as customers while significantly broadening a range and character of its applicability. At the same time it allows both parties to generate benefits in spite of passing time [1]. Changes resulting from a new wave technology can often radically change conditions of competition and factors allowing to achieve a competitive advantage. However, a tendency to use innovative solutions in the range of available IT

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technologies depends on numerous factors resulting from conditions of functioning of contemporary enterprises.

Market analysts are certain that in the near future a challenge of this kind can be a concept of the Internet of Things that enables to assign a completely new value to consumer goods. It is considered a breakthrough moment now, a new revolution evoking social, cultural or economic changes. It is impossible to determine unequivocally its scale and pace of impact, however, there is some evidence that it will change realities of market functioning. Therefore, enterprises of the future must understand its essence in order to use them in an optimal way in an implemented strategy because for businesses, the Internet of Things presents a new array of changes and revenue possibilities, from industrial machines to cars, refrigerators, and even people, plants or animals—can be connected to the Internet to collect and receive data [2].

The aim of the article is to determine possibilities of adaptation of the concept of the Internet of Things in the process of enterprise management. This is the first element of studies focused on identification of potential directions and dynamism of the development of that concept while taking into consideration specificity of individual market entities and sectors. Part One presents the definition of the concept of the Internet of Things as well as opportunities that it creates. The authors present also the examples of using it in various consumer goods. Part Two is based on the results of the authors' own research, which was an exploratory step in further quantitative and qualitative studies in the discussed area.

2 The Internet of Things in the Process of Enterprise Management

The 21st century is the era of information technology and dynamic development of electronics, which became an integral part of contemporary economics and business. It forces entrepreneurs to be flexible, open to new ideas and to accept unconventional solutions [3]. Fast civilization changes in which technology becomes an indicator of transformation from the industrial era to information era [4] determine a process of management. As a result we live in the world in which knowledge and its usefulness is not an addition but an integral element of everything that surrounds us [5].

The Internet is a solution that attracts attention of entrepreneurs, managers, investors or business observers. However, it has to be perceived exactly what it is—powerful technology enabling to use very efficient tools that can be applied in the majority of sectors and strategies [6]. As a result we use a growing number of devices than ever. The development of the mobile Internet that accompanies that contributes to a rapid increase in a number of users and activities which are undertaken by means of mobile devices. In Poland a number of used SIM cards is systematically growing. According to the Central Statistical Office at the end of

2014 Polish mobile networks disposed of 57.6 million active cards and their penetration amounted to 149.6 % [7]. Simultaneously, a considerable growth in popularity of mobile devices—smartphones and tablets, is observed. According to TNS research surveys up to half of the Polish population above the age of 15 have at least one phone with a touch screen, operational system and a possibility to install applications (44 %), and every tenth uses a tablet. According to the Gemius data concerning traffic generated by means of smartphones and tablets in Poland, in the first quarter of 2014 mobile devices generated 10 % of the whole web traffic and it is a result that is double the result from analogical period in 2013. Such a geometric increase has been observed since 2011 and the trend seems to maintain in the near future. Growing consumer knowledge and awareness in this area has an influence on an increase in the length of time devoted to online activity by means of mobile devices, the character of this contact and the level of expectations and purchasing preferences. Cisco estimates that up to 2018 a number of mobile devices users will grow globally by 700 million—from 4.1 million in 2013 to 4.8 million in 2018 and a number of mobile devices connected to the Internet by 3 billion (up to 10 billion in 2018) [8].

Such strong dynamics of mobile market creates new opportunities to improve existing level of competitiveness of enterprises and to undertake a struggle for a customer based on high quality of offered products and services as well as unique added value realized in the real time thanks to advanced IT Technologies. Simplicity in improving technologies and an increasingly lower cost of production of devices cause that more and more telephones and everyday products will have Internet access [9]. According to Gartner analysis a number of devices with Internet access will exceed in 2020 26 billion although according to Cisco estimate that number is lowered and it is predicted to be actually nearly twice as big [10].

The Internet of Things (IoT) is a new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other. The IoT is recognized as one of the most important areas of future technology and is gaining vast attention from a wide range of industries. It must be perceived as a specific ecosystem in which goods can communicate through a human or without their participation [11]. The Internet of Things is a solution that aims at bridging the gap between the physical world and its representation within the digital world [12]. The notions mentioned in the literature include: Internet of Everything (IoE), Internet of Smart Objects (IoSO) and communication based on Machine to Machine (M2M) solutions. Having been incorporated into the global network devices become intelligent. Their intelligence is due to opportunities to communicate with other objects as well as to collect and analyse data provided by them and then, on that basis to make analytical and business decisions [13]. Thanks to that a system is created and it is based on the structure of network technological connections that enable to collect information from internal sources (device user and their behaviour) as well as external ones concerning the environment (e.g. atmospheric conditions, traffic volume, etc.).

The novelty of the IoT is not the capability of smart object—already today many embedded systems are connected to the Internet—but in the expected size of billions or even trillions of smart objects that bring about novel technical and societal issues that are related to size [14]. As one can easily imagine, any serious contribution to the advance of the Internet of Things must necessarily be the result of synergetic activities conducted in different fields of knowledge, such as telecommunications, informatics, electronics and social science [15].

Thanks to rapid advances in underlying technologies, it is opening tremendous opportunities for a large number of novel applications that promise to improve the quality of our lives [16]. The Internet of Things will change everything—including ourselves because it is one of the most important and powerful creations in all of human history. IoT represents the next evolution of the Internet, taking a huge leap in its ability to gather, analyze, and distribute data that we can turn into information, knowledge, and, ultimately, wisdom. In this context, IoT becomes immensely important [17]. Smart connectivity with existing networks and context-aware computation using network resources is an indispensable part of IoT [18]. This will bring a new ubiquitous computing and communication era. Radio Frequency Identification techniques (RFID) and related identification technologies will be the cornerstones of the upcoming Internet of Things [19].

It is surely undeniable that we are living in the times of huge changes. They were always present, however, now they happen definitely faster and force companies to look for new ways of action [20]. IoT offers enterprises a chance to intensify the development of specific elements of their market offer, to create new areas of business activity including new market segments as well as modification of existing solutions in the area of production, logistics or warehousing. New solutions do force a necessity to find new alternative patterns and models of market behaviour. As the Internet of Things (IoT) will spread, the implications for business model innovation will be huge. Filling out well-known frameworks and streamlining established business models won't be enough. To take advantage of new opportunities, today's companies will need to fundamentally rethink their orthodoxies about value creation and value capture [21].

The combination of the Internet and emerging technologies such as nearfield communications, real-time localization, and embedded sensors lets us transform everyday objects into smart objects that can understand and react to their environment [22]. However, it will take some time before companies and their customers get used to functioning in the world in which everything is interconnected [23].

Solutions that are available on the market have, on the one hand, consumer profile and first of all, boil down to everyday equipment and devices, on the other hand, some solutions show a wider perspective and refer in a complex way to specific industries and economic sectors. The first group includes smart refrigerators that can make an analysis of their content and order missing products adequately to food preferences of their users. There are also smart cookers and ovens that allow to optimize a process of cooking. Thanks to mobile applications and a camera they allow to remotely control the state of prepared dishes online. Among smart white goods one can easily find smart vacuum cleaners that will clean a flat and then send a report to a mobile device of their owners. Some of them can also send a picture from a camera which will allow to check a status of implemented tasks. There are also smart kitchen scales, frying pans which calculate calories in the real time, kettles, food processors, coffee makers or cutlery that will be able to control the pace at which we consume our meals.

Smart technologies allow to steer windows and shutters depending on temperature or user's preferences during a day, lighting thanks to wireless LED light bulbs or a level of heat management in individual rooms. There are also e-keys that enable to remotely close and open doors by means of mobile devices as well as to turn on and off an alarm system. An extremely explicit trend in using mobile devices is the development of so-called wearables technology i.e. putting sensors on clothes, which are to perform a function of a smartphone and are voice-operated [24].

A very important platform to apply the concept of the Internet of Things is an automotive industry, in which applied solutions are to increase the level of safety and comfort of users. It concerns also systems enabling immediate location of a car, to park a car without a driver's interference or to increase functionality of navigation system. It is more and more common to hear about so-called connected cars, which will react in the real time to a situation on the road intuitively. Research of Gartner has forecast that one in five cars will be connected by 2020, leading to more than 250 million networked vehicles on the roads worldwide [25].

Yet, the Internet of Things is not only automated technology in buildings, smart flats, equipment or consumer solutions. The IoT means also an intelligent industry that enables to manage current resources better, including recycling and growth of safety of working conditions. It is also smart production that allows to optimize the whole process from the point of view of specific industries, generated costs and benefits of individual enterprises. The concept also works well in transport, environmental protection, including pollution control, management of energy from renewable and non-renewable sources as well as smart water management. Many beneficial solutions of the IoT are generated in the process of city management or its selected areas. It concerns also better management of individual media (water, energy, sewage) as well as traffic management and the analysis of its safety.

However, in spite of numerous potential benefits the concept carries a lot of serious threats. They are mainly related to a possibility to obtain information about the activity of users of specific devices and access to information, which might violate their privacy. There are also worries about a potential access to a panel that allows to change equipment parameters or systems in order to take control over them. One should also take into consideration flaws in system functioning and in information they provide. Decisions made on that basis can lead to the loss of enterprise liquidity and to weakening of their market position as well as they may pose a threat for the level of their customers' safety.

The Internet of Things is driving innovation and new opportunities by bringing every object, consumer and activity into the digital realm. At the same time, leading businesses are making similar changes within their enterprises by digitizing every employee, process, product and service [26]. A man becomes one of the elements of that system, next to fully autonomic devices. Having taken control over them they can decide on the level of complexity choosing these which will in an optimal way allow a man to establish relationships with the environment. Yet, it is not technology and applications that are the most important but the ability to use them. Forecasts seem promising but it is just the beginning of a dynamic process of penetration of mobile solutions to private and business life. It is likely that devices incorporated in the M2M system will more effectively influence people than the contents transmitted through them while allowing to maximize a customer's life value. What can be observed today is "not the only one precisely and ultimately set direction. What surrounds us today changes us and moves us as the society from one to another subsequent form of development" [27]. Thanks to that the mankind will have the knowledge and wisdom it needs not only to survive, but to thrive in the coming months, years, decades, and centuries [28].

3 Internet of Things in the Light of Own Research

The main objective of conducted survey research was to evaluate the level of interest in the concept of the Internet of Things and the degree of its absorption in the implemented strategy. The crucial points included:

- Evaluation of the level of awareness of the concept and the way of its comprehension;
- Identification of areas in which the concept of the Internet of Things can develop fastest in the next years;
- Determination of barriers that hinder the development of the concept of the Internet of Things;
- Influence of analysed issues on the strategy and a way of functioning of enterprises in the future;

Conducted survey research was, beside available literature on the subject, the grounds to prepare main assumptions of research concerning the development of the concept of the Internet of Things in Poland which allow to thoroughly explore mutual dependencies in the business and social dimension. Conducted research was based on interpretative approach that is relied on perception and description of phenomena as a result of interpersonal interactions.

The research was carried out among potential clients of products and services associated with the Internet of Things and on the basis of their responses the authors selected enterprises representing the main market areas that allow for the biggest applicability of the discussed concept. The assumptions stated that acquiring knowledge from various experiences of entities from the purchasing and supply part of the market, which allows to identify the major assumptions of the concept of the Internet of Things. Conducted research was idiographic, which means that its results do not allow to formulate general conclusions, but they concern only an examined group of entities and their local context. Having been treated that way they have to be the subject of further deeper studies and analyses.

Firstly, the focus was put on a potential customer assuming that it is the person who can become an initiator of directions of development of products and services based on the concept of the Internet of Things and/or a catalyst of the level of rationality and innovation in this area that is offered for them by enterprises. Such an assumption results from increasingly often observed concentration on customers' needs as the major dogma of contemporary management. The research comprised 215 students of colleges in Łódź. The sampling was purposeful and was related to the fact that students are one of the biggest group of Internet users as it is shown in the report by IAB Polska 2014 [29]. Moreover, market analysts indicate that majority of mobile Internet users are young people [30], so the representatives of Y generation. They show adeptness in using modern technologies and intensive usage of new media enable them to have constant contact with the environment while putting them into specific state of watching and changing the relations between the past, presence and future [31]. The research was conducted by means of a direct questionnaire whose measurement instrument was a survey questionnaire. It consisted of 16 questions, 6 of which were demographic questions. They concerned: gender, age, a type and subject of studies, place of residence as well as time devoted to everyday activity on the Internet.

219 respondents took part in the research and 206 correctly filled questionnaires were accepted for further analysis. Women were a predominant group—66.5 % of respondents. Nearly 80 % were people below 25 and 12.6 % were people between 25 and 34. It means that among respondents the dominant group were Y generation representatives. Their level of knowledge and expectations can become an indicator of their future purchasing attitudes and preferences for enterprises. In the conditions of increasingly growing market competition what plays a crucial role is to create unique values that allow enterprises to multiply achieved benefits that confirm a potential advantage. On the other hand, knowledge on current preferences and expectations of future customers allows to create and stimulate such in which enterprises can undertake a real competitive struggle.

The majority of respondents were people living in towns with more than 30,000 inhabitants (43.2 %) and below 5000 inhabitants (39.33 %). Every second person was a student of extramural studies, which may suggest that the analysed group comprised people who combine studying with working, which can have influence on their knowledge and opinions concerning discussed issues. Nearly 50.5 % of respondents studied management and 49.5 % administration.

Every third respondent came across the concept of the Internet of Things. They were mainly men who accounted for over 36 % of respondents in that group. Looking at women the value was 28.5 %. Taking into consideration the structure of age of respondents the biggest interest in the concept of the Internet of Things was observed in respondents between 25 and 34, which was indicated by every second respondent in that group, whereas among people below 25 this level was around 30 %. Therefore, both age groups seem to be strongly engaged in potential innovations offered by enterprises within the concept of the Internet of Things. However, in case of people below 25, due to their phase of life and relatively limited financial means, their purchasing power in this area seems also limited. The biggest interest in the analysed concept was observed in people from small towns with less than 5000 inhabitants (38 %) and towns with more than 30,000 inhabitants (31.5 %). Taking into consideration time that respondents spend on the Internet during a day, the biggest interest in the analysed concept was indicated by people who devote up to an hour for this activity (36.8 %) and from one hour to three hours (36.7 %). Type and subject of studies did not have any impact on respondents' decisions concerning their preferences and interest in the concept of the Internet of Things. Respondents gained information about the concept, its essence and opportunities first of all from online resources, generally defining them as:

- "*solutions based on mobile devices and applications thanks to which one can manage various equipment*"
- "*network by means of which devices will communicate with one another*"
- "*machine–to–machine idea—without human interference*"

Respondents claimed that the concept will have the biggest chances for development in the near future first of all in the area of home and/or flat management (19.3 % of respondents) as well as in white goods sector (18.6 %). Building management (energy, water, heating, etc.) was also considered important and pointed by nearly 10 % of respondents as well as energy management including alternative sources (9.3 %). The discussed concept was also considered attractive for industry sector, especially in the area of logistics and production, for trade and public administration units in the area of urban management (public transport, energy, water, sewage system, etc.). The least important solutions were consumer solutions that enable to provide information about expiry date, allergic components, calories in the real time and environmental protection).

Every fifth respondent was interested in buying mainly devices that would enable to monitor energy usage in the house, and almost 23 % would like to have smart household devices and RTV equipment. Nearly 13.5 % of respondents would find devices that allow to control media usage and their emission corresponding to customers' needs in real time useful, whereas 12 % of respondents would appreciate devices that increase safety. Respondents also pointed at interest in connected cars that intuitively, without engaging a driver, would react to situation on the road, smart devices for small children as well as smart clothing (wearables).

While enumerating potential benefits of the concept of the Internet of Things that customers could get, they first of all mentioned increase in comfort, which was declared by every fourth respondent. For more than 19 % of respondents an opportunity to systematically control own health was important and 18.6 % were convinced that thanks to that they would have a better chance to supervise efficiency of devices. 14 % of respondents stated that thanks to that they would be able to decrease energy usage, and every tenth mentioned lower costs of using appliances. So, it may seem that from the point of view of customers expected benefits boil down to, first of all, aspects increasing functionality of products and their economical dimension.

According to respondents the analysed concept is also beneficial for enterprises that adapt it. The biggest benefit was bigger opportunities of adjusting products to customers' needs in the real time, which was indicated by 18 % of respondents. It is of crucial importance from the point of view of customer satisfaction and creating their values in time. Avery important point was also a chance for better comprehension of their actual needs (15.44 %), which enables to optimize a product offer as well as to create an added value that precedes customer' expectations. So, the Internet of Things can contribute to increase in competitiveness of enterprises, which was indicated by 14.6 % of respondents. Respondents also mentioned opportunities to optimize level of efficiency of offered products (12.4 %), monitoring of a way of using them as well as access to information about the most frequent causes of failures (respectively 11.8 %). Potential benefits of IoT for enterprises were perceived first of all in categories concerning the improvement of their future market position.

The biggest worries connected with the development of the concept of the Internet of Things were evoked by potential loss of customers' privacy resulting from constant monitoring of their actions, which was indicated by every third respondent. ¼ of respondents were also afraid of increased risk of losing personal and confidential data of customers by enterprises, whereas 15 % were worried about losing control over devices in case of breakdown. Among other threats respondents also mentioned a risk resulting from the fact that equipment and devices can communicate without their awareness, so they have no influence on the range and character of transmitted information and a way of its management. It was also suggested that such advanced products and services will be sold at exorbitant prices, which may restrict possibilities to purchase them.

Barriers restricting dynamics of the development of the concept of the Internet of Things, according to respondents were conditioned by both, behaviour and attitude of customers as well as enterprises. The most important factor concerning both groups was lack of sufficient knowledge about the concept itself and opportunities of using it. It was indicated by nearly 22 % of respondents. The other important points were also worries of potential customers (17.6 %) which concerned mainly the level of functionality of products and a risk related to their usage as well as too high price of offered solutions in this area (15.8 %). Decrease of popularity of using solutions based on the concept of the Internet of Things according to respondents is also related to reluctance of enterprises (nearly 8 %). It can result from a need for modification of a current way of competition, change of current marketing, logistics or production solutions as well as changes in current infrastructure, including IT areas and creating new competence of employees and managerial staff.

The second element of conducted research was based on the empirical material that came from quantitative research and obtained results enabled to select industries that were associated by potential customers with the concept of the Internet of Things. As a result the research subject range comprised 5 enterprises connected with a practical application of the IoT, in particular with the following: the realization of projects called Smart House producing white goods, dealing with provision of energy, installing solutions from the area of alternative energy sources as well as media (water, sewage, air-condition). While choosing the criteria for the selection of companies the authors purposefully resigned from taking into consideration the following data: company size, time of functioning in the market, character of capital or a number of workers. The aim was to obtain the biggest possible spectrum of opinions and experiences related to the Internet of Things in the context of diversified conditions and frameworks of functioning of specific companies.

The research was conducted by means of in-depth interviews and their main objective was the evaluation of the process of diffusion of the concept of the Internet of Things to the philosophy of enterprise management. Special focus was put on the issues concerning changes in the way of management and market orientation of analysed companies.

Not all respondents were familiar with the notion of the Internet of Things, the concept often functioned as: "*smart houses*", "*smart home*", "*smart appliances*", "*smart systems*" *and* "*building management systems*". It can be assumed that the notion can be perceived by enterprises only through the prism of its functionality in terms of specific industries and market sectors. According to respondents the essence of the concept of the Internet of Things is known in analysed industries, both from the point of view of "*producers, investors, subcontractors as well as clients*", moreover, it is perceived as the technology of the future.

Enterprise representatives were certain that the biggest opportunities for the development of the concept of the Internet of Things in the next five years will be generated by such industries as: tele-technical and telecommunication, single and multi-family housing (e.g. hotels, hospitals, public facilities, etc.), energy, media and white goods and RTV devices. "*They will offer comprehensive solutions integrating all the systems and devices within one network: telephoning, computer, lighting, heating, media,* etc."

Among the benefits obtained by clients of devices and solutions based on the IoT respondents most frequently mentioned financial savings related to their usage, benefits connected with reduction of time needed to operate individual devices and related convenience. What was also mentioned were such points as: better monitoring of the way of using and an increase of safety, especially in case of alarm systems installed in buildings and informing about robbery, fire, gas and CO_2 leak, etc.

For enterprises the biggest advantages were connected with an increase in time efficiency, and significant improvement of level of performance. An important issue was also a possibility to improve a way of warehouse management and resources management, including financial resources achieved by better organisation of the working process. According to respondents the IoT could enable to have a higher level of automation of implemented processes, at the same time reducing the risk of potential mistakes. However, "it is not an advantage from the point of view of employed people as it can lead to reductions in workplaces in the future". They also mentioned a possibility of development of additional functional value of offered products and systems related to auto-diagnosis in case of failure as well as auto-repair in case of most frequent reasons. The scale of achieved benefits is, yet, in the opinion of respondents dependent on "*enterprise market position as well as a way of perceiving a brand/company as a creativity leader and creator of new solutions*".

Respondents were certain that the concept of the Internet of Things carries threats connected, first of all, with "*a risk of breaking into systems leading to changes in their work and loss of data*". Purchasing cost, albeit high, both from the point of view of enterprises and customers, allow in a relatively short time, to get a return from such an investment that is visible in costs of widely-understood exploitation.

The surveyed also pointed at social threats connected with behaviour and attitudes of employees and potential customers:

- "*People often stop thinking because machines work for them*";
- "*There is a threat that willingness to learn how machines, systems, devices work may disappear, which may reduce promptness in making a decision and a reaction, especially in case of breakdown.*";
- "*Such solutions will evoke interest mainly among young people, and an important factor here will be their material status.*"
- "*The solutions based on the IoT concept will not become common in a short time because not everybody wants to be dependent on new technologies*";

Among the factors that can decrease dynamics of the IoT development the surveyed mentioned technical constraints that can hinder a possibility to synchronize all systems while reducing freedom and comfort of clients. The constraints can be also linked with "*the fact that enterprises are used to previous time and way of work at the same time evoking resistance and reluctance to changes*". A key thing can be the level of customers' interest in such solutions and the level of acceptance in everyday life. "*It can be linked with their age, level of education, social status, level of income and consumer behaviour e.g. willingness to absorb innovations.*"

According to respondents the development of the IoT concept is already forcing a change in attitudes to a way of management. It concerns all the stages and processes implemented in an enterprise. Before devices and system start to be produced on a massive scale, the indispensable phase will be a conceptual phase directed at identification of benefits generated for clients. It is clients who make assessment of their value and usefulness. It forces a necessity to look at the market in a new way, especially in the context of customer and their real needs. It significantly changes a process of production, warehouse management, distribution process and pricing policy as well as a form and tools of communication with individual groups of stakeholders. Enterprises, in the opinion of respondents, while fighting for a competitive advantage will be forced to look for market niches and/or to create new market segments interested in a new level of functionality of offered systems and devices. Companies increasingly often undertake steps in order to create a high level of interest in new solutions "*treating advanced technologies in a prestigious ways*". "*By means of intensive, often aggressive marketing actions they sell modern solutions convincing customers that it is an inevitable standard.*"

4 Conclusions

It can be reasonably assumed that the Internet of Things will become one of the most important trends shaping business sphere in the near future. Contemporary market combines at present, more than ever before, the features of physical and virtual world which will still complement. This new market space in which every area of business is based on different practices, structures and segments. However, the more boundaries between them will disappear in the future, the more management process in enterprises will require holistic approach to market and processes observed in it. Synergy between them requires definitely mechanisms allowing to skillfully absorb advanced technology and its adaptation. That requires a need for looking for new models of business whose main pillar will be the Internet and based smart devices and systems. Enterprises and their customers will become one of many elements in a multidimensional chain of values while carrying social, economic and behavioral changes. The process of building a competitive advantage will then require a strategy aimed at, on one hand, new innovative solutions increasing value and on the other hand, it does not mean a need to resign from current market space and applied solutions. The world changes too fast so that companies could afford to remain idle. Organizations of the future must keep up with the times in which they have to function [32]. However, it requires knowledge and abilities to generate it as technology determines changes at all levels and areas of management while allowing to diversify their future potential. In the world of the Internet nothing is still. As a result of continuous transformations of technologies directions of actions that yesterday were right, tomorrow may turn out to be obsolete [33].

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Part IV
Industrial Robotics and Intelligent Automation

Development of a Human Factors Roadmap for the Successful Implementation of Industrial Human-Robot Collaboration

George Charalambous, Sarah Fletcher and Philip Webb

Abstract The concept of industrial human-robot collaboration (HRC) is becoming increasingly integrated into manufacturing production lines as a means for enhancing productivity and product quality. However, developments have focused primarily on the technology and, until recently, little research has been geared to understand the key human factors (HF) that need to be considered to enable successful implementation of industrial HRC. Recent work by the authors has led to the identification of key organisational and individual level HF. The purpose of this paper is to draw together the evidence from their studies and propose a HF roadmap for the successful implementation of industrial HRC. The roadmap will have profound implications as it enables automation specialists and manufacturing system engineers to understand the key HF that need to be considered optimise the efficiency and productivity of the collaboration between humans and industrial robots.

Keywords Human factors roadmap · Industrial human-robot collaboration · Trust · Organisational human factors

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1 Introduction

Despite the rapid integration of automated systems in manufacturing processes, a significant amount of assembly work still requires the flexibility of a human operator making the human element a vital part of the production chain [1]. In such processes, it is neither feasible nor cost-effective to introduce full automation. The manufacturing industry has shown growing interest in the concept of industrial robots working as teammates alongside human operators [2–5]. In light of recent technological developments, health and safety regulations have been updated to reflect that in some circumstances it is safe and viable for humans to work more closely with industrial robots [6]. Combining the advantages of human workers and industrial robots leads to the development of industrial human-robot collaboration (HRC).

The International Organisation for Standardisation [6] defines HRC as a "*special kind of operation between a person and a robot sharing a common workspace*". Successful implementation of industrial HRC can enhance manufacturing efficiency, productivity and quality whilst reducing operating costs since the weakness of one partner can be complemented by the strengths of the other [7–10]. However, the integration of humans and robots within the same workspace can be a challenge for the human factors (HF) community. For example, the installation of large assemblies requires operators to cooperate with large and high payload robots under minimised physical safeguarding [11]. The success of such an integrated close-proximity HRC system will be determined, not only by the technical capability of the system, but also by investigating the key HF at an organisational and individual level. However, developments in the field of industrial HRC have focused primarily on the technology and, until recently, little research has been geared at understanding the organisational and individual level HF that need to be considered in order to optimise successful implementation of industrial HRC.

Recent work by the authors has led to the identification of key organisational and individual level HF [12, 13]. Regarding the individual level HF, the authors have particularly explored the construct of *trust* in the robotic partner. The reason for selecting *trust* is because it has been widely identified in the human-robot interaction domain as a key element for the successful cooperation between humans and robots and can enhance human acceptance of robots [14–16].

The purpose of this paper is to draw together the evidence from these studies as a whole, in order to propose an initial Human Factors Roadmap for HRC implementation, which integrates all of the key factors that have been identified as important enablers to successful implementation of HRC into a set of guidance.

2 Literature Review

In this section we present a review of recent work carried out by the authors for the introduction of industrial HRC. Section 2.1 reviews their findings for the organisational level HF, while Sect. 2.2 presents their work in the development of a trust scale which is specifically addressing industrial HRC.

2.1 Organisational Level Human Factors

Earlier literature suggests that the implementation of a technological change should not be viewed simply as an engineering problem. The impact of the change will affect the organisation and subsequently the employees. With the concept of industrial HRC still at its infancy, it is crucial to understand which organisational human factors are of most importance. To our knowledge, a framework with the key organisational human factors that need to be considered by organisations for the successful implementation of industrial HRC does not exist. Recent work by Charalambous et al. [12] made the first attempt to identify the key organisational HF for the successful implementation of industrial HRC. Their work enabled to: (i) develop a theoretical framework with the key organisational human factors relevant to industrial HRC and (ii) identify whether these factors are enablers or barriers through an industrial exploratory case study. Although it is not the purpose of this paper to reinstate their work (detailed information can be found at [12]) a brief summary of their findings is listed below.

- *Major enablers*: operator participation in the implementation, communication of the change to the workforce, visible senior management commitment and support to the project, provision of training to the workforce, empowerment of the workforce and existence of a process champion during the implementation.
- *Major barriers*: lack of union involvement, lack of awareness of the manual process complexity by the system integrator, capturing the variability of the manual process prior to introducing the automated system and allocation of resources for the development of the automated system.

2.2 Trust in Industrial Robots

The development of trust is essential for the successful operation of any team [17]. Lee and See [18] defined trust as "*the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability*" (p. 54). In the context of human-automation teaming, trust can influence the willingness of humans to rely on the information obtained by an automated system, particularly in risky and uncertain environments [15, 19]. Lack of trust will eventually lead the operator to intervene and take control [20]. In the context of human-robot interaction (e.g. social, military and healthcare robots), earlier literature suggested that trust development can be influenced by robot attributes, such as appearance, movement, reliability and predictability. However, until recently, very little was known regarding trust development between humans and industrial robots.

Charalambous et al. [13] developed a trust measurement scale suitable for industrial HRC. Although full details on the methodology can be found at [13], a summary of the scale is provided in this section. The scale identified three key components (i.e. factors) which influence human trust in industrial HRC. The factors extracted accounted for 63.5 % of the total variance in the sample with a Kaiser-Mayer-Olkin of 0.812 while Bartlett's test of sphericity was found to be statistically significant ($\chi^2(45) = 465.6$, $p < 0.001$), suggesting that the factors were unlikely to have occurred by chance. A short description of each of the key factors along with the statistic reliability achieved is provided below:

- *Factor 1—Safe co-operation*: The perception held by the human operator of how safe it is to collaborate with the industrial robot. This component. This factor consisted of four items and exhibited a reliability of 0.802.
- *Factor 2—Robot's and end-effector's reliability*: The perceived reliability of the robot and the end-effector (e.g. gripping mechanism) by the human operator. This factor consisted four items and achieved a reliability of 0.712.
- *Factor 3—Robot's motion and pick-up speed*: The degree to which the robot's motion is perceive to be fluent and non-disruptive by the human operator as well as the speed at which the robot picks up and manipulates components. This factor consisted of two items and achieved a reliability of 0.612.

2.3 Summary

Taking the evidence as a whole it appears that there is an inter-relation between some of the factors at the organisational level and the developed trust scale. At the organisational level, two of the key human factors that emerged were: (i) provision of training to the workforce and (ii) operator empowerment. These two factors can be utilised along with the developed trust scale to provide a tool with which operators' trust levels in the robotic teammate can be continuously calibrated. This is described in the next section.

3 Human Factors Roadmap for HRC Implementation: Guidance for Practitioners

The development of the roadmap is segregated in two parts, each of which provides a set of propositions:

- Part 1: It discusses how the trust scale can be utilised in an initial training programme to assist operators' initial trust calibration. The benefits of this proposition are presented. In Sect. 3.1.
- Part 2: This part discusses how operator empowerment is vital for continuous trust calibration which in turn will dynamically optimise operators' trust in the robotic teammate. The benefits of this proposition are presented in Sect. 3.2.

3.1 Part 1: Operator Training Programme for Initial Trust Calibration

To describe how training can be used to influence human operator's trust calibration in the robotic teammate, the literature from mental models will be used. When humans interact with an entity (e.g. robot), mental models are used to assist the user perceive and interpret the entity's intentions and actions [21]. At the same time, it must be noted that humans tend to have incomplete or even inaccurate mental models [22]. In an industrial HRC scenario humans will be requested to share the same workspace and collaborate with an industrial robot to complete a task. An inaccurate or incomplete mental model can potentially lead the human operator to either overestimate or underestimate the abilities of the robotic teammate. This has been described in the literature as misuse (i.e. overestimation) and disuse (i.e. underestimation) [14]. Both can be equally detrimental. The key is to achieve appropriate trust calibration. To calibrate appropriate trust in the robotic partner, it is vital for the human to hold a sufficiently developed mental model of the robot, whereby robot's capabilities are acknowledged [23]. Therefore to assist human operators to develop a sufficient mental model of their robotic teammate, it is proposed to incorporate the trust scale findings in an operator training programme.

The aim of this training programme would be to provide operators with an understanding of the robot's abilities and limitations of the key robot characteristics, rather than simply understanding how to use the robot to complete a process. This approach can help operators develop an appropriate mental model of the robot they will be requested to collaborate with. For instance, a key trust factor identified in the trust scale is the "perceived robot and gripping mechanism reliability". Does it mean that if the robot or the gripping mechanism is not 100 % reliable all the time they are useless? According to Wickens and colleagues [24], automated systems are expected not to be perfectly reliable due to technological limitation and/or due to software and hardware failures. Therefore, in a HRC scenario it is expected that at some point, the performance of the robot (i.e. the robot itself and/or the gripping mechanism) will be less than perfect. What we need to remind ourselves is that appropriate trust calibration is primarily influenced by the "*human's mental model of the robot's ability and limitations, than the ground-truth reliability of the robot itself*" [23, p. 63]. In other words, perception and reality are not necessarily the same and, as suggested by Merritt and Ilgen [25], trust can be heavily driven by user's perception of the robot irrespective of whether this perception is correct, partially correct or completely incorrect.

In summary, an initial training programme, before the implementation of the robotic system, could be used as a strategy to raise operators' awareness regarding the ability and limitations of the robot and assist matching operators' perceptions with the system's actual capabilities. The next section describes how operator empowerment can be used to refine human mental models of the robot and achieve continuous trust calibration.

3.2 Part 2: Operator Empowerment for Continuous Trust Calibration

The development of mental models is a dynamic process and these models are refined through continuous interaction [23]. Similarly, trust development is not a static process. Human trust in a system (e.g. a robot) evolves over time from dispositional (i.e. upon first encounter) to history-based trust (i.e. cumulative collaboration) [25]. As this transition occurs, humans retrieve history-based mental models to interprete the actions of the system they are working with. If the mental models created during the subsequent exposure (i.e. history-based) are not sufficiently developed, this is likely to lead to trust miscalibration. In an industrial HRC scenario, the more operators are collaborating with a robot, the more likely it is to experience a variety of real failure, errors or system deviation scenarios (particularly during the early stages of implementation). While these events occur, it is vital for operators to understand the sources of these events and the possible outcome of these events (whether a failure, error, or deviation). Also, through exposure they will be in a position to identify factors that diminish or enhance the robot's ability to perform as well as detect cues that suggest a potential malfunction. According to [22] trust can be calibrated by providing an accurate understanding of the factors that may lead the robot to fail and the outcomes of those failures. To leverage this potential and enable effective HRC, it is proposed that operator empowerment can be a key strategy.

Operator empowerment was found to be one of the key enabling organisational humans factors. In a highly complex system, higher operator control and empowerment once the system is implemented will lead to operators obtaining a better understanding of the new system and task requirement [26]. Through operator empowerment, the operators' already established mental model of the robot (from the initial training programme) will be updated based on their history of collaboration. If on the other hand, operators are not empowered but an expert is called (e.g. manufacturing engineer) without the operators being involved, then operators are likely to be alienated from the system. This could potentially reduce operators' ability to develop an in-depth understanding of the system's source of events (i.e. failures, errors, deviations) as well as their ability to recalibrate their trust is reduced leaving them with an incomplete mental model.

This is not to say that experts (e.g. manufacturing engineers and/or robot experts) should not be involved. Operator empowerment should not be viewed as “all or nothing”. A reaction plan will be issued which will highlight the necessary steps according to the events. However, it is crucial, at all stages for the operators to be involved rather than simply turn into passive monitors of the system. This will enable them to obtain a greater understanding and awareness of the source of the event, thus making the system more transparent and understandable.

Finally, the knowledge gained by the operators, can then be passed into the training programme. Then, the training programme of future novice operators will be updated with real event scenarios. Subsequently this will accelerate appropriate trust calibration of novice operators during the initial training programme by enabling greater match between their perceptions of the system and the actual system’s capabilities.

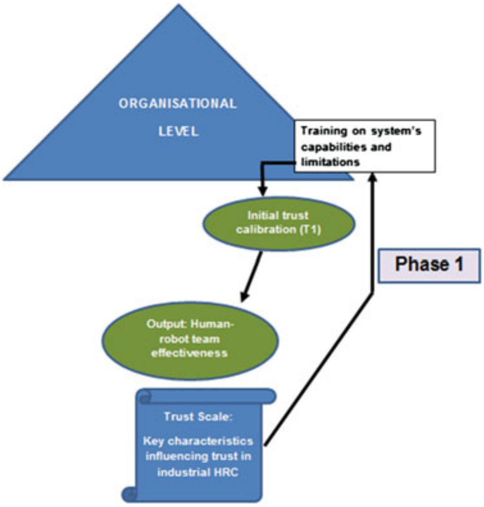
3.3 *Summary of the HRC Roadmap*

The propositions suggested in Sects. 3.1 and 3.2 can be merged in a guiding framework for practitioners to assist appropriate operator trust calibration. The guiding framework has three key phases, each of which is described below:

Phase 1. This is shown in Fig. 1. For clarity purposes, the remaining organisational human factors have not been included in the guiding framework.

Phase 1 takes place when the system is still at a pre-production stage. Phase 1 suggests that the operators selected to use the robot (e.g. major users) receive training not only on how to use the robot to complete the task, but also to understand the system’s capabilities and limitations as highlighted by the trust scale (i.e.

Fig. 1 Initial trust calibration via a training programme



perceived robot's motion; perceived robot and gripping mechanism reliability; perceived safe cooperation). This in-depth training can be provided by the system integrator (i.e. robot supplier). The training will assist operators to shape their expectations and make an initial calibration of their trust in the system (e.g. T1 on the schematic above). As operators spend more time collaborating with the robot, the experience gained during this time will start shifting their trust to history-based. Any experienced robot failures, errors or deviations will influence their mental model formation. The more they collaborate with the robot the more they will retrieve these history-based events to make sense of the robotic teammate. If their dynamic mental model formation is incomplete or inaccurate, then this will result in trust miscalibration which will eventually be reflected in the effectiveness of the team. For this reason, the second phase of the guiding framework suggests that operator empowerment is crucial.

Phase 2. Phase 2 is shown on the left hand side in Fig. 2:

Empowerment will allow operators to understand the reasons behind the events, helping them to form an accurate mental model of the robot. Table 1 shows how empowerment can serve as a vehicle for or operators to achieve an accurate mental model of the robot based on historic events.

Assume the robot produces an error and stops operating (first column of the table). This anomaly, challenges operator's existing mental model of the robot operating reliably (second column of the table). The operator is empowered to take rectification action and/or be part of the recovery process (third column of the table). This assists the operator to understand the source of the error as well as understand how the robot's system operates (fourth column of the table—how it "reads" the position of the component). This new knowledge assists the operator to

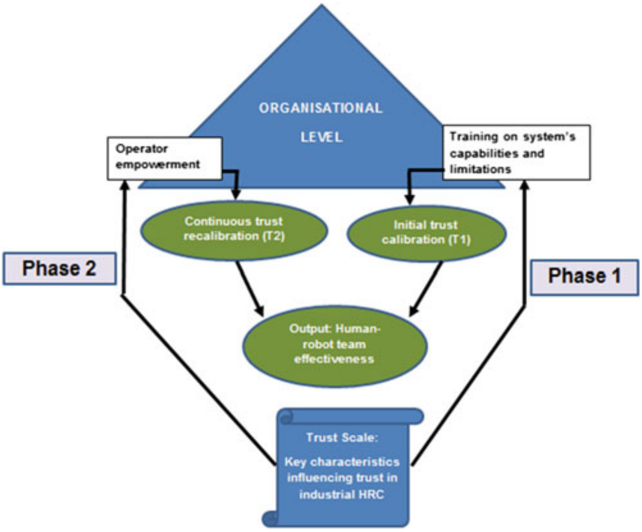


Fig. 2 Enhanced operator empowerment to enable continuous trust calibration

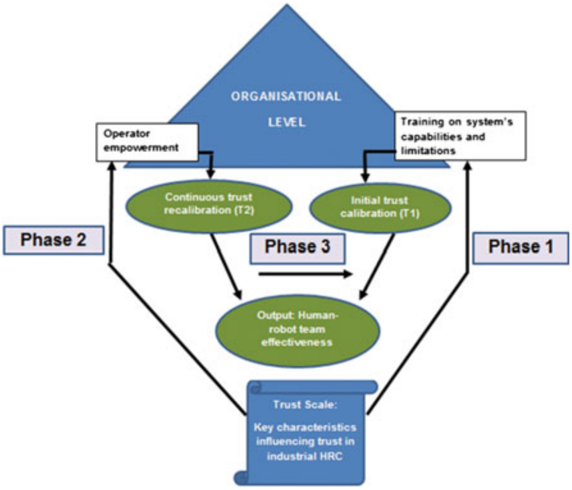
Table 1 Dynamic trust calibration through operator empowerment

Event	Existing operator mental model is challenged by the event	Operator empowerment	Why did it happen?	Operator new mental model of the robot	Impact on operator's trust in the robot
Robot produces an error—it stops operating	"*I thought the robot was Reliable. It never did this before—I wonder why*; *is something wrong with it*?"	Operator becomes involved in the rectification	E.g. Component mis-positioned on the fixture—Therefore, the operator now can understand how the robot "reads" the position of the component	"*This robot is very sensitive to material positioning—I must inspect more carefully the positioning of the component on the fixture*"	Trust is recalibrated based on this event

mould a new mental model based on this event (fifth column of the table). Subsequently, his or her trust in the robotic teammate is recalibrated. If for example, the "Action" (third column) did not take place, then the operator would not be in a position to understand the reason for the error, hence leaving them with an outdated mental model. Subsequently, the operator will attempt to update their outdated mental model based on their perception, potentially leading to trust miscalibration.

Phase 3. Finally, in phase 3, the knowledge gained by the exposure is fed into the training programme which will then be used to accelerate appropriate trust calibration for future novice operators. This is shown by the "Phase 3" arrow in Fig. 3 which completes the guiding framework:

Fig. 3 The finalised guiding framework for calibrating appropriate levels of operators' trust



4 Conclusion

Until recently, very little work was geared to understand the human factors for the successful implementation of industrial HRC. Recent work by the authors has identified a number of organisational HF. Also, the authors explored the construct of trust in the robotic partner. This work led to the development of a scale to evaluate trust in industrial HRC.

This paper draws together the evidence from these studies as a whole and proposes an initial HF roadmap for the successful implementation of industrial HRC. The roadmap provides propositions in a guiding framework for practitioners to assist appropriate trust calibration to the robotic teammate:

- *Training programme*: First, it is proposed that a training programme is developed which will incorporate the robot's key characteristics identified in the trust scale (i.e. perceived safety, perceived reliability and robot motion and pick-up speed). The training programme will enable operators understand the abilities as well as limitations of the robotic teammate, rather than simply receiving training on how to use the robot to complete a process. By openly addressing the actual capabilities of the robot, will enable human operators to develop an appropriate, and more realistic, mental model of the robot they will be requested to collaborate with.
- *Operator empowerment*: As operators gain additional experience collaborating with the robotic teammate, it is crucial to enhance operator empowerment particularly during degraded events, such as robot failures, errors or deviations. Empowering operators (along with robot specialists) will allow them to understand the reasons behind the events, helping them to form an accurate mental model of the robot.

By employing this approach, automation specialists and manufacturing system designers can dynamically calibrate human workers' trust in the robotic partner to optimise the efficiency and productivity of the collaboration.

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Investigating the Effects of Signal Light Position on Human Workload and Reaction Time in Human-Robot Collaboration Tasks

Teegan Johnson, Gilbert Tang, Sarah R. Fletcher and Phil Webb

Abstract Critical to a seamless working relationship in human-robot collaborative environments is effective and frequent communication. This study looked to assess whether placing a light source on a robot was more effective for informing the human operator of the status of the robot than conventional human-machine interfaces for industrial system signaling such as light towers. Participants completed an assembly task while monitoring a robot and changes to the light sources: either from one of two light towers or LED strip lights attached to the robot. Workload was assessed by measuring reaction times to light changes and by counting number of completed assemblies. Although both the ANOVA and Friedman tests returned none significant results, total misses per condition showed that the participants did not miss any of the robot lights, whereas signals were missed for the light towers.

Keyword Human-robot communication · Collaboration · Human factors · Eye tracking

1 Introduction

It is not currently feasible to fully automate all processes completed by human operators within manufacturing, as a result of limitations in both automation and robot systems. The limitations and strengths of both humans and robots have been

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detailed in function allocation models, particularly Fitts List [1] which still persists in its usefulness today [2]. As a result of these differences in capabilities, humans and robots can complement each other in areas where full automation is not possible [3]. This may include robots supporting human operators in their work, such as holding heavy objects that cannot be safely lifted by an operator, or completing fetching and carrying parts or tools. Unhelkar and colleagues [3] provide an example of this in their study which looked to introduce a mobile robotic assistant that delivers tools and materials to workers in an automotive manufacturing plant. By complementing the weaknesses of a human operator with the strengths of a robot device and vice versa, production efficiency can be improved.

Critical to seamless collaboration in this working relationship is effective and frequent communication between the robot system and the human co-worker. Endsley's [4] model of situation awareness highlights this; it states that the first stage of processing before making a decision is the operator's perception of elements in the current system. If this information is wrong or miss understood, the wrong decisions are made. Poor control and display design has been implicated in many accidents [5]. Furthermore, within both the fields of aviation and transport a loss of situational awareness due to attentional and perceptual errors were identified as significant causal factors [6–8]. Therefore, learning from this research, communication in collaborative robotic tasks needs to be both effective and efficient. Particularly where the robot and human operator truly work together on a task and therefore working in close proximity to each other.

Because manufacturing plants are noisy environments, visual systems are employed to provide information to operators regarding the status of machinery. Some of the current indication methods used within manufacturing for automated and robot systems are light towers (as seen in Fig. 1), industrial light towers use the traffic light system to inform operators or mangers of the state of the system. They

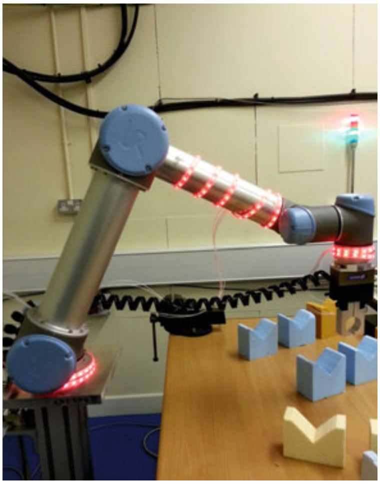

Fig. 1 UR 5 with LED wrap around lights

are stationary light sources that are generally placed on top of fully automated systems so that a single manager can easily assess the state of multiple systems [9].

The original design application for light towers does not lend itself to effective communication between a human operator and a robot during collaborative tasks. The standards in place that dictate the best placement of light towers [10], combined with the need to place the tower light outside of the robot's working area to prevent it from hindering the robot's movements. These factors lead to light tower placement at a distance from the robot, and may place the light tower in the periphery of the operator's vision. This places the light tower in the peripheral vision of operators, which may result in missed signals as a result of the limitations of peripheral vision with regards to static objects [11]. This is a concern in highly collaborative environments because it may mean that the operator's attention is split three ways (between their task, the robot completing its task and the light tower). Additionally during a collaborative task the light tower may be ignored because the robot is the main area of interest. This may lead to lower task efficiency, and missed signals which could lead to errors, mistakes and potentially accidents.

A solution to this is to reduce the number of areas vying for the operator's attention, by placing the lighting on the robot. As a result the warning system would be larger in size than a light tower, attached to the object of interest within the collaborative work, and will be moving. All of which help to increase the detectability of the light, movement is known to enhance the visibility of objects, particularly in the peripheral vision where stationary objects may not be seen [11]. Therefore the expected effects for the human co-worker are lower workload, faster reaction time and fewer missed signals. However an investigation was required to examine these assumptions and to identify whether the attachment of strip lighting to the robot would have a positive impact for the human co-worker, compared to a traditional industrial light tower.

Consequently the aim of this research is to assess the effectiveness of attaching an indication system to a collaborative system, compared to traditional light tower.

2 Method

2.1 Participants

10 participants, 6 female and 7 male, were recruited using random sampling (age range: 22–58 years, mean: 32.9, SD: 13.71).

2.2 Design

A within-subjects 3 × 2 experimental design was used to investigate the effect of indication light sources (independent variables) on reaction time and workload (dependent variables). The three conditions are two light towers (Harmony XVC6, Schneider Electrical) (one placed at a traditional distance and the second placed opposite the robot) and 5050 RGB LED strip lights placed on a UR5 robot (Universal Robots A/S). The second light tower was placed opposite the robot to identify whether distance between the light tower and the participant affected the dependent variables. All participants completed an assembly task and reacted to the light sources by pressing a button used to measure reaction time.

2.3 Apparatus and Laboratory Set up

The experiment took place in a 3960 mm × 3900 mm laboratory area surrounded by 4 sides of wall, with no direct sunlight to ensure that the lighting level was kept at a constant 400 lx throughout the entire experiment. Figure 2 shows the laboratory set up, the robot used was a single armed UR5 robot that completed a pick-up and place task using PVC pipes on a worktop directly in front of it. As can be seen in Fig. 1 LED lights were wrapped around the UR 5, covering the area between the elbow and wrist and the wrist and base.

Two industrial light towers were used; one was placed in a location replicating current manufacturing placement, and using the British Standards Institute's standards for the set up requirements of indication systems for industrial machinery [10, 12]. It was positioned at a height of 1210 mm, and ensured that it was within 10° of the horizontal line of site, and not obstructed by the robots movements. The second light tower was placed directly opposite the robot, at an equal distance from the central line of the worktop used by the robot. For simplicity, only the green and red lights were used on the indicating devices. Both green and red lights on the tower

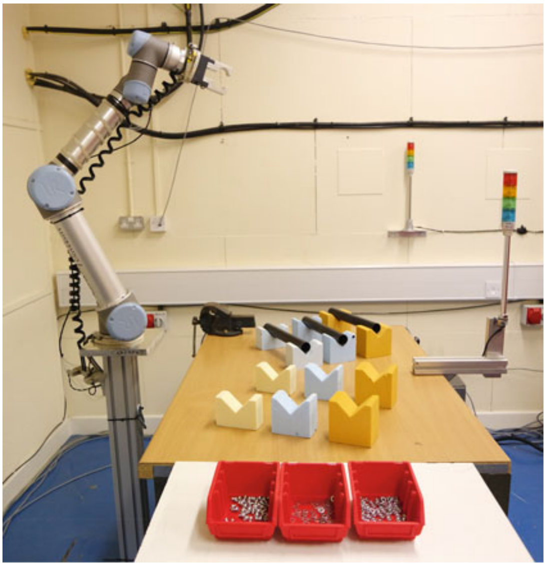

Fig. 2 Experimental cell layout

lights emitted 1300 lx while the LED light strip emitted 600 lx in green and 230 lx in red due to the limitation of the lighting system.

As can be seen in Fig. 2, a workbench was set up in front of the robot worktop at the same height, for the participant to complete the assembly task on. On the worktop, three containers were placed on the table each holding, nuts, washers and bolts, these could be moved around by the participants for ease of use. A button to measure reaction time was attached to the table on the left hand side. This button was connected to a National Instruments logging system to record participants' reaction time and any misses of the light sources.

2.4 Procedure

After being briefed about the experiment participants were lead into the laboratory area and fitted with a pair of head-mounted eye-trackers (ETG-1.7, SensoMotoric Instruments). To minimize learning effects the participants were asked to complete a pre-task assembly; this involved the participants completing 10 assemblies as quickly as possible while being timed. The assembly task for the experiment involved threading a washer onto a bolt and then attaching a nut to the bolt. Upon completion of the assembly participants were familiarized with the robot movement and the light sources.

The task was then explained to the participants; they were informed that their task was to complete as many assemblies as possible while monitoring the light sources. If they saw a green or a red light they were to press the button on their left hand side, which would turn the light off. If the robot did anything unusual, the participants were asked to make a mental note of it. It was emphasized that their primary aim was to complete as many assemblies as possible, while staying aware of what was happening around them. The participants completed this activity three times, with a different light source used in each task.

Cyclical counterbalancing was used for the presentation of the light sources to prevent practice effects [13]. After each task they were asked three questions regarding the task they had completed, their assessment of the light source, and the robots movement. This was to enable the researcher to remove the completed assemblies for counting, and to gain an understanding of how the participant found the task and the light source. Upon completion of the final task, participants were thanked for their time and debriefed about the aim of the research.

2.5 Analysis

The eye trackers were used to capture participants visual dwell times while taking part in the experiment, this data was analyzed using Begaze software (SensoMotoric Instruments) utilizing Area of Interest (AOI) semantic gaze mapping. The AOIs that were mapped included the manual task work top, robot work top, and the UR5. Workload was assessed by capturing reaction times or misses of the light signals, and by counting the number of assemblies completed per condition.

3 Results

The study looked to investigate the effectiveness of placing an indication light on a robot compared to a traditionally placed light tower, and a light tower placed in line with the robot.

Normality tests were applied to dwell time for the manual workbench, the robot work bench and the robot, across each of the light conditions. None of the data sets were normally distributed; therefore the Friedman Test was applied to the data. No significant differences were found between in length of dwell time as a result of indication light conditions (manual work bench: $\chi^2(2) = 5.600$, $p > 0.05$; robot workbench: $\chi^2(2) = 3.800$, $p > 0.05$; robot: $\chi^2(2) = 4.200$, $p > 0.05$). The total dwell time results are presented in Table 1. Results show that the total dwell time on the robot and the manual worktop is longest in the robot light scenario (236924.5 ms). However, dwell time on the robot workbench is highest (453196.3 ms) when the nearer tower light was used.

A repeated measures ANOVA with a Greenhouse-Geisser correction determined there was no significant main effect of light source on reaction time ($F(1.178, 10.606) = 2.830$, $p > 0.05$). The reaction time and number of misses for each participant are presented in Table 2.

Table 2 presents the reaction time and total number of misses for each participant. As can be seen none of the participants missed any of the robot light signals, but the total missed signals for the tower lights are 13 and 8 in the wall mounted and bench positions respectively. The robot light had the shortest total reaction time (13.45 s) whilst the wall mounted tower light yielded the longest reaction time (14.74 s).

Between each condition the participants were asked how they found monitoring the light source and at the end of the experiment were asked which light source they preferred out of all of the options and why. Although no significant differences were found in dwell time and reaction time between the light sources there was a preference for the robot light over the two light sources for the participants. Eight of the ten participants preferred the robot light source (Participants, 2, 3, 4, 5, 7, 8, 9, and

Table 1 Dwell time total (ms)

	TL (wall)	TL (bench)	Robot light
Robot	171176.8	166486.9	236924.5
Robot workbench	318387	453196.3	276114.5
Manual worktop	149189.5	119214.2	185870.1

TL = Tower Light

Table 2 Reaction time (RT) and number of misses

Participant	TL (wall)		TL (bench)		Robot light	
	RT (s)	Misses	RT (s)	Misses	RT (s)	Misses
1	1.72	1	1.46	1	1.46	0
2	1.35	1	1.56	1	1.42	0
3	1.38	2	1.50	0	1.48	0
4	1.51	0	1.54	2	1.53	0
5	1.15	0	1.27	0	1.06	0
6	1.21	0	1.20	0	1.21	0
7	1.47	1	1.38	1	1.28	0
8	1.45	1	1.15	0	1.13	0
9	1.57	5	1.51	3	1.40	0
10	1.92	2	1.42	0	1.48	0
Total	14.74	13.00	14.01	8.00	13.45	0.00
Mean	1.47	1.30	1.40	0.80	1.34	0.00
SD (2 d.p)	0.23	1.49	0.15	1.03	0.17	0.00

10), the reasons given were that the movement (Participant 2), size of the light source on the robot (Participants 2 and 9), proximity (Participant 3), and the fewer areas requiring attention (Participant 4) meant that participants felt they were able to see the light source with greater ease than the light towers. Additionally participants 5 and 8 stated that the light at the base of the robot made it easier for them to see light signals while they were paying attention to the assembly task, because it was within their line of sight.

Participant 1 found the robot light too bright and therefore distracting; and participant 6 had no preference other than they found the wall light task more difficult because it was further away, participant 2 and 9 had the same responses. Three of the participants (Participants 3, 4, and 7) stated that they had used their peripheral vision to register light changes, which would not have been picked up as dwell time lengths on the light sources.

4 Discussion

Participants were asked to focus on a manual task and react to any light signal, while paying attention to the activity being completed by a robot. This activity was chosen because it reflects current industrial practices providing the light task with a level of validity. Although the statistical analyses were not significant the eye tracking results seen in Table 1 revealed that the participants paid more attention to the robot and the manual task when the light signal to be monitored was positioned on the robot. On the other hand, robot workbench receives more attention when the light signals were coming from a tower light positioned next to it. In comparison, the participants' attentions were extended to the other two AOIs when the wall mounted tower light was used. This could be an indication that when the robot light signals divert less users' attention away from important AOIs.

The reaction time to light signal was generally shorter when the robot light was activated when compare to the tower lights. The robot light has also received a hundred percent hit rate whilst over half of the participants have missed at least one of the tower light signals. This shows that participants could observe the robot light more easily while carrying out a manual task. Furthermore, it was noticed from the eye tracking recording that most participants relied on their peripheral view to observe light signals from either of the tower lights. This is corroborated with the interview data, 3 of the participants stated they had made a conscious effort to use their peripheral vision to track the lights. This aligns with previous research that stationary objects in peripheral are more likely to be missed [11].

Further research is required with a larger sample size, and a complex task. The current task was simple and enabled participants to complete the assemblies without paying visual attention. Therefore the cognitive load from the activity was low, and meant that participants were able to use their remaining available cognitive resources to monitor the lights and the robot activities. A task requiring more attention may see a change to the results, with an increase in the number of light signals missed. Although the overall aim of this activity was to assess the effectiveness of light sources in human-robot collaborative environments, the task is one of proximity not collaboration one. The reason for this was used to establish a bench mark for attention before progressing towards a collaborative activity.

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Gesture Detection Towards Real-Time Ergonomic Analysis for Intelligent Automation Assistance

Chika Edith Mgbemena, John Oyekan, Ashutosh Tiwari, Yuchun Xu, Sarah Fletcher, Windo Hutabarat and Vinayak Prabhu

Abstract Manual handling involves transporting of load by hand through lifting or lowering and operators on the manufacturing shop floor are daily faced with constant lifting and lowering operations which leads to Work-Related Musculoskeletal Disorders. The trend in data collection on the Shop floor for ergonomic evaluation during manual handling activities has revealed a gap in gesture detection as gesture triggered data collection could facilitate more accurate ergonomic data capture and analysis. This paper presents an application developed to detect gestures towards triggering real-time human motion data capture on the shop floor for ergonomic evaluations and risk assessment using the Microsoft Kinect. The machine learning technology known as the discrete indicator—precisely the AdaBoost Trigger indicator was employed to train the gestures. Our results show that the Kinect can

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be trained to detect gestures towards real-time ergonomic analysis and possibly offering intelligent automation assistance during human posture detrimental tasks.

Keywords Microsoft kinect · Kinect studio · Visual gesture builder · Robots

1 Introduction

A high incidence of Work-Related Musculoskeletal Disorders (WMSDs) in the manufacturing and construction industries due to daily repetitive manual handling activities that involve lifting, lowering, pulling, pushing, carrying or moving [1–3] by workers calls for adequate ergonomic evaluation and correct risk assessment. However, correct application of ergonomic assessment tools requires systematic and comprehensive approach to data collection [4, 5]. A tool that can enable this as well as provide an opportunity for real-time feedback is the Microsoft Kinect [6].

This paper investigates how the Microsoft Kinect v2, henceforth called Kinect, can be trained to detect the manual handling activities on the shop floor towards enabling accurate data collection for ergonomic evaluations and risk assessment. It further describes how the Kinect is trained to capture data for automatic ergonomic assessment with the eventual goal of providing real-time feedback to both a human and a robot-cooperation system. Such feedback will inform the human to take corrective posture changes and also provide commands to enable the robot-cooperation system take a decision on when it is needed by the human for assistance. Our contribution ensures that only data related to a manufacturing activity of focus (such as lifting or lowering of loads) is recognized and recorded. This leads to more accurate ergonomic analysis as well as lower data and computational processing requirements during real-time monitoring. The Kinect v2 is a low-cost, gaming, depth sensing device utilized for human motion capture as well as human-computer interactions. It consists of a depth sensing technology, a built-in color camera, an infrared (IR) emitter as well as a microphone array and is an upgrade from the previous v1 model [7]. It is able to sense the location, movement and voices of people and can track up to six people and 25 joints for each person.

1.1 Literature Review of Camera-Based Data Collection for Industrial Ergonomics Analyses

Literature survey has shown that in order to collect human motion data on the shop floor for ergonomic analysis, real-time monitoring of workers is a key requirement. This is because lifting and carrying among operators in factories if not well monitored can be detrimental to the worker's health [8]. When workers are monitored and guided during any manufacturing process, it leads to overall reduction in production errors. To achieve this, video capture systems are often used. In [9], a video camera was used to monitor the working postures of palm oil harvesters. It involved taking snapshots of awkward postures with the significant postures captured for onward ergonomic assessment. A similar technique was used by [10, 11] to collect data for ergonomic risk assessment. It involved monitoring and taking photograph of operators while performing a lifting/lowering task on an auto parts shop floor as well as technicians while changing brake shoes of freight wagons at a railway maintenance. In another experiment to investigate the risk of developing WMSDs among bicycle repair workers, [12] used still photography and video photography to collect the data needed for the risk assessment. These methods, though easy to use, are time consuming, unreliable [13], and do not give the 3D information as well as accurate joint information of workers in congested workplaces.

In order to find a more suitable and more convenient method for data collection on the Shop floor, [5] compared the use of Kinect for data collection with the use of observation methods during an ergonomic assessment of postural load using OWAS. The Kinect was found to yield many benefits as it is easy to use, required less time for data processing and does not interfere with the work process—all at low cost. Consequently, this work focuses on the use of the Kinect sensor for more accurate capture of 3D data.

Experiments have shown that the Kinect is capable of generating accurate Kinematic information required to fill an ergonomic assessment grid such as the RULA grid. The accuracy of the Kinect to perform this function was ascertained by Plantard et al. [6], using large set of work poses at different Kinect positions with the joint positions, joint angles as well as RULA scores as inputs. The result showed that the accuracy of the pose estimation is influenced by the Kinect position and that error occurred when the human arm aligns with Kinect. They however, concluded that Kinect is a useful motion capture tool for ergonomic evaluation. A Kinect—based real-time ergonomic analysis of only lifting operation has been developed in the past. This work integrated a static ergonomic model with the Kinect and the system was found to measure the recommended weight limit and strain on worker's skeleton [8]. Prabhu et al. [14] in their study demonstrated that the Kinect can be used in a real world setting. Paliyawan et al. and Uribe-Quevedo et al. [15, 16] used it to monitor the posture variation of seated human operators so as to detect any deviation from the correct posture. In [17], Kinect was used to collect data for postural control assessment during a functional reach and standing balance task. In [18], it was used to monitor lifting operations by tracking in real-time, the body joint angles during the operation with the aim of recommending correct and safe lifting techniques. In order to ensure continuous coverage of large spaces, [19] used multiple Kinect sensors integrated with JACK human simulation software to track skeletal data of operators performing fastening operation so as to scale the Kinect data into JACK for onward real time ergonomic evaluation using the Rapid Upper Limb Assessment (RULA) tool in JACK.

The use of ergonomic analysis with robot-cooperative system for purposes of reducing WMSDs has also been investigated in various forms in literature. For example, [20] proposed the Human Centric Automation concept using robots and Kinect. Their work involve using the Kinect to capture real time motion data for automatic ergonomic assessment so as to utilize the ergonomic scores obtained as a feedback to inform the system on when robots are needed to assist. This leads to reduced physical workload, minimized production errors, decreased risk of WMSDs, as well as increased performance.

However, the previous researches in which the Kinect was used to monitor and track human operators faced significant challenges because the version of the Kinect used was the Kinect v1. Unlike Kinect v2, Kinect v1 could not detect gestures associated with manual handling as a result of the absence of the Visual Gesture Builder as well as the Kinect Studio which are special tools found in the Kinect for Windows Software Development Kit (SDK) 2.0. The importance of gesture detection cannot be overemphasized as it helps to ensure more accurate data capture for ergonomic evaluations. This work will describe in details, how the Kinect v2 can be trained to detect gestures applicable to manual handling activities. The goal is that through gesture detection, real-time ergonomic analysis can be achieved with real-time feedback to both human and robot-cooperation system so as to possibly offer intelligent automation assistance during human posture detrimental tasks, thereby leading to a reduction in overall data analysis as well as overall production errors.

2 Methodology

In this section, we discuss how the SDK tools for the Microsoft Kinect were used to detect gestures to trigger data recording for analysis. We focus on two gestures: load lift and load lowering.

Basically, the two main methods of detecting gestures using Kinect are the detection method which comprises of the Heuristic approach, and the Machine Learning (ML) which involves data sources and recording of clips using the Kinect studio [21]. In this work, the ML approach is employed because the VGB has the ability to facilitate ML techniques into the user's gestures by employing both the recorded and the tagged data.

Usually, for ML in VGB, data is recorded in clips using the Kinect Studio. The Kinect Studio which enables developers to record clips which are imported into the VGB solution for proper training and testing of the gestures [22]. In this work, the Adaboost Trigger indicator, which is a detection technology that produces discrete results, was used to train the gestures. This is because the gestures are trained as discrete gestures.

The methods involved in the creation of gesture, training and analysis of the gestures include: (i) the skeletal data of the trainer is recorded while lifting and lowering some load, using the Kinect Studio. The trainer is recorded while performing these operations at a particular position from the Kinect, called the central location. (ii) The processed (XEF) files which are in clips are imported into the VGB by creating new solutions in VGB in which the clips are added to projects. The project, when created in the new solution, automatically splits into two, one for the building/training data and the other for the testing/analysis data. (iii) The gestures are tagged in VGB. (iv) The gestures are then built and analyzed using VGB. (v) The trained gestures' file known as the .gbd file are then used to write the codes in the Discrete Gesture Basics tool which is a tool in the Kinect for Windows SDK 2.0. (vi) The gestures are further tested on other locations on another environment in front, beside, and behind the central location to establish if the gestures can be trained in an environment and be detected on another environment and also to establish the points beyond which the gestures can no longer be detected in the workplace.

2.1 Experimental Setup

The components used in this experiment is the hardware component which is the Kinect v2 sensor, a Laptop, tables of the same height, a work piece for lifting, and the software component which include the Color Basics, the Kinect Studio, the VGB Preview, the VGB Viewer—Preview and the Discrete Gesture Basics. The software components are all found in the Kinect for Windows SDK 2.0.

In order to investigate the effectiveness of the Kinect in detecting gestures at various distances and angles, measuring points in the environment were set up as depicted in Table 1 and Fig. 2. These points are taken within the field of view of the sensor. At each point, the confidence level of the Kinect at detecting gestures was

Table 1 Detailed experimental design

Angle (°)	Distance from the Kinect		
	Low (1 m)	Mid (2 m)	High (3 m)
60	P_1	P_4	P_7
90	P_2	P_5	P_8
120	P_3	P_6	P_9

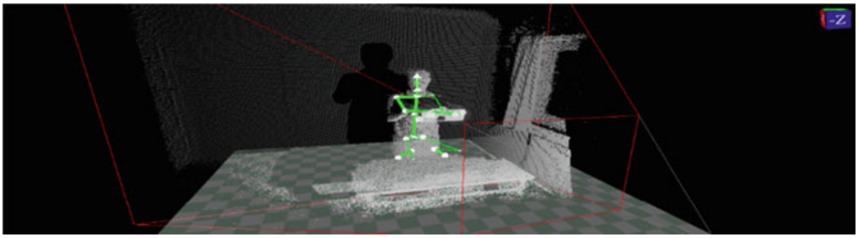


Fig. 1 3D representation of the training environment

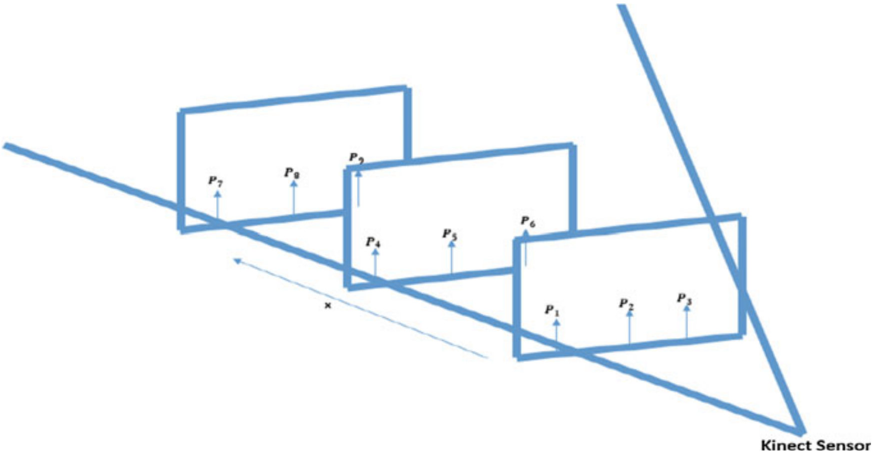


Fig. 2 Schematic representation of the experimental set up showing the various locations

tested. In these experiments, a lifting gesture and a lowering gesture is carried out in a room to depict the actual lifting of a part by an operator in a manufacturing environment (Fig. 1).

3 Results

3.1 Gesture Training Results

Figure 3 depict the training of the lifting and lowering gestures. During training, 30 lowering gestures were used resulting in 2742 labelled examples with an average Root Mean Square value (RMS) of 0.243 and over 253 frames while 32 lifting gestures were used resulting in 3079 labelled examples with an average RMS of 0.299 and over 445 frames. Furthermore, an accuracy of 100 % was obtained while the error was found to be 0 %.

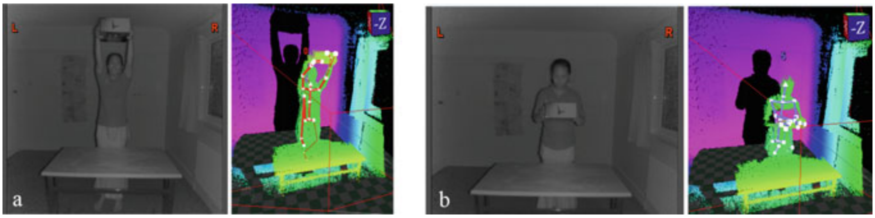


Fig. 3 Training of the Lifting Gesture (**a**) and training of the Lowering Gesture (**b**)

3.2 Testing of Trained Gestures Using the Visual Gesture Builder Viewer (Live Preview)

The gestures were tested on various locations in another environment as seen in Table 1 and Fig. 2 using the VGB Viewer, with the results of the lifting gesture shown in Fig. 4. The result shows that at P_3 and P_9, the confidence of the Kinect at detecting gestures was very low and could be questionable. This suggests that Kinect placement in the environment will affect the accuracy of the gesture detection.

3.3 Coding the Gestures Using the Discrete Gesture Basics

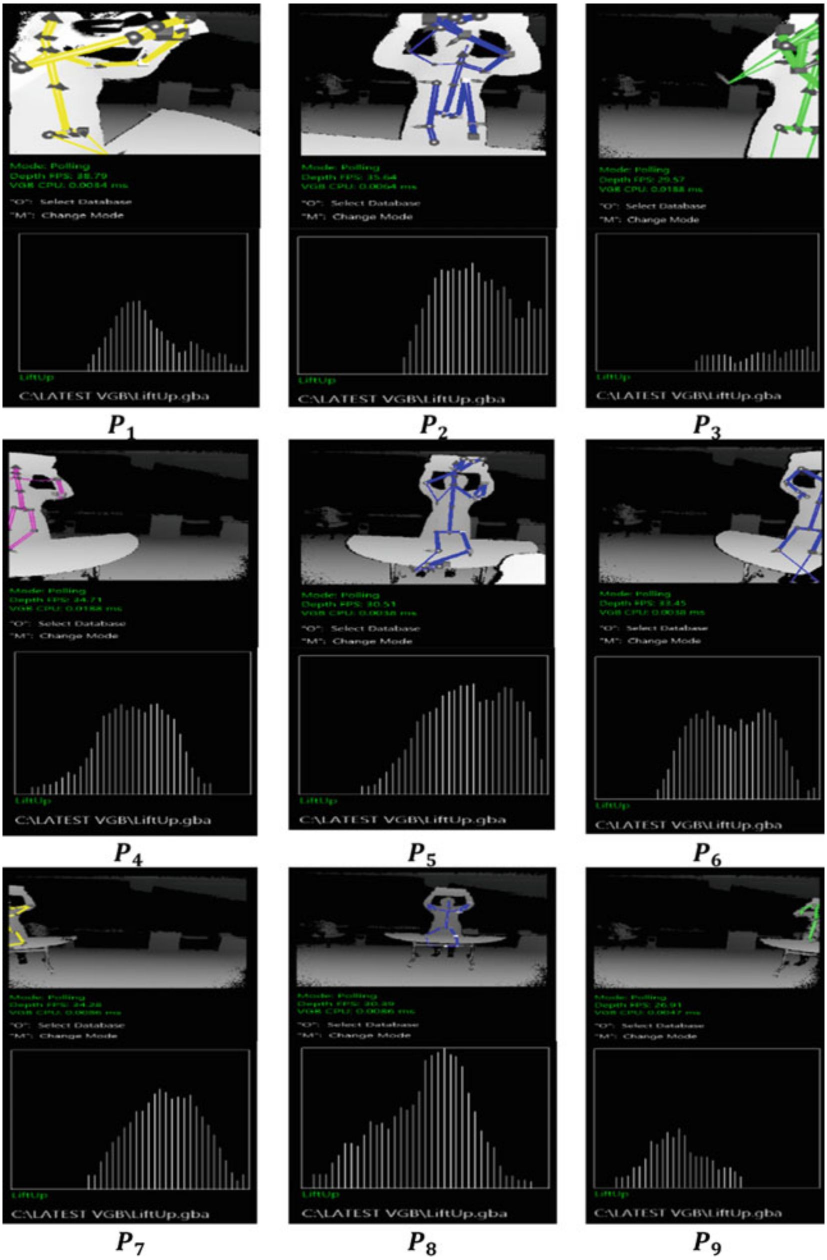
The .gbd file data generated after training and testing the gestures are utilized by the programmer as a criteria for creating both lifting and lowering gestures using the Discrete Gesture Basics of the Kinect for windows SDK 2.0 and used for coding discrete gestures. It provides the best thresholds as well as the .gbd files required for coding the gestures. Prototyping with VGB is very important as the classifiers generated is useful for the coding in the Heuristic approach. The program developed is then utilized for detecting lifting and lowering gestures during real time ergonomics evaluation.

4 Discussion

To collect motion data on the shop floor for Ergonomic evaluations and correct Risk Assessment, an application has been developed which utilizes the motion sensing technique of the Microsoft Kinect sensor. The application detects manual handling gestures such as lifting and lowering on the shop floor. The details are discussed as follows: As mentioned previously, Training accuracies for the gestures used were 100 % while the error was found to be 0 %.

Figure 4 depict the live previews of the lifting gesture at different locations as represented in Table 1 and Fig. 2. It was obtained when the gestures were tested on other locations in another environment in front, beside, and behind the central location to establish if the gestures can be trained in an environment and be detected on another environment and also to establish the points beyond which the gestures can no longer be detected in the workplace. A closer look at these data shows that at points 3 and 9, the confidence of the Kinect to detect the gesture is slightly lower than at other points. One can therefore conclude that below angle 60° and above angle 120°, the Kinect may not be able to detect any gesture.

Finally, the result of the trained data is utilized in writing the appropriate code in the Discrete Gesture Basics so as to enable the Kinect to detect the gestures. Figure 5 shows the Kinect tracking humans while lifting and lowering an object. A minimum of six workers can be tracked at the same time using this sensor.



P_1 P_2 P_3

P_4 P_5 P_6

P_7 P_8 P_9

Fig. 4 Live previews at points 1 to 9

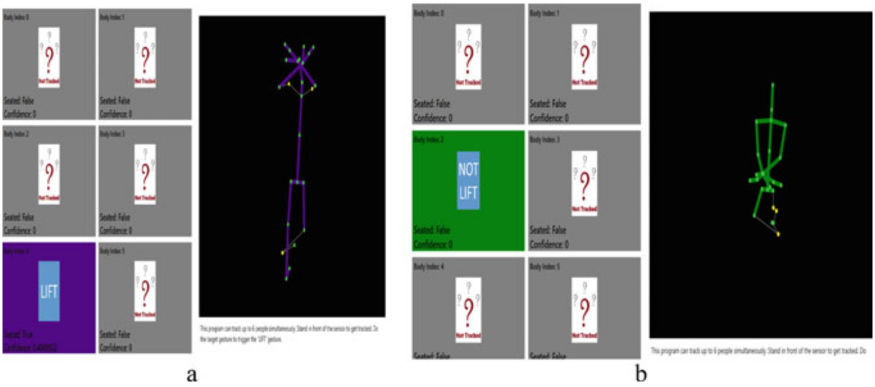


Fig. 5 Lifting Gesture (**a**) and lowering gesture (**b**), after coding with the Discrete Gesture Basics

This application, is intended for use by integrating it with another data collection application developed by the authors of this paper which is a program developed using the Application Programming Interfaces (APIs) provided by the Kinect for Windows SDK 2.0 and which include the Windows Runtime APIs, .NET APIs and

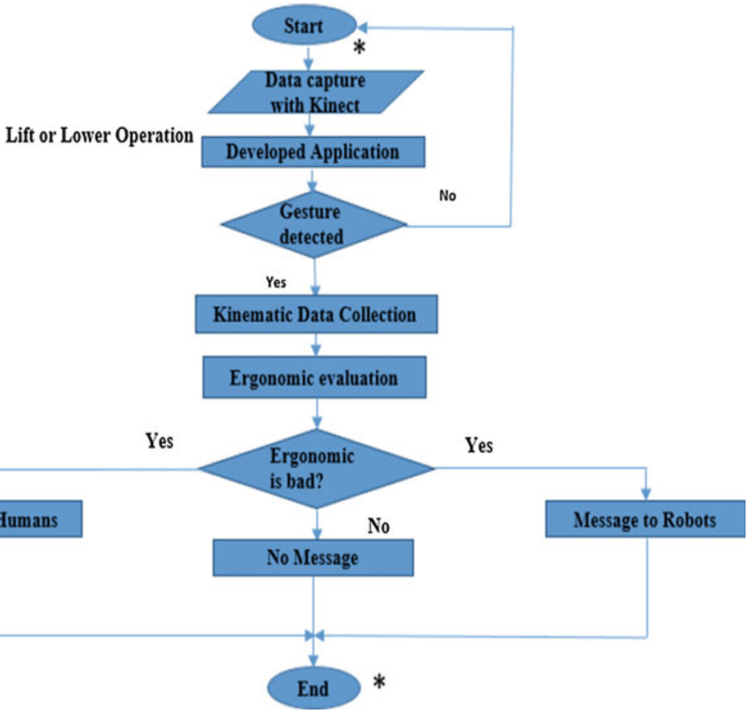


Fig. 6 A framework for Real-time data collection for Ergonomic evaluation using Kinect

a set of native APIs, precisely the Windows Presentation Foundation (WPF) Application of the .NET Framework 4.5 in Visual Studio 2013. It can track, measure and record the angle of the joints of any human and the 3D skeletal joint positions (X, Y, and Z) in millimeters. The framework in Fig. 6 shows how the Kinect can utilize both the developed application and the written algorithm to effectively extract the motion data of human operators for real-time ergonomic evaluations and correct risk assessment with the view to offer intelligent automation assistance during human posture detrimental tasks on the manufacturing shop floor.

5 Conclusion

In the past, several methods were used to collect human motion data on the shop floor for ergonomic analysis. These include the self-report such as interviews and questionnaires; Observation methods such as video capture and Direct methods using the wearable marker sensors. The use of marker less sensors such as the Microsoft Kinect, which is a low-cost, gaming, depth sensing device utilized for human motion data capture, has been employed recently to capture data for ergonomic analysis. However, none of the technologies employed by previous researchers have considered the detection of gestures and how this can improve the accuracy of the data collection process.

This paper therefore presents an application developed to enable real-time human motion data capture on the shop floor for ergonomic evaluations and possible automation assistance through gesture detection, using the various tools in the Kinect for windows SDK 2.0. In the work, an experiment was conducted in which the Kinect was trained to detect manual handling gestures of the workers. This can be beneficial on the manufacturing shop floor to monitor in real-time, the workers with the overall aim of collecting their motion data for ergonomic evaluation with adequate feedback to both human operators and robot cooperation system.

Finally, a framework, which shows how the developed application can be used to collect real-time human motion data on the shop floor towards ergonomic evaluation and intelligent automation assistance, is presented.

6 Future Work

In the future, we plan to complete the research by conducting the ergonomic analysis using an appropriate tool and also to develop a feedback system using the Kinect which gives feedback to the human operators concerning any detrimental work postures and the robot cooperation system on when the robots are needed to assist, as shown in Fig. 6.

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Assessing Graphical Robot Aids for Interactive Co-working

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Abstract The shift towards more collaborative working between humans and robots increases the need for improved interfaces. Alongside robust measures to ensure safety and task performance, humans need to gain the confidence in robot co-operators to enable true collaboration. This research investigates how graphical signage can support human–robot co-working, with the intention of increased productivity. Participants are required to co-work with a KUKA iiwa lightweight manipulator on a manufacturing task. The three conditions in the experiment differ in the signage presented to the participants—signage relevant to the task, irrelevant to the task, or no signage. A change between three conditions is expected in anxiety and negative attitudes towards robots; error rate; response time; and participants' complacency, suggested by facial expressions. In addition to understanding how graphical languages can support human–robot co-working, this study provides a basis for further collaborative research to explore human–robot co-working in more detail.

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Keywords Human–robot interaction · Graphical signage · Anxiety towards robots · Negative attitudes towards robots · Trust · Manufacturing tasks · Co-working

1 Introduction

Robots are becoming more than passive/programmed or autonomous tools for humans to use; as they become more sophisticated and automated co-working partners, the relationship between humans and robots will change to more resemble interaction between two individuals [1]. This shift in industry for manufacturing tasks to incorporate human–robot co-working increases the need for improved interfaces to make this interaction more efficient. As the requirements on autonomy, complexity and safety of robots increase, human operators need to gain confidence in robots and their capacities to enable true collaboration. These issues are exacerbated by the introduction, and up-skilling, of workers without robotics experience. These factors increase the need for effective information communication to users to aid human–robot interaction in manufacturing settings. One reliable and effective means to clearly and rapidly communicate necessary information is through graphical signage.

A main aim of signage is to provide information, and by providing information to allow people to respond to a given situation or instruction in appropriate manner, with confidence. Graphical signage as a means of communicating can be especially beneficial in industrial settings, if designed according to ergonomic rules and principles [2].[1] One of the most important aspects of signage design is to communicate information in a quick and concise manner. Graphical signage can decrease the time necessary to navigate in unfamiliar locations when signage is displayed compared to when there is no signage present [4, 5]. Furthermore, in manufacturing and road/highway settings, where information has to be presented in a quick and clear way, effectively designed signage can reduce the number of accidents [6, 7]. One of the possible reasons for this decrease is the decline in cognitive load required as the individual has to process smaller amounts of information before making a decision [8].

Graphical instructions are one of the most efficient methods of displaying instructions for individuals with little or no prior-experience [9]. Examples of this approach include the instructions for assembling Ikea furniture; non-skilled individuals manage to assemble furniture by following visual instructions with no or little text-based explanations. Moreover, this kind of symbol based instruction can be universal: understood across cultures and not dependent on written language

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[1] Though care must be taken in designing signage to reduce ambiguity in interpretation [3].

[10]. Finally, succinct, clear symbolic displays in the work environment can benefit not only non-native language speakers, but also individuals with learning disabilities such as dyslexia [11]. Combining easy readability and a clear message is an effective way of delivering information.

Besides physical factors, graphical languages in human–robot co-working can reduce human psychological distress and help workers to adapt to the changing scenarios in the work place. As discussed, graphical signage is often designed to help people understand the requirements of unfamiliar situations, which can lead to greater empowerment and a sense of control. In a healthcare context, well-designed booklets and information leaflets can not only make patients aware of facts and give advice, but also encourage discussion and prompt questions [12]. Furthermore, leaflets that encourage patients to raise issues and discuss symptoms in the consultation process can improve patient satisfaction and perceptions of communication [13]. Access to information relating to a patient's condition and treatment has been shown to lead to a feeling of more control and greater empowerment [14]. This informed sense of empowerment and control can decrease the levels of stress experienced [15–17].

Higher stress and anxiety levels can be triggered by perceptions of danger and insecurity [16, 18]. Following on from this, anxiety and negative attitudes can influence trust levels [19] which are important not only for collaboration in the social context of human-human interaction [20–22], but also for human–robot interactions in collaborative manufacturing tasks [23, 24]. In the manufacturing context, without clear instructions and training, an individual's cognitive load is often already high [25] and there can be little capacity beyond undertaking a complex activity for monitoring co-workers while performing an industrial task. In addition, stress and decision-making anxiety can influence mental and physical illnesses [26], and it is expected that reducing uncertainty through the use of graphical signage can help improve the mental and physical well-being for the individual.

Although past research shows that experience of human–robot interaction can decrease participants' negative attitude towards robots [27], this decrease in anxiety depends on the robot's behavioral characteristics [28], and the individuals expectation of the experience and interaction, which can be communicated and prefigured by the use of graphical signage [29]. In this project, the use of the graphical signage is expected not only to aid human–robot collaboration to help achieve higher production levels in a shorter time, but also to decrease uncertainty and anxiety, leading to safer and healthier working environments. The aim of this project is to investigate whether and how graphical signage can aid human–robot interaction in the manufacturing context. This will be achieved by observing human participant behavior in the manufacturing context under three signage display conditions: relevant to the task, irrelevant to the task, and no signage.

2 Methods

2.1 Experimental Design

This study will use a mixed design of three independent conditions: signage relevant to the task (experimental), signage irrelevant to the task (active control), and no signage (baseline control). Repeated measures within conditions will be used: participants first complete baseline measures of attitudes and anxiety towards robot (see Sect. 2.5 Measures) and again after the robot interaction scenario.

2.2 Participants

Ninety students from the University of Sheffield will be recruited to participate in the study (30 participants per condition). They will have normal or corrected-to-normal vision, no emotional and learning disorders and be between 18 and 35 years old. Participants' experience of working with robots, programming and computer usage, risk taking attitude, and anxiety and negative attitudes towards robots will be accounted for between the groups. Participants will be offered an opportunity to win one of five £10 Amazon vouchers for their participation in the study. It will be emphasized that the possibility to win will not dependent on their performance but on participation in the experiment. The study has been approved by the University of Sheffield ethics committee.

2.3 KUKA iiwa Lightweight Arm

In this study, a KUKA Intelligent Industrial Work Assistant (iiwa) will be used for the human–robot co-working task. The KUKA iiwa is a lightweight robot for industrial tasks developed by KUKA Robotics Group (KUKA Roboter GmbH). The design of this robot is based on a human arm with seven axes of movement and it is able to lift up to 7 kg of weight (Fig. 1). The KUKA iiwa is developed as a collaborative robot, specifically allowing direct human–robot interaction, and has a set of configurable safety measures suited to co-working. For this study the robot will be set to be operated in a compliant safe mode 'T1' with limits on speed and a requirement for human monitoring.

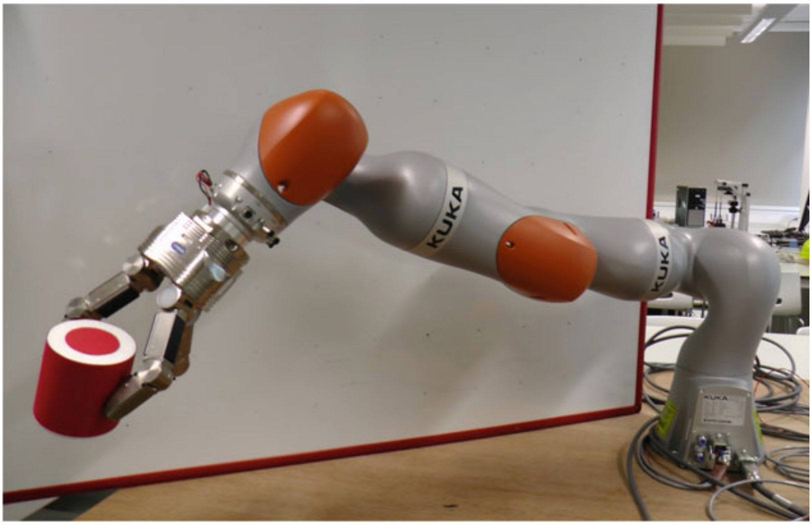

Fig. 1 KUKA iiwa

2.4 Design of the Graphical Signage

For the project a bespoke set of graphical symbols are being developed to test the research proposition. In developing the look and feel of these new signs ISO graphical signage conventions have been considered [30]. The project designers have undertaken experimental designs with different visualization options (see Fig. 2). These are refined in consultation with the broader project community. Consideration as to where signage should be placed in the experiment, size and form (digital or physical) has also been undertaken.

The intension is that the project symbols will form the foundation for a larger system of symbols that can be used for a range of human–robot interaction scenarios. For this specific experiment, how to visually represent the following key human–robot interaction events have been considered, to help inform a co-worker that:

1. You can touch the robot
2. You will be within its' area of operation
3. The robot arm will move along the x and y axis
4. The robot arm will move at a certain speed
5. In your interaction with the robot arm there will be active and passive states
6. You should use a certain amount of force to move the robot arm
7. The robot will have a certain amount of force

Due to experimental design, two sets of signage have been developed—signage representing the necessary knowledge required to co-work with the robot (for

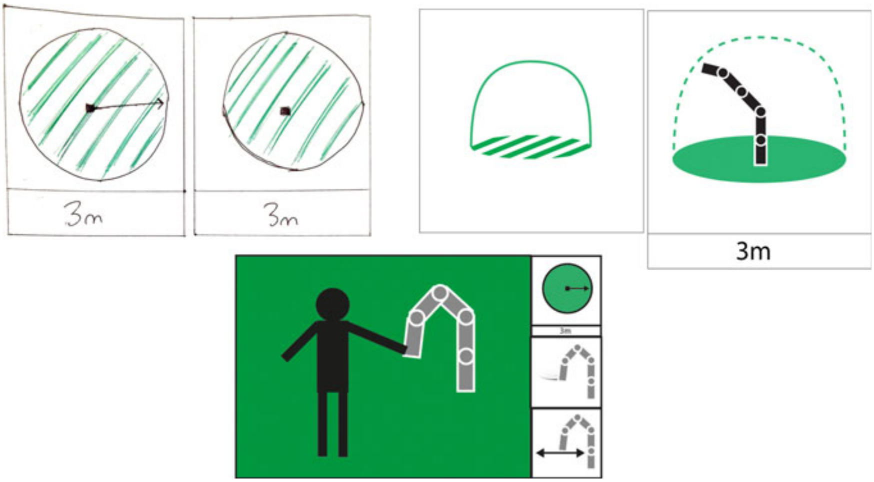

Fig. 2 Examples of graphical signage at the early development stage

example, speed, and reach parameters of the robot; Fig. 2) and signage which does not provide task-specific information for the robot user (for example, optimal temperature for the robot to operate).

2.5 *Measures*

Negative Attitudes towards Robots Scale (NARS). This scale consisting of 14 statements was developed by Nomura et al. [31]. Here participants indicate their level of agreement on each statement on a five-point scale (from 1—strongly disagree to 5—strongly agree). NARS is composed of three sub-scales; measuring negative attitudes towards interaction with robots, towards social influences of robots, and towards emotions in interactions with robots. In this experiment the sub-scales of attitudes towards interactions with robots and towards social influences will be administered pre- and post-experiment.

Robot Anxiety Scale (RAS). This scale measures anxiety affecting participants' interactions with robots [32]. The scale is divided into three sub-scales measuring participants' anxiety towards the communication capability of robots, behavioral characteristics of robots and discourse with robots. As the current experiment will be measuring participants' performance on a manufacturing task, only the sub-scale measuring anxiety towards the behavioural characteristics of robots will be conducted pre- and post-experiment. In this questionnaire, participants indicate how anxious they feel about each statement on a six-point scale from 1 "I do not feel anxiety at all" to 6 "I feel very anxious".

Risk Taking Index (RTI). A six statement scale assessing participants' everyday risk taking attitudes now, and in the past, on a five point scale (1—never, 5—very often) was developed by Nicholson et al. [33] and will be administered pre-experiment.

Experience with Robots. This scale containing 5 questions assesses how often participants attended robot-related events, read literature, watched media, had physical contact with a robot, or have built or programmed a robot [34]. Participants will indicate their answers on a 6-point scale (0, 1, 2, 3, 4, 5 or more times) before interacting with robot.

Graphical Signage Effectiveness. This scale was adapted from the Experimental and Survey Studies on the Effectiveness of Dynamic Signage Systems in the context of fire safety [35] to fit robot related material. The questionnaire contains two sub-scales; three statements assess participants' perceived general effectiveness of signs, and five statements assessing effectiveness of the signage on the purpose of assisting people in interacting with the robotic arm. Participants indicate how much they agree with each statement on a 5-point scale (from 1—strongly agree to 5—strongly disagree. An additional option indicating that they did not see any graphical signs was added for the benefit of the control condition with no signage). Participants will fill in this scale after interacting with the robot.

In addition to the previously mentioned measures, prior to the experiment participants will be asked to indicate how many hours per week they use computer for assignments/work, for browsing/socializing, and for playing computer games (indicating which category of games they prefer). Their programming expertise will be self-assessed on a 5-point scale (1—very inexperienced, 5—very experienced). After they have completed the main experimental task and the graphical signage effectiveness questionnaire, they will have to indicate which signs they had seen during the experiment.

All the questionnaires in this study are computerized and will be presented through the Qualtrics Insight Platform.

Behavioral Measures. The following behavioral measures will be recorded throughout interaction: (1) participant error rate, (2) time taken to complete the task, (3) participant facial expressions during success and fail attempts to complete a single trial/industrial part, (4) count of instances participants turn away from the robot while the robot is operational. Measures 1 and 2 serve as behavioral indexes of task achievement. Measures 3 and 4 serve as behavioral indexes of participants' anxiety towards working with the robot. Facial expressions (mean intensity and duration) are coded automatically with Noldus FaceReader version 5; FaceReader offers automated coding of expressions at an accuracy comparable to trained raters of expression [36].

2.6 Procedure

After signing the consent form, participants will be sent a hyperlink to an online questionnaire to fill in before taking part in the main experiment. The questionnaire will measure the participant's robot anxiety (RAS), negative attitude towards robots

(NARS), computer usage, computer game and programming experience, risk taking attitude (RTI) and experience with robots.

When participants come to the main part of the experiment, participants are told they are going to be co-working with the KUKA robotic arm on a task requiring human–robot interaction. They will be told that on the table there are 16 holes with narrow tubes and 6 of them contain small, industrial parts. These parts need to be put into a collection box. The industrial parts are inaccessible to the human (placed in narrow and long tubes), however the robotic arm can access them. Although the arm can reach and pick the objects, it is unable to locate the exact tubes where the industrial parts are needed, the participants help is required to locate them. The participants can only complete the task by collaborating with the robotic arm. The maximum time to complete the task is 15 min. During the experiment, a collaborator observes the participants' performance behind closed curtains as a safety measure in case the experiment needs to be aborted.

Participants are informed that they are going to be video recorded during the experiment, and the material collected will be used for data coding and further statistical analysis. However, measures are taken to keep the data anonymous and confidential.

After the main part of the experiment is completed, participants complete an online questionnaire measuring their perceived effectiveness of graphical language and recollection of the signage they have seen during the experimental task with robot. Their robot anxiety (RAS) and negative attitudes towards robots (NARS) are measured once again. Finally, participants are debriefed explaining the aims of the experiment. The whole experiment lasts about 30 min.

3 Anticipated Outcomes

The expected results from the study include observing decreased error rate and task completion time in the experimental group compared to the active control and control groups. This effect has been observed in human navigation studies of unfamiliar environments [4, 5]. Furthermore, past research shows that after having interacted with robots, participants' negative attitudes towards robots decrease [27], however the decrease of the anxiety also depends on the robot's behavioral characteristics [28]. Therefore, we expect that participants' anxiety levels and negative attitudes towards robots will decrease after the interaction with robot. This effect should be stronger in the experimental group, as the signage will influence their expectation of robot abilities and maneuverability [29]. Following this, the experimental group participants are expected to have turned their back towards robot on more occasions, compared to control groups, thus indicating higher levels of trust.

4 Predicted Implications

At the time of this paper being written, the results for this study are only being collected; therefore only the predictions of what we expect to see are discussed. In addition, the investigation uses a novel approach and the research question has not been explored previously which leaves some of the predictions exploratory and can only be speculative until all the data is collected and analyzed.

However, if the initial study predictions prove to be accurate, we should be able to observe how graphical signage related to the robots working characteristics can make human–robot co-working more efficient. First, by decreased error rate and the time necessary to complete the task. Second, decreased anxiety and negative attitudes towards robots and an increase in operator confidence should result in less human psychological distress in the work environment. Following this, an increase in the number of times individuals turn their back towards the robot during the co-task should also indicate more trust and comfort in co-working with the robot. Overall, these factors should reveal that the general mental state of the operator is more positive and that they feel more comfortable co-working with a robot on manufacturing tasks. Furthermore, this might influence greater levels of attention and concentration in the work setting. Decreased attention and cognitive function has been observed to be related to the number of minor injuries and even accidents at work [37]. Therefore, it is hoped that the use of a graphical language in the human–robot interaction might have some influence in deceasing workplace accidents. However, this would need to be explored in future studies. Further investigations will also examine what environmental factors are required to maximize the advantageous effect of graphical signage.

In summary, we expect that the use of graphical signage will have a positive effect not only for manufacturing industry, but also for people working in these settings, potentially increasing production by reducing levels of anxiety, and increasing trust towards robots in co-working scenarios.

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High Value Intelligent Aerospace Turbofan Jet Engine Blade Re-manufacturing System

Richard French and Hector Marin-Reyes

Abstract Development of any advanced, intelligent robotic welding system requires correct interrogation of welding parameters and output. Advanced programming of robots, data interpretation from associated sensory and feedback systems are required to mirror human input. Using process analysis to determine stimuli, replacement of human sensory receptors with electronic sensors, vision systems and high speed data acquisition and control systems allows for the intelligent fine tuning of multiple welding parameters at any one time. This paper demonstrates the design process, highlighting interaction between robotics and experienced welding engineers, towards construction of an autonomous aerospace turbofan jet engine blade re-manufacturing system. This is a joint collaborative research and development project carried out by VBC Instrument Engineering Ltd (UK) and The University of Sheffield (UK) who are funded by the UK governments' innovation agency, Innovate-UK and the Aerospace Technology Institute (UK).

Keywords Robot · Ergonomic · Machine vision · GTAW welding · Re-manufacturing system

1 Introduction

High value aerospace gas turbine blades are subjected to extreme temperatures during operation, resulting in wear, deformation and distortion over time. After ~30,000 h of operation, turbofan jet engines are entirely overhauled. The compressor blades are

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removed then inspected and where possible repaired using manual weld deposition. Investigations into the intelligent automation of the GTAW (Gas Tungsten Arc Welding) process for turbofan blade re-manufacturing has demonstrated that highly skilled welding engineers are required to carry out what is perceived to be a simple task.

Existing standard practice for the re-manufacturing of high value compressor blades is predominantly performed manually, on-site under extreme environmental constraints (noise, heat and restricted spaces). However with such high value components, a high yield of re-manufacturing is required, but not achievable with current manual processes providing less than 50 % yield.

Experienced welding engineers use their knowledge and apply their skills almost automatically by subtly fine tuning multiple welding control parameters to achieve the required results. Their dynamic inputs alter the weld deposition characteristics such as; size, shape, depth and micro-structure. The variable parameter changes are termed CLAMS (current, length, angle, manipulation and speed). CLAMS detailed in a welding procedure schedule or document is used to provide numerical input for the manual operator to achieve correct results with high yield.

A prototype system will be built in this study which will be interfaced to a robotic welding arm to prove that the system can operate in a representative environment. The system has great potential to be developed not only in robotic welding but also for other automated robotic systems that require locational and structural information to determine the appropriate procedure required and optimize control. A route map of commercialization will be produced to develop commercial products in different industries.

2 Reducing Human Labour in Re-manufacturing Aerospace Turbo Fan Compressor Blades

Aero engine gas turbine compressor blades are subjected to extreme temperatures during operation, resulting in wear, deformation and distortion over time (Fig. 1 shows a Rolls-Royce Trent1000 turbofan engine). The overhaul process is predominantly undertaken manually. In this instance we discuss the high value compressor blades which are stripped from their mountings, removed and repaired using manual weld deposition then refinished.

The aviation industry, driven by tight profit margins, strict safety profit margins and safety regulations, has become an extremely well developed remanufacturing industry. Half of all overhauled compressor blades are reclaimable through the remanufacturing process (Fig. 2 shows the re-manufacturing industry life cycle). However, there is a problem because current re-manufacturing yield of compressor blades is only around 80 % of that half owing to high heat input during welding and poor practice.

Fig. 1 Cross sectional rendering of Rolls-Royce Trent1000 turbofan engine detailing the removable compressor blades in the central section

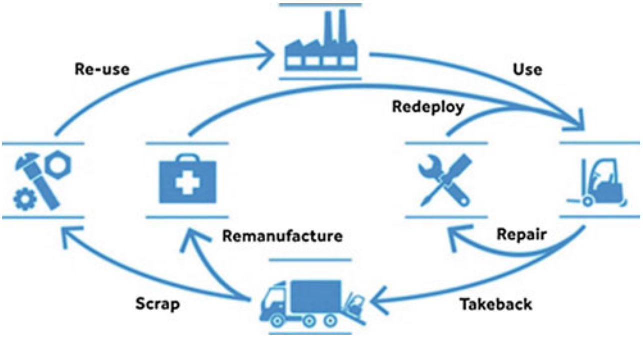

Fig. 2 Diagram of re-manufacturing industry life cycle asset management process

Major problems have been identified through errors in the manual weld build-up process and it is desirable to assist the human operators with robotic solutions. With air travel set to increase, there will be even more demand for remanufactured components and systems. With new materials and technologies being incorporated into aircraft, it is important that science keeps pace with technology to repair these parts and detect faults before they fail.

Turbine compressor blades experience dimensional and metallurgical degradation during engine operation. Dimensional degradation derives from wear, nicks, dents and hot corrosion. The current solution is to grind back the blade tip to a predetermined globally approved specification which results in non-defective sectors being reworked unnecessarily which significantly reduces the lifespan of the part (Fig. 3 shows the manual weld build up process).

This current practice evolved from the need to build in low tolerance manual welding and hand grinding of very high tolerance components. Manual processes

Fig. 3 Photograph of welding engineer carrying out the manual weld build up process

are still widely used because there is very limited amounts recorded welding knowledge or data available. The remanufacturing industry relies instead on highly skilled welding staff to “feel” their way through a blade repair (Fig. 4 shows compressor blades after manual weld deposition).

Combined with existing manufacturers’ inability to utilise accurate component wear identification with good welding power supplies and non-destructive testing (NDT) weld monitoring systems provides an ideal opportunity to reduce human labour in this process.

Automated solutions to address this area of concern have been attempted before. Existing solutions do not offer anywhere near the proposed level of intuition simply through the lack of correct use, or development of sub-systems to aid the welding and inspection processes.

Fig. 4 Photograph of compressor blades after manual weld deposition

By providing a high fidelity process for a high tolerance component the system relieves dependency on the dwindling supply of highly skilled welding engineers through automation. Data captured from the welding and inspection process can then be fed back to the manufacturers both as further fine tuning of the welding system but more importantly providing hyper-accurate wear data for each identified part.

3 Ergonomic Considerations in Existing Manual GTAW Processes for Re-manufacturing

If robots are to share the same environment, cooperate and assist in manufacturing tasks by substituting humans, then designing robots based on knowledge of human cognitive processes offers a good starting point. Use of robotics will significantly enhance the product by providing their complementary capabilities dexterity and repetition in an ergonomically efficient and more user-friendly working environment. To begin to understand the environmental constraints, we must first examine the background of the existing hazards in manual GTAW processes. We must then apply these findings to the robotic solution for the re-manufacturing and discuss how these parameters and constraints can be challenged.

3.1 Manual GTAW Welding

Hazard. Manual GTAW welding of aero engine compressor blades can expose workers to prolonged periods sitting down (Fig. 5 shows the manual weld deposition operation). Research has suggested that remaining seated for too long is detrimental

Fig. 5 Photograph of a skilled welding engineer performing a manual weld deposition operation on a compressor blade

to your health, regardless of how much exercise you do. Studies have linked excessive sitting with being overweight and obese, type-2 diabetes, some types of cancer, and premature death. Prolonged periods of sitting are thought to slow the metabolism, which affects the body's ability to regulate blood sugar, blood pressure and break down body fat [1].

Solution. The use of robotic systems for welding operations, removes the necessity for workers to endure prolonged periods sitting down. Furthermore robotic systems are more productive because they can operate in a continuous manner for long periods of time without stopping.

3.2 *Manual Handling of Wire Welding Units*

Hazard. Heavy wire welding units or drums must be either transported or carried to the work location by each worker. The wire unit must then be manually loaded into the machine wire feed or manually mounted onto a spool feed. Electrical cables and welding leads (power, cooling and electrical earth) can become tripping hazards.

Solution. Automatic wire welding and loading units can be attached to the autonomous system eliminating the need for workers to carry and load the wire units. Elimination of tripping hazards is simply achieved by system design. Through enclosing the welding operations in a closed chamber or cell, hazardous trailing electrical cables are eliminated.

3.3 *Wrist Fatigue During Welding*

Hazard. Manual wire welding is a primary element in the re-manufacturing of high value compressor blades. The use of standard right or left handed welding techniques and conventional welding torch design, forces the worker to flex the wrist towards and load the little finger. CTS (Carpal tunnel syndrome) may also be associated with the use of straight welding whips for long periods [2].

Solution. Through use of a 6 DOF articulated robot which is capable of automatic wire feeding and welding allows for autonomous aerospace turbofan compressor blade re-manufacturing. In this manner, the robotic end effector, not the welder's wrist is bent.

3.4 *Contact Burns*

Hazard. Welding engineers involved in the re-manufacturing processes can be subject to sparks and hot metal spatter generated by either a human error or defect in the weld bead. The severity of a burn injury is related to the power of the arc, the distance from the arc, and the duration of exposure.

Solution. The use of a robot arm will remove the welder from risk of burns by eliminating contact with the hot metal and sparks.

3.5 Eye Damage (Arc Eye)

Hazard. The use of high frequency constricted arc welding power supplies to deposit weld beads on aerospace turbofan compressor blades is hazards to human welding engineers. This is because the pulsed and constrained electrical arc technology creates a very intense electrical arc faster than the protective photosensitive (auto dimming) welding lenses or masks used for eye protection can react to the change in brightness.

Solution. Machine vision can operate as stand-alone system feeding information back to the system of a successful or failed output dependent on the criteria specified by the welding engineer throughout a program.

4 Robotics in Re-manufacturing

The remanufacturing industry differs from the Original Equipment (OE) sector. It is primarily a ‘service sector’ and is subject to different market dynamics and regulatory environment. Across the globe, airlines, armed forces, corporations, cargo and charter operators combined, operate over 110,000 aircraft. So whilst in any one year, the world’s aircraft manufacturer’s build about 4500 new airframes, there is a dynamic, operational and service-demanding supply chain keeping 110,000 aircraft flying safely and reliably, wherever they are. Engine overhaul is a huge area of remanufacturing (Fig. 6 shows an overhauled engine), currently work is outsourced to competitive third party bases e.g. Lufthansa Technik and independents like MTU and Vector Aerospace but also includes OEMS such as Rolls-Royce, GE and Pratt & Whitney [3].

Robots have traditionally been used and are well established within manufacturing environments. Generally they are confined to simple pick and place tasks with little decision making autonomy. However, the current trend with newly emerging light-weight and flexible robots is to develop fully autonomous capabilities. Thus, efforts are directed towards the mechanical design of such robots, control and automation techniques, locomotion techniques, intelligence and autonomy. A more specialized market is the operation of robotics. By closing of the loop between the vision system and the robotic welding arm this allows information from the vision system to be used by the robotic arm enabling autonomous operation. For re-manufacturing applications, this represents a significant advancement,

Fig. 6 Manual maintenance, repair and overhaul for aircraft engines

as the robotic system can make decisions based on the information received from the vision system eliminating the need for a human to be involved in the process.

The aim of this specific prototype system will be to detect the incoming parts, assess the shape, profile and type, inspect the condition then move the robotic arm ensuring correct position for the weld to be conducted. This is of critical importance to the aerospace re-manufacturing industry as many parts consist of unique shapes, profiles and sizes. Not only will the automated process result in direct cost savings for industry, when combined with advanced real-time weld monitoring systems it will also allow non-destructive testing and component evaluation for system control during the welding process.

The primary aim of the study is to produce a dynamic, high resolution stereo camera system with area matching software and autofocus capabilities for integration with automated welders. This system will enable real-time monitoring, inspection and repair of high-value aerospace components. Survival of the harsh environment will be a key factor. The system will have adjustable focus through the use of liquid lenses allowing it to be used on different types of materials and be capable of automatically working on different shaped components at different working distances, taking the technology beyond current commercially available systems.

The automated process will result in direct cost savings for industry and it will also allow a non-destructive test of component evaluation for system control during the welding process. The feasibility of this approach carries a high risk with a number of unknowns, including factors such as achieving the required speed in the stereo vision matching algorithm and if the automatic calibration techniques proposed will operate in practice with sufficient accuracy.

5 Modules of the Autonomous Re-manufacturing System to Mirror Human Cognition

The automated system is to be constructed in modules to mirror human cognition which will allow operation of the autonomous re-manufacturing system. Each unit has its own modular capability. The inspection module dictates the automatic loading and unloading of blades, the automatic part recognition, selection of the weld program, weld torch with wire feed and work piece tooling block. The system automatically loads the part into the correct set of tooling, thus different types of blades can be continuously loaded and unloaded via the robot whilst the repair welds are undertaken. Three robust universal weld chill fixtures accommodate different parts to be welded (Fig. 7 shows an early system design). These will require resources including: supporting camera identification system, a profile camera system via imaging software, 3D weld monitoring system and dimensional scan equipment to monitor the weld process. This is later interfaced with the welding machine. A real-time weld evaluation data acquisition (DAQ) system has been developed to measure the HMS InterPulse welding system [4, 5], this FPGA based DAQ system performs both power analysis and arc measurements. This module interfaces with the camera systems and weld controller to provide operator with visual confirmation of faults. Interfacing of the modules with software and development of GUI provides overall system control throughout.

In the following section the main unit modules will be explained. Further adjustments are needed to fully incorporate the ergonomic considerations in existing manual GTAW processes for re-manufacturing, discussed in Sect. 3.

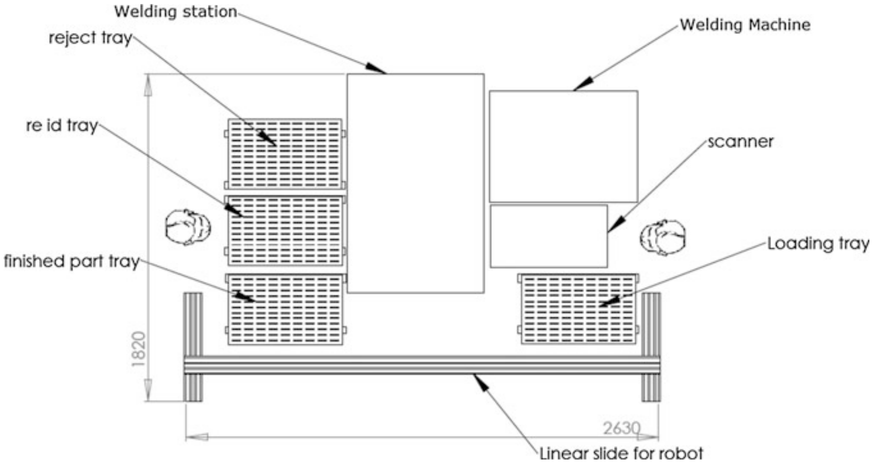

Fig. 7 Modules of the aerospace turbofan engine blade re-manufacturing system

5.1 6 DOF Articulated Robot

A 6 DOF robotic arm with rotating wrist will be use to move parts through the system to the main chassis (welding station) to carry out the welding operations. Modern lightweight and flexible robots carry out automated, repetitive and dangerous tasks with payloads of up to 5 kg. Processes for payloads less than 5 kg, such as picking, placing and testing, lend themselves well to modern lightweight robotic arm design.

With a working radius of up to 850 mm, places everything within reach, freeing up operators' time to add value to other stages of the production. Modern lightweight robots are easy to program, fast to set up, collaborative and safe. Like other similar collaborative robots, they quickly achieve rapid industrial investment payback [6].

5.2 The Machine Vision Sensor

In order to guide the robotic arm a machine vision system with a very high frame rate and analogue camera configuration was considered. The analogue camera captures an image and stores it in its buffer. A signal is issued to the DAQ hardware which reads out the image. The DAQ converts and processes the data, then delivers it to the host PCI bus. The host can then analyse the image. The acquisition can be triggered externally or via the DAQ. High frame rates demand a high speed GPU computing based DAQ in order to process the video information in real-time. First tests performed showed that using single camera stereo was good enough because the pattern was simple and well defined which gives precise and fast measurements despite the use of a low resolution camera.

The use of a laser and optical filters tuned to the specific spectra of the welding power supply's electrical arc was used to reduce the intensity of light allowing image capture under any light conditions.

Key technology developments for engine overhaul are to maximize the productivity of this service network. A machine vision system which is interfaced with a robot effectively provides the "eyes" and cognition for the robot. The machine vision system equipped with the latest 3D algorithms and is able to detect weld defects and cracks and obtain depth information for objects.

5.3 GTAW Welding System

Use of new welding processes and increased use of automation and robotics will take place slowly and gradually, only justified where the introduction creates significant gains in productivity or cost reduction. As such, these changes can be expected particularly in situations where skilled labour is short, where welding cells can be kept fully occupied or when customized, made to order components are needed [7].

Automated repetition of CLAMS data enables production of the correct weld deposition with high repeat ability but with the inability to respond to a change in dynamics or conditions. True response requires intelligence which has proven exceptionally challenging to develop when welding complex profiles (curves) and super alloy materials (heat input and distortion) now utilized by aerospace engine manufacturers with the GTAW technique.

The GTAW welding machine operation involves monitoring signals and generating commands over an interface; these signals are protected against welding current interference by galvanic isolation. Arc current measurements were performed at 46.875 kHz using a bespoke high speed phase current shunt sensor. Signal filtering is performed in real-time and the filter method selected was low-pass.

6 Conclusions

Advanced programming of robots, data interpretation from associated sensory and feedback systems required to mirror human input were considered for the development of a high value intelligent aerospace turbofan jet engine blade re-manufacturing system. Ergonomic considerations in existing manual GTAW processes for re-manufacturing were introduced in the design process, highlighting interaction between robotics and experienced welding engineers, towards construction of an autonomous aerospace turbofan jet engine blade re-manufacturing system.

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Safety System for Industrial Robots to Support Collaboration

Gunnar Bolmsjö, Mattias Bennulf and Xiaoxiao Zhang

Abstract The ongoing trend towards manufacturing of customized products generates an increased demand on highly efficient work methods to manage product variants through flexible automation. Adopting robots for automation is not always feasible in low batch production. However, the combination of humans together with robots performing tasks in collaboration provides a complementary mix of skill and creativity of humans, and precision and strength of robots which support flexible production in small series down to one-off production. Through this, collaboration can be used with implications on reconfiguration and production. In this paper, the focus and study is on designing safety for efficient collaboration operator—robot in selected work task scenarios. The recently published ISO/TS 15066:2016 describing collaboration between operator and robot is in this context an important document for development and implementation of robotic systems designed for collaboration between operator and robot.

Keywords Human-robot interaction · Collaboration · Robot safety

1 Introduction

Industrial robots have been in use for more than five decades and used for a variety of applications. Automotive has been a driver to develop applications from beginning and is still a major industrial sector. Robots are used in repetitive and deterministic operations within production lines or robotic stations in increased

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variety of operations ranging from object manipulation, machine tending and assembly to in process operations such as welding and polishing [1]. These systems usually offer full automation solutions and operate separated from operators providing safe operation. Although robots are characterized by its flexibility, automated production systems are in general not as flexible as expected. To apply automation, work processes must be reasonable simple and consistent, and production volume and batch sizes fairly large. For product variants, processes should be similar as well as products to make efficient use of the same system related to hardware and software, so that task programs and control algorithms can be adapted, if needed, to work with different variants of a product [2]. In addition, resetting of robots and machines should not be too frequent as that will reduce the productivity of the system. If these conditions are present, robotic production systems work excellent if conditions are stable over a long period of time.

An interesting trend is increased automation within customized product manufacturing which put the issue of product variants and low batch sizes into focus. When capability of robots increases, the possibility to automate more operations and tasks will become a reality [3]. This is also the situation with a consumer oriented market pushing product development to more customized products in combination with shorter product life cycles [4]. Making use of robot automation given these requirements put high demand not only on the robot but on the efficiency, simplicity and flexibility to actually deploy and use robots in manufacturing stations and production lines in short batches and low volume production. As a consequence, market oriented competition require more products to be developed and offered in less time than before, and produced for the market with more customizable options. At the same time, new technologies offer new materials to be used in products with new work processes to master in the manufacturing system. Thus, the challenge is on implementation, efficiency to automate and produce products, and also to adapt to new opportunities as they appear. In this context configuration of systems becomes important as well as collaboration between robots to perform tasks in a flexible way [5]. As a result, there is a need to develop work procedures for tasks with a high degree of product variability and related re-setting of robot systems.

Thus, it can be expected that production system of the future will be characterized by a need to produce customized products on order resulting in frequent changeover between products [6]. Such production system is likely to increase in complexity (hardware, software, operation, etc.) and a need for competent operators to solve complex problems on the floor. In order to cope with this situation, the operator should be supported by proper tools which makes the work tasks efficient and manageable [7, 8].

This paper will focus on design of safety system for collaboration and challenges where an operator is needed to work in collaboration with robot(s) to perform the tasks in a highly flexible production system. This is aligned with safety standards ISO 10218-1 and 2 and the newly published ISO/TS 15066 “Collaborative Robots” [9–11]. The baseline for this work has been to identify industrial use cases which has a clear need for automation as well as collaboration between operator(s) and robot(s). For this purpose, demonstrators has been designed and setup in a laboratory environment using industrial equipment but with scaled down work objects.

Even if the concept of collaboration in production has attracted a lot of research, real applications in production using collaborative concept is for most part implemented as demonstrators or pilot cases in industry. For industrial robots, the safety standards and the collaborative capabilities are developing into industrial systems that can be applied today. Examples can be found at many robot manufacturers like ABB Robotics and KUKA Robot Group which have synchronization between robots to perform a common task, such as welding or manipulation. For safety, functions such as "Safe Move" functionality a dedicated safety controller monitors the path and motion of the robot manipulator in time and space. However, the application and actual use of such features for safe collaborative systems is rare and a lot of implementation work is left to the system integrator if the full potential of collaboration is to be explored.

This paper focus on safety system to support collaboration and related challenges. An information infrastructure is described using ROS as a tool for service oriented architecture which facilitate flexibility and reconfiguration. Specific challenges are addressed related to low volume production, such as task programming and supporting tools for the operator [12]. The design and implementation of a safety system which meets current standard as well as flexible production is a challenge.

2 Collaboration

The ISO/TS 15066:2016 supplements the industrial robot safety standards ISO 2018-1 and ISO 10218-2 and provides guidance specifically addressing collaboration. The general meaning and reason to work with collaboration within the context of robots relates to the need and possibility combine the repetitive and controlled performance of robots with the skills and reactive ability of operators. From a general point of view, humans have an outstanding capability to perform tasks in an unstructured and imprecise environment, while robots perform tasks with precision, power and control. Thus, the combination operator–robot is in many cases interesting and opens up new opportunity in tasks and applications which otherwise is not possible to automate by using robots.

Collaboration means to work together in a shared workspace. This calls for specific safety arrangements which not only relate to hardware and software, but other issues such as risk assessment, design of the work station and task to be executed, documentation, training, etc. The general layout of a robot station with a collaboration work space is depicted in Fig. 1 The robot station has protective measures which ensures safe operation in non-collaborative mode using practice of today with fences, light beams, safety PLC, etc. The collaborative workspace is a specific part of the workspace of the robot dedicated to collaboration. As shown in Fig. 1 the workspace is in this case monitored by safety scanners which ensures that

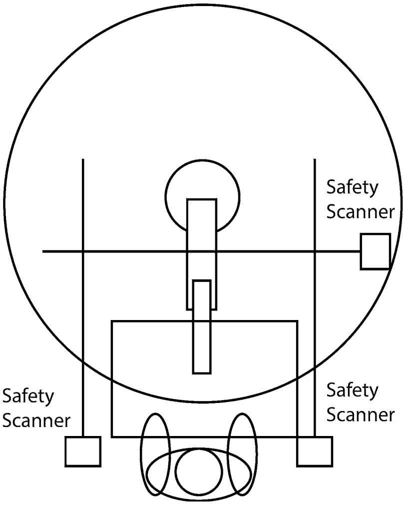

Fig. 1 Robot station with collaborative workspace

no human is entering a part of the workspace which is not belonging to the collaborative workspace. In collaboration mode, robot and operator can work together in close proximity while the robot is under power, including physical contact between the operator and the robot. Safety scanners are not needed to ensure the collaborative workspace from the operation space but provides a flexible way to reconfigure the workspace as found feasible.

During collaboration, different modes of interaction may occur which include direct contact or collaboration when a minimum distance exist. For the collaborative workspace, the priority is to eliminate or reduce hazards or risks which can be foreseen during shared task execution. During this design process the following considerations should be taken:

- Establish limits in space for the collaborative workspace
- Define access and clearance for the collaborative workspace
- Identify ergonomic issues related to human machine interfaces
- Identify limitations in collaboration

For collaboration, special attention should be made related to risk assessment, specifically concerning intended direct contact and potential unintended contact. In this work, a hazard identification should be made which include, but are not limited to, hazards related to robot, robot system and the application and process executed.

An assessment of the risks associated with collaboration should be made related to identified hazards. Principles of this relates to inherently safe design to reduce hazards, protective measures such as limiting speed, limiting forces, stopping contacts, etc., protective equipment, and training support.

Usually, an enabling device is used when entering a robot station during production. In collaborative mode, the operator may need to use both hands and hence, an enabling device may not be included. The collaborative operations can include, but is not limited to, hand guiding and speed separation. Hand guiding allows the operator to guide a work object usually attached to a robot. This can be accomplished through force sensor and controller functions complemented by additional features like allowed movement directions for the intended operation.

Speed and separation monitoring allows the robot and operator to move and work concurrently within the collaborative workspace. The collaboration is based on the principle that a protective separation distance is defined and risk reduction is maintained by securing that this distance is kept during collaboration. If the robot and operator gets closer, the robot system stops. When the distance is above the defined value, meaning the operator has moved away from the robot, the robot system can resume its operation automatically. Based on this principle, the separation distance can be decreased if the speed of the robot system is decreased or alteration of the motion during execution of a task. In collaboration, a variable speed setting is possible and is based on the assumption the system incorporate tracking sensors. Different approaches are being investigated which include predictive analysis of motions of the operator, or finite states of the task to be carried out.

If direct contact is part of the task execution specific consideration should be taken with respect to analyzing hazards and risk reductions. A specific method is to apply power and force limiting during such operations as well as design the work area and task to execute so as to avoid hard edges or clamping and crushing situations.

3 Task Scenarios

Collaboration between operator and robot opens up new opportunities to apply robots in automation. The use of robots in automation are within applications with production volumes and batch sizes which are not disturbed by frequent change over between products. In practice, this means preparation time including programming, deployment and set-up for a product has to be a minor part of the cost and time to produce a product.

However, collaboration introduces operators into the shared workspace and task execution. As discussed in the earlier section, this introduces hazards, risk assessments and risk reduction measures. One important aspect in this concerns the speed of operation. Tasks to be executed in collaboration have to be made in the pace of a human operator, meaning, in most cases, much slower speed than most tasks are operated in using robot alone. Moreover, collaboration will only be considered for tasks which cannot be automated in full by means of robots or other machines, and where the task benefit for being semi-automated by using a collaboration execution mode. In this section, selected task scenarios will be described suitable for early investigation for collaboration.

During an initial study, a demonstrator was setup for robotic handling, nailing and screwing wood structures. In this study, the assumption was related to small series production or even custom products made on order. Although different, the products had similarities and automatic programming techniques could be applied as well as deployment practices by the operator. Based on this work it was concluded that important features in collaboration and safety systems should include:

1. Automatic slow down, stop and ramp up of production
2. Enable collaboration where the operator needs to monitor the task
3. Enable powered static positioning of objects
4. Enable task sharing while both robot and operator is moving

The production efficiency was considered to be important which is why a safety system should have a collaboration feature to detect the presence of an operator, enter collaboration mode, and resume production speed when the operator leaves the collaboration workspace. This gives operator an ability to react on production disturbances in a quick way. Many disturbances are simple issues and fixed within a minute, but stopping a traditional robot system in a safe way is usually complex and take longer time than fixing the actual problem. Hence, an automatic detection which enables the operator to walk in, correct the fault and walk out provides a significant improvement.

An added feature is to allow for monitoring task execution at close proximity in order to verify task execution and quality. In many cases, the operator has to monitor the task based on quality related indicators and adjustments or tuning of control parameters within the task execution has to be made. In other cases, there might be specific quality checks by random or for every product, which include an operator and is hard to automate.

Assembly often includes positioning objects in a static position and orientation. This was the case in construction of family houses where windows with a weight up to 100 kg should be assembled to the wall. Positioning and static holding by a robot is a good example of collaboration where the robot is slow or at zero velocity keeping the position under powered operation. This also address the potential to use one or several robots for collaboration in order to hold and positioning objects while the operator is performing task specific operations, such as assembly, arc welding, etc.

Finally, tasks can be shared while both the robot and the operator is moving. However, this was considered to have the lowest priority based on the assumption that this will result in low productivity and high demand on risk assessment and risk prevention.

Flexible production where batch size is down to lot size one means in reality a new product every time a task program for the robot system is deployed. For this purpose, emphasis must be on simplicity in operation and understanding what the robotic system will produce, how the operation will be performed and what is expected by the operator.

Development of tools which support safe and efficient operator–robot collaboration is an important part to make the transition from high volume manufacturing to customization of products efficient. Some key aspects related to this is the need to make preparation and re-setting efficient when the number of product variants increases, and collaboration during the task execution, if needed.

From an operator point of view, many operations will increase in complexity simply by the fact that more variants are produced and mixed in the production system. Even if the same product type has been produced before, an upgrade of a product may have been implemented and alterations in programs for a robot have been made due to changes of the CAD model by automatic procedures.

This represents a challenge related to collaboration where hazards, risk assessments, risk prevention and measures has to be made to allow for proper task sharing. If preparation time for robots is a critical factor in traditional automation, the risk assessment and prevention measures is an even bigger issue for flexible production and collaboration combined. Work methods must be developed in order to make the analysis of hazards, risk assessment and safety measures efficient, at least for similar tasks.

4 Safety System for Collaboration

Based on the standard ISO 10218-1/2 and ISO/TS 15066 for industrial robots a framework for safe collaboration is developed as a demonstrator in a laboratory setting. The robotic laboratory consist of several ABB industrial robots of which one is equipped with safe move controller, meaning a soft rated supervising system from the robot manufacturer which is capable of supervising the motion of the robot. The parameters for supervision can be defined using RobotStudio, a dedicated software tool from the robot manufacturer to configure, program and simulate ABB robots.

The safety arrangement within the robot laboratory are based on general principles using safety rated equipment with safety PLC and sensors such as light beams and safety rated scanners. Scanners has the advantage to be programmable meaning that they can be used in a more flexible way that a light beam. It is found that scanners are reliable and produce no false alarms detected in our setting, although more expensive than simpler sensors. For collaboration the scanners are used to detect and set the system into a collaborative mode of operation. They also provide means to define the collaborative workspace.

A concern in designing a safety system is its flexibility related to changeover between products being produced. This may in the simple case only affect the robot program, but in more complex situations lead to reconfiguration of the robot station. Thus, different hardware and software components should be easy to connect with a reliable functionality which support the safety system. In our work we use the Robot Operating System (ROS) as a tool to test concepts related to reconfiguration of robot systems and safety related issues presented here.

ROS offers a message delivering interface between different ROS services that are attached on the network. ROS can be installed on Linux, Linux-arm, Android, and other platforms. Programming to develop software components should be done using tools such as Python, C++, Java or Android. By using ROS, the programming is in practice not limited by platforms and languages. As an example, a sensor can publish its sensor values via software components developed in C++ on a Linux platform, and other devices or software components can subscribe on these sensor values developed for an Android platform. The Android programmer do not have to know any details about the source of information and the same for the components on the sensor side which publishes data values. The principle behind this is shown in Fig. 2, where every line represents an interfacing demand. By using ROS as a message interface, we can reduce the complexity in interfacing different devices and software components. Since all the programs are written with the same message standard, it is easier to organize and record data. Furthermore, during developments, programmers only need to know their own part related to the respective device (sensor, robot, etc.), changes and enhancements can be made incrementally as needed.

The general idea behind collaboration is to share common tasks between operator(s) and robot(s). This should also be supported by the information infrastructure in a production setting. Information about the task to be carried out should be present and accessible for the operator as well as data on the fly. Such data could be generated during a task from sensors or software services which are needed to alter the execution of a task. To provide this information and set up a proper information infrastructure, ROS facilitates to provide information from the devices such as sensors to other devices or services in a suitable way as all the information is online in a format which is standardized and readable. Instead of making connection between all devices such as monitoring functions, sensors, etc., we attach all devices to ROS, which reduces and simplifies the number of programs as shown in Fig. 3. An important aspect of this is that fewer safety related software components will be developed as needed, which also can be tested according to specification. For collaboration ROS also simplifies HMI development and the use of different platforms to convey information between an operator and robot. Examples of this include larges screens, wearable devices, etc.

Within the infrastructure of ROS, interconnected devices and software components can be used as services for execution of certain tasks. Through orchestration

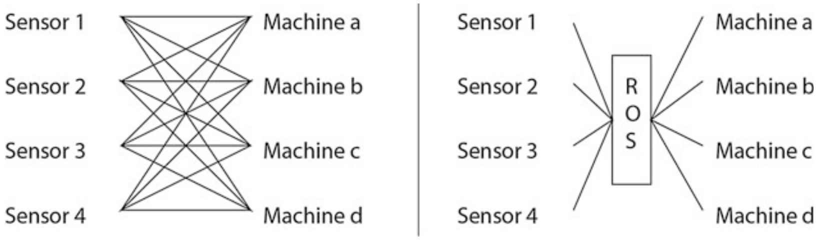

Fig. 2 Interfacing different devices. Using a tool such as ROS facilitates simplicity in configuring a system

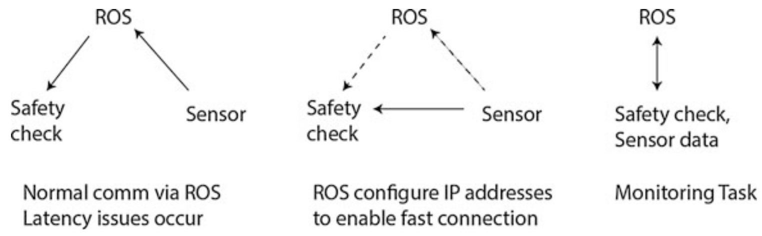

Fig. 3 Information infrastructure combining the standard robot systems with PLCs and ROS

of selecting proper services, tasks can be created through combination of different services to automate a task, automatic programming or alter generated tasks.

PLC is commonly used in robot cells to read sensors and handling communication between robots and equipment in the robot system. In a larger system comprising several robots, as in our robotic lab, a master PLC is used to manage the whole system and communication between different PLCs. To adapt service oriented architecture (SOA) to this system we can consider this production line with robots and PLCs connected as one larger production system. Our approach is that a ROS server should be connected to this larger system through the master PLC using an interface to a standard Modbus on the PLC side. This makes it possible to get status and values about the process in the production line without changing the design of the robot systems or other parts of the production line. A ROS service could also send information to the master PLC to change the production within the limits given by the system. In this way we can add a SOA to an existing production line without changing existing practice of programming robot cells.

In collaboration between operator and robot, a shared workspace will be present. To design a safety system which comply with current safety standards we use the option to change the operating speed of the robot during collaboration as this makes it possible to work close to the robot without stopping, depending on results from a risk analysis. For this, different sensors are used to monitor and track humans. A ROS service called "safety" compare the human position from the service "Vision" with position of the robot to determine a safe velocity for the robot. The robot position can be collected directly from the robot controller. The communication with the robot controller is made through an API from the robot manufacturer. To make the "Vision" as a service in the system it is connected to the ROS server. This make it possible to be used by any service in the system besides the safety related functions.

From a safety system point of view, it is not desirable to communicate through ROS directly because of time delays. To reduce time delays ROS would only provide current and up to date information how to access devices and information such as IP addresses or port numbers to the relevant services. This is managed by a query service which requests the information needed for the safety system used in collaboration mode. In this way the structure of service oriented architecture is kept as is, but also allows special demands such as streaming data. This method is

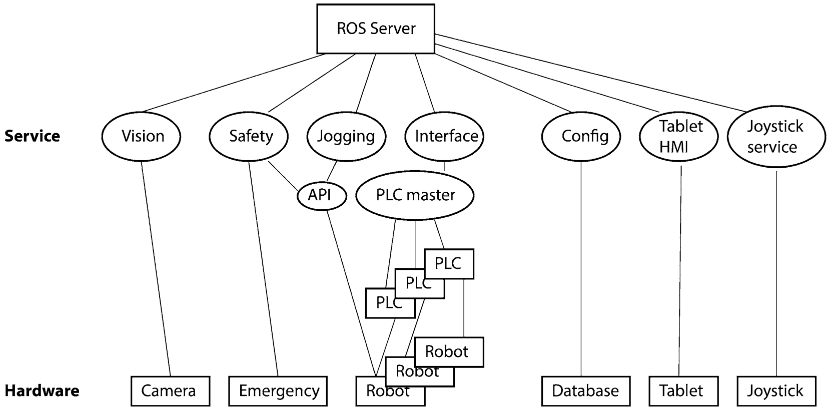

Fig. 4 Configuration information through ROS to enable direct fast data connection for safety related data

showed in Fig. 4 which indicates information flow directly between devices and service components from an initialization and configuration routine in the ROS server.

The ROS server is empty when started, so a configuration is necessary for the production line which is stored in a database. This also facilitates for reconfiguration as necessary. The configuration is currently managed manual through a web based HMI which is a ROS service "config". However, the structure allows for automatic reconfiguration at a later stage. Another important configuration is relationships. If we have several tablet computer with the same software, the configuration could define which tablet belong to which person. In this way we make it possible to collect several items in the system and bind them to one person. It also make it possible to get an overview of the entire system. A service could use this information to create a virtual version of the factory.

For the collaboration study, a combination of RGB-D camera and Beacon detector has been used. The idea behind the chosen combination of sensors was to find a solution on the problem to localize an operator within the collaborative workspace and also include a sensor which relates to an individual which is authorized to be within the collaborative workspace. The Beacon is a small tag which represents a wearable sensor and identifies the operator. The Beacon detector should be installed in a way to detect any tag (meaning operator) within the collaborative workspace. In practice, it covers the workspace including most of the workspace within the robot station. A depth camera of a Kinect type, RGB-D, is used to detect and track an operator and publishes the localization data. A Beacon detector publishes beacon signals to ROS. The Beacon detector software runs on a raspberry pi computer written in python in the experimental setup. A dedicated software analysis the location and beacon signals and publishes the results who and where the person is. Any devices attached on ROS is able to listen to data within the ROS server, such as the presence and localization of an operator within the

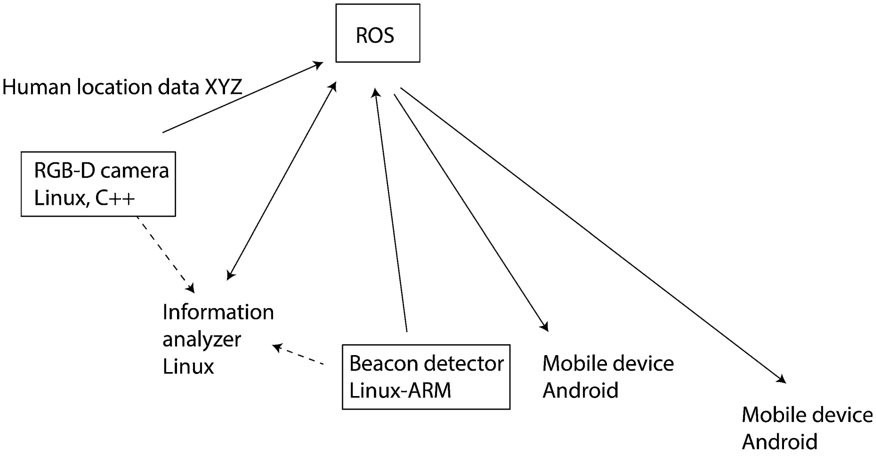

Fig. 5 Principles of interconnection between services to track, localize, detect and identify an operator within the collaborative workspace. Sensors used are RGB-D camera and Beacon detector

collaborative workspace. Such devices can be optimized to convey dedicated information, but in our setup tests have been made with Android tablets and phones. In such case, the data can be used as a graphical representation of an active collaborative workspace including the localization of the operator, and identity of that person. If identity is uncertain, the information will call for an error code during collaboration, which means to stop the operation of the robot. The principle for services and information structure is depicted in Fig. 5.

5 Discussion and Future Work

Collaboration means to share a common workspace between an operator and robot. To address this, a new technical specification ISO/TS 15066 has been published which, based on existing safety standards for robots and robotic systems provides a guideline to design and operate robot systems for collaboration. As described in this paper, work is ongoing in this area but the nature of collaboration in real life application put specific challenges on task sharing. In our work we have previously looked into the issue of how and when to apply collaboration. Not surprisingly, collaboration was of importance to overcome situations where automation was difficult to apply and a semi-automated approach was found feasible. In addition, production volume is low and frequent change over between products. Although products and process to be executed are similar for a selected robot station, this is in opposition to common practice to use robots in automation and specifically related to risk assessment and measures to prevent hazards. A system integrator is usually responsible for designing the whole system including the safety system. This again limits the use of robots in highly flexible systems where safety and hazards has to be analyzed in time consuming processes for each product. In many cases it is stated that specific safety related issues should be analyzed or assessed by the system integrator. However, to enable flexible production, reconfiguration of systems must be common practice, either by automatic methods or supported by staff on-site.

In order to apply collaboration the safety system has to be designed to take reconfiguration into account. Our approach is to work with existing practice in setting up robot systems, either as stand-alone robots or in a production line, using PLCs for each station and a master PLC, as needed. To enable reconfiguration a ROS server is used to manage services attached, as well as devices such as sensors publishing data and software components which produce specific analysis based on subscribed data within the system. This structure enables services to be used in a flexible way for different tasks. However, it was identified that for safety, latency has to be minimized as well as reduced possibility for overloading if safety related data is managed by ROS. For this purpose, ROS is managing the current configuration of the different services and devices and provides up to date configuration. Using this information, the safety system can create direct communication between software services which uses specific hardware such as sensors, and up to date configuration and status from ROS.

A demonstrator robot station is set up as a demonstrator and task scenarios as described in this paper. To apply collaboration in flexible production it is important to develop methods related to the work flow of the tasks to be carried out. Our approach is to develop automatic methods in order to minimize possible errors produced by manual written code or subjective judgements related to hazards and measures to minimize risks. Hence, tools should be developed to analyze tasks and indicate possible hazards. These could include motions which include high accelerations on servo drives, usually related to close to singularity areas, configuration changes, possible clamping or crushing between robot, work object and work table during collaboration. Another issues relates to information and HMI for the operator to properly understand the task to be carried out in collaborative mode, especially if this is done only once.

Safety system which support collaboration is a demanding challenge, specifically if this will be applied in flexible production with frequent change-over and reconfiguration of the robot system. The development of a safety system described in this paper address the configuration aspect where different components within the system can interconnect via a ROS server, as well as create direct connection links to reduce latency issues while sending information between sensors and service applications.

To summarize, to make collaboration feasible in real production settings, the steps taken here is to design a service based infrastructure which allow for flexibility in configuring the data flow as well as automate generation of software components related to safety. However, it is recognized that collaboration should be implemented on an incremental basis, introducing simple collaboration mode with few hazards identified in the first place to validate the functionality. In this context, research will be needed to fully make use of collaboration in truly one-off production where the robot is acting as a co-worker together with a human.

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Current Challenges for UX Evaluation of Human-Robot Interaction

Jessica Lindblom and Rebecca Andreasson

Abstract The development of socially interactive robots is expected to have an increasing importance in everyday life for a growing number of people. For social robots to provide long-term added value to people's lives, it is of major importance to stress the need for developing a positive user experience (UX). The human-centered view emphasizes various aspects including acceptance, usability, and credibility, as they emerge in the interaction between humans and robots. In current human-robot interaction (HRI) research, UX is reckoned to be important, but is often taken for granted. However, a positive user experience does not appear by itself but has to be systematically designed and evaluated. In this paper, we focus on the role and relevance of UX in HRI and present three challenges related to the evaluation of UX in interaction with robots, addressing the need for interdisciplinary research in order to achieve long-term success of socially interactive robots.

Keywords Human-robot interaction · User experience · Evaluation methods · Hedonic qualities · Pragmatic qualities · Human-computer interaction

1 Introduction

The recent and rapid development of autonomous technology emphasizes the importance of considering various aspects of human-robot interaction from a human-centered perspective. Taking on the human-centered view, stressing the importance of creating a positive user experience in the study of human interaction with robots, is of major concern in order for technology to provide a long-term added value to people's lives [1]. Consequently, many evaluation methods and techniques have been developed [e.g. 2]. This clearly highlights the importance of

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evaluating the quality of the interaction. This results in evaluations of different aspects; including acceptance, usability, learnability, safety, trust, and credibility. While some of the aspects are covered in depth, some are just briefly touched upon in human-robot interaction (HRI) research.

Lately there has been an increased number of socially interactive robots in human environments and furthermore, their level of participation in everyday activities are becoming more sophisticated [e.g. 1, 3]. The field of HRI is a young but growing research field that is facing several challenges. For example, there is a need to build a foundation of theories, models, methods, and tools. There is a particular need for new evaluation techniques and useful inspiration can be derived from the fields of human-computer interaction (HCI) and user experience (UX) [1]. In this paper, we argue that a good way to proceed is to adopt existing techniques from HCI and UX, and use these appropriately adapted to HRI.

Robot developers sometimes create their own evaluation methods without sufficient knowledge of appropriate methodologies, resulting in questionable validity and reliability of these so called "quick and dirty" methods [4]. The aim of this paper is to disentangle several issues related to the evaluation of social human-robot interaction and we present three challenges for the effective incorporation of UX evaluation in HRI. In doing so, we highlight the need for HRI evaluation methods that have methodological validity and reliability as well as practical applicability. We advocate an interdisciplinary approach in HRI that may in the long run improve the societal impact of social robots.

2 HRI and Social Robots

HRI is a relatively new and growing research field that is concerned with the ways humans might work, play and interact with different kinds of robots. According to Dautenhahn and Saunders [5], there are several disciplines that contribute to HRI and bring different views and approaches to the field. They argue that it would be beneficial to consider and incorporate research from a wider outlook that may challenge and enhance existing frameworks and embark on new frontiers in HRI. More specifically, Dautenhahn [6] emphasizes that useful inspiration can be derived from the study of HCI and UX, particularly methods and techniques for designing and evaluating various aspects of human-robot interaction. According to Dautenhahn et al. [7], the key challenge and characterization of HRI can be phrased as follows:

HRI is the science of studying people's behavior and attitudes towards robots in relationship to the physical, technological and interactive features of the robots, with the goal to develop robots that facilitate the emergence of human-robot interactions that are at the same time efficient (according to the original requirements of their envisaged area of use), but are also acceptable to people, and meet the social and emotional needs of their individual users as well as respecting human values.

Robotic technologies can be grouped into three main categories based on their area of application: industrial robotics, professional service robotics, and personal service robotics [3]. Industrial robots and professional service robots both manipulate their physical environment. While the first is strictly computer controlled, and operates in industrial settings, the second mainly functions outside industrial settings and provides assistance for example by cleaning up nuclear waste [8] or inspecting abandoned mines [9]. Out of the three categories, the personal service robots have the highest expected growth rate in society. These robots assist or entertain people in domestic settings and examples include robotic vacuum cleaners, receptionists, and robot assistants in elderly care and in therapy [3].

The development from industrial robots to robots operating in the same physical and social spaces as humans puts higher demands on the quality of the interaction between the human and the robot. In the past, issues related to the autonomy of robots have focused on safe interaction with the material environment, but the growth in the area of personal robots that act in human environments results in robots that to a larger extent need to act in relation to social and emotional aspects of interaction.

Socially interactive robots are defined as "robots for which social interaction plays a key role" [10, p. 145]. They should display social intelligence, i.e. qualities that reflect human social expressions, such as emotional appearance and perception, advanced dialogue capabilities, and be able to make use of gaze and gesture as part of communication [10]. When it comes to social interaction with robots, HRI research can be categorized into three different approaches: robot-centered HRI, robot cognition-centered HRI, and human-centered HRI [1] (see Fig. 1). While robot-centered HRI views the robot as an autonomous entity and the human as the robot's "caretaker" who should identify and respond to the needs of the robot, robot-cognition HRI views the robot as an intelligent system and the fundamental problem is to provide these robots with a cognitive capacity. In the human-centered HRI, the human perspective is emphasized and issues related to design of robot behavior that is comfortable for humans are included in this approach. This

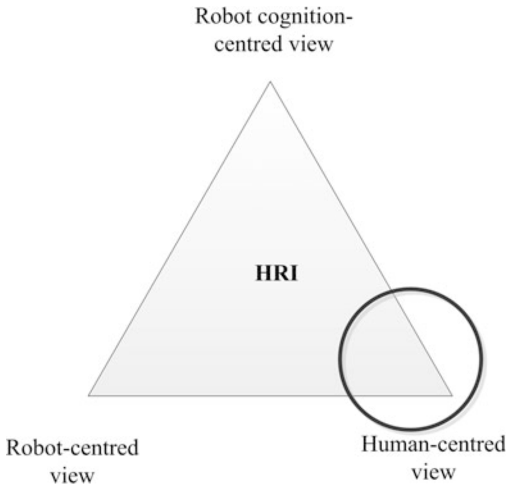

Fig. 1 The conceptual space of approaches for social interaction in HRI research (modified from [1, p. 685])

involves acceptability and believability, as well as humans' expectations of, attitudes towards, and perceptions of robots [1]. In order to get robots to "inhabit our living environments", the three approaches need to be synthesized to enhance social interaction [1]. However, historically human-centered HRI has not received as much attention as the other two approaches.

Recently, however, different aspects related to the emotional quality of the interaction have been addressed in the HRI literature, including engagement, safety, intentions, acceptance, cooperation, emotional response, likeability, and animacy. However, user experience has largely been omitted. This is the topic to which we now turn.

3 User Experience (UX)

Broadly speaking, UX addresses the feelings created and shaped by the use of technology and how technology can be designed to create a user experience that evolves the required feeling [e.g. 11, 12]. As pointed out by Hassenzahl and Tractinsky [13], UX has become a buzzword in the area of HCI and related fields as a result of more mature advanced technology that allows for more interactive products, beyond the functional capabilities that are necessary but not sufficient for high quality technology use. Since the inception of the term in the mid-1990s, the notion of UX has been embraced by both practitioners and researchers because it offers a possible alternative to the more traditional and instrumental HCI. However, many researchers and practitioners use and apply the UX concept in a loose and poorly understood manner with negative consequences. While UX is hard to characterize, it can be viewed as: "the totality of the effect or effects felt by a user as a result of interaction with, and the usage context of, a system, device, or product, including the influence of usability, usefulness, and emotional impact during interaction and savoring memory after interaction" [11, p. 5]. This is consistent with the ISO defining UX as: "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" [14]. In effect, UX is an umbrella term that embraces the totally of the user's emotions, beliefs, preferences, perceptions, and accomplishments, that emerge before, during, and after technology use in a certain situation.

Hassenzahl and Tractinsky [13], among others, differentiate between pragmatic and hedonic aspects of interactive products. Pragmatic aspects relate to the usability component of UX and have their roots in HCI. These aspects include effectiveness, efficiency, satisfaction, ease-of-use, and learnability. Usability is defined in ISO 9241-11 as follows: "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [15]. It should be stressed that usability relates to the outcome of interacting with a system and as defined in the ISO standard, usability is not an attribute of a system although appropriate attributes of the system can contribute to being usable in a particular context of use.

Hedonic aspects relate to component of UX beyond the instrumental aspects addressed in HCI. The hedonic aspects are usually portrayed as the emotional impact that emerges when the user interacts with the system [11]. Negative UX can have its cause in poor interface design or a perceived lack of functionality, resulting in a negative emotional experience during interaction with the system. Hassenzahl and Roto [16] suggest an alternative characterization of both the pragmatic and hedonic aspects, differentiating between the functional view of usability and the phenomenological view of emotional impact. They argue that humans have and use technology because they have tasks to accomplish, e.g. write texts, make phone calls, organize agendas, or search for information. They refer to this as "do goals". These can be evaluated by usability aspects and they correlate with the pragmatic quality of the interaction with the system. Beyond these "do goals", humans have psychological and emotional needs, e.g. personal goals, staying socially connected to others, being satisfied and have quality of life. They refer to this as "be goals". These can be evaluated by emotional impact and phenomenological assessments of the hedonic quality. Accordingly, the positive expectations when a new, cool, high-tech system is launched can very quickly shift from amazement to annoyance if the usage of the technology fails, since high-tech is not a causative factor of positive UX [11]. Thus, positive UX is not built in the product itself. Instead, it is an outcome of the interaction that depends on the internal state of the user, the quality and attributes of the product, and the particular situation [11, 13]. It is not possible to guarantee a certain UX since it is the subjective feelings of a user. Therefore, good user experience is difficult to define but easy to identify [17]. Nonetheless, by designing a high quality interaction with the intended users and the usage context in mind, it is possible to have a positive impact on the experience.

The UX design cycle is iterative and consists of the four key elements of UX activities; analyze, design, implement, and evaluate that Hartson and Pyla [11] describe as the "UX wheel". Briefly stated, "analyze" refers to understanding the users' work and needs. "Design" refers to creating conceptual design ideas and the fundamental "look and feel" of the interaction between the user and the intended product. "Implementation" refers to the more detailed interaction situations with the use of different kinds of product prototypes, which vary from low fidelity to high fidelity of details. Finally, "evaluation" refers to the different methods and techniques that can be used to investigate and analyze to what extent the proposed design meet the users' needs, requirements, and expectations. The whole "wheel" corresponds to an iterative UX lifecycle that is accompanied by defined UX goals.

4 Role and Relevance of UX in HRI

It is becoming increasingly important to design technologies that ensure the interaction is experienced by the user as not only acceptable and safe, but also as positive. Just as with all interactive systems, positive UX is necessary for robots to achieve the intended benefits. If the user experiences the interaction with the robot as negative, the consequence might be reluctance to interact with robots, which in turn may inhibit the acceptance of future robotic technologies [18]. Positive user experience underpins the proliferation of social robots in society. A positive user experience does not appear by itself but has to be systematically designed and evaluated [11, 12] and, therefore, the UX of social robots needs to be a central issue of concern when developing these kinds of robots.

As pointed out by Alenljung and Lindblom [19], there are four trends in HRI research concerning the role and relevance of UX related to socially interactive robots.

- UX is reckoned to be of major importance and is used as an argument for stating that something is positive. Examples of this tendency can be found in [20–23]. Accordingly, user experience is used as a catchphrase for highlighting that certain aspects have to be studied or to what degree a specific feature has a positive impact on the users' experience of the robot system.
- UX is often treated superficially and its deeper aspects are seldom addressed in HRI research [e.g. 24–27]. Unless UX is problematized—unpacking it to expose its many complex facets—there is a significant risk of reducing the validity of the outcome of the design if the complexity is not properly considered. That is, the robot will fail to deliver the desired user experience.
- UX aspects are often omitted in favor of studying robot-related aspects, i.e. how the robot as such affects the user instead of studying the interaction between the two [e.g. 20, 28–30]. It should be noted, however, that if such studies do not address the many facets of user experience, the outcome may be less useful than it otherwise could be. Hence, the recognition of the complexity of UX may contribute to more valuable research results.
- UX evaluation is of major importance although the investigations often are conducted after the actual interaction, making the subjects reflect on their experience afterwards, at the very end of the study, which might bias their responses [e.g. 2, 31–34].

There is a need for more theoretical as well as methodological knowledge about methods and techniques that are appropriate for evaluating UX in HRI. As pointed out by Bartneck et al. [4], many robot developers are unaware of the extensive knowledge about methodologies and techniques for studying various aspects of human cognition, and therefore sometimes run rather naïve user studies and experiments to verify their robot design. Although unwinding the many interdependent factors in UX is an essential step in the right direction, we want to address the need for conducting valid usability and UX studies in order to exploit UX to its full effect and to improve positive UX of socially interactive robots. HRI research faces complex challenges which do not have easy solutions. We will address these challenges in the next section, but here we note that these challenges can be met by drawing on the fields of HCI and UX, for example with design processes, theories, models, methods, tools, and evaluation approaches that may provide starting points for the design, analysis, and evaluation of HRI studies.

5 Challenges Related to Evaluation of UX in HRI

We identify three major challenges which, if met, will result in a better, broader understanding of UX evaluation. The list is not exhaustive, but provides a useful starting point in order to close the gap between the different approaches to social interaction in HRI identified by Dautenhahn [1] (see Fig. 1). A truly interdisciplinary perspective will require researchers to adopt a wider set of concepts, theories, and methods in their own research, which implies the need to read a broader spectrum of literature as well as correctly applying the methods in practice.

The *first challenge* is the need to adopt an iterative UX design process in HRI. This poses a dilemma because of the high cost of rapid prototyping in robotics. From the robot developers' perspective, Lohse et al. [35], for example, emphasize that long-term studies in HRI are mostly exploratory and they argue that iterative design is necessary to optimize the robot behaviors. They identify some reasons for the lack of iterative design approaches in HRI when they conducted such a process themselves. For example, given that robots act autonomously, the interactions with the users may vary from trial to trial depending on the circumstances. Furthermore, Lohse et al. [35] highlight that robots are the result of an engineering process that include a large number of hardware and software components integrating aspects from various research areas such as navigation, social perception, computer vision, and cognitive modelling of social skills. This further mitigates against an iterative process. A related issue is what the authors refer to as 'reusability', i.e. enabling easy integration of different software frameworks between different robotic platforms. While the work of Lohse et al. [35] seems to be from a human-centered perspective, they primarily view robotic developers as users rather than the targeted end-users. Due to the high cost of rapid prototyping in robotics, iterative work is rarely compatible to the UX view on iterative design.

The *second challenge* is the need to incorporate UX goals to ensure positive UX. A positive user experience does not appear by itself but has to be systematically designed and evaluated. Hartson and Pyla [11], among others, point out that defining UX goals is a key part for working correctly throughout the UX design cycle. UX goals are high-level objectives, which should be driven by representative use of a system and should identify what is important to the users, stated in terms of anticipated UX of an interaction design. The UX goals are expressed as desired effects, e.g. ease-of-use, learnability, acceptance, and emotional arousal [11]. Unfortunately, the fundamental activity of specifying relevant UX goals is often overlooked in HRI, either because of lack of knowledge or because of lack of time. This can diminish the potential of what can be accomplished during UX evaluation. In order to evaluate UX optimally and reflect upon the obtained evaluation results, it is essential to identify specified UX goals which can be used as evaluation criteria. It should be noted, however, that stating UX goals is not the same as assessing the robot's behavior and functionality. Instead, UX goals focus on the interaction quality between the human and the robot. Furthermore, UX goals offer support throughout the development lifecycle by defining quantitative and qualitative metrics, which provides the basis for knowing when the required quality of interaction has been achieved. During the UX design cycle, it is possible to conduct both formative and summative evaluations.[1] By performing several formative evaluations during the iterative design process, it may be possible to compare and contrast the evaluation results obtained during the whole development process (for more details, see [11]).

The *third challenge* is the need for robot developers to acquire knowledge about proper UX evaluation, in theory and in practice [36]. Although these techniques arrive from other fields, e.g. HCI, cognitive psychology, artificial intelligence, and human factors, it should be noted that the methods need to be adapted and modified in order to suit UX evaluations in HRI, such as those reported by Young et al. [37] and Weiss et al. [2]. Young et al. [37] present an appropriate framework for evaluating UX holistically since it emphasizes the importance of the hedonistic qualities of UX. However, it lacks concrete guidelines on which methods are appropriate and how they should be applied in practice. The framework provides a UX lens rather than concrete guidelines for the evaluation of a positive UX. The USUS framework developed by Weiss et al. [2] provides a promising, comprehensive and holistic view of the aspects that can affect both usability and UX in HRI. In contrast to the framework developed by Young et al. [37], USUS provides instructions on the methods and techniques that are appropriate to use when evaluating single aspects of HRI. Their detailed descriptions of what and how to evaluate provide clear guidance on which evaluation method is suitable for evaluating certain usability and UX aspects that are useful for both experts and novices. It also provides the possibility of easy extension to include other relevant methods or techniques depending of what needs to be evaluated. One disadvantage of USUS is that it may be too time consuming to apply if all usability and UX factors that are included in the framework are to be evaluated. Another disadvantage relates to the fact that the USUS framework does not explicitly address the need to specify UX goals. This is a major shortcoming although it would not be difficult to modify and develop the framework to address these identified deficiencies.

Many of the available methods and techniques for evaluating UX in HRI have roots in HCI but are modified or adjusted to better fit the pragmatic and hedonic requirements. Commonly used evaluation methods in HRI include scenario-based evaluations, questionnaires, interviews, Wizard of OZ, focus groups, expert evaluations, and physiological measurements. Many of these methods and techniques are often applied without first-hand experience of the interaction situation and they often are conducted afterwards. This might bias the validity of the conclusions. The interpretation of the physiological measurements poses problems because you cannot be sure that what is being measured is causatively connected with what is being assessed, e.g. pupil dilation can indicate many different things [2]. Another related aspect is the possible gap between the objectives and principle of different

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[1] Briefly stated, formative evaluation is typically performed during the early development of a system, while summative evaluation is performed at the end of a design process.

methods and their practical application. This creates a risk for misunderstanding the factors evaluated, resulting in biased outcomes. There are two aspects of this: on the one hand, the evaluator needs to have a proper knowledge and understanding about the method and its intended use. On the other hand, the participants in the UX study need to have an understanding of the criteria they are evaluating. This undermines that each evaluation method or technique, no matter how trusted, needs to be regularly assessed to ensure validity and reliability, irrespective of whether hedonic or pragmatic qualities are being evaluated.

6 Summary

The purpose of this paper has been to address the role and relevance of incorporating UX methods and techniques in HRI, resulting in an increased knowledge of how to successfully evaluate user experience of social robots. We have identified three challenges highlighting the need to adopt an iterative UX design process, to incorporate UX goals to ensure positive UX, and to acquire an understanding of how to apply UX evaluation principles in theory and in practice. The third challenge should not be underestimated: the sophistication of UX methodologies is often overlooked by HRI researchers and their full power goes untapped. By employing the various methods and techniques in HCI and UX evaluation, we can narrow the gap and synthesize the different approaches to social interaction in HRI identified by Dautenhahn [1] (see Fig. 1).

If the issues and the challenges that we have raised in this paper are addressed, and we believe that they can be, there is great reason to be optimistic that what we know from UX can be successfully applied to HRI. As a result, HRI will benefit and the users of robots will benefit even more.

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Assistance Systems in Manufacturing: A Systematic Review

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Abstract With this paper we provide an overview of current trends and approaches related to assistance systems in industrial manufacturing contexts. We systematically reviewed publications relevant to the domain in order to extract and describe recent developments and application scenarios. Further, we took account of current use cases, technologies, and design strategies. Having laid out the state of the art we proceeded to identify current challenges for assistive technology in the realm of industrial production. We concluded with discussing the findings and giving an outlook regarding future research questions and possible developments.

Keywords Human factors · Human-system integration · Assistance systems · Smart factory · Virtual reality · Augmented reality · Tangible user interfaces · Smart environments · Augmented workplaces · Industrialization 4.0 · Adaptive systems

1 Introduction

Current production systems are characterized by a very high degree of automation [1]. However, with shorter product lifecycles and increasing need for product variations, a full automation of all production processes seems to be not feasible. The need for product variations and production strategies such as "build-to-order" and "design-to-order", used by many companies, have actually increased the need for human operations [2]. At the same time, the advancement of technology, such as Augmented Reality technology (AR) has tremendously enhanced the perception of factory workers by providing an interface that augments the worker's field of view

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[3]. Research has already shown that there is a large potential for the application of AR technology in production environment (see, e.g. [4–6] or [7]). These technologies could help to assist human operators in processing and handling large and complex systems in manufacturing contexts.

Consequently, we observed a growing need for adaptive and flexible assistance systems that support production workers to master the rising demand of customization and enable the systems for the support of manual workers to guide them through the process of manufacturing [2, 8]. These "smart" and multimodal assistance systems use sensors embedded in the production facilities and products to capture real time contextual information and provide individualized process support. Within the broad context of manufacturing, intelligent systems are applied to several areas such as assembly and dismantling, information management, training and inspection [3]. Most of the assistance systems proposed are based on augmented reality technology and often rely on sensory inputs, such as motion recognition or depth monitoring.

With this paper we seek to provide an overview of current trends and developments regarding adaptive assistance systems in manufacturing contexts. We looked for major design principles used in these systems and identified challenges they currently face. Finally, a discussion around possible future research directions for intelligent and assistance systems is provided in the end.

2 Application Areas for Assistance Systems

In a first step we reviewed the literature focusing on areas within the domain of industrial manufacturing where Assistance Systems are employed. A useful classification can be found in [3] so that we further investigated some of these areas.

2.1 Assembly and Dismantling

Assistive systems can be seen at many assembly lines where human operators receive live information from the system while working on assembly tasks. There are factories where operators make use of light barriers to identify the correct container to pick, this is known as "pick-by-light" [2]. Also, real-time assembly line visualization on computers is made possible by utilizing motion recognition technology in assistive systems. At the same time, assembly speed could also be easily calculated using the concept of "trigger areas" [2]. Another relatively new application approach has been around assembly design assisted by AR technologies. Researches have shown that AR environment could be useful even in the early design stage of assembly by improving both the workflow structure and the efficiency [9].

2.2 Information Management

With the help of AR technologies, it is possible to collect critical data directly from built-in sensors. This also allows for the worker to receive just-in-time support in terms of data visualization that is useful for the work at hand [3]. The usage of AR-based assistive system also allows the workers to be free from reading up physical manuals or guidelines while performing the task since this information could be stored in the database and strategically displayed into the workers' field of view through AR technology [10].

2.3 Training and Inspection

AR-based assistive systems can also be seen in industrial training environments. They are adopted in order to boost productivity as well as effectiveness of training. In their work, Lin et al. [11] have described one of the early approaches and architecture frameworks for establishing an environment of production training based on AR technology. They have demonstrated the feasibility as well as effectiveness of such training environments while Stadtler and Wiedenmaier highlight that such an environment does not present the same level of feedback one would receive from non-virtual environment [12]. Assistive systems also play a role in quality assurance in manufacturing lines. In their work, Zhou et al. [10] explained how spatially augmented reality technology could enhance the effectiveness and efficiency of the spot welding inspection process in automobile manufacturing.

3 Approaches for Developing Assistance Systems

3.1 Human Factors

To ensure a high usability and performance, the assistive system also needs to be designed in accordance to human factor engineering principles [13–15]. Among others, following an ergonomic design is imperative to HMDs, as it affects the success and acceptance of these displays [14, 16, 17]. In one of the studies done by Edelmann et al., they found that although there is no short term effect on visual acuity by wearing HMDs, most of the subjects did report an impairment of well-being [18]. This might be due to three problems identified by Reuss and Menozzi [19].

- *Accommodation Problem.* To avoid users incapable of accommodating when HMD's viewing distance is different from the subject, HMDs need to have flexible or adjustable viewing distance.
- *Navigation Performance.* The performance, defined as the average time to hit a target, is significantly affected when comparing HMDs and desktop

configurations. Assistive systems need to evaluate their designs through benchmarking navigation performance.
- *Display Units Resolution.* Display units available in the market have low resolution compared to human factor requirements and this affects the display quality as well as quality of receiving information.

As for HMDs, more ergonomic principles need to be followed in order to ensure maximum usability of the device. The device that is mounted on the user needs to be small and not obstructing user's movement. Also, it needs to be placed securely on the user so that it withstands any physical movement without falling off the original position. Lastly, the problem that these display units are causing eye strain on the user needs to be addressed [19].

3.2 Relevant Technologies Enabling Assistive Systems

Head-Mounted Displays (HMD). Head-mounted Displays (HMD). HMD, sometimes also referred to as Head-up Display (HUD), is one of the key technology enabler of AR application. As the name suggests, such device is usually worn by the user on the head and allow the user to superimpose physical environment with virtual information [20]. According to Schreiber, HMD could be classified according to their method of image creation, namely Optical-See-Through systems and Video-See-Through systems [20].

Projection. The use of projection is also becoming widely common as an integral part of smart environments in general [21–25] and manufacturing and production settings in particular [26]. Such a system, driven by software or camera, allows users to see and interact with the information, objects or images projected onto various kinds of surfaces [26]. Zhou et al. describes a spatial augmented reality system that employs data projector to project virtual images onto physical environment [27]. In another system whereby user is able define their own tangible controls, projector is also used as the primary technology for displaying digital information onto physical spaces [5].

3.3 Strategies for Interacting with Assistive Systems

Augmented Reality (AR). AR is a relatively new and advanced human-machine interface [26]. Such an interface allows computer-generated/virtual objects to be displayed on objects of the real environment through enabling technologies [20]. User-facing display. An order picking system that is assisted by cart-mounted display is analyzed and compared with other order picking methods such as pick-by-light and pick-by-paper [28]. Overlaid display. An example of overlaid display is an order picking system that is assisted by HUD. Relevant information is displayed directly onto the field of view of the user [28]. Spatial AR (SAR). SAR is different from many attached AR technologies, it makes use of projector technology to project data information directly onto physical surfaces, and users can view and interact with information being displayed in the physical space. One of the applications is in automotive spot welding inspection [27].

Tangible User Interfaces (TUI). Prominent types of user interfaces are tangible user interfaces (TUI) [27, 29–32]. They make use of projection, motion detection and depth sensors to superimpose virtual reality information onto physical objects. In one type of TUI, user-defined TUI, the user is able to define his or her own physical control and connect it to pre-defined "digital functions" [33].

Motion Recognition. The most commonly used sensory input in a smart system setup is motion recognition technology. It is used to recognize user's physical movement and enable natural interaction with the system [34, 35]. Motion recognition technology usually consists of hardware and software. The hardware is the actual sensor in the physical space, responsible for collecting information, whereas software is a software program pre-installed in a PC, responsible for storing and processing information collected. Pairing the hardware with motion recognition software, it is able to create a live feed of what is going on in the plant and measure the speed of each station [2]. In an augmented workplace set up by Funk et al. [33], Kinect and Leap Motion sensors were used to track user input through hand movements and gestures by understanding both 2D-touch interaction and depth changes. The Kinect system developed by Microsoft Inc. is as a technology that understands human body language and lets users interact naturally with games through hardware like depth sensor, color camera and microphone array [36].

3.4 *Further UX Design Approaches*

Gamification. Gamification is the process of applying modern gaming elements into other activities. These elements, such as point scoring and competition with other players are proven to be capable of improving user experience and encouraging more user engagement [2]. Over the years, gamification has been applied to many non-gaming settings such as healthcare and education [20, 37–40], whereas industrial application is still a relatively new area [26].

One of the important implications of such applications is that assistive systems need to be designed in a way as to adapt the level of challenge to the ability of the user, similar to the way in which games adapt to its players [2]. Another design decision influenced by gamification is that instantaneous visual feedback, such as solving a puzzle or climbing a pyramid, can be represented as the work progress the user is currently doing. This set up is studied by Korn et al. with regard to assembly speed and quality. Parts assembly time is shown to be significantly reduced by integrating gamification design elements in the system [2].

4 Current Challenges for Assistance Systems

4.1 Product Quality Versus Completion Speed

The meaning of product quality might not be the same for different tasks in which assistive technology is integrated. For example, in an assembly line, product quality may be defined as the quality of the finished products, i.e., defects in a batch. If AR is applied in assisting inspection tasks, product quality might be defined as the number of defective products that is approved by the inspector [10]. So far, research has focused primarily on taking advantage of AR technologies to improve manufacturing quality and completion speed. This is supported by indeed many evaluations that concluded with a great potential of AR technology applications in manufacturing environment [8, 12, 16, 41].

Although most of the researches have shown a positive implication on productivity, quality or efficiency when AR technologies are used in manufacturing processes, the degree of such implications varies. While Korn [2] found a statistically insignificant increase in production speed, Stadtler and Wiedenmaier [12] mentioned that previous research has shown an increase of 30 % in productivity with the help of AR technologies. Disparities in effectiveness of AR-based assistive systems exist mostly due to differences in the complexity of the assistive system itself [42]. The effectiveness of these systems on improving product quality and finishing speed are influenced by its usability as well as extra workload exerted on the user. This will be discussed in the sections below.

4.2 System Unpredictability Versus Worker's Mental Load

Assistive systems are made intelligent in the sense that they could help with the performance of the manufacturing environment. However, the fact that this is essential human-machine interaction, the question of system predictability becomes a key to minimize the so-called "automation surprises" [43]. In his work, Sheridan suggests that there is a positive relation between system predictability and the amount of mental workload exerted on the user [43]. One of the incentives of developing such an assistive system is to reduce the mental load of worker in work place, this goal is difficult to achieve if the system is not reliable, or the user might often have to guess "What is the automation doing now?" [43]. Rötting also suggests that system unpredictability can happen when a user is required to deal with complicated interfaces [42]. Generally, the mental workload of a user is increased when he has to process the information presented on the interface and make decisions based on that. Research on assistive driving systems has shown that a low complexity, highly integrated interface could minimize distractions to the driver, in other words, the mental workload for the driver [42].

4.3 Production Benefit Versus Implementation Cost

Current research has focused mainly on evaluating the potential benefits that assistance systems could bring to production environments. This paper summarizes some general benefits:

- *Saving Time*. By facilitating the operations, assistance systems have the potential to save cycle time in many processes, for example during design [9], production, assembly and inspection [10].
- *Saving Cost*. Cost saving could be achieved by many ways in the environment where the system is employed. More efficient process could translate into higher productivity, which essentially means more output using less input. For example, Stadtler mentioned an estimated productivity gain of up to 30 % [12].
- *Improving Reliability*. Production reliability could also be enhanced by intelligent adaptive systems. With the help of such systems, products could be produced with higher quality and fewer defects [10]. Another way of improving the reliability of production lines is that assistive systems lower the training difficulty of new products or new employees, which reduces the dependency on few more experienced operators and hence facilitates job rotation as well as continuous production [28].

On the other hand, we only found little research on the implementation cost of such assistive systems in production settings. Most of the papers reviewed suggested the cost of such systems to a limited extent whereby there is no research specifically focused on the cost evaluation:

Setup Costs. Assistance systems usually need support from both hardware (i.e., sensory input) and software (i.e., databases). Depending on the complexity of the system installed, the cost of implementing hardware and software will vary [41]. Setup costs also include the customization efforts made to tailor the system to the production environment.

Training Cost. Training costs include both the initial training needed for the assistance system, as well as the training for workers who work with the system.

4.4 Challenges Related to Sensory Input

As a key part of assistance systems, sensory inputs, for example from depth sensors and motion recognition devices, currently face challenges that are limiting the performance of the system. Visual input/output is usually a crucial part of the assistive system, lighting conditions largely affect the consistency of these sensors' performance. For example, the effectiveness of certain depth sensors depend on the lighting condition of the environment to accurately measure [33]. Also, lighting condition affects the visibility of projected information in automated inspection applications, e.g., spot welding [10]. Another shortcoming of visual sensors, as mentioned by Funk, is that they are not able to distinguish two exactly same objects [33]. Many assistive systems employ leap motion sensors to register 3D movement, however, these sensors require that there must not be objects interfering the motion so that accurate detection can be achieved [33]. As for assistive systems which rely on outputting information through projection, finding a suitable and consistently visible object surface is a challenge. The object's shape and size determine the suitability of projection, the amount and the complexity of information that can be projected on the surface [10].

5 Discussion

We have seen that most of the assistive systems we extracted from our literature research are mainly based on Virtual respectively Augmented Reality technologies, typically with sensory inputs such as depth sensors and motion recognition devices. There are also assistive systems which make use of technologies such as light barriers [6]. Further research could explore more on assistive systems which are utilizing technologies which are not VR/AR related. Besides technology-related factors, we also noted that design paradigms from other disciplines could potentially be appropriate to be applied in the design of assistance systems. The use of gamification techniques for example showed positive influences also in production environments [2, 26]. These assistance systems are developed to be integrated into manufacturing processes so that production is more efficient, safer and more reliable. While current examples of AR devices are demonstrating a great potential of increasing the capabilities of production facilities, many ergonomic issues are still unsolved and result in a lack of comfortable and effective long-term usage. Another concern is the trade-off between the level of system unpredictability and the mental workload for workers. This is caused by the fact that truly adaptive systems are more unpredictable to its users compared to traditional systems, whereas having more control over the system behavior would increase mental workload of the worker.

6 Conclusion and Outlook

In this paper, we reviewed current trends and approaches regarding assistance systems in industrial production environments. We analyzed the relevance of various interaction paradigms, such as the use of Augmented Reality (AR) technologies including Head Mounted Displays (HMD) or the use of Tangible User Interfaces (TUI). We have also identified some of the application areas of such adaptive systems in production environments and their current development progress. Sensory input, as a crucial constituent of such systems, has also been considered.

We took account of the various challenges related to the inspected systems. One common issue identified in this process involves the trade-off between product quality and completion speed, which we consider as one of the most important challenge. Yet, this problem may be overcome by putting more emphasis on error detection and auto-correction mechanisms when designing assistance systems where finishing quality is as important as completion time.

Another concern is the interaction between the user and the assistance system. Incorporating principles from human factors engineering into the design of such systems is necessary to cater for a high degree of usability and meaningful user experiences. Further research has to be performed on how to design for and evaluate the usability and user experience within the industrial domain due to its specific requirements. Criteria for these new production-relevant contexts need to be developed where safety and usability criteria are adapted. This is a problem to be fixed in the future, once production assistance systems are more established.

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Part V
Ergonomics Design of Manufacturing Processes

Goal-Based Manufacturing Gamification: Bolt Tightening Work Redesign in the Automotive Assembly Line

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Abstract Recent productivity-oriented technologies (e.g., industrial robots, assistive wearable tools) have more focused on production capacity rather than workers roles and experiences in the manufacturing process, and as a consequence, task have become simple and repetitive which is detrimental for work motivation. Researches have been conducted to improve worker's motivation and experience during this monotonous work (e.g., bolt tightening), and gamification has got attention as a useful way to improve worker's intrinsic motivation by augmenting playful goal and feedback to previous demotivating context. The present study aims at examining the effect of gamification for improving the worker's flow and

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emotional experience which are related with intrinsic motivation in the workplace. An empirical study was carried out by five participants. They were instructed to tighten bolts in three different interface conditions (e.g., default condition; reactive condition; and gamification condition). During the task, their flow level and emotional state were assessed by experience sampling method (ESM). The benefits of the manufacturing gamification in the worker's flow experience and positive emotion are also discussed.

Keywords Manufacturing gamification · Intrinsic motivation · Flow experience · Emotional experience

1 Introduction

Simple and repetitive task in the modern factory, which is beneficial for increasing production capacity, actually have some side effects on the worker's mental and physical well-being [1]. For instance, long labor time for monotonous task induce great perceived fatigue and boredom [2]. Also, working with the same position repetitively can cause musculoskeletal disorders like carpal tunnel syndrome and tendonitis [3, 4]. These mental and physical shortcomings gradually decrease worker's motivation [5], and negatively impact on the atmosphere of overall workplace environment [6].

To solve the above-mentioned problems, some approaches have been proposed. For example, Toyota proposed and applied TPS (Toyota Production System) based on three principles (elimination of waste movements by workers, consideration for workers' safety, and self-display of workers' capabilities by entrusting then with greater responsibility and authority) [7]. Beginning with the practice from Toyota, various researches have been conducted, such as worker education based on the analysis of the different steps and operation characteristics [8], tool development/improvement to reduce the worker's physical burden [9], and the intelligent robot system for automated factory environment [10, 11]. From the efforts to reduce physical pain and fatigue, more recent studies consider the way to improve worker's innate motivation and mental well-being. Incentive, an extrinsic reward for workers, is one the most prevalent example [12]. When workers got an extrinsic reward (e.g., an end-of-the-year bonus, performance-related pay) their efficiency for work significantly increase [13]. However, this extrinsic reward has a pitfall. When workers framed by the extrinsic reward system, their innate value for work is decreased. They perceive their work less important and start to depend on extrinsic reward; that is, when extrinsic reward declines, workers' motivation and satisfaction for work more severely decrease [14].

Advanced from the extrinsic reward, 'flow theory' propose a concept of intrinsic motivation—an interest or enjoyment in the task itself rather than relying on external reward—as a solution to increase worker's motivation [15]. This intrinsic motivation can be designed through balancing the level of task and worker's skill.

While working, when both challenge and skill are well-balanced, workers flow into what they are doing, and this experience induce more innate forms of motivation (e.g., flow experience and positive emotion) [15]. Gamification, the use of game design elements in non-game contexts, might be a proper approach to generate intrinsic motivation. Recent studies support this idea, such as when user have a flow experience through a gamified content this can produce intrinsic motivation [16]. Also, gamification scenario impact user's positive emotion which also can be related with intrinsic motivation [17, 18].

We believe that gamification in manufacturing context can successfully increase worker's flow experience and positive emotion. Gamification design gradually provide various level of goals and these can change previous simple and repetitive task into a more challenging one (i.e., higher challenge level). In this study, to verify the effectiveness of industrial gamification by the perspective of flow experience and positive emotion, a bolt tightening work in the automotive assembly line was gamified, and compared with other interfaces (e.g., default condition; reactive condition).

2 Related Work

2.1 Intrinsic Motivation

Intrinsic motivation is the "motivation that comes from inside an individual rather than from any external or outside rewards… the motivation comes from… the task itself or from the sense of satisfaction in completing or even working on a task." [19] Various studies have been conducted to understand how intrinsic motivation can be increased. For example, Davis et al. [20] studied how to increase intrinsic motivation and satisfaction in workplace environment, and proposed an enjoyment as a critical design factor. Elliot and Harackiewicz [21] analyzed about the relationship between goal setting, achievement orientation, and intrinsic motivation, and found that intrinsic motivation is highly related with focusing on goal setting. Feedback, outputs of a system as part of a chain of cause-and-effect, is also important to increase intrinsic motivation. De Treville and Antonakis [6] emphasize the role of feedback as a pursuit for current goals and use it to assess intrinsic motivation level. In sum, researches show that intrinsic motivation is influenced by enjoyment, goal setting, and feedback from the context.

2.2 Gamification for Intrinsic Motivation

Gamification, use of game design elements in non-game contexts [22], can provide gradual goals and matching feedback for users which can lead to intrinsic motivation, flow experience, and positive emotion [23–25]. In this context, various studies in [26, 27] used gamification approach with motivating purposes. For instance, Dickey used game avatars to set a goal and to give a feedback for users. Hanus also used badges and leaderboard to improve user's intrinsic motivation. The effects of gamification can even applied for the elderly or impaired people who work in the manufacturing environment [28]. Thanks to the proliferation of gamification examples, now people start to be curious about how can we actually conduct a gamification design approach. Recent rigorous research show that careless use of specific gamification elements (e.g., game avatars, leaderboard, and badge) cannot be successful to increase intrinsic motivation because of a lack of continuity and task-irrelevant goal design [29]. In this regard, context-based gradual goal setting and feedback design is necessary to conduct a successful gamification design approach. In this study, we redesigned a bolt tightening work in the automotive assembly line by considering this gradual goal setting and feedback design approach.

3 Gamification Interface Design

In the automotive assembly line, one day work is consisted of total four processes, and each process is consisted of 120 cycles. During this cycle, workers have to tighten averagely four bolts (i.e., from three to five) within 1 min (see Fig. 1). While tightening a bolt, workers should follow a prescribed torque level for safety issue. When workers tighten a bolt well (i.e., follow a prescribed torque) "OK" sign will be delivered through machine. "NG" sign will be delivered in the opposite case (i.e., violate a prescribed torque). Through the gamification interface design, we tried to link this simple and repetitive bolt tightening work with gameful elements (i.e., enjoyment, flow experience, and positive emotion). Especially, our primary focus was to redesign previous demotivating work context into more challenging and interesting environment, by considering gradual goal setting and feedback design.

Oprescu et al.'s recent study show us a way to consider gradual goal setting and feedback design by considering short term, medium term, and long term goal differently [30]. In the short term, the goal of a gamified workplace may be to train workers in new work processes with reactive feedback. Medium term goals may be

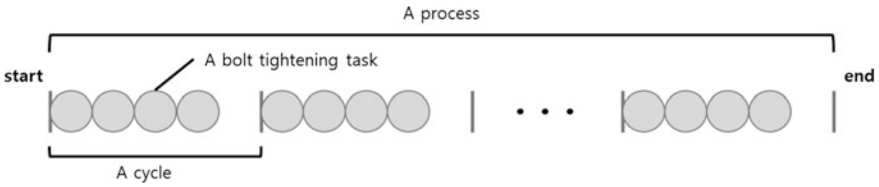

Fig. 1 A process, cycle, and each bolt tightening task

Table 1 Short term, medium term, and long term goal design

	Goal design	Description	Example
Short term	Reactive feedback	Direct reactive feedback for user's action	Provide audio-visual feedback depending on compliance to prescribed torque (OK/NG)
Medium term	Progress visualization	Visualization of work process and user's current position	Progress bar for total task number and current task
Long term	Meaning	Epic purpose for overall work experience	Epic, gameful world tour concept; task is no more simple/repetitive work, it is a tour

to enhance productivity through progress visualization, and long term goal may be to foster work and organizational wellbeing through meaning. By considering these three perspective (i.e., short term, medium term, and long term), a gamified interface for bolt tightening task was developed.

While conducting a redesigned bolt tightening work, workers can experience gradual goals (see Table 1, Fig. 2). For a short term, by providing a reactive audio-visual feedback depending on each bolt tightening task performance, workers can more focus on their direct task. For a medium term, through a tour progress bar feedback, workers can focus on their continuous performance and anticipate remaining working hours (which is crucial to perceive the locus of control about work). Last, for a long term, overall score during a process will be presented through badges (e.g., trophy, medal, or stars) which give an epic meaning for workers. These gradual goal setting and feedback can improve worker's flow experience and positive emotions [31].

To verify the effectiveness of goal-based industrial gamification, we compared a gamification interface with other interfaces like default condition (e.g., no goal or feedback for bolt tightening task) and reactive condition (e.g., short term reactive feedback only for bolt tightening task). Our hypothesis are like below:

- H1: Gamification interface will improve worker's flow experience compared to other interfaces (e.g., default condition, reactive condition).

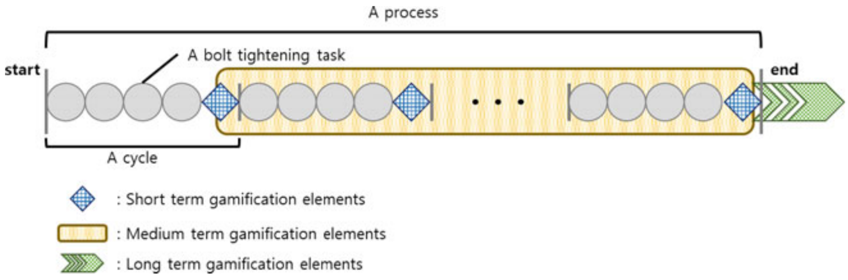

Fig. 2 A redesigned process, cycle, and each bolt tightening task with gamification

- H2: Gamification interface will improve worker's positive emotion compared to other interfaces (e.g., default condition, reactive condition).

4 Method

4.1 Participants

Total five participants (all male) aged 25–27 years (mean = 26.2, s.d. = 0.75) were participated in this study. They were recruited from a pool of students from University and receive a voucher for participation.

4.2 Procedure

To mimic the actual assembly line condition, experiment was conducted for total 8 h and 30 min (see Fig. 3). Each participants conduct a bolt tightening work for 2 h in each three conditions (within-subject design; three condition—default, reactive, and gamification), and break time (from 20 min to 1 h) was given between each conditions. When participants arrived, they were explained about the experimental procedure and get the consent form. After that, through the training session, participants are get used to a bolt tightening work. Default interface was set as a first condition, because it is as same as a current work procedure so good to make participants get used to a bolt tightening work. The second and third condition are either reactive condition or gamification condition (counterbalanced order). During each condition, experience sampling method (ESM) was used to assess participants' flow level and emotional state.

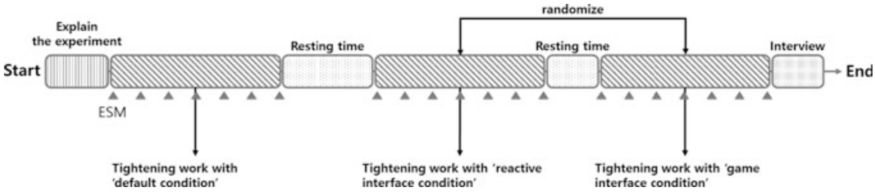

Fig. 3 Experimental procedure

4.3 Material

Experimental setting is consisted of two monitors, a work-board, and a tool for bolt tightening. In Fig. 4, right side monitor (see ①) presents a task-relevant information with three different conditions (e.g., default condition; reactive condition; gamification condition). The monitor on the left side (see ②) is a metaphor for the cycle time of a conveyer belt. During one minute, a car animation is moving from left to right in this monitor, and participants have to conduct their bolt-tightening work within this time limit (as same as a cycle time). Last, in the middle of Fig. 4, there are a work-board and a tool for bolt tightening (see ③). Participants conduct their task (tightening the 15 mm bolt) on this work-board with a tool named Nutrunner from AtlasCopco^{TM}.

During the experiment, three different interface conditions (i.e., default, reactive, and gamification interface) are presented through right side monitor (see ①). First, *a default condition* shows only the number of bolts to tighten within each cycle time. Whether workers tighten bolts good or bad, they don't represent any goals or feedback. Second, in *a reactive interface condition*, the number of tightening tasks in each cycle is represented by the number of boxes (see middle in Fig. 5). When participants tighten a bolt, a reactive feedback is represented depending a tightening

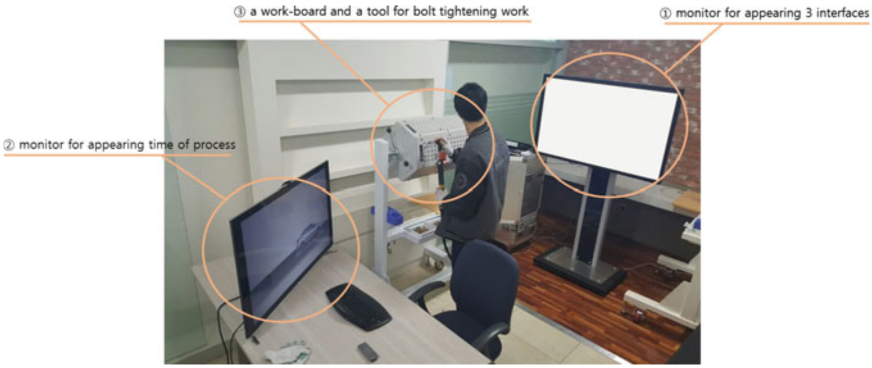

Fig. 4 The experimental setting (blinded-screen due to security policy)

Fig. 5 A participant performs bolt tightening work within three different conditions. From the *left* to *right*: default interface condition, reactive interface condition, and gamification interface condition (blinded-screen)

performance. When participants follow a prescribed torque (which means “OK”), one of the box’s color change to green with a positive sound feedback. On the contrary to this, when participant violate a prescribed torque (which means “NG”), the box’s color change to red with a negative ‘beep’ sound. This red box changes to green again when participants re-tighten the bolt. After tightening overall bolts in a cycle, a monitor shows the number of boxes (i.e., the number of tightening tasks) for a next cycle. Last, in the case of *gamification interface condition*, participants will tighten bolts within the gamified context (see Table 1). The number of tightening tasks in each cycle also represented by the number of boxes and depending on participants compliance on the prescribed torque, audio-visual feedback will be presented (similar with reactive interface condition). The difference between a gamification interface and reactive interface is the existence of medium term and long term goal and feedback. For instance, in the gamification interface, participants’ current cycle among the total cycle number is represented through progress bar visualization. Also, after finishing the overall cycle, badges (e.g., trophy, medal, or stars) which give an epic meaning for participants, are given based on the working performance like the number of “OK” signs.

4.4 Measure

The experience sampling method (ESM) was used to assess participants’ flow level and emotional state while conducting a bolt tightening work. ESM is a method to collect a process of experience from simple questions, and can obtain empirical data about continuous psychological states (e.g., flow experience, emotional state) [32]. In this study, we used modified version of the ESM method like Table 2. Participants have to reply for ESM seven times per condition (see Fig. 3).

Table 2 ESM questions for flow level and emotional state

Measure	Question
Flow level (5 point Likert scale)	Does the degree of difficulty of the task stimulate your challenge? (extremely low–extremely high; higher is better)
	How do you rate your performance in this task? (extremely low–extremely high; higher is better)
Emotional state (7 point Likert scale)	Describe your mood as you were beeped. (bored–excited; higher is better)
	Describe your mood as you were beeped. (worthless–worth; higher is better)
	Describe your mood as you were beeped. (passive–active; higher is better)
	Describe your mood as you were beeped. (uncontrollable–controllable; higher is better)

5 Results and Discussion

ESM results for flow experience show changes of participant's perceived challenge and perceived skill level for a bolt tightening task (see Fig. 6). Perceived skill level (right in Fig. 6) shows no difference between each three interface conditions, which means participants perceive their skill constantly high in every conditions. On the contrary, perceived challenge level (left in Fig. 6) shows differences between each interface conditions. More specifically, there are no difference for perceived challenge level between default interface and reactive interface; participants perceive higher challenge level while conducting a task within the gamification interface. For a flow experience, both perceived challenge and skill have to be balanced, and in this context, gamified interface show improved flow experience compared to other interfaces thanks to the improved challenge level ("*H1: Gamified interface will improve worker's flow experience compared to other interfaces*" verified).

ESM results for emotional state show changes in participant's four emotions (e.g., Bored/Excited; Passive/Active, Worthless/Worth, and Uncontrollable/Controllable). In Fig. 7, participant's emotional state is higher when they conduct their work within the gamified interface. Especially, "exited" graph show that participants experience more exciting emotion when they conduct their job with gamified interface. Not only excitement but also worthful meaning for job ("worth" graph in Fig. 7) increased thanks to gamification interface. Based on these results, it might be said gamification interface can successfully stimulate worker's positive emotion ("*H2: Gamified interface will improve worker's positive emotion compared to other interfaces*" verified).

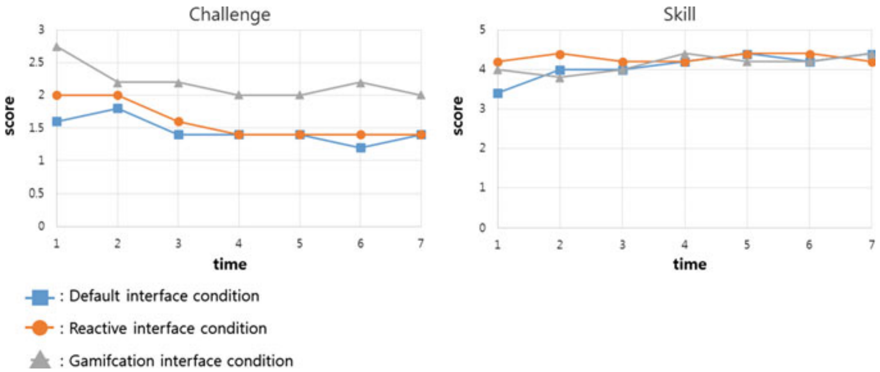

Fig. 6 ESM results for flow level (*left* Challenge; *right*: Skill)

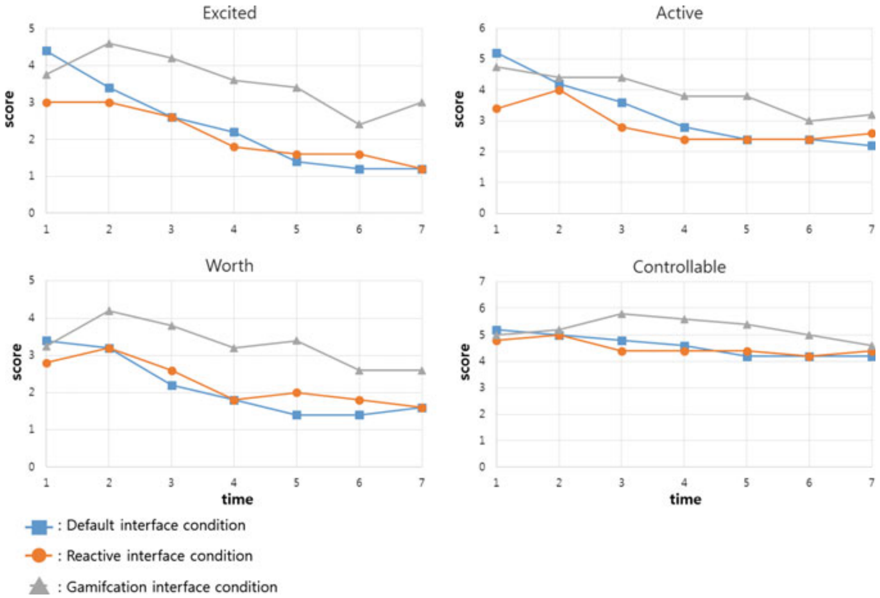

Fig. 7 ESM results for emotional state (from *left top* to *clock wise* Excited; active; controllable; and worth)

6 Conclusion and Future Work

To improve worker's intrinsic motivation while conducting a simple and repetitive work in manufacturing environment, recent work environments started to pay attention to gamification design method. Especially, we are interested in how to design successful gamification in manufacturing environment, so we redesign a monotonous bolt tightening work into a gradual goal and feedback based gamified interface. Thanks to goal-based gamification design, previous demotivating work is changed into multiple goal-based work (with short term, medium term, and long term perspective). Results show that our gamification interface was successful to improve worker's flow experience by improving perceived challenge level compared to other interfaces. Worker's positive emotion, such as excitement level and worthful emotion, were also increased.

Our study has a few limitations. First, the number of participants is not enough, so we couldn't conduct any statistical analysis to verify our hypothesis. A rigorous study with more participants is need in near future. Also, we proposed only one example for designing short term, medium term, and long term goals and feedback. Various examples and concrete framework to design goal-based manufacturing gamification will be helpful for future researchers who try to conduct gamification design in the manufacturing context. Despite all these limitations, we believe that our study has a meaning as a first study to try to change previous demotivating factory work context into a playful and gamified environment.

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A Case Study in an Automotive Assembly Line: Exploring the Design Framework for Manufacturing Gamification

Jiyoung Lee, Jihyo Kim, Kyoungwon Seo, Seunghwan Roh, Changho Jung, Hyunwoo Lee, Jongho Shin, Gyunghyun Choi and Hokyoung Ryu

Abstract Industrial revolution which is represented by specialization, standardization, and simplification significantly improves productivity, however it makes tasks in production line more simple and repetitive. This monotonous work environment affects most factory workers to be suffered from lack of motivation and boredom, so consequently makes workers to perceive their job unsatisfied and meaningless. We believe that gamification approach can make this tedious workplace more playful and motivating. In this context, a case study was conducted for a bolt-tightening task in the automotive assembly line. Especially, we explored our five-step design framework which can be useful as a basic procedure for the manufacturing gamification: (1) target system analysis; (2) goal and constraints

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identification; (3) concept generation; (4) concept evaluation; and (5) scenario development. Based on this design framework, a gamified interface for a bolt-tightening task was developed. The effectiveness of gamified interface was evaluated by lab-based experiment with semi-structured interview, and lessons learnt and related design suggestions are also dealt with.

Keywords Manufacturing gamification · Design framework · Automotive assembly line · Bolt-tightening task · Worker motivation

1 Introduction

After the industrial revolution in 18th century, the most of tasks in manufacturing industry have been arranged and designed based on the principles such as specialization, simplification, and standardization. An efficiency and effectiveness of the work performance have been improved thanks to these principles, however tasks have become much more simple and repetitive for workers. This monotonous work pattern makes workers suffering from lack of motivation and boredom at the work place [1]. This leads workers to become apathy and passive in the short term, and consequently make them not to give a full effort for work. Moreover, if a lot of workers suffer from the same problems (i.e., lack of motivation and boredom), workplace's overall atmosphere can be badly influenced (e.g., moral hazard) [2].

Various human factors and ergonomics research, such as motion analysis, job rotation, and a systematic ergonomics approaches [3, 4], have been conducted to address above problem. These approaches were partially successful to satisfy workers by the perspective of worker's physical dimension and boredom. However, it cannot fundamentally help to improve worker's motivation for work itself [5]. Extrinsic reward (e.g., economic compensation) was studied as a next step to improve worker's low motivation. At a first glance, it seems to successfully increase worker's motivation, however it was only effective for short-term manners and not work for long-term intrinsic motivation [6, 7].

More recently, gamification, the use of game design elements in non-game contexts [8], was proposed as a solution to improve workers' motivation and experience in long-term perspective [9, 10]. Proponents for gamification suggest that the game design elements that make playful experience and the nature of gamification itself, are intrinsically motivating, so effective to stimulate long-term motivation [38]. In this regard, the effectiveness of gamification has been proved in many ways, however there are no rigorous framework/clear instructions for gamifying work in factory context and only few cases exist (e.g. assistive gamified

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system for sheltered workers [11], elderly or impaired person [12]). So, when non-experts try to apply gamification design in manufacturing context, actual implementation is hard and often malfunctioning [13]. For instance, some previous studies only focused on reward system such as points and badges to apply gamification design, so actual results were rather detrimental for users' intrinsic motivation [14–16].

In this paper, we propose a design framework for manufacturing gamification based on previous studies and apply this framework for a case study. This case study is about creating gamified interface for bolt-tightening task in the automotive assembly line. Procedure to develop a gamified interface will be presented and a brief evaluation of this interface will be followed. We also share our lessons learnt and design suggestions based on our manufacturing gamification experience. The paper is structured as follows: in Sect. 2, we will present our detailed five step gamification process and introduce a gamified interface which is the outcome of our own gamification process. In Sect. 3, evaluation method for this gamified interface and its result will be presented. Lessons learnt about manufacturing gamification process will be followed in Sect. 4. Finally, through Sect. 5, we will wrap up with conclusions and future works.

2 Design Framework: The Manufacturing Gamification Process

Based on previous gamification studies which considered about gamification procedures [17–19], five-step design framework was developed to support a manufacturing gamification process (see Fig. 1). As a first step, *target system analysis* is conducted to understand target task, worker, and workplace environment. Through this step, *persona*—a fictional character created to represent the different user types in target system [20]—is derived. In the second step (*goal and constraints identification*), gamification's goal and constraints are identified based on the *persona*'s characteristics, and this result allow us to identify the role and solution space of the gamification (e.g., what to deliver through gamification). In the third step (*concept generation*), multiple concepts for gamification are generated by PLEX Brainstorming method [21] with descriptions about theme and flow. These concepts are evaluated by the subjective workload and flow experience, and the most appropriate concept is selected (the fourth step, *concept evaluation*). Finally, in the fifth step (*scenario development*), a detailed gamification scenario and prototype interface are developed. In this case study, we applied five-step framework to develop gamified interface for a bolt-tightening task in the automotive assembly line.

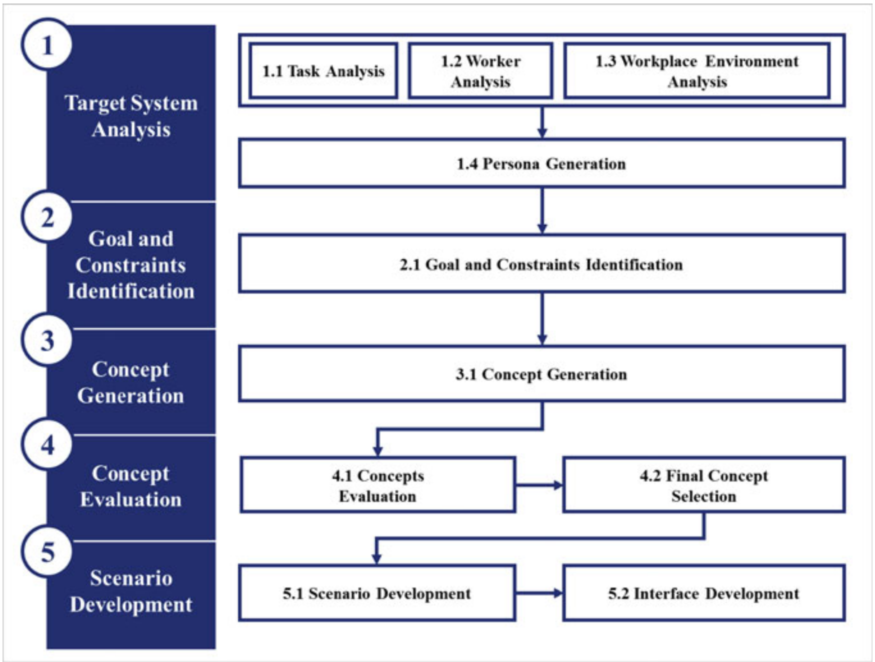


Fig. 1 Five-step design framework for manufacturing gamification

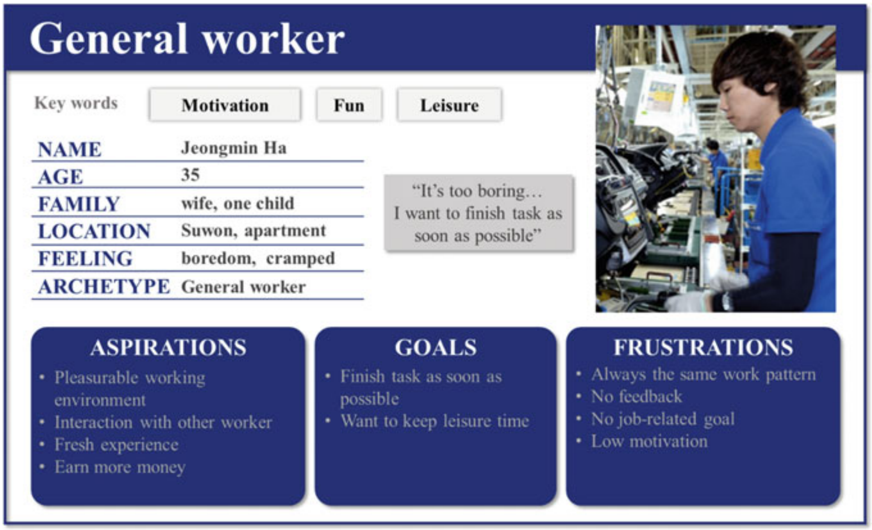
2.1 *Target System Analysis*

The target system analysis is a starting point to understand our gamification context. Formative researches stressed out the importance of understanding a genuine target context (especially, task, worker, and workplace environment) [17, 22], because the better understanding of target system is critical to deliver more suitable gamification outcome. In this respect, a context was rigorously analyzed by three sub categories: task, worker, and workplace environment (1.1, 1.2, and 1.3 in Fig. 1).

For the target system analysis, two assembly line observations were conducted. Through the observations, worker's daily activities, schedule, work pattern, social relationship, habit were analyzed. The results show that our target task of the gamification is a bolt-tightening task in the automotive assembly line. Typical example of a bolt-tightening task is like below:

The goal of this task is to tighten bolts to a vehicle body with a target torque on the conveyer belt. A worker has to comply with predetermined target torque, because the quality of vehicle can be degraded or even dangerous if a target torque is not followed. The conveyer belt moves regularly based on prescribed cycle time and a new vehicle body is arrived after this cycle time.

Next, our target worker, the potential user of our gamified interface, is male around age 30–50 years old. Since a bolt-tightening task is very easy to become



General worker

Key words **Motivation** **Fun** **Leisure**

NAME	Jeongmin Ha
AGE	35
FAMILY	wife, one child
LOCATION	Suwon, apartment
FEELING	boredom, cramped
ARCHETYPE	General worker

"It's too boring… I want to finish task as soon as possible"

ASPIRATIONS
- Pleasurable working environment
- Interaction with other worker
- Fresh experience
- Earn more money

GOALS
- Finish task as soon as possible
- Want to keep leisure time

FRUSTRATIONS
- Always the same work pattern
- No feedback
- No job-related goal
- Low motivation

Fig. 2 Primary persona: general worker

skillful enough, most workers are confident about their expertise. Therefore, they have no motivation to perform their job better and no goal to proceed. They just do the work that has been placed in front of their own which make them passive to their job. The activity pattern shows workers' boredom and low motivation level. Last, our target workplace environment is an automotive assembly line. The atmosphere was passive and individual, so interactions between workers were relatively sparse. There was an interface system which provides information about overall working progress, however the information was too complex and not directly relevant with workers, so no one engaged in it.

Based on the knowledge from task, worker, and workplace environment analysis, we developed our primary persona (see Fig. 2), which represents the characteristics of the primary targets for the new interface. In the next step, this persona can be used to enable more thorough consideration about characteristics of our target context [34, 35].

2.2 *Goal and Constraints Identification*

The purpose of this step is to define the core contributions (i.e., goal) and restrictions (i.e., constraints) of gamification context. By identifying and defining clear goal and constraints for gamification process, entire design process can be well-aligned and consistent [17, 23]. To do so, persona-based expert interview with two manufacturing senior experts from the automotive domain and one expert psychologist was conducted. The aim of this interview session is to propose goals and constraints by considering the characteristics of persona. Two major goals and three constraints for the gamification were identified: (1) Develop the gamified interface containing the *useful monitoring system*, which shows the task progress and performance; (2) Set the *step-by-step goals* in gamified interface to improve the workers' motivation.

The major constraints derived from target system analysis are following: (1) The gamification outcome must not disturb the task itself, since the bolt-tightening task is a crucial to durability of vehicle; (2) Competitive and surveillance-like interface has to be avoid, due to support cooperative atmosphere between workers.

2.3 Concept Generation

The third step, concept generation, is an ideation stage, which generates various concept candidates for playful experience. These concepts are outline of gamified interface, which will set an overall design direction of details in later steps. In our approach, we decided to focus on playfulness as a concept of gamified interface. Lots of studies have been conducted to understand design method for pleasurable and playful experience [24]. Among the various methods, the PLEX (PLayful EXperience) Framework [25] is the most popular approach which covers 22 different kinds of experiences. Based on this framework, 'PLEX Brainstorming' method had emerged, which is useful to generate a playful design concept with three different kinds of playful characteristics. A detailed procedure of PLEX Brainstorming is stated in [26]. In our case study, we generated five concepts of gamified interface like below.

Concept 1: Collecting the Cookie. Concept is based on PLEX like 'Completion', 'Challenge', and 'Fellowship'. The aim is to bake a cookie with other team members (i.e., fellow workers) by a bolt-tightening task. When workers performed task well (i.e., comply the target torque), an empty cookie starts to fill. When empty cookie is filled, team members are rewarded a real snacks during the break time.

Concept 2: The King of Lottery. Concept is based on PLEX like 'Thrill', 'Challenge', and 'Suffering'. This is kind of a lottery game in the factory. Individual workers can set there lottery number based on their task performance. More specifically, when individual worker performed task perfectly, he receives a point, and workers can exchange this points with a numbered ball, which is a lottery number. Workers can enjoy the company-organized lottery, which held once a week.

Concept 3: The World Tour. With PLEX 'Exploration', 'Challenge', and 'Completion', we generated a world tour like task environment. Every-day, workers can explore cities around the world, but only a worker who scores high task performance can successfully complete the tour. Workers can review his journey through world map and other workers' current location.

Concept 4: Breaking the Gourd. Based on PLEX 'Completion', 'Competition', and 'Fellowship', we generated a gourd-breaking concept, which is similar to Piñata. Workers select the daily gourd in the beginning of a day. Workers who select the same gourd form a team. Depending on a bolt-tightening task, a virtual avatar throws a ball to the gourd, and it only breaks after lots of consecutive better task performance.

Concept 5: The Bolt-Tightening War. With 'Competition', 'Challenge', and 'Thrill', we developed a competition game. The worker can select the opponent among other workers. If selected opponent accepts the match then the match starts. During the work period, two players' task performance is recorded. According to task performance of each player, the characters attack the each other. The winner gets higher winning rate.

2.4 Concept Evaluation

In this step, the most appropriate gamification concept is selected among the multiple concept candidates which are generated from the previous step. Proper concept selection is important because only a well-matching gamification can successfully enhance engagement/intrinsic motivations for activities [27]. Also, this engagement even can influence a difficulty estimation of the task, which means the playful experience can lower the perception of workload [28]. In this context, we evaluate the multiple concept candidates with two main questions: first, "*whether the manufacturing task in that system enhance the engagement for activities than original system*", and second, "*whether the working environment with that concept requires lower subjective workload*".

Three game designers (5, 6, 10 years working experience) and two experts from manufacturing industry were attended to evaluate total five concept candidates. The evaluation was conducted after listening the presentation about each concept candidates through a storyboard[1]: detailed description about a type of PLEX, overall flow, and core mechanics (i.e., goal and the way to achieve a goal). After that, each concept's motivation level was measured by five point Likert scale (the higher the better) questionnaire for '*Attention*', '*Intrinsic interest*', '*Curiosity*', and '*Control*' which is based on the 'flow theory' of Csikszentmihalyi [29]. Second, the subjective workload was evaluated through the NASA TLX (National Aeronautics and Space Administration, Task Load indeX) survey with seven point Likert scale (the higher the better) [30]. It measures subjective workload by the level of '*Mental demand*', '*Physical demand*', '*Temporal demand*', '*Performance*', '*Effort*', and '*Frustration*'. Results are like below (see Table 1 and Fig. 3).

---

[1] A storyboard is a graphic organizer in the form of illustrations or images displayed in sequence used for pre-visualizing an animation, motion graphic, or interactive media sequence [37].

Table 1 Results of concept evaluation

Measures	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Flow experience	12.4	10.6	14.8	14.8	**15**
Subjective workload	24.2	**26.6**	25	19	21.8
Total	36.6	37.2	**39.8**	33.8	36.8

The value of *Flow experience* is sum of values of four sub-items and the value of *Subjective workload* is sum of values of six sub-items. The higher value of *Flow experience* means more engaged, and the higher value of *Subjective workload* means less subjective workload required, which is more preferred

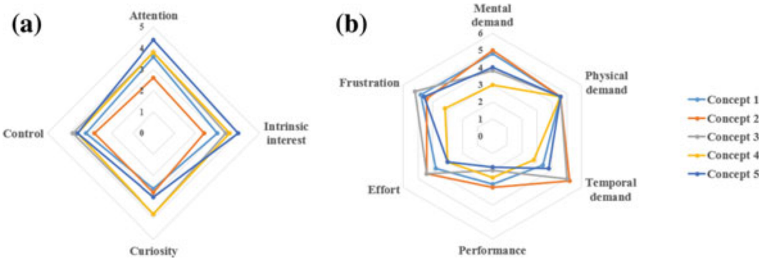


Fig. 3 Visualization of evaluation results. **a** Flow experience. **b** Subjective workload

According to the evaluation results, 'The Bolt-Tightening War' (concept 5) gets the highest score in flow experience mainly due to high values of 'Attention' and 'Intrinsic Interest' but gets the relatively low subjective workload score (total score: 36.8). 'The King of Lottery' (concept 2) gets the highest score in subjective workload mainly due to high value of 'Temporal demand' but gets the lower score in flow experience (see Fig. 3; total score: 37.2). The proper concept should deliver both high flow experience and low subjective workload [27, 28], and in this regard, 'The World Tour' (concept 3) which receives the highest total score based on relatively high scores in both flow experience and subjective workload was selected as the most appropriate gamification concept (total score: 39.8).

2.5 Scenario Development

The final step is to concretize the selected concept by adding detailed game elements, which make gamified interface more playful and motivating. Based on this scenario, a prototype of gamified interface was developed (screenshots of gamified interface are not presented in this paper, due to security policy).

The following descriptions are scenario of gamified interface. When player press the start button, player first selects the city to travel. After selecting a city to travel, the main playing screen shows up. The background of main playing screen is changed depending on the selected city's unique characteristic (e.g., tourist attraction). The bolt-tightening tasks are grouped into a process, which involves 3–4 tightening tasks. When player tighten the bolt with prescribed torque, the engine bar starts to be filled. According to task performance, the feedback shows up, such as 'Excellent!!'. After finishing one process, the car moves with visual effect based the work performance. After finishing overall process, the performance is summarized and represented as a tour result screen. Next tour city become available only player's tour performance exceed certain level.

3 Evaluation

3.1 Methods

To verify the effectiveness of our prototype gamified interface, a lab-based usability test was conducted with two different working environments: an original working environment and a gamified interface (see Fig. 4). Total 10 male participants (age mean = 26.2, s.d. = 0.75) were gathered from the local university community and get a voucher for their participation. They conduct a bolt-tightening task in two working environments (i.e., original and gamified) with counterbalanced order for 2 h for each, i.e., total 4 h. After finishing the task, a semi-structured interview was conducted with two questions: (1) "*Which condition was more motivating*?" to assess participants' motivation; and (2) "*Which condition was more interesting*?" to measure a level of playful experience. We also measured the torque compliance ratio, which is quantified value for task performance.

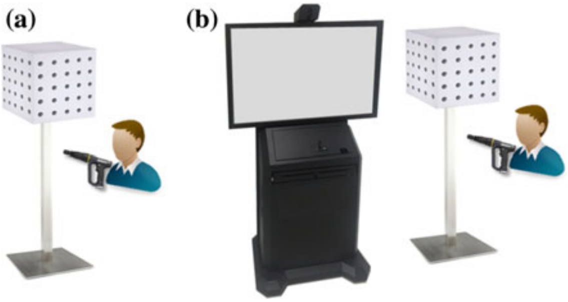


Fig. 4 Two experiment conditions (gamified interface is blinded due to security). **a** Original environment. **b** Gamified interface added environment

3.2 Results

90 % (9 out of 10) participants replied that gamified interface was more motivating (question 1) and more interesting (question 2) compared to original environment. About the reason for high motivation, participants responded that the concept of ‘city tour’ in gamified interface creates the concrete goal and purpose for the task, and these were helpful to generate higher work motivation. The participants also said, the direct feedback of task performance and current progress was useful and made them feel interesting. Thanks to this goal-related feedback, participants feel achievement and satisfaction after finishing the tour successfully. In terms of task performance, with gamified interface, the participants show higher compliance to the target torque (torque compliance ratio mean = 98.8 %). However, in original environment, despite the given instruction of complying the target torque, participants become apathy to this instruction as time goes on (torque compliance ratio mean = 86.5 %). In sum, it might be said that the gamified interface improves work motivation and playful experience, and consequently this leads to compliance on the target torque (i.e., high task performance).

Participants also proposed following suggestions for advanced gamified interface. Three participants who want ‘*hard fun*’—generated from opportunities for challenge, strategy, and problem solving [36]—recommended that the complex and more various goals would help improving motivation. Also most of participants recommend us to use more various sound effects (e.g., dynamic background music) to maximize the playfulness during a bolt-tightening task.

4 Discussions

Based on our case study experience, we found three lessons which can be useful for future researchers to conduct manufacturing gamification projects.

4.1 Designer as User for Target System Analysis

Understanding a user is the most important part in design process. Lots of design approaches like ‘user-centered design’ or ‘participatory design’ are methods which can be useful to extract user’s true needs and goals [31]. During the first step in our framework (*target system analysis*), we conduct two workplace observations and actual bolt-tightening works, and these were critical to develop interface details. To understand actual workers well and to create a good persona during manufacturing gamification, experiencing actual situation of worker by designer herself/himself is recommended.

4.2 High-Fidelity Prototype for Concept Evaluation

According to previous studies, the use of low-fidelity prototyping techniques was preferred throughout the product development cycle [32] due to efficiency. However, our experience on evaluation step (see Sect. 2.4) suggests that the high-fidelity concept description may need to help experts' better understanding and facilitate the fruitful comments. The high-fidelity concept description may include the flow and core game playing mechanism (i.e., goal and the way to achieve a goal) by generating brief descriptive video clip or storyboard of each concept. However, we should be aware of the fact that high-fidelity prototype might requires more effort, time, and cost, which can be detrimental in some cases.

4.3 Role Playing for Detailed Scenario Development

Based on our experience, one of the most difficult thing in whole process was predicting worker's feeling and reaction to gamified interface. Especially in scenario development step (see Sect. 2.5), which is for selecting detailed game elements, we had to thoroughly consider the possible reaction of workers and interaction between workers and gamified interface. The 'informance', the role playing methods which create physical performances to communicate developed scenarios [33] can be used as a method to enrich and verify the idea for detailed scenario development. The person who takes the target persona's role performs an improvisational acting with respect to elements of gamified interface. During this role playing, lots of details and inspirational ideas were suggested (e.g., multi-level speed effect design for worker's long-term engagement), and these were beneficial for the scenario development step.

5 Conclusions and Future Work

Through our case study, we proposed our five-step design framework for manufacturing gamification. The first step of our framework, target system analysis, enables the deep understanding of the system. Based on the first step, the second step identifies role and solution space of gamified interface. The third step generates various gamification concepts, and fourth step evaluates and selects the most proper one. The final step concretize and actualize this concept into detailed scenario.

Developed gamified interface with this five-step framework was assessed its effectiveness through a lab-based experiment. The results show that, compared to the original bolt-tightening work environment, gamified interface provide higher motivation, playful experience, and better task performance. Of course, there are some limitations in our study (e.g., small number of participants), however our case study still shows the potential of five-step design framework as a useful procedure for manufacturing gamification.

There are several avenues for future work in manufacturing gamification. First, since we only tested our gamified interface with general people, not real workers, we are planning to apply our gamified interface "The World Tour" in real factory environment. Second, we plan to conduct additional case studies with other manufacturing tasks to further test and refine our five-step design framework in the manufacturing context.

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Prerequisites and Conditions for Socially Sustainable Manufacturing in Europe's Future Factories—Results Overview from the SO SMART Project

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Abstract This paper provides an overview of the EU project SO SMART (Socially Sustainable Manufacturing for the Factories of the Future), a coordinated support action (CSA) project. SO SMART examined the conditions in Europe for creating socially sustainable workplaces in the manufacturing sector, where factories flourish along with their social environment. The project was international (with partners from five countries), multidisciplinary and participatory, involving participation of several science domain experts and a wider community of academic

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and industry beneficiaries who participated in panels, workshops, conference events and an online forum created specifically for the project.

Keywords Social sustainability · Manufacturing · Production industry · Societal challenges · Well-being · Demographics

1 Introduction

The EU project SO SMART [1] (Socially sustainable manufacturing for the Factories of the Future, FP7 grant no. NMP2-SA-2013-608734) was a Coordination and Support Action project carried out between 2013 and 2015. It aimed at exploring the state-of-the-art of European manufacturing from a social sustainability perspective, and its objective was to establish a current state, create and validate scenarios and solutions, and provide guidelines for achieving a healthy and prosperous society where manufacturing enterprises, employees and society interact in ways that are socially and economically sustainable in the medium and long term. This paper is an overview of the body of knowledge that resulted from the SO SMART project. It is meant to give an overview rather than offer a high degree of detail, and wherever possible we refer to the project's existing body of publications for further reference.

1.1 Background: Future Challenges for European Manufacturing

European manufacturing stands before a number of challenges. Among many global societal influences called "megatrends", Siemieniuch et al. [2] describe eight global drivers of change that are particularly important to (and influenced by) manufacturing industry. Some of these are directly linked with the aforementioned social sustainability challenges; in particular, *Population demographics, Community security and safety, Transportation* and *Globalisation of economic and*

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social activity are tightly linked with human well-being and work-life issues, and it is pointed out by [2, p. 105] that these issues must be dealt with using "*(…) a connected, comprehensive approach; it is evident that tackling one, or another, is unlikely to have much impact by itself. (…) A combination of political persuasion and technology will be required to reach any satisfactory conclusion; a comprehensive socio-technical solution will be necessary*."

It has been pointed out by several other sources that changing demographics [2–4], renewal in technological paradigms in manufacturing industry [5–9], skills gaps that threaten the staffing of future manufacturing [10, 11], new business models for products and services [12, 13] and the quest for organizational structures that can handle all of the above will be a rising challenge for future work life and industries. This will certainly be the case for European manufacturing, where various demographic challenges such as an aging working population [4] are challenging manufacturing employers to provide safe, attractive workplaces that balance these challenges while remaining profitable and having a positive impact on their surrounding communities, in line with principles of Corporate Social Responsibility, defined by [14, p. 287] as "*the obligation of the firm to use its resources in ways to benefit society, through committed participation as a member of society, taking into account the society at large and improving welfare of society at large independent of direct gains of the company*".

At the same time, defining social sustainability for manufacturing purposes has proven a complex endeavor [15, 16] as its scope reaches across many different domains and system levels, and it is not always easy to determine the appropriate assessment indicators for a factory-level analysis and improvement [16]. This need for assessment frameworks was also tackled by the SO SMART project, which has consistently argued that a successful integration of Social Sustainability aspects into a productive and prosperous European Manufacturing industry must be achieved in an "ecosystem" balance between the needs and capabilities of the Individual, Industries and Society, balancing commercial and societal interests within the overall European landscape (Fig. 1).

1.2 About the SO SMART Project

The overall aims of the project were to:

1. Develop a socially sustainable ecosystem assessment framework, including guidelines to describe scenarios and a set of indicators needed in order to evaluate them, under the perspectives of economic and social sustainability.
2. Define and validate a future vision for socially sustainable *Factories of the Future*, and a number of future ecosystem scenarios in which industrial strategies drive interactions with human workers and society at large.

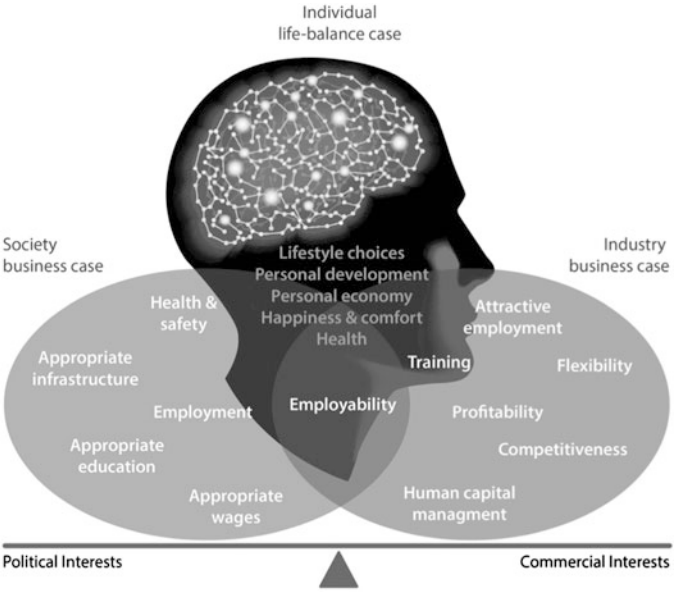

Fig. 1 The SO SMART ecosystem of social sustainability, which balances a complex interaction of concerns from the point of view of the individual worker, society and industrial employer (from a factory perspective)

3. Develop recommendations for companies and beneficiary groups on how to apply these scenarios and from the analysis of the gaps between "AS IS" and "TO BE" pilot scenarios, and build-up a future research roadmap.

The SO SMART project identified core challenges at an early stage; these are presented in Fig. 2.

Beneficiaries of the project's outcomes were identified via initial and continuous online and offline discussions about social sustainability with an international audience of industrial and academic stakeholders as well as a wider audience consisting of students, sustainability organizations, and the broad public. After the project ended, the academic partners in the SO SMART consortium incorporated some of the project results into their teaching at their respective universities [17].

In order to gather a picture of the current practices of social sustainability used in manufacturing, a mix of methods and studies was conducted to explore qualitatively and quantitatively how social sustainability is interpreted at both a theoretical and practical level, and to connect it industrial business perspectives such as success, corporate culture and profitability by means of various sub-projects. Many of these are described in various reports and literature, which are presented in the sections below.

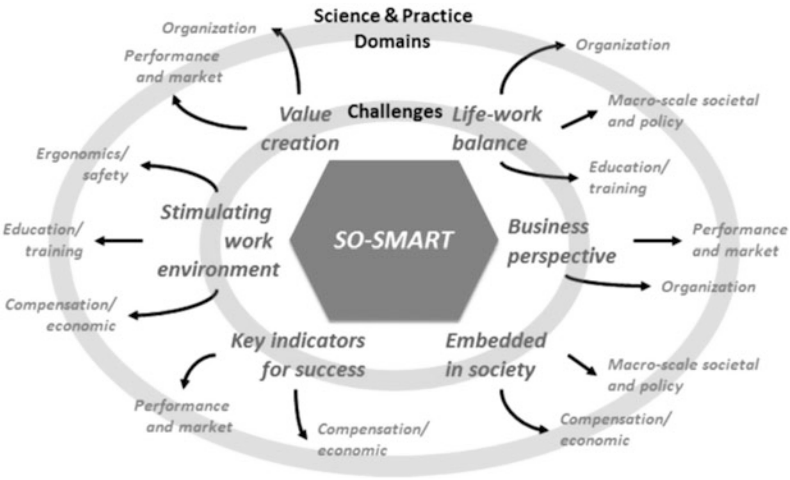

Fig. 2 The six SO SMART core challenges and their corresponding science/practice domains: value creation, life-work balance, business perspective, embeddedness in society, key indicators for success, and stimulating work environment

2 Results

2.1 Interactions with the Community: Workshops, Forums and Inventories

Workshops. A series of three international workshops called "The Socially Sustainable Manufacturing Ecosystems workshops" allowed us to collect inputs from experts, industrial and policy-making stakeholders interested in social sustainability issues in manufacturing. These workshops helped the project refine the ecosystem scenarios that were proposed in the roadmaps. The first of the three workshops focused on *envisioning models to be adopted in the future* in order to boost European industrial competitiveness and citizens' well-being. The workshop was held at Politecnico di Milano in Milan, Italy on June 30th, 2014. The participants, a heterogeneous group of sixty people, were asked to identify preliminary enabling factors (e.g., technologies, policies, values) that enable the realization of future Socially Sustainable Manufacturing Ecosystems. The results were grouped into six thematic areas, each one depicting a specific vision of socially sustainable manufacturing ecosystems: *urban factory and resilient inclusive communities; product/service life cycle extended quality and transparencies; new paradigms for product/service design; production and use; personal growth and new models of work; smart manufacturing networks; local governance;* and *educational policies* [18].

The second workshop of the series was focused on the concept of *future attractive workplaces*. It was hosted by Chalmers University of Technology in

Göteborg, Sweden on September 16th, 2014 and was attended by a group of fourteen people from industry and academia from four different countries. The six thematic areas being developed from the first workshop were turned into six scenario descriptions given to the participants as a basis for discussion. Results from the second workshop consisted of ideas for future attractive workplaces, and examples of corporate culture factors that would enable those attractive workplaces [19].

The third workshop of the series focused on the *visions and strategies for sustainable factories of the future*. It was held at Fastems Oy in Tampere, Finland on December 2nd, 2014. Twenty-two participants joined the workshop. The thematic areas that were chosen as basis for discussion were taken from the scenarios developed in the first workshop in Milan. The results of the third workshop consisted of a list of factors, enablers and roadblocks for future work-life balance and future work scenarios in Europe [20].

Forums and Inventories. Efforts were made to build a community willing to discuss and learn more about social sustainability as the project progressed. The community was grown at various conferences, industrial events, the project's own international workshops and via an online discussion forum [21]. A goal was to increase the public awareness of existing social sustainability initiatives and examples, which was done by setting up and maintaining online inventories of *social sustainability initiatives* [22] to address the European challenges, and *industrial good examples of stimulating workplaces* [23].

2.2 State-of-the-Art in European Manufacturing: Corporate Practices

The first stages of the SO SMART project were spent researching the baseline of social sustainability, including a literature study, a European-wide company pilot survey and interviews carried out with industrial and policy actors to examine the current social sustainability practices of European manufacturing companies. Using an online questionnaire and interviews, this gave a first insight into the landscape of socially sustainable manufacturing practices, from the factory perspective of companies.

The reported practices were examined within seven categories: *code of conduct for labor practices, human capital development, job design, work-life balance, talent management, employee turnover and satisfaction management,* and *stakeholder and community practices*. Overall findings indicated that among the surveyed companies, intentional action towards a socially sustainable workplace was uneven at best, with a limited perception of how to tackle upcoming challenges such as changing demographics. It was found that human capital development, job design and work-life balance were targeted by company efforts, but there was a lack of action towards future employability, adapting to a diverse workforce, talent management for all employees and practices targeting the local community and other stakeholders [24].

The pilot study confirmed the frameworks that were consolidated by the project from literature, and indicated some main topics for SO SMART to continue pursuing. The results of this preliminary probing survey and interviews are reported in [24–26].

2.3 Assessment Frameworks and Socially Sustainable Corporate Culture: Statistical Correlations

A substantial part of the SO SMART project focused on practices of using KPIs to measure business-critical developments, and examined whether existing KPIs could capture the social sustainability issues identified at the three levels ecosystem (Fig. 1) while targeting the economic profit. As a precursor, a long-list of economic sustainability assessment indicators was analyzed alongside a similar list for social sustainability indicators [27], in iterations reported in [28]. As an extended result, the long-list of social sustainability indicators was condensed at a preliminary stage into 11 "dimensions", which were later analyzed further.

As the understanding of the project's vision and the existing prerequisites matured, so did the statistical analysis. One major undertaking of the SO SMART project that is currently being worked into a scientific publication is a survey study based on panel data from employees in 15 European member countries (n = 971) and data from eight German companies (n = 207) who were able to provide publicly available data on their economic performance, in the form of EBIT (earnings before interest and taxes) and other parameters. Multivariate analytical methods were applied to the survey data in order to explore if there was a correlation between corporate social sustainability culture and company success. The underlying theories of this approach are based on [29]. Since the results of this rather substantial study are being prepared for submission to be published, we offer merely a brief overview here.

The survey study was pursued along two strategies: (1) surveying a large number of participants at different hierarchical levels from the same company, and (2) conducting a European-wide poll asking individual workers the same questions about the companies they worked at. In combination, the survey results led to the conclusion that the 11 dimensions of social sustainability could be condensed to four dimensions—*sustainability strategy and leadership; mission, communication and learning; social care and worklife;* and *loyalty and identification.* The study found that more than 40 percent of a company's success can be explained by the impacts of these four social sustainability dimensions.

The dimension '*Sustainability Strategy and Leadership*' is shown as the connection of social sustainability with the corporate strategy, as an inspired and innovative orientation, process-controlled implemented with continuous improvement, a quality of governance (leadership) that illustrates social competence.

The dimension '*Mission, Communication and Learning*' fosters employee development within the social sustainability approach. The advice for this dimension is to communicate a clear mission statement of social sustainability, which represents an attractive offer for a personal commitment from the employee and supports an attitude that recognizes social sustainability as relevant, and understands 'Learning' as an opportunity for advancing the development of each and every individual.

The dimension '*Social Care and Work-life*' emphasizes social aspects within the company, which can be perceived under work-life balance and reward systems of the company. This dimension is found to relate to corporate success only to the extent that it results from a sustainability strategy.

The dimension '*Loyalty and Identification*' concerns the employees' perspective regarding their employer. This includes loyalty and identification with the company, which can also be expressed simultaneously by job involvement.

Companies that were shown to strong performers in these four dimensions also displayed evidence of "economic success". The multivariate regression analyses that led to this conclusion indicated different strengths of correlation between economic success and socially sustainable corporate practices; the resulting hierarchy of order among the four dimensions suggests a procedure for companies of how to gradually approach a socially sustainable manufacturing strategy. This suggests that social sustainability is highly linked to corporate success if it is planned strategically and part of actively pursued leadership, and that it is possible to measure a baseline for the company, from which they can measurably improve their social sustainability culture and expect economic success in parallel. From this, we can derive the design of a "corporate culture of social sustainability" based on the four success-related dimensions.

2.4 Scenario-Building and Attractive Workplaces

A number of challenges related to demographics and future staffing of the manufacturing industry were reported on in [30]. Particularly, the issues of "attracting, recruiting and sustaining" a skilled and competent workforce was highlighted from the perspectives of an aging population, doubts among young people to pursue work in the manufacturing sector, work-life needs and requirements among specific demographic groups, and skills gap issues. Addressing these challenges was done by a combination of consolidation of input from the SO SMART workshop series [18–20], which chiefly used a back-casting approach [31, 32], and the online inventories of *social sustainability initiatives* [22] and *industrial good examples of stimulating workplaces* [23]. As a result of the workshops and inventories, a vision for attractive workplaces was formulated and incorporated into the roadmaps for Research and Education.

2.5 Roadmaps for Research and Education

In [27], it is emphasized that the European manufacturing industry's understanding of social sustainability challenges and what to do about them remains limited, and to remedy this, EFFRA [33] existing roadmap (which emphasizes the need for manufacturing in Europe to remain globally competitive while becoming more sustainable, safe and attractive) needs to be complemented with extensive knowledge creation on the subject of socially sustainable manufacturing ecosystems, to find ways to address the challenges towards the year 2020.

To this end, the roadmaps for research and education that are proposed by the SO SMART project combine scenarios developed and refined throughout the project's progression with suggested enablers, elements of attractive and economically successful companies, and synergetic ecosystem-level solutions that can address the challenges. Together, these project the project's vision for socially sustainable factories of the future, which can be summarized as "*Socially Sustainable and Successful Manufacturing Ecosystem: Good For Industry, Society and Individuals*".

The *Roadmap for Research and Education* draws its pathways to bridge the gaps between the SO SMART Vision and the current status, which resulted from the overall back-casting approach [31, 32]. The roadmap includes three main sets of recommendations:

Recommendations for Research Areas, in which Further Action is Needed.

- Sustaining people in the system
- Closing the skills gap
- Ageing workforce
- Socially sustainable product life-cycle
- Culture, strategy, business model innovation

Recommendations for Education.

- Tailoring interventions to enable individuals to develop throughout their life
- Strengthening relationships with industry
- Improving learning outcomes
- Developing reflective industrial societies
- Exploiting innovative technologies
- Sustaining educators' professional development

Recommendations for Policy Makers and Stakeholders.

- Improving company engagement in socially sustainable manufacturing and spreading good practices
- Integrating socially sustainable manufacturing concepts, models and approaches into research, education and training
- Supporting companies in promoting a positive image of manufacturing and track levels of attractiveness especially among young people

- Evaluating the endorsement of common accounting standards for company disclosure of social sustainability related information and performance, and improving reporting
- Evaluating the development of a EU voluntary label promoting social sustainability excellence in the life-cycle
- Better aligning European and global approaches to social sustainability in manufacturing, while maintaining sensitivity to regional and local issues
- Balancing innovation and regulation for new types of business and technology.

2.6 Roadmap for Socially Sustainable Factories

The separate *Roadmap for Socially Sustainable Factories* focuses on the company level and presents a six-step approach that manufacturers can adopt to address challenges of today, to approach the socially sustainable factory of the future (with the aid of internally generated and reported project deliverables):

1. Assess the company's current situation (using SO SMART's assessment framework and report on corporate cultural factors)
2. Select areas for improvement (Using recommendations for socially sustainable corporate culture and the model for profitable factories through social sustainability)
3. Identify activities, partners and resources (using pilot scenarios and the inventory of good examples)
4. Implement actions
5. Monitor change and assess progress (using the assessment framework and the report on corporate culture factors)
6. Adjust actions if necessary.

It also shows the models, recommendations and tools developed by SO SMART to help manufacturers to progress on this journey.

3 Conclusions

The project has moved from the idea that improving the well-being and performance of human workers in manufacturing must be achievable without sacrificing company success, to a clear vision for future socially sustainable factories and a good idea of the road ahead. The vision that has emerged for the future factories of Europe is to achieve "A socially sustainable and successful manufacturing ecosystem that is good for industry, society and individuals". To aid this journey for the European industry, the SO SMART project partners are pleased to contribute a roadmap for research and education, and 'vehicles' in the form of know-how, definitions, a lecture and report package, pilot scenarios, and measurement methods targeting corporate culture and economic success.

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Determination of Energy Expenditure of Direct Workers in Automotive Harnesses Industry

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Abstract The present research's main purpose is to analyze and develop a table of energy expenditure (EE), for the eight principal operational jobs of the automotive harnesses industry. These are: cable cutting, pressing, manual assembly, assembly on board, taping operation, electrical testing, quality inspection and material handling. Sample size consisted of 65 workers performing similar activities from three industries. Energy expenditure in the jobs studied varies from 2.21 kcal/min ±0.965 standard deviation to 4.24 kcal/min ±1.058 standard deviation. For each job their kcal/min were calculated and a model was constructed that could be used to determinate the energy consumption for those works.

Keywords Energy expenditure · Job description · Heart rate

1 Introduction

The application of ergonomics/human factors has been of interest for several decades. It was during World War II that the field of human factors had more emphasis [1]. In particular, it was found that some military equipment or tools could not be operated efficiently or safely by several people. An effort will be made to try to design workstations taking into account human considerations; the goal is the change of "adapting people to work with to adapting the work to man" [2].

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In relation to human considerations, the interest of some researchers was to determine energy expenditure related to the physical capacity of people. Niebel and Freivalds [3] gathered data on energy use in different types of jobs. One of the first collections is in the investigation by Passmore and Durnin [4] who established measures for energy consumption for different types of human activities, such as walking at different speeds, running, climbing stairs and steps, domestic work and other activities in the iron and steel industry. The relevant information has been adapted and presented by various authors [2, 5] and is still referred to in recent literature [3, 6, 7]. Another study is Bink [8], who based his work on tests of aerobic capacity from Robinson's 1939, according to research from Lehmann 1953 that establishes a standard measure of energy consumption, in order to propose an acceptable calories limit for an 8 h working day.

Likewise, there is an investigation from Humphreys and Lind [9] who defined an information dataset for the energy consumption from the main activities carried out work with different postures and rhythms of work in the mining industry in Britain. Several analyzes resulted in an estimated energy expenditure of 2000 kcal during an average 8-h shift. Among the studies of energy expenditure that have been made, are those related to the construction industry; Abdelhamid and Everett [10] studied 100 workers while performing typical construction activities and obtained the average oxygen consumption, heart rate, and energy expenditure of some activities, concluding that there is a need to promote and apply concepts of ergonomics in the workplace toward improving occupational health and safety in construction industry.

In Italy, the research "Measurement of energy expenditure in a group of construction workers During Work" [11], 10 construction workers were analyzed and they determined and verified the high level of energy expenditure in this industry. Similarly, in the study "Assessing physical strain in construction workforce: A First Step for Improving safety and productivity management" [12], they conclude that the knowledge of the physiological demands is important for analyzing its relationship with safety and productivity.

Most studies have focused on the construction industry, but manufacturing has been absorbing the workforce. For example, in Mexico, more specifically Ciudad Juarez that has 15 industrial parks and about 332 industries engaged in different branches, there are three main categories: first, the industry related to the automotive sector, subdivided into two groups, manufacturing harnesses, making the garment seat; other category is mainly electric-electronics manufacturing electronic boards, capacitors, computers, televisions, alternative systems for aircraft, sensors, solenoids, motors, vacuum cleaners, among other products; finally, there are the companies that make medical products [13]. The automotive harnesses industry is one of the largest in Ciudad Juarez, employing more than 23,000 people [14]. This research focuses on analyzing the current level of energy expenditure of employees who work in the manufacturing harnesses industry on eight different types of direct activities carried out in this industrial branch. Since knowledge and analysis of the measurements of energy expenditure of employees in the automotive harnesses industries provides the Department of Industrial Engineering with tools needed for designing or redesigning workstations, balancing workloads and assuring that the work does not exceed the workers physical capacity and avoiding fatigue. Also, the information can be used to determine energy expenditure, rest times and define appropriate types of food.

2 Methodology

Throughout the years such studies have continued using different methodologies and tools to estimate workloads to measure energy consumption, such as analyzing the maximum oxygen consumption, or by double labeled water test. Both processes are expensive and difficult to apply in industry, however, in this day there a practical tool for measuring energy consumption, namely, Suunto® system a device developed by Firtbeat Technologies, Ltd. This system is used to measure energy consumption in this study. The methodology develops during the research consists of four steps that are described as follows.

2.1 Work Categories

The first step was to determine which categories of direct employees were involved in the different stages of a harness assembly. Those are: (1) cable cutting, (2) pressing, (3) manual assembly, (4) assembly on board, (5) taping operation, (6) electrical testing, (7) quality inspection and (8) material handling. To avoid ambiguity in the categories, a job description was developed for each, in order to

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JOB DESCRIPTION (3)

Job Title: Operator of manual fixture board assembly

Summarized work: Responsible for assembling components in various parts of the product following the working method indicated by the industrial engineering department in compliance with product quality and quantity.

Immediate boss: Production Group Leader
Subordinate: No

Detailed work done: Responsible for assembling components such: as wires, connectors, padlocks, ties, clips, among others. According to the method indicated by the industrial engineering department in compliance with the quality and quantity requirements.
Periodic functions: Cleaning Workspace.

Occasional work: cleaning the work area.

Equipment, tools and materials : Fixture to hold harness; tweezers ties application; cable or hose; etc.

Fig. 1 Job description of manual fixture board assembly operator make comparisons between companies. The contained information is: the job title; summarized work; immediate boss; subordinates; main, regular and occasional activities; equipment, tools and materials used in their activities. Figure 1 shows a job description example for a fixture board assembly operator.

2.2 Sample Size

For this study, 3 of the 11 industries were selected in the manufacture of automotive harnesses in Ciudad Juarez México, which will be identified as A, B and C. We studied 65 workers from eight different types of direct activities, of which 32 were men and 23 women, with the following characteristics: age range between 19 and 60 years; weight from 54 to 101.8 kg; height of 152–179 cm; and work experience from 0.34 to 20 years. In addition, this sample contains six smokers and different personal physical activity level according to Suunto® classification. The sample size was limited because each of the companies determined how many people of each category would be monitored. The numbers of workers provided from each company were: 15 from A, 17 from B and 33 from C. According to type of work, there were 6 workers in category (6); 7 in (1), (2) and (7); 8 in (3) and (6); 10 in (5); and 12 in (4). Table 1 shows a example of the personal data of workers obtained of Company “A”.

2.3 Energy Consumption

Energy consumption data were obtained using the Suunto® system. A chest belt was strapped to the worker containing a memory in which the energy consumption was recorded during the performance of working day activities. After the study, information is recover using the Team Manager Software Suunto®. Table 2 shows the energy expenditure in kcal/min for each worker, sorted according to work type.

Table 1 Example of the personal data of workers obtained of company “A”

Personal data of workers								
N	Sex (M/F)	Age	Weight (kg)	Height (m)	Smokes (Y/N)	Activity level Suunto	Suunto category	Experience (years)
1	M	50	74	1.64	No	1	2	4
2	M	28	80	1.66	No	1	2	2.5
3	M	47	63	1.54	No	1	2	1.5
4	M	35	90	1.70	No	3	2	2
5	F	48	105	1.63	No	0	3	11
6	M	47	89	1.74	Yes	2	1	11
7	M	65	54	1.65	No	1	5	14
8	M	37	75	1.65	No	2	8	8

Table 2 Energy consumption of each worker according to type work

No. job title	Name	Industry	Energy expenditure kcal/min	No. job title	Name	Industry	Energy expenditure kcal/min
1	Fernando	C	2.39	4	Daniel	B	3.26
1	Edén S.	C	2.48	5	Luis G	C	2.51
1	Gerardo.	C	2.79	5	Jesús A.	C	4.15
1	René	C	2.00	5	José L.H.	C	3.37
1	Lorenzo.	C	2.36	5	Manuel.	C	2.08
1	Genaro	A	2.77	5	Juan J.	C	2.81
1	Luis A.	B	2.93	5	José G.	C	2.35
2	Manuela.	C	1.00	5	Marcelino	A	5.03
2	Maria R.	C	1.54	5	Alma	B	3.16
2	Irene G.	C	1.09	5	Inés	B	3.02
2	Ignacio	A	3.06	5	Edith	B	3.12
2	Manuel	A	3.07	6	José R.	C	2.30
2	Eleazar	A	2.80	6	Jorge L.	C	2.67
2	Juan A	A	2.99	6	Jaime L.	C	2.08
3	Ana L N	C	2.73	6	Erick F	C	3.29
3	María C.P.	C	1.32	6	Liborio S	C	2.47
3	María E.G.	C	1.37	6	Higinio L	C	3.65
3	Patricia	A	3.10	6	Marisela	B	2.54
3	Manuela	A	2.63	6	Patricia	B	3.20
3	Jorge	A	2.70	7	Rosa M M	C	2.00
3	Rosa	A	3.01	7	Patricia S.	C	1.46
3	Ismael	A	2.57	7	Socorro	A	2.44
4	Marco A	C	3.16	7	Josefina	A	1.62
4	Rubí A. P.	C	2.20	7	Sofía	B	2.70
4	Miguel S.	C	2.99	7	Karla	B	2.17
4	Verónica	C	2.96	7	Jesús J.	B	3.22
4	Alejandra	C	1.96	8	Jaime N.O.	C	3.96
4	Juan P	C	3.75	8	Leonel V	C	3.06
4	Saúl	B	2.88	8	Alberto	A	5.09
4	Egustacio	B	3.45	8	Juan C	A	2.99
4	Luis A. G.	B	3.11	8	José G.	B	5.02
4	Nahúm	B	2.95	8	Benito S.	B	5.35
4	Javier	B	3.23				

2.4 Data Analysis

Mean, standard deviation and confidence intervals for each of the jobs types were obtained using the program Minitab®. Moreover, the multiple linear regression equations that try to explain the energy expenditure behavior based on weight, height and stature of the employees were determined.

3 Results

Table 3 shows the mean energy expenditure (kcal/min), standard deviation and confidence intervals for each of the jobs.

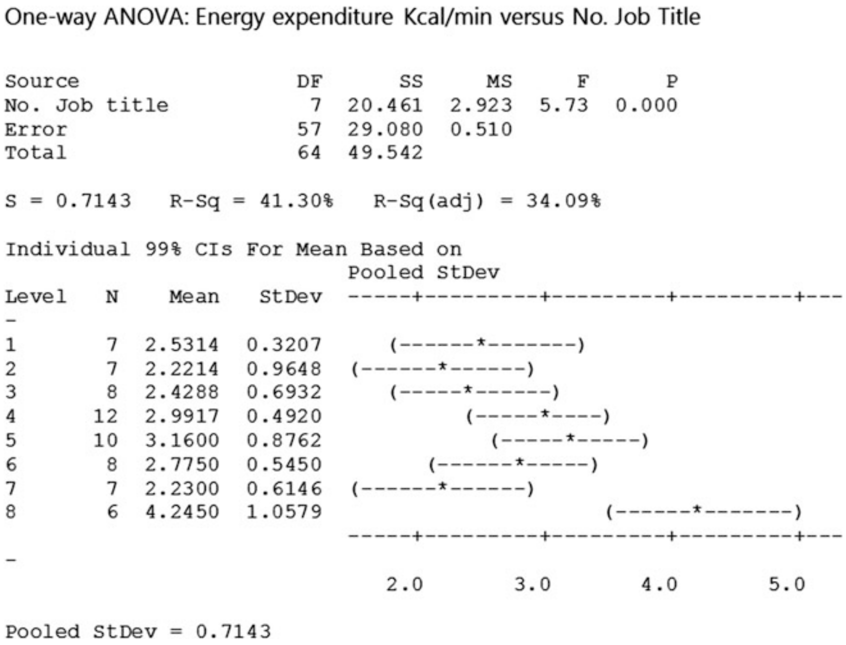
Using the collected workers energy expenditure data in different jobs types an analysis of variance (ANOVA) was made with one factor linear model to test the hypothesis. The hypothesis tested was: are the levels of employees' energy expenditure in the harness automotive industry different and do they vary according to the type of work done. H0: $\mu1 = \mu2 = \mu3 \ldots \mu8$ and H1: At least one pair of mean energy expenditure for each job is different. If the *p*-value $<\alpha$, for this research the significance level was 0.05. Note that in Fig. 2, a *p*-value of 0.000 is lower than 0.05, thus the null hypothesis is rejected because there is enough evidence to say that the energy expenditure of different job types is significantly different.

The assumptions for ANOVA were also verified. The normality was proved using the Anderson–Darling test for residuals, obtaining a *p*-value = 0.347, which is greater than $\alpha = 0.05$, therefore there is not enough evidence to say that the data are not normally distributed. The test of equal variances was also verified with Bartlett's test for residual data, concluding that the variances are not different since the *p*-value = 0.173 > 0.05 therefore there is insufficient evidence to say that the variances are different.

Therefore, we proceeded to explore the differences between the means. These were examined using the multiple comparisons Fisher (LSD) and the results are

Table 3 Statistical data of each type of job title

No./job title	Sample size	Mean (kcal/min)	Standard deviation	IC
1. Cable cutting	7	2.531	0.321	(2.082, 2.981)
2. Pressing	7	2.221	0.965	(0.869, 3.573)
3. Manual assembly	8	2.429	0.693	(1.571, 3.286)
4. Assembly on board	12	2.992	0.492	(2.551, 3.433)
5. Taping operation	10	3.160	0.876	(2.259, 4.060)
6. Electrical testing	8	2.775	0.545	(2.101, 3.448)
7. Quality inspection	7	2.230	0.615	(1.369, 3.091)
8. Material handling	6	4.245	1.058	(2.501, 5.987)



One-way ANOVA: Energy expenditure Kcal/min versus No. Job Title

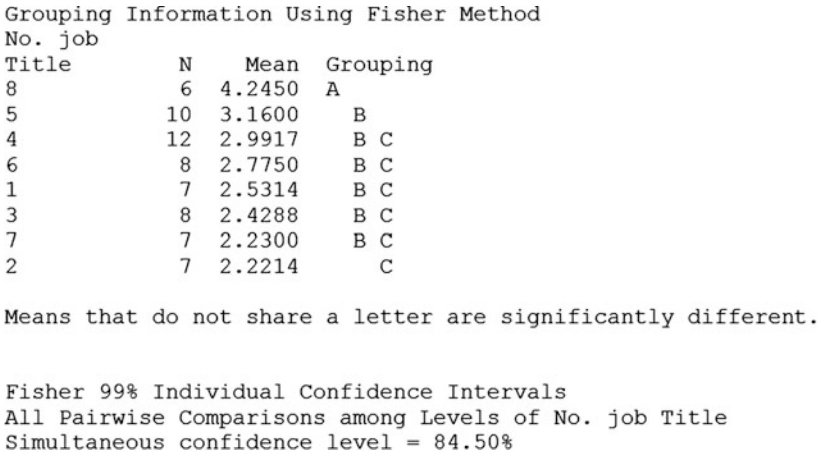
```
Source                 DF      SS      MS     F      P
No. Job title           7  20.461  2.923  5.73  0.000
Error                  57  29.080  0.510
Total                  64  49.542

S = 0.7143   R-Sq = 41.30%   R-Sq(adj) = 34.09%

Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+---
-
1       7  2.5314  0.3207     (------*-------)
2       7  2.2214  0.9648  (------*------)
3       8  2.4288  0.6932     (-----*------)
4      12  2.9917  0.4920           (-----*----)
5      10  3.1600  0.8762             (-----*-----)
6       8  2.7750  0.5450        (------*-----)
7       7  2.2300  0.6146  (------*------)
8       6  4.2450  1.0579                      (------*-------)
                           -----+---------+---------+---------+---
-
                              2.0       3.0       4.0       5.0

Pooled StDev = 0.7143
```

Fig. 2 Analysis of variance (ANOVA) of energy expenditure for job titles



```
Grouping Information Using Fisher Method
No. job
Title        N    Mean  Grouping
8            6  4.2450  A
5           10  3.1600    B
4           12  2.9917    B C
6            8  2.7750    B C
1            7  2.5314    B C
3            8  2.4288    B C
7            7  2.2300    B C
2            7  2.2214      C

Means that do not share a letter are significantly different.


Fisher 99% Individual Confidence Intervals
All Pairwise Comparisons among Levels of No. job Title
Simultaneous confidence level = 84.50%
```

Fig. 3 Multiple comparisons fisher of job means

Table 4 Multiple linear regression statistical data for job groups

No./job title	Mean (kcal/min)	Standard deviation	Normality of data	R^2	Normality residuals
1, 3, 4, 6, y, 7	2.640	0.589	0.467	9.60	0.808
2	2.221	0.965	0.036	55.6	0.112
5	3.160	0.876	0.303	54.3	0.547
8	4.245	1.058	0.179	63.2	0.607

Table 5 Multiple linear regression model for job groups

No./job title	Equations [W = weight (kg), A = age (years) and H = height (m)]
1, 3, 4, 6, y, 7	$-0.40 - 0.00874 * A + 0.0109 * W + 0.0152 * H$
2	$-5.39 - 0.18300 * A - 0.0396 * W + 0.0734 * H$
5	$1.12 + 0.05470 * A - 0.0137 * W - 0.0043 * H$
8	$-9.20 + 0.0737 * A + 0.0097 * W + 0.0601 * H$

presented in Fig. 3. The method identifies four groups of means that include A for job 8, B for job 5, BC for jobs 4,6,1,3, 7 and C for job 2.

Based on the results of the ANOVA and comparisons of means with the Fisher (LSD) method, jobs types according to their means were grouped and a multiple linear regression model were obtained with Minitab®, where behavior energy expenditure is explained using the variables of weight, age and height for different workgroups in a harnesses industry. This is presented in Tables 4 and 5 that shows that for jobs 2, 5 and 8 have an R^2 above 0.5, which is considered the model as a good fit with the described variables, considering, it is a study with people.

4 Conclusions

One of the main conclusions arising from the analysis of this research, reveals that there are differences in energy expenditure required by workers engaged in making direct manufacturing operations for the automotive harnesses industry. The job types analyzed can be grouped according to their means. Also, it can be concluded that the energy expenditure in activities for the industries studied agreed with Niebel and Freivalds [3], according to whom, the limit of energy expenditure must not exceed of (5.33 kcal/min) and (4 kcal/min) for man and woman respectively. However, the activity undertaken by the materialist exceeds the suggested limit for women, based on the limits proposed by Lehmann [15], of 4.2 kcal/min for men and 3.2 kcal/min for women, and thus should not be performed by a woman.

Moreover, knowing the energy expenditure of each job is essential, because with this one can determine if it is causing a work over load or which gender should not realize the work. If energy consumption is exceeded, absenteeism or long term turnover could affect. It also helps determine the caloric diet that the company should provide the worker according to the average energy expenditure required to carry out their activities.

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Managing OHS in Complex and Unpredictable Manufacturing Systems: Can FRAM Bring Agility?

Annick Melanson and Sylvie Nadeau

Abstract Manufacturing environments have become complex and unpredictable socio-technical systems, and now must cope with existing occupational health and safety (OHS) risks as well as anticipate emergent ones. The subject of this study is a new safety management paradigm called resilience engineering. In a dynamic and ever-changing business environment, socio-technical systems are subject to increasing variability. In this article, we propose an application of a new and innovative systemic risk assessment method for the management of emerging risks in the manufacturing environment, namely the functional resonance analysis method (FRAM). Based on the principles of resilience engineering, this method can be used to determine how variability in daily performance could affect the system and lead to desirable or undesirable events. The results showed clearly the importance of using a risk assessment method based on the variability of performance to manage risks emerging from the changing nature of today's manufacturing companies.

Keywords Functional resonance analysis method (FRAM) · Resilience engineering · Risk management · Manufacturing environment

1 Introduction

Since the beginning of the industrial era, manufacturing businesses have had to adapt to rapid changes brought by technological innovation, social progress and the opening of international markets. To remain competitive, they must now innovate and upgrade constantly. As a result, they have become complex and unpredictable

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socio-technical systems in which interaction between persons and the work environment is creating emergent risks for worker health and safety. Businesses must manage these risks proactively, anticipate them, or at least face them with resiliency. The ability to adapt and adjust quickly using the human resources available within the organization has become a major issue for manufacturing businesses.

In recent years, a new paradigm has taken hold in scientific research on occupational health and safety (OHS) management. Called resilience engineering, this concept is focused on improving system resiliency by analyzing the tasks that workers actually carry out on a daily basis. This makes it a proactive approach in comparison with conventional methods of OHS management. Resilience engineering is based on four fundamental principles [1]:

- OHS management cannot be based solely on knowledge of past events and calculation of the probability of system failure. It must also be proactive;
- Descriptions of activities are always under-specified. Individuals and organizations must adjust their ways of functioning to meet the needs of the organization using means that take into account the resources (personnel) available. Given the limits on resources and time, these adjustments are inevitably approximate;
- Some harmful events are attributable to system component malfunction or failure, while others are not. In the latter cases, the cause may be a summation of variability among some combination of operations varying within the performance ranges considered normal;
- OHS management cannot be treated independently of operational activities. Safety is a pre-requisite for productivity and profitability and must not be approached as a constraint but as an opportunity to improve operations.

The variability of human performance is at the very heart of resilience engineering. This variability is due to a variety of factors: psychological, social, environmental, organizational, physiological and technological. In today's context of rapid change, businesses must adapt and adjust constantly, and under such conditions, performance variability becomes the flipside of the flexibility required to ensure the smoothness of operations over time [2]. The following human capabilities come into play:

- Overcoming inevitable glitches such as design flaws and functional flaws;
- Adjusting performance to meet present demands of a situation;
- Interpreting procedures and applying new ones to adapt to current conditions;
- Detecting improper operation or failure and in many cases taking corrective action.

OHS management in today's manufacturing businesses requires methods of monitoring and managing all types of risks to which workers are exposed. Various methods of system analysis are used to identify risks to diminish or eliminate them. While those used in the manufacturing sector differ in approach, all share the characteristic of focusing primarily on the technical system of the organization.

Their main limitation is that they do not consider contextual factors or the impact of these on the occurrence of an undesirable event. Where performance variability is a necessity, these conventional methods do not by themselves provide sufficient understanding of how some accidents occur.

1.1 The Functional Resonance Analysis Method (FRAM)

The subject of the present study is the application of a new risk analysis method that takes into consideration the principles of resilience engineering. Called the functional resonance analysis method or FRAM, this method provides a description of how a system ought to function to meet its various objectives, and understanding of how possible variability of functions, alone or in combination, may lead to an event and hence how to avoid the event or improve system functionality. This is the functional resonance principle.

Numerous applications of FRAM have been published [3, 4]. The results of these studies are conclusive in the sense that FRAM brings a different dimension to the analysis and a way of identifying the types of variability that could be critical to proper system functioning. By taking performance variability into account, the system can be adjusted and adapted to new perturbations and thereby become more resilient.

The aim of this study was to evaluate the application of FRAM as a complement to other risk analysis methods in a manufacturing business. Although this method has been applied successfully in sectors such as health care and air transportation, its added value in terms of risk management remains to be validated in the manufacturing sector.

2 Methodology

This case study was carried out in a manufacturing company established several decades ago in North America. Employing nearly 1000 persons, the company manufactures and assembles transportation equipment intended for clients all over the continent. Since this is a large company, the project was focused on a specific sector of business activity. Following discussion with the managers, the choice of the sector was agreed upon easily for two reasons: it has the most workplace accidents and the greatest variability of human performance. These two criteria fit perfectly with the objectives of our study.

The study focused in particular on vehicle chassis assembly by a team of welders. This operation involves 26 workstations and about 95 welders distributed over a day shift and an evening shift. These employees may be assigned to one or several workstations throughout their shift, depending on demand.

For the purposes of this study, various means of data collection were used. The two principal sources of data were semi-directed interviews and direct field observations at the workstations. Analyses of data in company documents were also carried out I to corroborate the information obtained on the shop floor.

Since the principal goal of the study is to evaluate the usefulness of FRAM as a risk analysis tool in the manufacturing sector, the published methodology was followed [5]. This consisted essentially of the following steps:

1. Identifying and describing the principal functions of the system;
2. Characterizing the potential variability of performance for each of these functions;
3. Defining an overall performance variability;
4. Identifying the consequences of the performance variability.

Experienced welders, team leaders, one process technician, one industrial engineer and one sector supervisor for a total of 11 company employees were interviewed. Through this data gathering process, we developed our understanding and formulated our model of the normal functioning of the system, that is, how it functions in the course of daily activities.

3 Results

Table 1 lists the functions identified during interviews of employees. All of the system functions thus identified are of the human type, meaning that employees perform them. It is this type of function that has the greatest potential for variability.

Table 2 describes one of the system functions in terms of the six aspects of FRAM.

Figure 1 illustrates the nominal model of the system, the model that represents the system as it is supposed to function (work-as-imagined).

Table 1 Principal functions of the system under study

1	Planning the production sequence
2	Coordinating the department tasks
3	Supplying the work stations
4	Providing the assembly procedures
5	Constructing the sub-assemblies
6	Assembling the side (wall) structures
7	Assembling the roof structure
8	Finish assembling the roof structure
9	Finishing the welds
10	Standing the structure up
11	Inspecting the structure

Table 2 Description of the *planning the production sequence* function

Name of function	Planning the production sequence
Description of the function	Production scheduling by the industrial engineering team for each of the workstations within the sector
Aspects	Description of the aspect
Input	General plan of production provided
Output	Production schedule provided
Precondition	Date of manufacture (AM/PM/Evening1/Evening2) known Specifications of vehicles to be produced are determined The materials necessary for supplying the workstations
Resource	Not defined
Control	Not defined
Time	Not defined

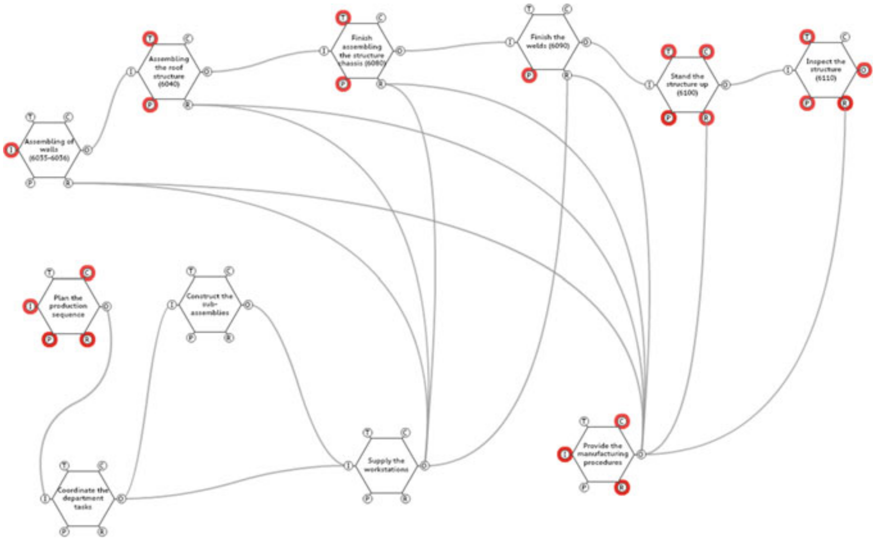

Fig. 1 Graphical representation of normal system functioning

3.1 System Instantiation

Variability of an output can have a functional resonance effect on functions downstream. Instantiations made using the nominal model provide understanding of how output variability will have desirable or undesirable effects on the input to the next function in the chain.

Table 3 Possible effects on the function finish assembling the roof structure

			Variability downstream from the output		
Upstream function	Output/input	Downstream function	Time	Precision	Effects on the function downstream
Assembling of the side (wall) structures	Roof structure assembly incomplete	Finishing chassis assembly	On time	Imprecise	Variability ↑

3.2 Potential Variability of the Function Finish Assembling the Roof Structure

For a variety of reasons, the tasks carried out normally at this workstation are not always completed when the unit advances to the next workstation. For example, a shortage of labor may create some degree of variability in the output from this function. Such shortages may be due to a scarcity of welders or to employee absence caused by illness, workplace accident and so on. This can have repercussions on the system if the company is not able to fill in such absences. In this case, the result might be that it will not be possible to finish the roof structure within the takt time set by the company. Table 3 illustrates how this will have repercussions on the other functions.

A delay in assembling the roof structure due to a labor shortage will force the shifting of certain operations to the next workstation, since the company is working with a takt time of 4 h. The chassis will have to move to the next workstation even if not all tasks are completed. The incomplete tasks will be completed under constraints such as:

- Installation of parts at a workstation other than the proper one;
- Installation of parts by employees working overtime (increased fatigue, distraction, etc.);
- Increased work pace;
- Increased number of workers at a workstation;
- Loss of precision due to worker inexperience at unfamiliar workstations;

4 Discussion

The results obtained by applying FRAM in this manufacturing company demonstrate the importance of taking into account the variability of work performance to ensure the smooth operation of the socio-technical system. To meet the needs of the company, workers adjust their performance as a function of the human resources available. It is clear that this occurs, since this company is seldom late with its production, in spite of frequent absences of welders.

FRAM is not a standalone risk analysis tool, primarily because it does not provide information about all categories of risk, in particular those associated with equipment or machines. In cases where such categories are relevant, FRAM is suitable as a complementary tool to be used in conjunction with a method such as failure mode effects and criticality analysis (FMECA). In the case of the present study, the risks associated with the principal activity (welding) are well documented in the literature and have been analyzed using methods such as FMECA. However, by neglecting the contribution of performance variability to the occurrence of workplace accidents, manufacturing businesses risk continuing to experience certain types of accidents without identifying their underlying fundamental cause. In these cases, managers inevitably conclude that human error is to blame.

Although FRAM offers several advantages over other risk analysis methods used in the manufacturing sector, it nevertheless has some weaknesses. One of the most significant of these is associated with its entirely qualitative aspect. The value of the results obtained is linked closely to the validity of the data gathering methods. The construction of a model for use with FRAM is time-consuming and requires thorough knowledge of the system under study. For this reason, it will not always be the method of choice among practitioners.

There are several limitations on the generalization of the results of this research. To begin with, since this is a case study of application to a single manufacturing company that uses very little automation, it provides little insight into how helpful FRAM would be in a highly automated or robotic setting in which human input is limited and highly specific.

The principal advantage of FRAM in the manufacturing sector is that it allows a company to monitor the yield of its production systems and to make adjustments when deemed necessary. This makes it possible to increase system resiliency and robustness, thus allowing quick adaptation to remain competitive in international markets.

5 Conclusion

Manufacturing businesses need to re-examine their methods of workplace risk management. Many among them still apply a reactive OHS management philosophy based on the concept of human error as an omnipresent factor that is to blame for the occurrence of accidents that are otherwise difficult to explain. They would benefit considerably from taking into account contextual factors and the ways in which workers adjust as resource availability (human or equivalent) fluctuates. This would allow them to adopt a more proactive mode of risk management, one based on the notion that human error is a controllable variable. FRAM meets this criterion.

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Analysis of Line Balance Sound Board Glue Production on Assembly Grand Piano Process: Case Study PT Yamaha Indonesia

Taufiq Immawan and Riyanto Kurniawan

Abstract In the face of increasingly fierce competition every company must make the production process efficient and continuous improvement. One of the ways to make the process efficient production by production line balancing. PT Yamaha Indonesia is a company that performing continuous improvement. The problems that still exist in this company is the balance that is less than optimal production line. Line efficiency sound board glue working group on the actual condition of 47 % and had a total time of 211.91 min idle by the number of work stations as many as 16 stations. The low value of efficiency and high idle time reflects the imbalance of production lines. To resolve these problems used two methods region approach and ranked position weight. Analysis of the balance using the region approach causes increased line efficiency by 76 %, total idle time dropped to 60.86 min and the number of work stations was reduced to 10 stations. Meanwhile, the analysis of the balance of the position ranked weight method can improve line efficiency to 84 %, lowering the idle time becomes 35.67 min and the number of work stations was reduced to 9 stations. It can be seen that the line balancing by using the ranked position weight can be applied to the company PT Yamaha Indonesia.

Keywords Line balance production · Line efficiency · Idle time · Region approach · Ranked position weight

1 Introduction

In the face of increasingly fierce competition, each company is required to always evolve for the benefit of all parties involved inside it. One of the ways that companies can evolve is to improve the performance and production. To achieve this is

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to improve the production process. Improvement of production processes need to be done continuously and constantly so that wastage of material and time can be minimized [1].

The company must still perform continuous improvement to maintain its competitive edge because the company has a variety of limited resources to perform each operation. In the midst of these limitations, companies are required to produce and submit products that are superior in terms of quality, flexibility, speed, and price (cost reduction) [2]. To fulfill this, the required effective production process. Effectiveness of a production system not only seen on the working methods, but also from the production line balancing [3]. Various ways have been done by some companies to balance the production line in order to smooth production process running smoothly. Ranging from small companies and large, have improved the balance of production lines, including large companies such as Yamaha corporation.

Yamaha Corporation is a company name that is well known worldwide as a producer of motorcycles and musical instruments that have been stood since 1887. One branch of Yamaha corporation is PT Yamaha Indonesia engaged in world of music that produces piano with two types are Grand piano and Upright piano. In the production process of the piano, the main material in the form of wood need some group work station in accordance with the model and eventually became a qualified piano.

To maintain quality and increase production, until now PT Yamaha Indonesia is still working to implement continuous improvement and continuously at each work stations. Because the production process piano each work stations, has a dependency with other work stations, then each work stations, needs to make improvements. No exception to work stations, at the sound board glue. In the Sound board glue work station there are several stations and several operator working on different processes. However, any process related to each other between one and the other so that the smooth the production process is strongly influenced by the balance line of work stations, and the number of work stations. The efficiency of each station and high idle time is still a problem that often happens at this station so that the production process becomes less than the maximum. Therefore, this study aimed to do a sound board glue line balancing, improve the efficiency of the assembly line at the Piano GP at the sound board glue, and reduce the idle time on the sound board glue.

In research conducted by Kusumaningtiyas (2012) entitled “Application of Line Balancing To Achieve Target Daily Production Rate And Simulation To Know Production Bottleneck On Dvd Player”, also found similar problems as the low level of efficiency and a high level of bottleneck line. The delay in the production process at the beginning of the station will lead to the next station idle. This can occur due to several factors, one of which is the workload at the station late still higher compared to the next station. In addition, the number of work stations, also affect the speed of the production line due to the greater number of work stations,, the more time it takes to transport (handling) the material.

2 Literature Review

The term balance of line or called balancing is a method of assignment of a job into work stations that are interrelated in a single production line so that each station has a time not exceeding the cycle time from the work stations [4].

2.1 Measurement Working Time by Time Stop (Stopwatch)

In the context of work measurement, stopwatch time study methods is a work measurement technique using a stopwatch as a measure of time indicated in the completion of activity was observed (actual time). Time successfully measured and recorded and then be modified taking into account the tempo of the operator and add it to allowances. There are three methods commonly used to measure the work elements by using a clock-stopping (stopwatch), the measurement of time continuously, repeatedly measuring time, and the measurement of time is a summation [5]. In this study, the measurement of working time with a stopwatch is used repeatedly (repetitive timing). The measurement of time of completion of a processing started since the first movement until the work was completed (called a cycle) and is repeated until sufficient statistical measurement.

From the measurement results obtained in this way will the standard time to complete a work cycle, then this time will be used as a standard completion of work for all workers who will carry out the same work.

The formula used to determine the number of measurements to be performed in this study are:

$$N' = \frac{\frac{Z\propto}{a}\sqrt{N(\sum Xi^2) - (\sum Xi^2)^2}}{(\sum Xi)} \tag{1}$$

where

N′	number of measurements/observations that should be implemented
N	the number of preliminary measurements have been done
Xi	the turnaround time measured at the ith observation
Zα	α: 5 % → Zα = 1.96
a	level of precision or accuracy

2.2 Calculation Standard Time

The standard time is the length of time required by a skilled worker to complete one cycle of work in normal speed is adjusted by an adjustment factor and factor allowances given to finish the job [6]. If the data have been sufficient condition N1 < N, then phase calculation to derive the value of the standard time job is as follows:

1. Calculate the cycle time by:

$$Ws = \frac{\sum X_i}{N}$$

2. Calculate the normal time by:

$$NT = Ws(1 + Rating\ Factors)$$

3. Calculate the standard time by:

$$ST = NT(1 + Allowance)$$

To determine the value of rating factors, can be done by providing value adjustment factor for factor that working. The factors assessed are as follows:

1. *Skill*
2. *Effort*
3. *Consistency*
4. *Condition*

And for values of the allowances is done by providing value factor allowances for workers based on factors that affect the operators work. Allowance factors afforded views of the following things:

1. Personal Needs
2. Environmental conditions
3. Labour Issued
4. Work Attitude
5. Work Movement
6. Eye Fatigue
7. Temperature Workplace.

3 Ranked Position Weight Method

Ranked Positional Weight (RPW) method is the earliest heuristic developed. This method was developed by Helgeson and Birnie. How to determine the weight of precedence diagram starting from the end of the process. RPW = Weight of the operation processing time + time processing operations that follow. Grouping operations into a work station on the basis of the order of RPW (from the largest) and also noticed a barrier of cycle time and work stations predecessor.

Steps to resolve by using Ranked Positional Weight (RPW) are as follows [7]:

1. Calculate the desired cycle time. The actual cycle time is the desired cycle time or the operating time greatest if the largest operating time was larger than the desired cycle time.
2. Create a precursor matrix based networks docking.
3. Calculate the weight of the position of each operation is calculated based on the amount of time the operation and the operations that followed.
4. Ordering operations start from the position of greatest weight to the weight of the smallest position.
5. Perform the workload of operations at the work station operating with weights from the largest position until the weight of the smallest position, with the criteria of total operating time is smaller than the cycle time.
6. Calculate the average efficiency of the work stations are formed.
7. Use the procedure of trial and error to find the workload that will produce an average efficiency is greater than the average efficiency in step 6 above.
8. Repeat steps 6 and 7 until no longer found work station that does not have an average efficiency higher.

4 Region Approach Method

This approach involves a tradeoff between job after the initial balance is obtained. This approach is not feasible for large networks and a combination of work that can be exchanged can be stiff. OPC is essentially transformed into a precedence diagram with the steps—steps as follows [8]:

a. Make precedence diagram.
b. Dividing operations in precedence diagram in some regions/areas from left to right with the requirements in the plan should not be operating interdependent. Accumulate all the work to the precedence of the last region. This will ensure that job with little dependence on at least considered for the final job in the schedule.
c. In each of the region a sequence precedence from the maximum job time to the minimum. This will assure the greatest work will be considered first, provided an opportunity to obtain a better combination with the jobs that smaller.
d. Accumulate jobs in the following order:
e. At first, leftmost region.
f. In an region initially performed the greatest job.
g. Classify operation in work stations, based on the terms which may not exceed the specified cycle time. At the end each of the work station, decide whether the use of time is acceptable, if not, check all job that has precedence relationships. Determine whether the use will increase when the exchange with the work being considered. If yes, do the exchange.

h. Continue until all the elements of the work are placed on all work stations.
i. Compose pattern of the production flow.

5 Research Methodology

5.1 Object of Research

This research was conducted in the sound board glue PT Yamaha Indonesia is located in the Industrial Area Pulogadung Jln. Rawagelam I/5 Jakarta 13930.

5.2 Data Source

The data used in this study are primary data and secondary data, both qualitative and quantitative. The primary data obtained through observation and interviews with the company mainly to the head of sound board glue section. Data retrieval starts from the beginning of November until the beginning of December 2015. Primary data were obtained, include:

a. Production process cycle time of each work station.
b. number of operators
c. The number of work stations
d. Production process flow
e. Balance the current line condition.

Secondary data is data that the company itself along with the literature data, research results, articles and journals. The data required are:

a. A brief history and organizational structure of the company.
b. Production capacity data.
c. Production planning data.
d. Effective working hours.
e. Schedule weekdays.
f. Table rating factors.
g. Journals, articles, and research results on the theme line balancing.

5.3 Data Processing Method

Once the data is obtained then performed data processing. The stages of data processing is carried out as follows:

a. Calculating the cycle time.
   After getting the cycle time, the first thing to do is to calculate the total time and average cycle time—average each work station.
b. Sufficiency test data.
   Test the adequacy of the data was conducted to prove that the data collected is sufficient. By searching for values N′ provided that the data is already sufficient if N > N′.
c. Uniformity test data.
   Data uniformity test was conducted in order to identify their data far away from the average is actually due to the data that is too large or too small. From the data obtained control limits will be tested, so that data can be said to be uniform if it is between the control limits. The control limits are divided into two, namely the Upper Control Limit (UCL) and Lower Control Limit (LCL).
d. Calculation of normal time.
   Normal time calculation is a calculation of time when operators start to finish the job without any interference, so penyelesaian job in a normal pace.
e. Calculation of standard time
   Calculation of standard time is a computation of time in which the normal time job multiplied by a factor predetermined allowances.
f. Balancing the production line.
   Balancing the production line is done in several stages:

   1. Perform the assembly line balance calculations initial conditions.

Table 1 Normal time and standard time

No.	Proses	ws	wn	wb
1	Planner *Back post*	2.2	2.31	2.54
2	Pengolesan kilsta	3.52	3.69	4.06
3	Press *Back post* Block	3.18	3.34	3.67
4	Cat Frame Support	0.53	0.54	0.6
5	Proses Pertama Arimizo 1	22.45	22.9	25.19
6	Proses Pertama Arimizo 2	20.53	21.76	23.94
7	Moulder	2.71	2.77	3.04
8	Proses Kedua Arimizo 1	14.1	14.38	15.82
9	Proses Kedua Arimizo 2	18.18	19.27	21.19
10	Planner Barbelt	4.65	4.88	5.37
11	Cukur dan Coak *Back post*	21.14	22.19	24.41
12	Proses Pasang Middle Beam	9.39	9.86	10.84
13	Proses pengecatan bagian dalam *back post*	4.05	4.33	4.77
14	Proses Crown	9.59	10.26	11.29
15	Proses Bokaki	9.11	9.75	10.73
16	Proses Press dan Buka Press	20.78	21.4	23.54
Total		166.1	173.63	191

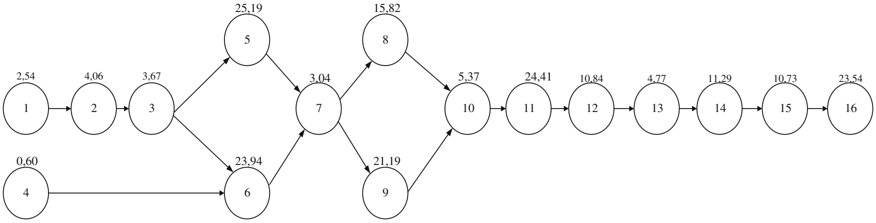

Fig. 1 Precedence diagram initial condition

2. Once you know the condition of the initial state assembly lines, line balancing will be performed by two methods: the method ranked position weight (RPW) method and the approach area (region approach) (Table 1, Fig. 1).

6 Research Results

6.1 Initial Conditions

At the initial conditions are 16 work stations and a cycle time of 25.23 min. From the calculations have been done the results obtained, namely the efficiency of the work station 1 by 10 %, which means at Station 1 only using 10 % (2.54 min) of the total available time (25.23 min) for one-time production process and so Similarly to the next station. At the work station 2 by 16 %, work station 3 by 15 %, work station 4 at 2 %, the work station 5 by 100 %, work station 6 by 95 %, work station 7 by 12 %, work station 8 by 63 %, work station 9 by 84 %, work stations 10 to 21 %, work station 11 amounted to 97 %, work station 12 by 43 %, work station 13 by 19 %, work station 14 by 45 %, work station 15 by 43 %, and 16 work stations by 93 %. Total idle time of 211.97 min meaning of the entire work station, there are still idle time of 211.97 min or 3.53 h occurs because division of labor is still uneven. The efficiency of production lines by 47 %, which means the level of efficiency—average of the overall work station that is only 47 %. Balance delay by 53 %, which means the entire work station are idle 53 % of the total time available. Smoothness index of 63.58, which means the waiting time rate relative who happens to all stations at 63.58 while balancing to achieve a perfect (perfect balancing) level relative waiting time is 0.

6.2 Region Approach Method

With this method the work stations will be combined in accordance with the respective regions—each with terms not exceeding cycle time and cycle time that is

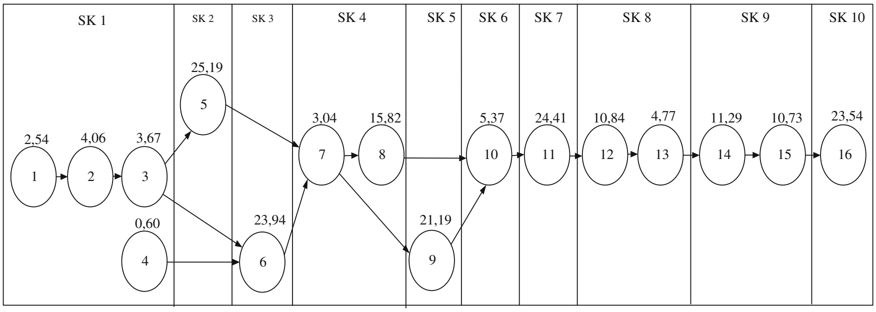

Fig. 2 Precedence diagram region approach

used together with the initial condition that is 25.23 min. From the result of the merger the number of work stations obtained work station is 10 stations. With details of the merger are the work station 1 consists of SK 1, 2, 3, and 4, at the work station 2 consists of SK 5. At work stations 3 consisting of SK 6, at the work station 4 consists of SK 7 and 8, at station working 5 consists of SK 9, at the work station 6 consists of SK 9, at the work station 7 consists of SK 11 at the work station 8 consists of SK 12 and 13 at the work station 9 consists of SK 14 and 15 at the work station 10 consists of SK 16 (Fig. 2).

The result of the calculation of the efficiency of each station is a work station 1 by 43 %, which means at the work station 1 using 43 % (10.87 min) of the total available time (25.23 min) for one-time production process and so is the next station, work station 2 at 100 %, work stations 3, 95 %, work station 4 by 75 %, work station 5 by 84 %, work station 6 by 21 %, work station 7 at 97 %, work station 8 by 62 %, the station 9 employment by 87 %, 10 work stations by 93 %. Total idle time amounted to 60.86 meaning of the whole work stations there are still idle time of 60.86 min, or 1.02 h occurs because the division of labor is still uneven. Line efficiency by 76 %, which means the level of efficiency—average of the overall work stations there by 76 %. Balance delay by 24 %, which means the entire work station there are 24 % idle time of the total time available. Smoothness index of 27.52, which means the waiting time rate relative who happens to all stations at 27.52 while balancing to achieve a perfect (perfect balancing) the relative level of the waiting time is 0.

6.3 Ranked Position Weight Method

With this method the work stations will be combined in accordance with the weight of each position—each work station provided this does not exceed the time cycle time and cycle time that is used together with the initial condition that is 25.23 min. From the results obtained merging work station work station number is 9 station. With details of the merger are the work station 1 consists of SK 1, 2, and 3, at the

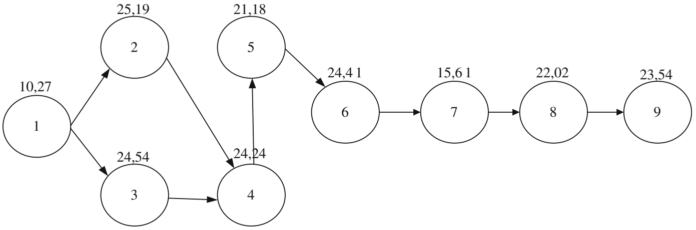

Fig. 3 Precedence diagram ranked position weight

work station 2 consists of SK 5. At work stations 3 consisting of SK 4 and 6, at the work station 4 consists of SK 7 and 9, at station 5 work consists of SK 8 and 10 at the work station 6 consists of SK 11 at the work station 7 consists of SK 12 and, at the work station 8 consists of SK 14 and 15 at the work station 9 consists of SK 16 (Fig. 3).

The result of the calculation of the efficiency of each station is a work station 1 by 41 %, which means at the work station 1 using 41 % (10.27 min) of the total available time (25.23 min) for one-time production process and so is the next station, work station 2 at 100 %, work station 3 at 97 %, work station 4 is 96 %, work station 5 by 84 %, work station 6 by 97 %, work station 7 by 62 %, work station 8 by 87 %, and work station 9 by 93 %. Total idle time amounted to 35.67 meaning of the whole work stations there are still idle time of 35.67 min, or 0.6 h occurred because the division of labor is still uneven. Line efficiency by 84 %, which means the level of efficiency—average of the overall work stations there by 84 %. Balance delay by 16 %, which means the entire work station, there are 16 % idle time of the total time available. Smoothness index of 18.57, which means the waiting time rate relative who happens to all stations at 18.57 while balancing to achieve a perfect (perfect balancing) level relative waiting time is 0.

7 Conclusion

From the research that has been done it can be concluded as follows:

By performing balancing of sound board glue production line then found the number of work stations on the initial conditions as many as 16 stations. After the line balancing, it is known that the number of work stations minimum of 8 stations. By using the method of region approach balancing the number of work stations to 10 stations and the balancing weight using the ranked position into a number of work stations 9 stations. Both methods can be seen that the method of weight is more optimal position ranked as the number of work stations closer to the minimal number of stations.

From the calculation of initial conditions, the calculation region approach, and ranked position calculation weight, the percentage of line efficiencies gained by 47, 76 and 84 %. So it can be seen that by using the method of region approach line efficiency increased by 29 %. While the method of weight ranked position line efficiency increased by 37 %. With line balancing has been done can reduce the idle time and the reduced amount of idle time is as follows: Total decrease in idle time by region approach, which amounted to 151.11 min of the initial conditions. Total decrease in idle time with the ranked position weight of 176.30 min of the initial conditions.

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Part VI
Organization Design and Management

Information and Communication Technologies Supporting Fuzzy Knowledge Management

Joanna Kałkowska

Abstract Information and communication technologies are the one of the key factors connecting technological progress and the globalization process in creating the knowledge-based economy, as well as in the context of enterprise development. Information and communication technologies are crucially important in achieving the concept of efficient knowledge management in enterprise. One of the main roles of information technology in knowledge management is to support the process of knowledge transfer and creation. These technologies also help the processes of collecting and organizing the knowledge in order to make this knowledge available for all potential users. This paper presents a general concept of information and communication technologies supporting knowledge management with the use of some fuzzy sets theory.

Keywords Knowledge-Based enterprise · Fuzzy sets · Knowledge management · Information and communication technologies

1 Introduction

Currently, the enterprises are searching for competitive advantage concerning quality of products, application of modern information and telecommunication technologies (ICT), implementation of modern concepts and tools of management as well as proper support of decision making process and knowledge management. To achieve this, enterprises need to possess the ability of the knowledge potential proper usage because widely understood enterprise's development is connected both with the permanent wining, transformation and usage of knowledge and information. This approach allow for the enterprises transformation into the knowledge-based enterprise. The goal of this paper is to determine a fuzzy sets

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theory to the knowledge management supported by the use of Information and Communication Technologies (ICT). The knowledge is the key resource of the organization. The efficient usage and knowledge implementation is possible through the information technologies application that allows both the knowledge codification and dissemination. Specifics of knowledge-based enterprises define needs in the new management approaches to be used by ICT. Such approach based on fuzzy sets theory supported by the information and communication technologies allows to create new kind of managerial decision addressed to the knowledge-based organizations.

2 Knowledge Management and Knowledge-Based Organization

The widely understood knowledge became a fundamental driver of increased productivity and global competition. Knowledge is also the most valuable source of competitive advantage as well as it is considered to be the prominent resource of enterprise in terms of its contribution to the value added and its strategic significance [1]. However, the dominance of the knowledge in the social and economic life resulted in the nineties of the 20th century with introducing into the economic theory and practice is the concept of "knowledge based economy" or so called "modern economy". Ambiguity in understanding the knowledge based economy causes that many sets of features with different degree of accuracy are being used in descriptions of this phenomenon. The classic definition presented in 1996 by the OECD shows a knowledge-based economy as an economy which directly is based on the production, distribution and using the knowledge and the information [2]. Knowledge is treated here as a fundamental driving force of the economy, as a factor stimulating to progress.

Taking into account the wider meaning of the knowledge economy development, it can be state that it is mainly connected with the two premises. First of it is connected with the growing importance of the knowledge as a dominant resource of social and economic development—the development of the information society, the growing importance of intellectual capital and the development of information and communication technologies (ICT) an their increase in the efficiency of their use in society favoring processing and management of knowledge resources. The second one is focused on the intensive growth and dominance in the economy processes causing an increase of the knowledge importance while undertaking the management decisions. Among them, the most important are the following: focus on the customer, the globalization of markets, turbulence, the changeability and uncertainty of the environment which requires the changes, flexibility and innovations as well as the intensive usage and development of information and communication technologies (ICT) in management processes and while undertaking the management decisions. According to this, it have to be considered that one of the most important factor of socio-economy development as well as improvement of competitiveness became an enterprise's transformation into requirements of knowledge based economy. The enterprises are searching for competitive advantage concerning quality of products, manufacturing costs, time of launching products, application of modern information technologies and using actual and valuable information. To achieve this, enterprises need to possess the ability of the knowledge potential proper usage because widely understood enterprise's development is connected with the permanent wining, transformation and usage of knowledge and information [3].

Summarizing the characteristics of the assumptions of the knowledge-based economy related to the organizations, it is possible to recognize the following features of knowledge-based organizations [4]:

- The structure of resources and investments in immaterial sources which constitute the majority element of the organization's market value. In particular it is about an intellectual capital which includes human capital (people and their knowledge, abilities, values, norms, attitudes, opinions, emotional intelligence, etc.), structural capital understood mainly as an organizational capital, created by the processes, internal and external, used methods, software, databases and documents; customer capital created by customers and intellectual property, including patents, licenses, copyright, trademarks, projects, etc.
- Knowledge management understood as conscious and intentional knowledge management, including aspects of strategy, structure, culture, technology and people. Shaping the relation with the environment using one's knowledge to get the beneficial localization in the economy network. It is a base of the knowledge transfer from the organization's environment, confronting with own knowledge and creating new knowledge resources.
- Organizational structure characterized by the high flexibility, openness for environment in frames of network and virtual structures, the broader exploitation of temporary teams and forming positions or teams for the knowledge management.
- Organizational culture adapted for the new conditions and supporting the knowledge management (intellectual programs of people behaving supporting knowledge creation and transfer, learning culture, team working as well as the mutual confidence in human relationships).
- Specific roles and scopes of people work. Widening the range and scope of people activities as well as the pressure on the initiative and searching for the system improving possibilities.

These features are certain aggregate definitions with the unclear border. For example, the sixth feature: specific roles and scopes of people work seem to be a part of the fourth feature: organizational structure. It is also obvious, that it is not only point of view, and intellectualizing of variables being characteristic of an examined object depends on a view point and the purpose of research. The existing diversity of the concept is a natural consequence of the system approach to the scientific researches. The whole of descriptions of the object from the different viewpoints gives the quite comprehensive image. The described above set of six categories of the knowledge-based organization has the model character containing features universally recognized of such an organization [5]. The set of listed features of the knowledge-based organization can be also considered with the co-management assumptions, specially while decision-making in a process of co-management adaptation [6].

The knowledge is the key resource of the organization. It is included in a potential of human capital working for the organization. The factors determining and characterizing the functioning of the knowledge organization can be divided into those that result from the internal structures of the organization and those that results from the relationship with the environment. The most important intra-organizational factors are the following: the growing importance of intangible assets and available knowledge and information resources, the changes in demand for the new knowledge, the employees skills and competences, the specific roles and work scope of employed personnel as well as the use of ICT technologies in widely understood management processes. Among the external-organizational factors it can be distinguished as follows: the level of changeability and unpredictability of the environment, innovation economy, IT systems, the economy saturation with ICT technologies as well as human capital development [7].

3 Knowledge Management, Information and Communication Technologies and Decision-Making Process

Knowledge management is essentially considered as the process of capturing tacit knowledge and transforming it into explicit knowledge. Tacit knowledge is understood as a collection of person’s beliefs, perspectives, mental modes and intuition. Explicit knowledge is deliberated as a formal knowledge that can be articulated through language, symbols and rules [8]. While creating new knowledge, we have to take into consideration the process of conversion of tacit knowledge into explicit knowledge. This conversion is a process (SECI model) which consist of four following phases:

- socialization (process of conversion tacit knowledge into new tacit knowledge through shared experience),
- externalization (process of conversion tacit knowledge into explicit knowledge),
- combination (process of conversion explicit knowledge into more systematic explicit knowledge), and
- internalization (process of conversion explicit knowledge into tacit knowledge) [9, 10].

Table 1 Recommended fuzzy scale for linguistic variable concerning ICT support in knowledge management and decision making

ICT technologies (n)	Knowledge conversion phases	Weights	Scale
E-mail, mailing lists	SOCIALIZATION	Very important	> 0,75
Bulletins		Important	0,5–1,0
Chats, discussion forums		Moderately important	0,25–0,75
Communicators		Not very important	< 0,5
Video-conferences			
E-learning	INTERNALIZATION	Very important	> 0,75
Workflow systems		Important	0,5–1,0
Data management systems		Moderately important	0,25–0,75
Search engine		Not very important	< 0,5
Text mining			
Web mining			
Semantic web	EXTERNALIZATION	Very important	> 0,75
Knowledge ontologies		Important	0,5–1,0
Systems of categorization and taxonomy		Moderately important	0,25–0,75
Content management systems		Not very important	< 0,5
Data management systems			
Groupware			
Knowledge conversion technologies	COMBINATION	Very important	> 0,75
Competitive intelligence		Important	0,5–1,0
Electronic data management		Moderately important	0,25–0,75
		Not very important	< 0,5

Source own study

Each of the above SECI phases can be supported by the information and communication technologies (Table 1) both while creating tacit knowledge and its gathering as well as make it available to the users. Socialization is supported by technologies which facilitate creating and knowledge share. These are tools enabling communication and e-discussion, video-conferences, groupware, etc. Externalization is focused on technologies which size personal knowledge of workers, customers, suppliers and change it to the knowledge comprehensible for whole organization. The most important are Content Management Systems. Separate category of externalization ICT support constitutes Semantic web and Knowledge ontologies. The goal of Semantic web is to cause creating and distribute the standards of Internet contents descriptions in a way enabling autosearch, transforming and content transfer by determining its semantic. Ontologies concerns abstractive and formalized description of reality fragment. They enable for

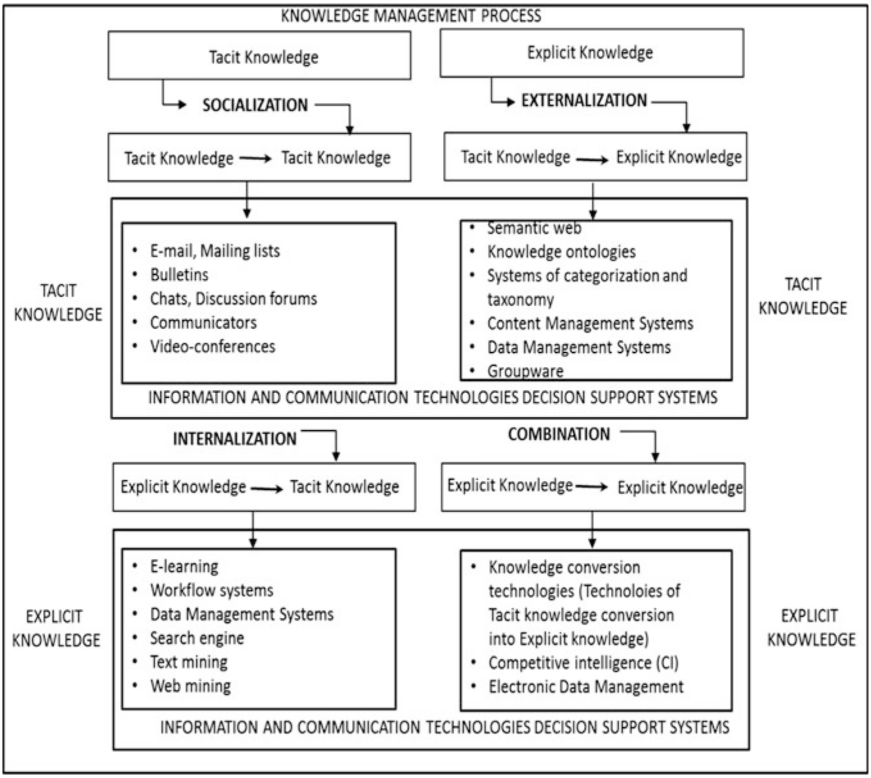

Fig. 1 Knowledge management process supported by ICT DSS *Source* own study on the basis on: 9, 11

transforming and transferring knowledge between different internet applications. Information technologies support concerning internalization are mainly dedicated to the use of explicit knowledge acquired in practice which results in forming tacit knowledge. This favours to utilize explicit knowledge contained in data management Systems, Workflow systems or Team work systems [9]. Combination process of the knowledge conversion is concentrated on Competitive intelligence tools (CI). Their goal is to feed the organizational decision process with information about the organizational environment in order to make possible to learn about it and to take better decisions in consequence. CI depends heavily on the collection and analysis of qualitative information [11] (Fig. 1).

At present, modern market offers quite huge amount of technologies and tools supporting tacit knowledge management. The enterprises need to decide what kind of software and dedicated tools are most appropriate to support and improve work of their employees, rising their efficiency and functioning. However, it have to be taken into account, that the implementation process of different tools supporting knowledge management will required particular approach to their integration. This is a quite huge challenge for the people who are responsible for these systems selection and purchase. The workers should carefully think over to make this purchase conscious and efficient as it is the most important for supporting knowledge management and decision making processes in enterprise.

ICT have also a very big impact on process of making of managerial decisions on every step proposing standard or adopted procedures and techniques. Nevertheless, the standard ICT decision making procedures to support knowledge management in enterprises can't be easily applied. The well-known attitudes to the decision making process may identify the following steps: (1) Identification of the problem and goal setting, (2) Information gathering, (3) Alternative decisions development, (4) Choice of the decision based on the criteria formulated, (5) Decision implementation and control, (6) Results valuation.

Actually, to make an effective decision, every step needs to be changed since it's necessary to use decision making tools adequate to the object to be managed. It's necessary to intellectualize these ICT procedures by involving into decision making an experience of managers. There are few tools allowing to incarnate human experience into ICT procedures. Such a tool which got a title of fuzzy sets theory was proposed by Zadeh [12].

4 Fuzzy Set as a Tool of the Knowledge Management—Concept of Application

The idea of the assessment of the ICT importance for the process of knowledge management can be based on fuzzy sets theory. A similar method was presented to describe the case of strategic management process in enterprise [13]. However, a lot of different applications of fuzzy sets theory were proposed for different managerial, economic and engineering tasks [13]. Nevertheless, there are few researches devoted to application of fuzzy sets for knowledge management and decision making. A lot of different applications of fuzzy sets were developed which proved the reliability of this tool. Generally speaking, a real fuzzy number N $[\alpha, \beta, \gamma]$ is an interval around the real number β with the elements in the interval being partially present. $\mu_N(x)$ is $\Psi_1(x)$, if $\alpha \leq x \leq \beta$, is $\Psi_2(x)$, if $\beta \leq x \leq \gamma$, and is 0, otherwise [1]. The partial presence of an element is defined by membership function μ_N (β): $\rightarrow$ [0, 1], where [0,1] means $0 \leq \beta \leq 1$. The other way to describe fuzzy set N including membership function is the following: $N = \{\beta, \mu_N(\beta)\}$.

Because of the complexity of the problem, this paper presents a concept to this approach focusing on ICT supporting knowledge management. To achieve this, some experts from enterprise were involved in a process of information technologies validation supporting knowledge management. The concept of this process is presented in Fig. 2.

Generally, the presented idea of the assessment of the ICT importance for the process of knowledge management is further developed and consist of few step. In

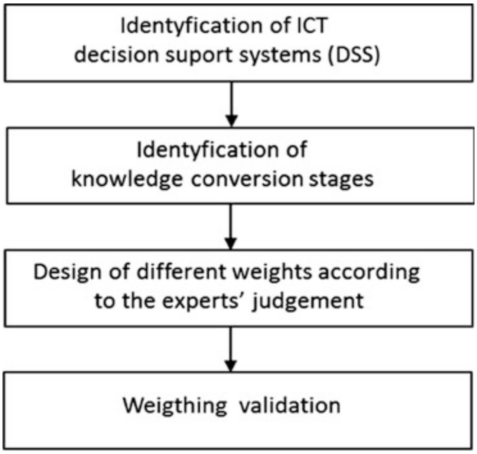

Fig. 2 The concept of ICT weighting validation *Source* own study

the first step, general knowledge about knowledge management and ICT supporting this process from the literature was acquired. In this step, the model of knowledge conversion as well as fundamental ICT technologies for knowledge management were defined. In the second step, the ICT were assigned to the particular knowledge conversion phases. In the following step, the weight of linguistic scale were defined and the experts were asked to assess the ICT importance according to the acquired scale. Then, on that basis, the experts' judgement is presented as a model of membership functions.

The most convenient way for experts to decide about the importance of ICT supporting knowledge management in enterprises is to use the linguistic scale as proposed:

1. ICT are very important while supporting knowledge management and decision-making in enterprise
2. ICT are important while supporting knowledge management and decision-making in enterprise
3. ICT are moderately important while supporting knowledge management and decision-making in enterprise
4. ICT are not very important while supporting knowledge management and decision-making in enterprise

There are an essential number of tools for external analysis. However, top managers of an enterprise, as experts, may use any of the proper tools for correct and comprehensive assessment. Thus, the main task is to transform qualitative results of an assessment located on a linguistic scale into quantitative figures; to digitalize it. The idea of digitalization rests on fuzzy sets theory. To formalize information gathered from the experts' judgment, expressed in linguistic scale, the fuzzy sets approach is used. Fuzzy sets makes possible to formalize the experts' knowledge by providing them with information in the form of linguistic scale, when

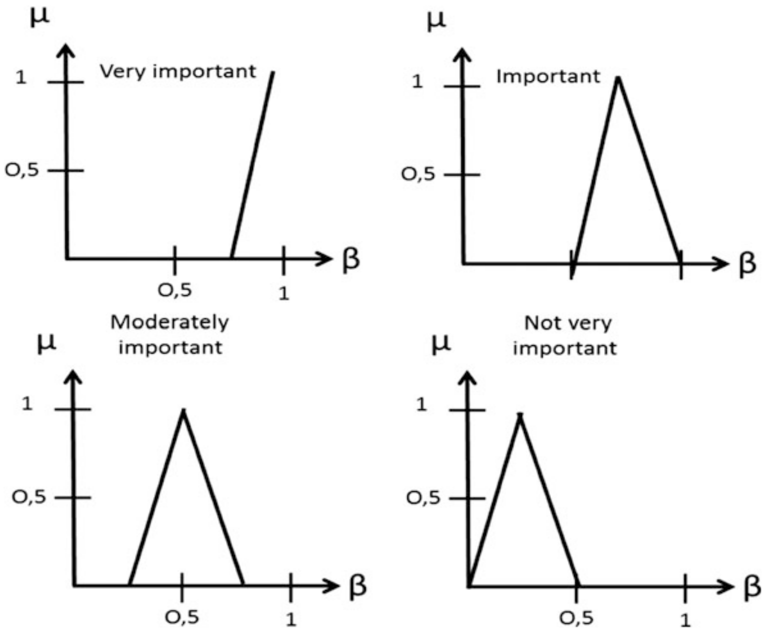

Fig. 3 The models of membership functions *Source* own study

it is impossible to get numerical data [14]. To perform such analysis, the fuzzy rule can be characterized by a weight. In this paper, the weights of the rules are expressed by the experts in terms of linguistic scale according to the importance of the ICT supporting knowledge management and decision making. Therefore, fuzzy linguistic variables were used as in Table 1.

Taking into account the use of a normalized fuzzy set, it can be received the following ICT importance presented as a model of membership functions for fuzzy sets. Figure 3 illustrates the factor's weight function where β is the factor's weight and μ represents the degree of membership in the fuzzy sets (Very important, Important, Moderately important, Not very important).

As stated [15], all fuzzy sets theory applications are to be proved by a practice. This particular concept of fuzzy sets application is not an exception. Only the comparison of results of modelling with practice can prove how well this model works in the real practice in the process of ICT support importance in knowledge management and decision making. A limitation of this concept is connected with the number of experts involved in assessment of ICT importance and the number of factors taken into consideration by the experts. A simplified model of such judgement is described in this study, based on a model of a few experts proposing an agreed opinion.

5 Closing Remarks

The efficient usage and knowledge implementation is possible through the information technologies application that allow both the knowledge codification and dissemination. The information technologies are a critical factor for the effective operation and prosperity of modern organizations. Moreover, ICT are considered as a one of the most important factors of modern enterprises development and competitiveness. ICT usage influence also on a number of indicators allowing for competitiveness estimation. Furthermore, thanks to the information infrastructure and proper software it is possible a quite fast coordination of all tasks carried out in enterprise. Besides, one of key factors of enterprise's management system is including information technologies into widely understood decision making and knowledge management processes. In that meaning, these technologies are treated as one of determinants of enterprises' transformation into knowledge based economy, enabling not only for increasing but also for creating of new organizational knowledge. Information technologies may dramatically enhance the coordination and control capacity of the enterprise, so that way can stimulate increased use of management system. There are many methods supporting knowledge management process, however the use fuzzy sets develop the combination of information and communication technologies capabilities and present it in a qualitative way. In fact, fuzzy logic provides an effective conceptual framework for dealing with some uncertainty.

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Agility of Knowledge-Based Organizations

Hanna Wlodarkiewicz-Klimek

Abstract Uncertainty and volatility of the environment in which modern enterprises need to operate require management concepts and methods to be continually monitored and adjusted so that the high level of market competitiveness and attractiveness could be maintained. It is possible to attain such a state thanks to taking full advantage of knowledge contained both in an enterprise itself and its environment. Enterprises aspiring to succeed need to shape their internal structure and management mechanisms in a way which will make it possible for them to achieve the level of a knowledge-based enterprise characterized by a high level of agility. An agile knowledge-based enterprise is marked by high sensitivity and ability to seize opportunities it encounters, which stem from its internal configuration of resources conducive to such a behaviour. The aim of the paper is to define agility features of a knowledge-based enterprise and to identify mechanisms which influence the improvement of an enterprise potential in areas favourable for agility development. The paper is a collection of theoretical cogitations which have led to formulating a multi-aspect model of a mechanism used to shape agility of a knowledge-based organization.

Keywords Knowledge-Based enterprise · Agile enterprise · Opportunities · Knowledge-Based economy

1 Introduction

The dominance of knowledge, as a primary resource creating social and economic reality, determines the structure and features of modern enterprises. Effective operation in the conditions of a knowledge-based economy and achieving the level of a knowledge-based enterprise create a need for a change in thinking and

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approach to the identification and application of resources with a particular focus on knowledge. A knowledge-based enterprise, due to the specific character of its internal resources and responsiveness to environmental factors, may be termed as agile. This means that an enterprise is sensitive and capable of quick perception and taking advantage of opportunities for its own growth and development. An opportunity comprises a wide range of phenomena, which, although initially appearing to be unstructured, later assume a developed form which is beneficial for the realization of business plans. An agile knowledge-based enterprise is characterized by a prompt reaction to opportunities emerging in its environment and a proper implementation of broadly-defined internal resources in order to make use of them. The aim of the paper is to define agility features of a knowledge-based enterprise and to identify mechanisms which influence the improvement of an enterprise potential in areas favourable for agility development. The paper is a collection of theoretical cogitations which have led to formulating a multi-aspect model of a mechanism used to shape agility of a knowledge-based organization.

2 Features of Enterprise Agility

The complexity of business environment forces enterprises to undertake activities based on responsiveness and flexibility in relation to customers' evolving expectations and advancing technological innovations. Survival and expansion impose upon enterprises a necessity for the adoption of solutions based on agility both in the sphere of manufacturing and management. This is tied with the concept of an agile enterprise whose idea is to react quickly and effectively in ever-changing markets, which are shaped by customers who co-create goods and services. The basis for an agile enterprise is the integration of highly qualified and competent staff, advanced technology as well as objects, IT systems and a business process strategy [1, 2].

As regards functioning, an agile enterprise is based on the concentration and combination of four key competences conducive for agility. They include [3]:

- core competence management,
- virtual enterprise formation,
- capability for reconfiguration,
- knowledge based enterprise.

Core competences are integrated by means of specific features which include:

- spotting opportunities thanks to core competences,
- building an organizational structure which ensures operational effectiveness,
- securing resources which enable an effective performance of tasks,
- integration of activities on the basis of knowledge management.

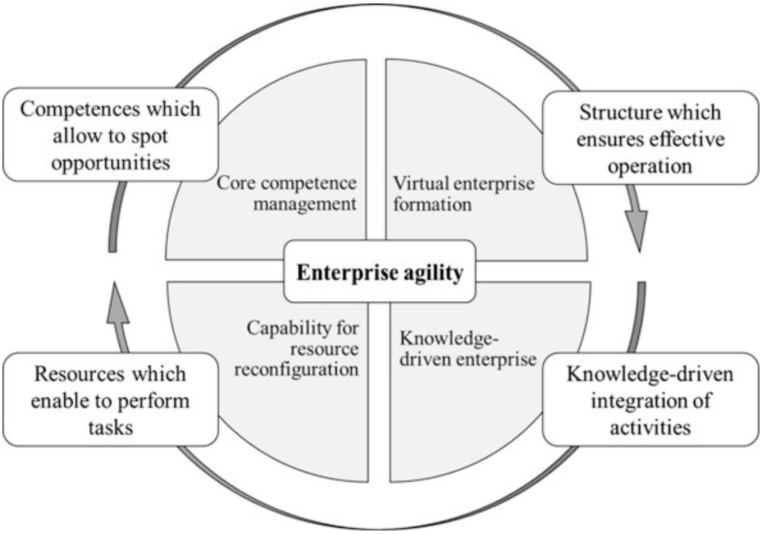

Fig. 1 Relations between factors shaping enterprise agility

Figure 1 shows relations between factors shaping enterprise agility.

Managing core competences refers to two special spheres in an enterprise. They are human capital competences and the ability to create a product in accordance with market expectations. In the range of managing human capital competences, concentration should focus on three closely related levels of perception and development of human capital. The first level is the level of an individual where management is based on individual knowledge, skills, attitudes and experiences. Activities within this realm, which will favour agility development, concentrate on investing into education and facilitating the integration of skills by an employee. This helps to retain and expand knowledge about the market and about present and future needs of customers. The second level refers to the level of human capital in an organization, which comprises employees forming teams and various organizational units. In this area agility is enhanced by the development of team learning, increase in the effectiveness of communication and knowledge exchange, work organization and integration of various skills and knowledge streams, including non-organizational ones. The third level of spotting and shaping human capital is connected with noticing opportunities offered by human capital at the level of entire society. The ability of an enterprise to perceive changing trends regarding human capital brings twofold benefits. The first one is the possession of knowledge related to social developmental trends. Such knowledge allows to understand and shape work environment, particularly in the context of ensuring employees' welfare in accordance with modern job market standards. On the other hand, awareness gained by enterprises impacts the formation of relations with customers. It is linked, in particular, with acquiring knowledge about current and potential tastes and preferences in a constantly "new" and evolving information society. It also forms a basis for the creation of an effective information channel with customers represented by different age groups and showing different preferences as regards the level of integration while at the same time involved in co-creating goods or services. It sharpens the ability of an enterprise to perceive market opportunities as far as demand gaps are concerned. Effective management of core competences should in the long run ensure access to the entire spectrum of the market and offer a customer the added value of a product, often never ensured before. Achieving such a state is possible through the integration of scattered resources and competences found directly in a given enterprise and other organizations such as suppliers, co-operators and competitors. Such activity is typical of virtual organizations.

Enterprise virtuality contributes to shaping agility in relation to an increased potential of resources and competences as a result of creating a network of relationships between co-operating enterprises. Enterprise virtuality is one of the ways to provide a product quickly to a customer. Thus, creating or making a quick use of opportunities is increased. A key aspect in creating enterprise virtuality is access to diverse resources while maximally bringing down the cost of owning them and being flexible in their use. Such a situation is possible when an enterprise tends towards making its organizational structure virtual. As a result, it consciously limits the maintenance of its own resources. Instead, it makes use of external resources by collaborating on the basis of cooperation, outsourcing, strategic alliances or other forms of partnership. It is essential that along with reducing its own material resources, an enterprise increases knowledge resources and access to information. This aims to enhance the capability of quick reconfiguration of resources to ensure enterprise effectiveness compliant with market expectations. Depending on the availability of resources, we can identify a solution found between the extreme ones: from full physical, often excessive, maintenance of resources—a traditional enterprise to a virtual security of resources—a theoretically agile enterprise. Figure 2 shows relationships between the availability of material resources and knowledge resources and a type of an enterprise.

Numerous publications underline the interdependence between enterprise virtuality and creating the concept of organization agility, e.g. [3–7]. They stress that enterprises gain a competitive edge thanks to cooperation with qualified outside partners provided with necessary material resources, personnel knowledge and skills and modern technology. Therefore, it is possible to ensure a quicker and multi-dimensional customer service and diversify market activities. This brings a range of benefits to enterprises, such as saving money, reducing wasteful practices, maintaining only indispensable resources, customer loyalty and increasing access to current knowledge and information related to the sector in which an enterprise operates.

Capability for resource reconfiguration is connected with the easiness of effecting changes in the configuration of material and non-material resources of an enterprise. Such activities create possibilities to use quick changes taking place on the market, in particular through reaching a customer with a special offer prior to competitors, thus creating a need which a customer has not been aware of before. The capability for a quick resource reconfiguration allows to capture an opportunity

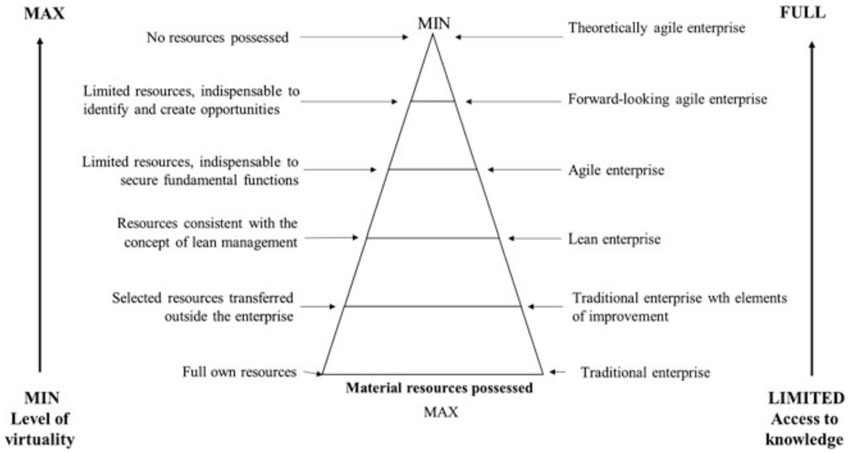

Fig. 2 Relationships between the availability of material resources and knowledge resources and a type of an enterprise

and makes it possible to create opportunities in the environment in an independent way. Obtaining the capability for resource reconfiguration depends largely on:

- Full identification and awareness of possessed material resources, including technological, manufacturing and logistic possibilities,
- Acquaintance with the level of knowledge, skills and competences of employees and the ability to predict and create knowledge and features useful in future activity,
- High flexibility in shaping the organizational structure of an enterprise (e.g. forming task-oriented groups, building relations between members of an organization, reconfiguration of organizational units),
- Openness towards including, permanently or incidentally, resources of other organizations into the structure of own operation (virtuality),
- Ability to create and maintain effective communication within the framework of mutually cooperating units and individuals.

A knowledge-based enterprise recognizes knowledge as a key resource determining the effectiveness of all activities in an organization and the hallmark of business success. Achieving the agile character of an enterprise is contingent on the level of acquiring, implementing and managing organizational knowledge. This type of an organization requires a high degree of development and knowledge integration at three levels: individual, group (organizational) and interorganizational. The ability of an enterprise to spot opportunities depends on the effectiveness, smoothness and level of access to knowledge. It is important to reveal the ability to assess the possibility of acquiring knowledge and to further configure necessary resources within an organization and outside.

3 Opportunities as a Source of Creating Enterprise Agility

A knowledge-based economy concentrates on generating the distribution and application of knowledge and information. The competitiveness of enterprises operating in such an economy is, first and foremost, based on the resources and potential of knowledge, which becomes a strategic factor of development. A knowledge-based economy, through a mechanism created thanks to the adopted strategy and the developing infrastructure, influences the internal changes of enterprise operation [8, 9]. Such an influence is particularly visible at the level of human capital development as well as in creating investment, implementing IT solutions and export activity [10].

Knowledge which the structure and development of a knowledge-based economy entails is the primary source of opportunities for an organization. An opportunity may be identified as both a result of unpredictable, turbulent activity of the environment and as a result of specifically-oriented changes undertaken to realize the adopted organization's developmental strategy. An opportunity is a conjunction of favourable events brought about intentionally or being a consequence of positive dynamic changes in a volatile environment whose dominant capital is made up by accumulated knowledge. Opportunities, being of diverse character, make up a different value for an organization. It is an individual question how they are taken advantage of and it depends on an enterprise's aims and available resources, in particular knowledge possessed. An opportunity may be a result of an enterprise's intentional activity [11] or may exist independently of an enterprise's activity and its perception [12]. Finding an opportunity may be an intentional activity or may be connected with the element of surprise [13]. Kirzner [11] believes that opportunities may be found without intentional searching for them because an enterprise is ready and possesses necessary resources to make use of them. Enterprises may create opportunities through activity, combination of various resources, improvisations and effecting changes without serious involvement into the process of searching for opportunities [14]. Shane [13] believes that opportunities arise as an enterprise's response to changes taking place in an enterprise's environment (technological, political/regulatory, social and demographic). Whereas Alvarez and Barney [12] interpret creating opportunities as a process of generating and transforming knowledge and resources.

A key factor determining the use of opportunities is time necessary to configure required resources. The very emergence of an opportunity is objective, but its capture and use is dependent on knowledge, experience and potential of a decision-maker. In such a situation, the speed of reaction and ability to make an effective use of an opportunity potential are possible thanks to an appropriate level of enterprise agility. The level of enterprise agility, in accordance with the concept presented earlier, is influenced by knowledge which determines the development of core competences, capability for resource reconfiguration and the level of enterprise virtuality. Figure 3 presents relationships between a knowledge-based economy and enterprise agility as far as responding to opportunities is concerned.

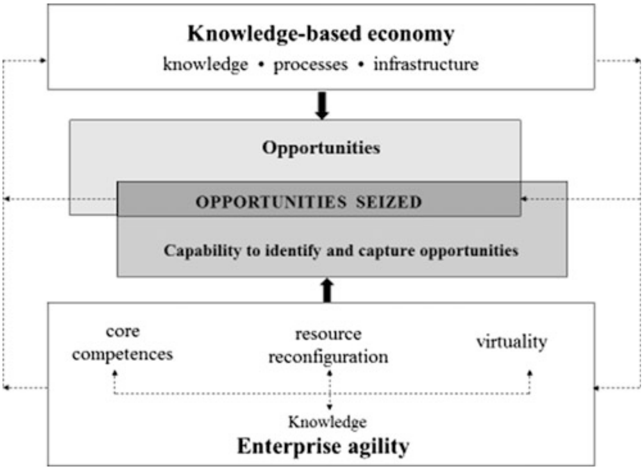

Fig. 3 Relationships between a knowledge-based economy and enterprise agility as far as responding to opportunities is concerned

The area of opportunities captured and used by an organization appears at the meeting point between opportunities themselves and an enterprise's ability to identify them. The included opportunities are favourable for generating new knowledge within an organization and outside.

4 Model of Shaping Agility of Knowledge-Based Organizations

A knowledge-based organization is an organization whose structure is subject to and directed at creating added value on the basis of the effective application of knowledge [15].

A knowledge-based organization, with regard to the specificity of its internal resources and response to environmental factors, can be termed as an agile organization, i.e. sensitive and capable of a quick identification of opportunities and their implementation into its own growth and development [16].

An agile organization is particularly differentiated by:

- the structure of resources, in particular non-material ones, constituting an organization's intellectual capital expressed by the level of innovativeness, entrepreneurship and positive attitude to changes,
- special meaning of knowledge managed consciously by an enterprise,
- shaping and maintaining conscious relations with the environment, including the creation of a network. It forms a basis of knowledge transfer between market participants as well as determines factors of perceiving and taking advantage of opportunities,

- the internal structure of an enterprise specifying the distribution of tasks, level of flexibility as well as necessary competences of employees.

The level of agility of a knowledge-based enterprise depends on an appropriate configuration of knowledge resources and the ability to spot, assess and make use of opportunities. The probability of seizing an opportunity increases along with the high level of knowledge in an organization which is conducive to identifying opportunities and an enterprise's high-level ability capability for quick resource configuration. The synergic influence of the above factors, which creates the level of enterprise agility, can be assessed by means of the following dimensions:

- Brightness—skill in the quick perception of market opportunities and threats coming from the surroundings,
- Flexibility—skill in using the available resources consisting in widening the scope of their application,
- Intelligence—an enterprise's ability to understand situations and react appropriately to them,
- Shrewdness—skill in using knowledge to deal practically with new situations [7].

Concepts presenting a mechanism of shaping agility of knowledge-based organizations can be expressed by means of a model shown in Fig. 4

Evolution taking place in an organization is the result of a constantly realized process of managing knowledge. During the process, individual and organizational knowledge is transformed and augmented, which causes an organization to embark upon continuous learning. The active process of conscious management of

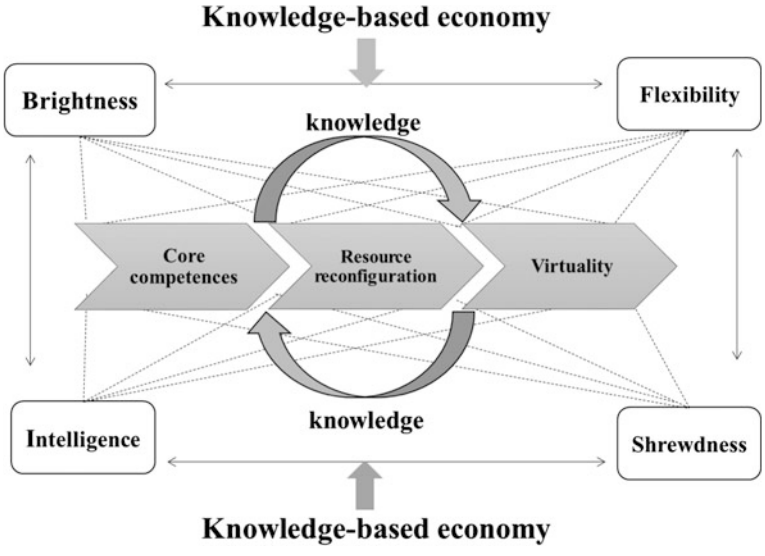

Fig. 4 Model of shaping agility of a knowledge-based enterprise

knowledge and an organization's involvement in learning is identified through the features of organizational agility expressed by brightness, flexibility, intelligence and shrewdness. In the context of the intensification of agility features, there will be an evaluation of the development of a knowledge-based enterprise expressed by the level of the adaptation of an organization (taking an opportunity) to the conditions of a knowledge-based economy.

5 Summary

An agile knowledge-based enterprise has the ability to achieve success in a competitive environment. The key source of success is made up by two types of potential. The primary one is broadly-understood knowledge. It is accumulated in an enterprise's resources, in particular in human capital which obtains it, makes use of it and expands it. The second source is the ability to notice opportunities, which is conditioned by the potential of knowledge and an organization's capability for resource reconfiguration.

The model of shaping agility of a knowledge-based enterprise presented in the paper reveals the concept of a conscious management of knowledge and an organization's willingness to learn. This is identified through an organization's agility dimensions expressed by brightness, flexibility, intelligence and shrewdness. The whole picture is complemented by an enterprise's agility features related to core competences, capability for resource reconfiguration and virtuality.

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Achieving Mass Customization Through Additive Manufacturing

R.M. Mahamood and E.T. Akinlabi

Abstract Mass customization aim to achieve customized product at a rate similar to mass production rate. Additive manufacturing (AM), an advanced manufacturing method, is capable of producing customized product, no matter the complexity simply, by adding materials layer after layer and building of the part in one unit. Unlike in traditional manufacturing process where a complex part needs to be broken down to smaller units and then assembled at a later stage, AM produces a complex part directly from the computer aided design (CAD) model of the part by adding materials in layers as against material removal in the traditional manufacturing process. Consumer product is moving from standardized product to customized product. For manufacturing companies to be able to keep up with this demand trend; there is a need for manufacturing process that deliver. This study looks at how AM can be used to achieve customized product with mass production efficiency.

Keywords Additive manufacturing · Advanced manufacturing · Mass customization · Traditional manufacturing

1 Introduction

Consumer demand is greatly moving away from standardized product to highly customized product [1]. The cost of producing customized product is higher when compared to standardized products that are manufactured through mass production. To remain competitive company must be able to meet this demand at competitive price. Mass customization is the answer to this. Mass customization was first

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proposed by Stan Davis [2]. He thought of how customized products could be manufactured at a cost achievable in mass production. This is not only possible but achievable and can also surpass the conventional mass production through the use of new manufacturing and communication technologies while also satisfying the exact requirement of the customer at no additional cost [3]. The main aim of mass customization is to deliver products that are meant to satisfy individual customer's needs while still keeping the near-mass production efficiency [4]. The key feature of mass customization is the capability to integrate the product varieties derived from the individual customer's needs and desire and the efficiency of mass production, so that the product is affordable due to low product cost achievable through mass production. In this competitive manufacturing world, for companies to survive and continue to be able to meet consumers' demands, they must be able to deliver the required product promptly and at competitive price. To be able to achieve this aim, there is need for manufacturing process that is able to produce customized components within short period of time and at lower price too. The candidate manufacturing process is additive manufacturing (AM) technology [5]. Additive manufacturing process is an advanced manufacturing technology that can produce highly complex parts directly from the computer aided design (CAD) model of the required part by adding materials layer after layer until the building of the part is completed [6, 7]. This means that more than one components can be produce simultaneously just by sending the CAD model of the desired parts to the AM machine at the same time.

In this competitive manufacturing world, consumers now demand more customized products and at competitive prices, additive manufacturing is the manufacturing technology that is able to satisfy this demand due to the following advantages offered by this technology: It reduces component lead time, material wastage [8], cost, and above all, energy usage that in turns reduce the carbon footprint [5]. Additively manufactured components are lighter in weight as a result of elimination of additional materials used in fastening, joining and coupling of parts. Light weight parts also consume less energy especially in the automobile and aerospace industry. In addition, AM technology has the potential to enable novel product designs that could be difficult or unable to be fabricated by the traditional manufacturing processes. AM technology can also be used to extend the life of in-service parts through the innovative repair that were prohibitive in the past [9]. The next sections briefly review different types of manufacturing processes and how additive manufacturing technology can be used to produce customized product with mass production efficiency.

2 Traditional Manufacturing Processes

For the purpose of this research work, manufacturing processes are subdivided into three major parts namely: Subtractive manufacturing, formative manufacturing, and additive manufacturing.

2.1 Subtractive Manufacturing Process

Subtractive manufacturing process is a traditional manufacturing process of shaping components that involves material removal [10]. This manufacturing technology starts the manufacturing process with a single block of material that is larger than the final size of the desired part. This block of material is gradually removed using fabrication processes (machining processes) such as milling, turning, drilling, planning, sawing grinding, EDM, laser cutting and water jet cutting until the desired shape is achieved. Different stages are involved in this type of manufacturing process and the products are designed based on the ease of manufacturing.

2.2 Formative Manufacturing Process

Formative manufacturing process is a traditional manufacturing process that shapes component through compression/consolidation process. In this manufacturing process, components are made with application of pressure. These processes include: forging, pressing and bending. This manufacturing process is energy intensive as subtractive manufacturing processes. A lot of material, time and energy are wasted in these traditional manufacturing processes [11]. A large part of these energies are wasted for scrap disposal which makes the overall cost of production to be very high [5]. A major drawback of these traditional manufacturing processes is the high lead time involved in the introduction of new product from concept, prototype, to final introduction of the product to the market. With the increase in demand for customized products, these traditional manufacturing processes cannot deliver on the promise of mass customization. Hence, there is a need for an improved manufacturing process that is able to offset some, if not all of the drawbacks of the traditional manufacturing processes. To remain competitive in this highly dynamic environment, there is need for flexible manufacturing system (FMS) which will be able to cope with the constantly changing consumer demand as well as manufacturing process that will be able to reduce the lead time required for introduction of new product and also keeping the material usage on a low side. The promising manufacturing process is additive manufacturing [12, 13].

3 Additive Manufacturing Process for Mass Customization

Additive manufacturing process is an additive manufacturing process in which a material is added layer by layer to form the desired object. The objects are produced directly from the digital image of the desired object. AM process is referred to as 3D printing [14] and it promises to change the entire way we design and manufacture products. Additive manufacturing is capable of producing parts with complex geometry and highly sophisticated, at low production cost because there is no need for expensive tooling which make it possible to manufacture part in large quantity without additional cost. The benefit of AM technology include: the ability to shortening the supply chain, the ability to reduce material wastage, the ability to achieve mass customization, short time of production, the ability to redesign product or optimize design even during the production process which is not possible in the traditional manufacturing process. All these benefits contribute to the economy of the AM technology. Additive manufacturing is achieved by simply adding materials layer-upon-layer. The process starts by using three dimensional (3D) Computer Aided Design (CAD) software, to produce a digital image of the desired part. The CAD model of the part is sent to the additive manufacturing machine, where the CAD model is sliced into hundreds of two dimensional (2D) cross sectional geometries depending on the building orientation to be used. After the slicing process, the additive manufacturing machine then follow the paths dictated by this 2D geometries to deposit or fuse the materials along its path. This process is repeated in succession thereby adding the materials layer after layer until the building process is completed [5]. The building process simply follow the 3D model of the path with no mold or tooling required, jigs and fixtures are not required to hold the work in place, and no manual process is required [15]. Any additive machine can produce any CAD data loaded on it so this offer flexibility for designer. That is the part are design based on the desired functionality and not base on the ease of manufacturing which is the practice in the traditional manufacturing process. This will also offer the manufacturer the new opportunities to recreate the CAD model of all the needed customized product as a single CAD file and send to the additive manufacturing machine. The machine will build all the products simultaneously therefore achieving the mass production of these customized products. This unique opportunity will not only make possible the mass customization of products but also simplify the supply chain system. This will undoubtedly revolutionize the manufacturing system as there will be less man contact and less error which will in turn reduce the overall production cost. The competitiveness of AM technology for mass customization cannot be overemphasized, when compared with the traditional manufacturing process, for example, when a new product is to be manufactured using the traditional manufacturing method: new mold needs to be created and for different customized products different mold is required. The mold may become useless after the production of the part since it is one of its kind product. Additive manufacturing process on the other hand does involve the use of molds or tooling to produce different products. It only requires the CAD data of the part to be produced and the machine just build the part by adding materials layer after layer. Mass customization is the ability to create customized products with mass production efficiency, production time and production cost. Additive manufacturing can leave up to this promise because different customized product can be built simultaneously no matter the complexity. Since Consumer are now consistently demanding new, unique, cheap and quality products and customers satisfaction lies with the ability of a manufacturer fulfilling these needs then the candidate manufacturing process that can fulfill these demands is additive manufacturing process. The AM process has the ability to produce each consumer desires at the rate at which standardized product are manufactured. The urge to buy customized cars is on the increase but the cost of these cars is very high when produced using the traditional manufacturing process. The automobile manufacturers can have a competitive advantage by using AM process to manufacture customer unique custom cars. A number of customers can be satisfied within a short period of time because different designs can be built simultaneously which is not possible using the traditional manufacturing route. And the cost of producing this cars will be cheaper because the customizations are achieved at no extra cost, this is because it will not require the new molds thereby, the lowering cost and saving materials. Also in the medical industry where custom medical implants are required (individuals are different). AM is now being used for the creation of these implants e.g. Hearing aids. In the past these hearing aids were produced manually and only one piece can be made at a time by skilled technician. Additive manufacturing can be used to produce a number of hearing aids for different people at the same time thereby reducing the cost of production. It is also possible to mass produce custom dentures using AM process. AM does not require the creation of new molds for various customized products, and items can also be produced where need, then, it reduces the lead time and the cost of production is also greatly reduced. Another important advantage of using AM technology is the weight saving and low material usage achieved during the manufacturing process. Close to the exact raw materials needed are used up and parts can be made in a single piece no matter the complexity. The extra weight gotten from joining or assembly of smaller parts produced through the traditional manufacturing route are absent in the additive manufacturing process. A large amount of material is saved because less material is used, and a higher throughput is [14]. The light weight product achieved through additive manufacturing process also has a great influence on the fuel consumption and carbon footprint in automobile and aerospace industries. Additive manufacturing is the manufacturing process for future products and it will leave up to the expectation in fulfilling the need by the current trend of mass customization.

4 Conclusion

The use of additive manufacturing to achieve mass customization has been presented in the paper. There are many potential benefits that could be achieved using the AM process for mass customization. It can give industries competitive advantage over their counterpart by producing individualized product at mass production rate and cost. The industries that can immediately benefit from this technology include medical, dental, automobile, and aerospace industries. These are industries in which mass customization are needed because of different consumers demanding individualized products, Also light-weight parts are of importance in automobile and aerospace industries because it reduces fuel consumption, this will also shortens the supply chain. The traditional manufacturing technologies cannot compete with AM technology when it comes to one of its kind product which are now being demanded in various forms and in large number because AM does not require molds or tooling to manufacture products. Hence AM can deliver this products at lower prices.

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Organizational Structure and Agile Enterprise. Anticipated Effects and Empirical Results from Polish Enterprises

Edmund Pawlowski and Krystian Pawlowski

Abstract This paper focuses on an organizational structure in a context of agile enterprises with the aim of summarizing the theoretical postulates and their empirical verification. The theoretical model of agile enterprise is described in four dimensions: 1. Shrewdness of the enterprise, 2. Resource flexibility 3. Enterprise's intelligence. 4. Smartness of the enterprise. These agile dimensions are interpreted from the "Aston concept" of five dimensions of an organizational structure: 1. Configuration, 2. Specialization, 3. Centralization, 4. Standardization, and 5. Formalization. The theoretical model of anticipated effects of agile in organizational structure has been verified as a part of two larger empirical research projects undertaken at the Faculty of Engineering Management of Poznan University of Technology. The first project from 2012, called "Adjustment of enterprises' management systems to knowledge-based economy", and the second one from 2014, called "Determinants of implementing modern methods and technics of management in Polish enterprises". The both empirical research surveyed 150 of enterprises represented Polish economy.

Keywords Agile enterprise · Organizational structure

1 Introduction

Theory and practice of knowledge based enterprises has a tradition of almost 50 years now. Main features of knowledge based organizations are [1, pp. 33–38]:

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1. Structure of resources and investments in intangible assets, which are the major component of the organization's market value.
2. Knowledge Management.
3. Developing relationships with the environment in a way to gain a favorable location in the business network through the use of own knowledge
4. The organizational structure characterized by: high flexibility, openness to the environment within network and virtual structures, wide use of temporary task groups,
5. Organizational culture adjusted to knowledge management,
6. Specific roles and scopes of work for people. The gradual blurring of the differentiation between employees and management.

The development of the concept of knowledge based economy includes:

- learning organization,
- competitively learning organization,
- intelligent organizations,
- network and virtual organizations,
- agile organizations.

The last model of knowledge based organization is the agile organization. An agile organization, through its structure and management process, quickly and smoothly activates its social capital to generate value for customers in face of emerging market opportunities [2, pp. 42–43].

Organizational structure is one of the important distinguishing feature of an agile organization. The subject of deliberations in this paper are postulated and actual features of the organizational structure of knowledge based enterprises, and in particular the postulates of an agile enterprise. These deliberation are empirically based on two large empirical research projects undertaken at the Faculty of Engineering Management of Poznan University of Technology. The first project conducted in 2012, called "Adjustment of enterprises' management systems to knowledge-based economy", and the second one in 2014, called "Determinants of implementing modern methods and technics of management in Polish enterprises".

2 Research Project Conducted in 2012

2.1 Methodological Assumptions of the Research

The research was a part of a bigger project named "Adjustment of enterprises' management systems to knowledge-based economy". The project was realized in the Faculty of Engineering Management of the Poznań University of Technology. The material scope of examinations in the project included: the strategy, organizational structure, IT technology and human capital. The survey was made in 2012. A method of direct interviews with owners of companies or the general

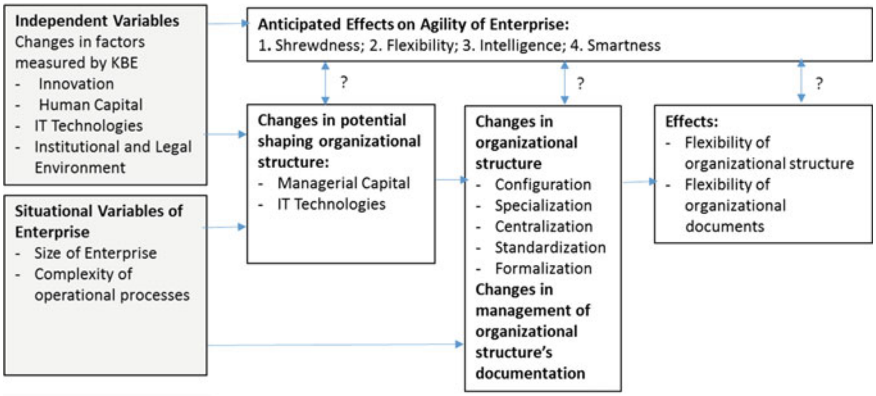

Fig. 1 Changes of organizational structure in a context of internal and external changes, and anticipated effects on agility of an enterprise. *Source* own elaboration

management (chairmen, vice chairmen or directors) was applied. The study was conducted in 150 enterprises. Criteria for the selection of the sample were defined in the preliminary stage of the project (30 % of small business, 40 % medium and 30 % large enterprises).

In regard to the analysis of trends, two points in time were defined: year 2007 (as the beginning of implementation of the Lisbon Card in Poland, which meant the beginning of knowledge-based economy) and the year 2012—in which the research was conducted. Other aspects of the project have been published in: [3–7]

Diagram of research methodology is presented in Fig. 1. The independent variables are the changes in the Polish economy measured with indicators KBE (Knowledge Based Economy), and situational features of the enterprises. The dependent variables are the characteristics of Agile enterprises, in particular the organizational structure. The interpretation of features of agile enterprises according to the concept of Trzcielinski was used [8, 9]. Trzcielinski's model of agile enterprise that describes an agile enterprise in four dimensions: 1. Shrewdness of the enterprise, which is a function assigning to the turbulent environment a string of potential market opportunities 2. Resource flexibility of the enterprise transforms the string of potential opportunities into a string of resource available opportunities. 3. Enterprise's intelligence is an ability to understand situations and find deliberate reactions to them, that is to activate proper resource to weaken the threats or use the opportunities. 4. Smartness of the enterprise is an ability to quickly use the opportunities in a benefit brining manner.

Anticipated effects of an enterprise increasing its agility were the basis for the creation of a survey questionnaire. The study of organizational structures includes three research phases:

- changes in the potential shaping the organizational structures (potential of managers and IT support)
- changes in the organizational structure itself (measured in five dimension—according to the Aston study [10, 11])
- the effects of changes in individual dimensions of organizational structure, and in the documentation of the organizational structure and the management of organizational changes.

Anticipated effects of increasing agility in regard to organizational structures are presented in Table 1.

2.2 Results of Research

The research on changes in company organisational structures was carried out in the context which was on one hand broader by studying the potential influencing the development of organisational structure and on the other hand, by studying the results of such changes.

Changes in the Potential Shaping Company Organisational Structures. Changes in the potential shaping company organisational structures were studied with respect to two criteria: SP1/ changes in staff potential, mainly the management, who decide about structural changes, as well as SP2/ changes of resources and information technologies, which simplify or impede management of organisational documents and communication with employees. Potential opportunities or barriers created in the surroundings (ISO) were analyzed as independent variables causing changes in the potential (SP1 and SP2),

SP1. Company staff potential has improved with respect to all the analyzed criteria. In the studied period 2007–2011 the number of companies implementing employee competence development increased by 10 %. Among 29 % of the companies, the percentage of employees with high competence increased to 47 % of all the employed. Companies pledged the use of all knowledge management tools. About 35 % of the respondents said top management knowledgeability in organisational structure design methods and organisational change management had improved. The increase of knowledge level was noticed by 27 % of small companies, 32 % of medium companies and 47 % of big companies. More than 55 % of the surveyed claimed the level of knowledge remained unchanged.

SP2. Quality (innovativeness) of IT resources, their range and availability for organisational units and employees may become a factor which simplifies, impedes or makes it impossible to implement modern solutions for organisational structure documents and change management. Over half of the companies make use of all the basic information technologies, however, only 50 % of the companies use intranet. Among all the surveyed companies, 88 % were not active in raising external funds for IT development. The smaller the company, the lower the activity.

Table 1 Agility dimensions and changes expected in organisational structure

Agility	Feature characteristics	Changes expected in organisational structure
Shrewdness	Is a function assigning to the turbulent environment a string of potential market opportunities	S1. Companies develop and strengthen their external network structures S11. Companies create or join relatively permanent (recurrent) consortia or other cooperation contracts in order to implement similar contracts S12. The need for market monitoring increases, marketing activities flexibility grows
Flexibility	Transforms the string of potential opportunities into a string of resource available opportunities	S2. Organisational structure flexibility increases S21. The role and number of task and project teams grows S22. The role and range of matrix structures increases (increase in number of product/project/contract/customer managers) S23. The number of hierarchical levels in organisational structure decreases S24. Decentralisation grows S25. Specialisation range of employees and organisational units becomes broader S26. The level of business process and organisational behaviour standardisation decreases S27. The level of formality decreases
Intelligence	An ability to understand situations and find deliberate reactions to them, that is to activate proper resource to weaken the threats or use the opportunities	S3. Top management knowledgeability in organisational structure and structure design methods has improved S4. The quality of organisational documents has improved (The following were implemented, besides organisational schemes: S41. Process classifiers S42. Competence tables S43. Ranges of organisational unit activities S44. Process management documents—process maps) S45. Process management documents—process review cards S5. The level of document digitalization rose (documents in intranet) enabling quick adjustment of the structure to variable conditions and strategies
Smartness	An ability to quickly use the opportunities in a benefit brining manner	–

ISO. Factors in the surroundings making potential opportunities for changes in the potential shaping organizational structure are: availability of venture capital, access to the newest knowledge and professional standards, the role of IT technology for business development. In order to summarize the changes in potential opportunities with probable influence on the potential shaping organisational structure in companies, one may point at:

a. Only one positive trend, which is access to the newest knowledge and professional standards, mainly including improvement in communication between companies and universities.
b. Availability of Venture Capital as support for innovative ventures (including innovative structural solutions) declined significantly.
c. The role of IT technology for business development measured in ICT expenses as a percent of GDP varied in the studied period and did not create a new trend.

Changes in Organisational Structure of the Studied Companies in the Context of External Changes and Situational Features of Companies. The independent variables are: ISC—surroundings changeability, ICC—company complexity. The dependent variables are: SC1—changes in organizational structure, SC2—changes in organisational documents and change management.

ISC—Changes in the Surroundings as a Premise of Structural Changes. The basic feature of the surroundings which influences company organizational structure is the changeability of the surroundings. In order to summarise the characteristics of the changeability and complexity of the surroundings in the period 2007–2011 one may point at:

a. Increase in general economic situation insecurity (alternate growth and decline of GDP);
b. Insecurity increase in direct investments on foreign markets (alternate growth and decline);
c. Low insecurity and big complexity on local competition market (high but consistent level of local competitiveness);
d. Low insecurity on the export market of technologically advanced products (consistent, positive growth);
e. Low insecurity on Research and Development market (consistent growth of R&D sector proportional share in GDP, small changes in company own investment in R&D),
f. Increase in complexity and insecurity in terms of work division in value creation chains (fragmentation of company specialisation results in higher complexity of cooperation, as well as higher complexity of coordination mechanisms in the value chains).

The surroundings are not highly turbulent, however, three of the above mentioned trends should persuade companies to increase their organisational structure flexibility.

SC1—Changes in Organizational Structures of the Surveyed Companies. The changes were studied in five dimensions of organizational structure: configuration, specialization, centralization, standardization and formalization.

There are little changes in the configuration dimension. Structural expansion of business behind internal company borders (in the form of network structures) is noticeable, however, only in few percent of the companies. The number of task teams increased in the studied period in 25 % of the companies, this included the increase in 41 % of big companies. The number of subject managers (product, project, customer managers) rose in this period in 17 % of the companies. The difference between small and big companies is surprising: the use of task and matrix structures rose more noticeably in small rather than in medium companies. In the studied period no crucial changes in terms of flattening of organisational structure were seen. In 73 % of the companies the number of hierarchical levels remained unchanged, it rose in 11 % of the companies, the number of hierarchical levels fell in 6 % of the companies. In order to summarise the changes of configuration dimension, one may note changes in network structure development by a few percent and an increased role of interior task and matrix structures in about 20 % of the studied companies.

Changes in specialization dimension. Increase in specialisation range of employees and organizational units occurred among 29 % of the studied companies. This mostly concerns (49 %) big companies and it foresees changes diminishing the level of organisational structure flexibility.

Changes in centralization dimension. The level of decentralisation rose in 16 % of the studied companies, the bigger the company, the higher the rise. A growth of centralisation was declared only in 1 % of the companies.

The level of standardization rose in 19 % of the companies and the level of formalisation rose in 15 % of the companies. 1 % of the surveyed noted a fall in standardisation and 6 % of the companies noted a fall in formalisation. Similar to the specialization dimension, the rise in standardisation and formalisation results in the tendencies diminishing the flexibility of organisational structure.

SC2—Changes in Management of Organizational Structure Documents and Change Management. With respect to the year 2007, increase in the range and level of kaizen method implementation was noted, the number of “inactive” companies decreased from 27 to 23 % and the implementation level increased from 1, 8 p. to 2, 2 p. (scale from 1 to 5) in all the studied companies. Lack of activity in terms of organisational structure overview concerned 21 % of the studied companies and it did not change in the period 2007–2011. However, the level of activity did change (measured from 1 to 5) from 2, 2 p. in 2007 to 2, 7 p. in 2011. The range of activity (number of companies) and the activity level increases along with company size. The range of organisational structure documents usage varies in the particular parts of the documents. Changes in the number of the companies which modernised their organisational structure documents can be seen on a low level, from a few percent of the companies for competence tables to 25 % of the companies for organisational structure schemes.

Effects of the Changes in Organizational Structure and Organizational Documents of the Studied Companies. The effects were studied in two dimensions: SE1—changes in flexibility of organisational structure, SE2 and SE3—changes in the quality and flexibility of organisational structure documents.

SE1—The Effects of Changes in Organisational Structure. Opinions about the general evaluation of the changes in company organisational structure flexibility in the period 2007–2011 seem to vary: 40 % of the respondents reckon that flexibility rose (mainly big companies—51 %), and 47 % notice a fall in structure flexibility (mainly small companies—53 % and medium—48 %). It seems crucial to notice that 60–70 % of the studied companies did not observe any changes in any dimension of organizational structure. In terms of the configuration dimension, internal flexibility rose in 20 % of the companies, in terms of external flexibility (network structures)—in a few percent. In terms of centralization flexibility rose too, which was observed in 16 % of the companies. The flexibility of the specialization dimension, however, fell (in 29 % of the companies) as well as in the standardization dimension (19 %) and formalization dimension (15 %). Study results do not confirm the expected increase of flexibility in all the dimensions of the organizational structure, two of which increase flexibility, the remaining three decrease flexibility. The study showed that organisational structure flexibility differs for various company functional areas. The highest flexibility rise was observed in the following areas: operational activities, marketing, sales and purchases, as well as research and development. The lowest increase occurred in administration.

SE2 and SE3—The Effects of Changes in Organisational Documents and Change Management. In the majority of the studied companies the most simple forms of documents are used: schemes of organisational structures (65 %) and ranges of organisational unit activities (57 %). 23 % of the companies declare using business process classifiers, and only 7 % of them use competence tables. About 29–39 % of the companies declare possessing process management documents, but only 13 % overview their processes systematically. It may be presumed that process management documents appear as the result of the implemented quality management system and the lack of process overviews does not confirm the practical application of process management in these companies. The respondents were also asked if the role of the particular documents rose in the last 5 years. The vast majority of companies pointed at organisational structure schemes (25 %) and ranges of unit activities (27 %). An increased role of process documents was observed by 15 % of the companies, but an increased role of process overview was noticed by only 8 % of the companies. The companies declare that on average 49 % of the organisational documents is placed in intranet or on the network drive. The range of organizational documents digitization rose in 58 % of the companies. In the summary of the quality of the organisational structure documents, it may be stated that it represents a poor level and the improvement in the studied period was little. However, what did improve is document flexibility measured by the level of digitization and easy access for organisational units and lawyers.

Table 2 Changes in flexibility of organizational structures of polish enterprises in the periods 2014 and 2007–2012. *Source* own elaboration, Research 2014

	Research 2014 (Changes in 2014) Increase/decrease [%]	Research 2012 (Changes in 2007–2011) Increase/decrease [%]
Configuration: Number of task teams	19/6	25/2
Configuration: Number of Product/Project/Client Managers	15/9	17/0
Configuration: Number of managerial levels	10/8	11/6
Centralization: Decentralization level	17/6	16/1
Specialization: of organizational units and posts	21/9	29/0
Standardization	11/9	13/0
Formalization	12/7	11/4

3 Research Project Conducted in 2014

The research data presented here are derived from the larger research project undertaken in 2014 at the Faculty of Engineering Management of Poznan University of Technology called “Determinants of implementing modern methods and technics of management in Polish enterprises” [12, 13]. The empirical research surveyed 150 of enterprises represented Polish economy. One of determinants considered within the project was flexibility of organizational structure. The results of this research (from 2014) compared with results from the previous research (2012) are presented in Table 2. The changes in particular dimensions of organizational structure in 2014 present the trends similar to the trend from 2012: the increase of flexibility in configuration and centralization, and decrease in specialization, standardization and formalization. The smaller differences between increase and decrease of dimensions can be the effect of different retrospect of research (four years—2007–2011, and one year 2014), and may be the stabilization.

4 Summary and Conclusions

Hypothetical process of changes in knowledge based enterprises which increase their agility is the following:

1. Increasing uncertainty and complexity of the business environment should encourage companies to increase their level of shrewdness, intelligence, flexibility and smartness.
2. Changes in the flexibility of the organizational structure are related to the three characteristics of agility: shrewdness, flexibility and intelligence

3. Level of organizational structure flexibility increases, with:
    (a) increasing of flexibility of configuration
    (b) decreasing level of specialization of organizational units
    (c) increasing level of decentralization
    (d) decreasing level of standardization and formalization

The research conducted in years 2012 and 2014 showed that business environment of enterprises had a tendency to increase uncertainty; also moderate chances of using the joint venture capital and financial support for R&D and IT infrastructure development appeared.

Reactions of companies indicated an increase of the flexibility of organizational structures, but the level of this increase was small and ambiguous in particular dimensions of organizational structure. Positive trends in dimensions of configuration and centralization were reported, while at the same time the organization became more rigid due to the growth of specialization, standardization and formalization.

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Organizational Learning and Knowledge Management—Insights from Industrial Managers

António Amaral, M. Madalena Araújo and Cristina S. Rodrigues

Abstract There is an increasing recognition that the competitive advantage of firms depends on their ability to create, transfer, utilize, develop and protect the Organizational knowledge assets. Therefore, the projects context should be wisely used for properly foster the learning collection through the lessons learned gathered during project life cycle. However, organizations do not seem to learn from their mistakes, rarely exploring the reasons for their projects' success or failure, and very rarely applying those lessons learned to the business management. In fact, there is little or no point in learning unless management adapts its behavior accordingly. Usually top management does not give sufficient resources for activities such as reflecting and learning. This research is focused on assessing the organizational environment in order to properly explore the factors and dependencies amongst the social demographic variables. The questions addressed intent to highlight the key determinants that might foresee a proper learning and knowledge management environment.

Keywords Knowledge management · Organizational learning · Industrial managers

1 Introduction

The process of learning is emphasized in all organizations as a way to improve performance, to manage projects, processes and activities more effectively, and thus, it is of extreme importance to the business in general. The company's per-

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formance and capability to create value depends on the combination of different organizational assets [1, 2], and on its ability to implement strategies that respond to market opportunities by exploiting their internal resources and capabilities [3]. As reference [4] long ago said, we are now living in a ‘knowledge-based society’, where knowledge is the source of the highest-quality power. In a world where markets, products, technology, competitors, regulations and even societies change rapidly, continuous innovation and the knowledge that enables such innovation have become important sources of sustainable competitive advantage.

There is an evident necessity for developing systems and processes for promoting the organizational learning. As pointed by Ref. [5], the learning lessons from projects are determinant for the creation of the corporative knowledge. As mentioned by several authors, the absence or impracticability of the efficient solutions presented for promoting the organizational knowledge, enable the following scenarios: (1) the predisposition for occurring the same problems and failures [6]; (2) decreased ability for assessing and deciding [7]; (3) less ability to manage the organizational resources in processes as crucial as the planning, interaction with the market and its players, logistics and operations, etc.; (4) decrease of organizational results, and consequent delay in the process of differentiation from competitors; and (5) poor Organizational Maturity [8, 9].

Our research is focused on studying the organizational context as being a favorable habitat for observing the learning and knowledge management through the perceptions and experiences of the industrials managers. We thought that this will help us disclose key aspects to fully understand the underlying aspects of the learning creation, transfer and combination with the aim of capitalizing knowledge into organizational value.

2 Organizational Learning Environment

In the late 1990s, “the learning organization” and the concept of “organizational learning” became unavoidable for managers, consultants and researchers. For any business or organization, the ability to learn better and faster than its competitors became an essential core competency [10].

The Human learning is constructed through continuous reciprocal interactions between people and the environmental stimuli and context [11–13]. Learning is profoundly linked to people and to their actions, as well as to the conditions underlying its generation [14, 15]. Regardless of the externalities’ type, each organization seeks to sustain itself in competition and cooperation with other entities that rely on the same finite pool of resources. The fundamental challenge is to manage and allocate accurately the organizational scarce resources [16]. For that reason, there is a need to integrate organizational learning into existing business processes. However, this is only possible and feasible when managers see it as manageable [17]. The building of a learning organization begins with the commitment and strong support of top management. The leaders of the organization have the responsibility to create an appropriate environment for learning [18]. To this end they must provide operational guidance [18]. Additionally, they must communicate explicit and credible learning agendas and support them regardless of short-term success or failure [19].

Reference [20] points one key factor, which is the combination of explicit knowledge with tacit knowledge in project-oriented organizations, encouraging people to learn and to be involved in the continuous process of learning, since it constantly improves the processes and practices used in the project management. Organizational knowledge creation is a continuous and dynamic interaction process between tacit and explicit knowledge, the two main types of knowledge. Based on this interaction, the SECI (Socialization, Externalization, Combination, Internalization) model for organizational knowledge creation was built [21].

Organizations create knowledge dynamically, interacting and converting the two types of knowledge between each other. In the conversion process, tacit and explicit knowledge expand in both quality and quantity [22–25]. The four modes of knowledge conversion are: (1) Socialization from tacit knowledge to tacit knowledge; (2) Externalization from tacit knowledge to explicit knowledge; (3) Combination from explicit knowledge to explicit knowledge; and (4) Internalization from explicit knowledge to tacit knowledge. Knowledge needs a physical context if it is to be created: ‘there is no creation without place’. Reference’s [26, p. 16] mentions that ‘Ba’ (which roughly means ‘place’) offers such a context. Projects play an important role in achieving the learning that takes place within many organizations [19, 27]. Organizations also acquire new knowledge through experience [28] or learning by doing. Through trial and error experimentation, organizations can learn about new approaches to accomplish the work at hand [18, 28, 29]. An organization can also learn from feedback on the consequences of its actions, learning about projects by feedback and experience, developing project work, and transferring the lessons learned to other projects [21].

A study conducted by McKinsey & Company and Darmstadt University of Technology [30] revealed the complicated and dynamic nature of knowledge. After more than 400 personal interviews at 39 companies around the world (18 in Europe, 11 in North America and 10 in Japan), they discovered that knowledge is an asset: (1) that means different things to different people; (2) that can become outdated instantaneously; (3) that initially is often tacit, not codified; (4) the value of which increases when it is shared among people; (5) the generation of which cannot be planned scientifically; and (6) that can be recycled independently of ownership of physical assets.

Therefore, this article intends to explore the factors and dependencies in the organizational context that could favor the learning environment, as well as to identify the key determinants which might enhance the proper habitat for managing the organizational knowledge.

3 Methodology

A structured questionnaire survey was developed based on the literature studied, and its adoption was decided since it is an appropriate method to collect attitudes and perceptions on a significant scale. The target group comprises industrials managers with project management experience. The questionnaire was available online during approximately 3 months. The implementation of the questionnaire allowed a total of 167 valid answers. Table 1 shows the demographic breakdown of the sample: nationality, gender, age, academic qualifications, years of work experience, job position and years of experience in job position.

Table 1 Profile of the respondent (n = 167)

Percentage of respondents		Percentage of respondents	
Nationality		Years of work experience	
Portuguese nationality	72.14 %	Less than or equal to 7 years	25.6 %
Brasilian nationality	13.17 %	Between 8 and 14 years	26.8 %
Swedish nationality	2.40 %	Between 15 and 21 years	25.6 %
Canadian nationality	2.40 %	Greater than or equal to 21 years	22.0 %
Other nationalities	9.89 %	Job position	
Gender		Administrator	8.38 %
Male	68.26 %	Executive board	10.18 %
Female	31.74 %	Top manager	37.13 %
Age		Middle manager	22.75 %
Less than or equal to 32 years	28.14 %	Office clerk	3.59 %
Between 33 and 37 years	23.95 %	Others	17.96 %
Between 38 and 45 years	25.15 %	Years of experience in job position	
Greater than or equal to 46 years	22.75 %	Less than or equal to 3 years	34.73 %
Academic qualifications		Between 4 and 5 years	20.36 %
High school education	1.80 %	Between 6 and 9 years	20.36 %
Bachelor	8.38 %	Greater than or equal to 10 years	24.35 %
Graduation	38.92 %		
Master's degree	29.34 %		
PhD	8.98 %		
Post graduate and other specializations	12.57 %		

4 Questionnaire Results

The organizational learning environment was accessed through six different questions. In addition to the descriptive analysis of the responses, the paper analyses the existence of dependency relations by conducting chi-square tests with variables that characterize the respondent (gender, age, years of work experience, etc.) and the organization (number of employees and activity). The first question points that the learning process is emphasized in all organizations as a way to improve performance, make management more effective, and thus capitalize the sustained development of the organization. The respondents were asked to indicate the level of agreement with four different learning factors using a Likert scale, ranging from 1 (I totally disagree) to 5 (I totally agree). Figure 1 illustrates the answer distribution.

All statements registered a significant percentage of agreement, totaling more than 60 % in the set of options “I agree” and “I totally agree”. Noteworthy is the statement 3 (“Your organization has process or any method oriented to development of knowledge or learning”) with 81.9 % of positive responses, and the statement 2 (“The environment and organizational culture foster the development of knowledge and learning, applying the lessons learned in the present …”) with 79.5 %.

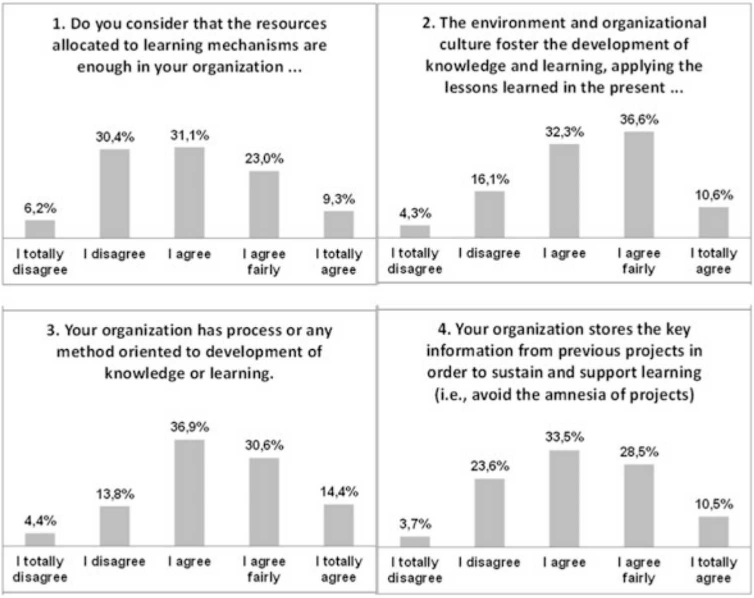

Fig. 1 Learning factors

Following the qui-square tests, several dependency relationships were found for:

- Statement 1 ("Do you consider that the resources allocated to learning mechanisms are enough in your organization …") only depends on respondents' nationality ($X^2(4) = 14.628$, $p < 0.01$);
- Statement 2 ("The environment and organizational culture foster the development of knowledge and learning, applying the lessons learned in the present …") depends on the nationality of the respondent ($X^2(4) = 8.593$, $p < 0.10$) and the size of the organization ($X^2(12) = 18.665$, $p < 0.10$);
- Statement 3 ("Your organization has process or any method oriented to development of knowledge or learning") only depends on nationality ($X^2(4) = 8.094$, $p < 0.10$);
- Statement 4 ("Your organization stores the key information from previous projects in order to sustain and support learning (i.e., avoid the amnesia of projects)") depends on nationality ($X^2(4) = 8.136$, $p < 0.10$), years of work experience ($X^2(12) = 22.692$, $p < 0.05$), years of experience in job position ($X^2(12) = 19{,}668$, $p < 0.10$) and organization's activity ($X^2(16) = 26.006$, $p < 0.10$).

The second question of the organizational environment assesses the degree of agreement of the respondent with seven potential causes for not learning from the errors committed (Likert scale ranging from 1 (I totally disagree) to 5 (I totally agree):

- Cause 1. The high pressure of time for completion of the project and team dispersal to new tasks
- Cause 2. Lack of human, technical and/or technological resources
- Cause 3. Lack of a standard methodology for the review of projects, activities and organizational processes
- Cause 4. Lack of motivation and willingness to learn from the mistakes of the people involved
- Cause 5. Lack of communication of previous experiences between the project team due to "false modesty" (with positive experiences) or fear of negative sanctions…
- Cause 6. Existence of a very vertical organizational structure in which the hierarchy is very delimited, preventing the communication and the possibility of exchange of ideas…
- Cause 7. Project teams with very different skills, lack of a "common language" and levels of training very heterogeneous.

Figure 2 illustrates the distribution of positive responses. All the causes given showed high percentage of positive responses (all above 65 %). Still, it is possible to identify an order of perceived importance (see Fig. 2).

Figure 2 identifies as the most important causes for learning errors the time pressure (cause 1) with 95.18 % of positive responses, the lack of communication from previous experiences (cause 5) with 87.27 % and lack of a methodology

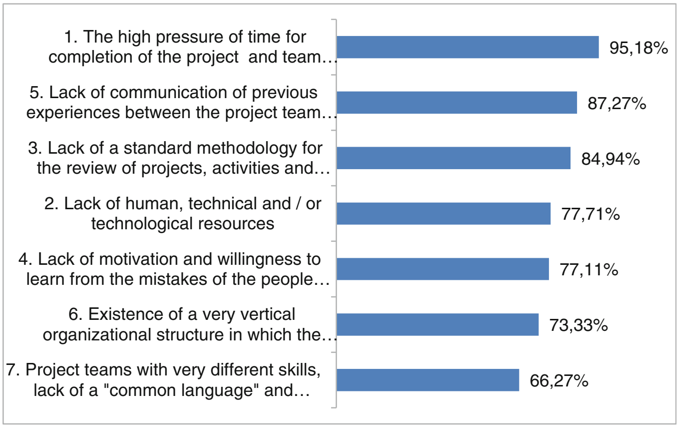

Fig. 2 Potential causes for learning errors (in descending order of % positive responses)

review (cause 3) with 84.94 %. Moreover, the causes perceived as less important are those related to heterogeneous teams (cause 7) with 66.27 % and the existence of a very hierarchical structure (cause 6 with 73.33 %).

The chi-square tests identified the following dependency relations:

- The cause 3 (lack of a methodology review) depends on the nationality of respondent ($X^2(4) = 12.924$, $p < 0.05$), and age ($X^2(12) = 23.380$, $p < 0.05$);
    - The cause 4 (lack of motivation) depends on the years of professional experience ($X^2(12) = 21.764$, $p < 0.05$), and the size of the organization ($X^2(12) = 22.238$, $p < 0.05$);
    - The cause 6 (the existence of a very hierarchical structure) depends on the nationality of the respondent ($X^2(4) = 9.255$, $p < 0.10$) and the size of the organization ($X^2(12) = 22.228$, $p < 0.05$).

The third question is related to the level of importance of a knowledge management system (KMS) and organizational learning to incorporate some of the following aspects, namely: Cultural aspects; Values system; Linguistic differences; Emotional reactions (such as commitment, disappointment, irritability); and Manifestation of another type of feeling or expression, whether it be in-person interaction software, or even person-interface-person. The level of importance was measured on a five levels scale: 1—"not important", 2—"unimportant", 3—"fairly important", 4—"important" and 5—"very important"). Figure 3 illustrates the descending percentage of more positive responses (i.e., the sum of responses 4—"important" and 5—"very important").

The elements with higher perceived importance, are the system of values (element 2) with 75.8 % of responses, the cultural aspects (element 1, with 68.5 %), and the linguistic differences (element 3, 58.3 %). In the chi-square test only three dependency relationships were found:

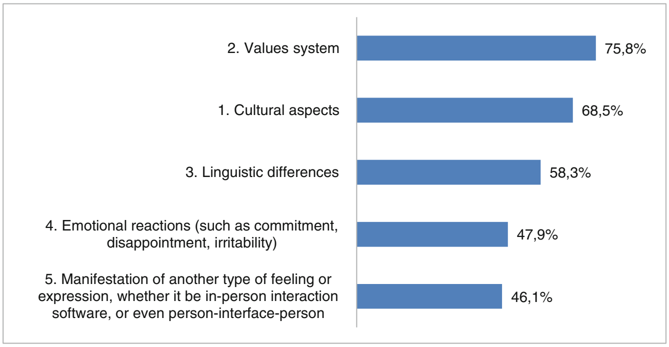

Fig. 3 Elements of the management system of knowledge and learning—the perceived importance (in descending order of positive responses)

- the value system (element 2) depends upon the years of professional experience ($X^2(12) = 19.764$, $p < 0.10$);
- the linguistic differences (element 3) depend on the years of experience in job position ($X^2(12) = 18.573$, $p < 0.10$);
- the direct emotional reactions (element 4) depend on the years of professional experience ($X^2(12) = 19.434$, $p < 0.10$).

The fourth question looks at the perceived importance of three factors in socialization, according to the SECI model, as an important step in the conversion and transfer of tacit knowledge: (1) living spaces (physical or virtual) for encounter and interaction between different members of the project team, (2) provide extra-organizational activities to create team spirit (team building), and (3) provide technologies to foster communication between members. The perceived importance is measured with a scale with five levels, 1—“not important”, 2—“unimportant”, 3—“fairly important”, 4—“important”, 5—“very important”. Figure 4 illustrates the descending percentage of more positive responses (i.e., the sum of responses 4—“very important” and 5—“very important”).

The factor identified as most important is the provision of extra activities (factor 2) with 75.9 % of responses of high importance. The factor perceived with lesser

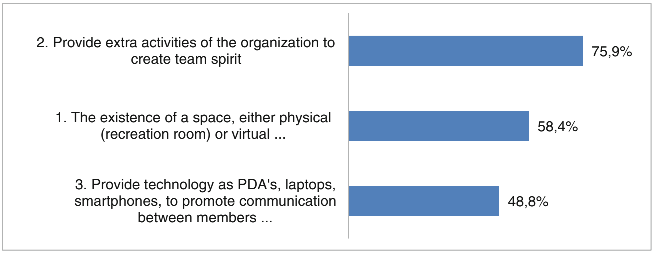

Fig. 4 Socialization factors—perceived importance (in descending order of positive responses)

importance is the availability of communication technologies (factor 3) with 48.8 % of responses of high importance. The tests of chi-squared only confirmed the following links:

- The importance of a physical space for socializing (factor 1) depends on the years of experience in job position ($X^2(12) = 21.965$, $p < 0.05$);
- The importance of offering extra activities (factor 2) depends on the size of the organization ($X^2(12) = 19.458$, $p < 0.10$).

The fifth question examines the perceived team effect into the knowledge creation during projects. The question asks the level of agreement with three different statements (Likert scale with five levels, ranging from 1—"I totally disagree" to 5—"I totally agree"). All statements recorded high percentages of agreement (all higher than 98 % considering the sum of answers 4—"I agree" and 5—"I totally agree") (see Fig. 5). The following dependency relationships were identified:

- Interaction and dialogue as a key element (statement 1) depends on the age of the respondent ($X^2(6) = 12.400$, $p < 0.10$) and years of professional experience ($X^2(6) = 14.146$, $p < 0.05$);
- Interaction and dialogue results into concepts, terms or common methods (statement 2) depends on the nationality of the respondent ($X^2(3) = 8.674$, $p < 0.05$);
- The contribution of a reflection environment (statement 3) depends on the organization's activity ($X^2(12) = 19.168$, $p < 0.10$).

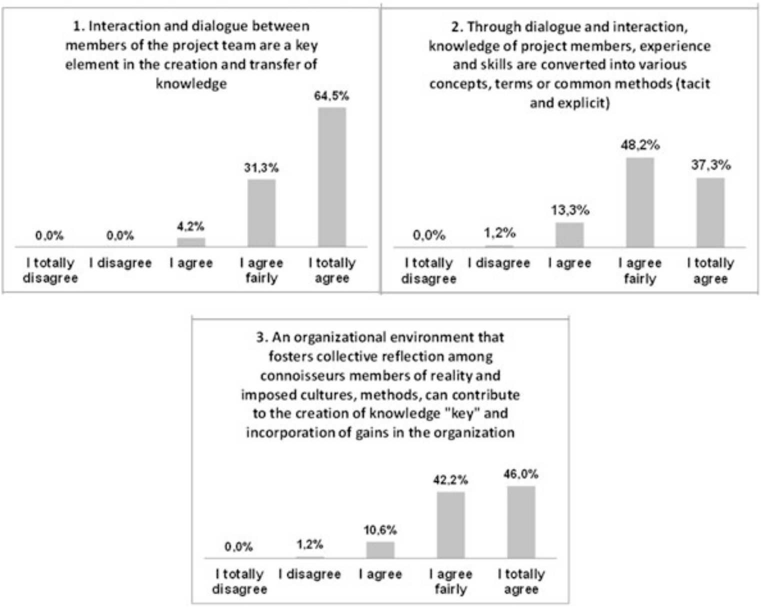

Fig. 5 The perceived project team effect into the knowledge creation

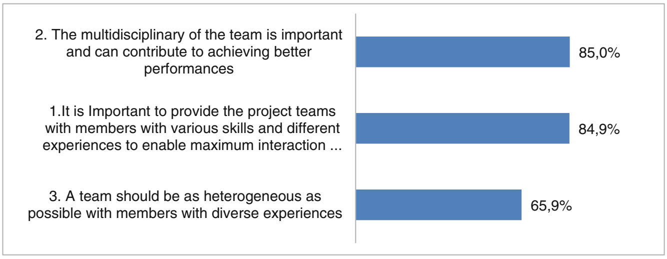

Fig. 6 The transmission of knowledge within the team—the perceived importance (in descending order of positive responses)

The sixth question assesses the transmission of experience within the team considering three different statements (use a scale with five levels of importance). Figure 6 illustrates the percentage of positive responses (sum of responses 4—“important” and 5—“very important”).

Respondents considered of high importance the multidisciplinary within the team (statement 2, with 85.0 % of positive responses) and the multiple skills of the team (statement 1, with 84.9 % of positive responses). The lower perceived importance is related to the heterogeneity of the team (statement 3 with 65.9 % of positive responses). Only one significant dependence relation between heterogeneity of the team (statement 3) and the size of the organization ($X^2(12) = 23.458$, $p < 0.05$) was found.

5 Conclusions and Further Research

As mentioned by Ref. [31, p. 58], “Good intentions are not enough to guarantee improvements—commitment, support and skill are all essential. Furthermore, a clear and shared understanding of the organization’s objectives is important if organizations are to learn collectively and thereby reap the significant benefits associated with collaborative reflection”. Many of the most valuable efforts to encourage knowledge creation and distribution have little to do with new technology, especially when the knowledge is complex and tacit, and therefore resists codification.

The organizational context for enhancing learning and knowledge management continues to present countless challenges and difficulties. Some of these were identified in our exploratory study, namely:

- the high level of agreement between the affirmations regarding the number of resources allocated to learning, the organizational culture, the processes and methods used as well as the storage of key information, is clear; despite that, a peculiar factor is presented by its level of dependency in the response pattern

dealing with the variable nationality. It gives support to previous literature mentioned, pointing out that according to the nationality under consideration, knowledge could represent different things to different people;
- there are several contextual constraints associated with learning, such as high pressure of time to projects completion; lack of communication among project members, lack of human, technical, and technological resources; commonly accepted by an expressive level of agreement. The dependency tests indicate that the "lack of motivation to learn" has a significant dependency with the years of work experience and the size of the organization. It is an important clue to explore in future research. In turn, the "lack of a methodology review to learning" presents a significant dependency with the respondent's age. This suggests the existence of differences in the pattern of responses by age groups of industrial managers' respondents, and requires further research to explore it;
- the development of an organizational knowledge management system (KMS) by embedding the value systems, the linguistic differences as well as the emotional reactions presented a significant dependency with the level of work and job experience. It is possible that this level of dependency could be related with the ability of senior managers to appreciate some characteristics like non-verbal expressions that give them precious information during the project execution, just by observing behaviors and expressions of theirs staff;
- the socialization process is seen as an important way to facilitate the knowledge conversion. The perceived importance of physical space for socialization has a dependency with respondent's job experience. This dependency might suggest that this feature is more relevant in the beginning of the job function where the level of confidence and know-how is lower and somehow dependent of some references. The perceived importance of outdoor socialization of teams with the purpose of gaining confidence and team spirit (team building) has a dependency with organizational dimension. Results suggest that small organizations regard this as highly important. In our view that might be explained because in big organizations the project staff rotation is higher and the awareness among peers is more incipient;
- the dialogue and interaction between project team members is seen as a key element to create and transfer knowledge, with 95.8 % of agreement. Results indicate a dependency with age and with professional experience. These dependencies might suggest that experience favors the human relation through personal contact and dialogue which properly managed could convert the personal knowledge, experience and skills into several concepts, terms, or common methods enhancing teams performance.

Thus, it is our belief that the opinions gathered from expert respondents will allow us, among other things, to identify key determinants that can contribute for different stakeholders gaining higher awareness about the knowledge acquisition and learning. Other factors like technological environment and leadership profile will be considered in a broader view for assessing their impacts and measuring their importance for this theme. Hereafter, this research will proceed developing and validating a formal theoretical model.

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Flexibility of SMEs

Stefan Trzcieliński

Abstract Contemporary enterprises can choose one of the two approaches to cope with the increasing changeability of environment. The first, used mostly in big sized enterprises that present high technological and organizational culture, is lean management. By implementing it the enterprise protects itself against the disturbances generated by the environment by elimination and reduction of waists. The second approach is to be agile enterprise what means to be able to identify and use short life time opportunities. One of feature of agile enterprise is its flexibility. Flexibility is meant as the ability of enterprise to extend the repertoire of undertaken opportunities (performed tasks or manufactured products and provided services). In this paper some results of research on flexibility of Polish SMEs are presented. The results include evaluation of both the environment's changes and how Polish SME's adopted themselves to the changes. The considered period of the adaptation is 5 years.

Keywords Agile enterprise · Flexibility · SMEs · Knowledge based economy

1 Introduction

Since the turn of 1980s and 1990s an intensive development of themes associated with knowledge management have been observed.[1] Scientists and researchers have introduced to the literature and practice concepts like: intellectual capital, learning organization, knowledge workers, knowledge creating company, intelligent organization, knowledge economy, and others similar. The last term, i.e. knowledge economy or knowledge-based economy (KBE) was introduced in 1966 in the book The Effective Executives by Peter Drucker. In 1996 OECD defined it as "economies

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[1] Among others, the process is described by Dalkir [1], Grant [2], and Trzcieliński [3].

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which are directly based on the production, distribution and use of knowledge and information. This is reflected in the trend in OECD economies towards growth in high-technology investments, high-technology industries, more highly-skilled labour and associated productivity gains" [4]. In current use the term is meant as it was defined by Powell and Walter as „production and services based on knowledge-intensive activities that contribute to an accelerated pace of technical and scientific advance, as well as rapid obsolescence. The key component of a knowledge economy is a greater reliance on intellectual capabilities than on physical inputs or natural resources" [5]. Passing the stylistic differences between different definitions of KBE it is stressed that among its basic factors are: information, knowledge, and human/intellectual capital. Countries that develop these factors present faster expansion in output and employment in high-technology industries, such as computers, electronics and aerospace. The high-technology share of manufacturing production and exports as well as knowledge-intensive service sectors, such as education, communications and information, are growing even faster. It is estimated that more than 50 % of GDP in the major economies is knowledge-based [4]. Premising such effects the European Commission agreed in Lisbon in 2000 a new strategic goal for the Union in order to strengthen employment, economic reform and social cohesion as part of a knowledge-based economy [6]. In 2010 it was replaced by the Europe 2020 Strategy that among others see Knowledge-Based Economy as a component of Smart growth, i.e. one of three priorities[2] of the strategy [7].

One of effects of KBE is a change of firms behavior. Enterprises expect from employees work qualities such as initiative, creativity, problem-solving and openness to change, and are willing to pay premiums for these skills [4]. This is because firms need to be more flexible or generally speaking more agile. To compete in turbulent environment they must be able to undertake quickly short life time opportunities. The agility of enterprise is characterized by four features: (1) brightness—that is the ability to perceive the opportunities, (2) flexibility—the ability to extend the repertoire of undertaken opportunities (performed tasks or manufactured products and provided services), (3) intelligence—that is the ability to understand the situations in which the company functioning and find intentional reactions in these situations, and (4) shrewdness—the ability of an enterprise to use quickly the opportunities in beneficial mode [8].

The importance of KBE did motivate a group of researchers from Poznan University of Technology to investigate if Polish enterprises adopt themselves to the conditions the economy creates. An assumption was made that the enterprises should become more agile. This paper examines only if flexibility of small and medium sized enterprises followed the changes of KBE in period from 2007 to 2011.[3]

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[2] The three priorities are: Smart growth, developing an economy based on knowledge and innovation; Sustainable growth, promoting a low-carbon, resource efficient and competitive economy; and Inclusive growth, fostering a high employment economy delivering social and territorial cohesion.

[3] Some results of the research on flexibility of medium sized enterprises was published in work [9].

2 The Methodology of the Research

2.1 Identification of Changes in KBE Impotent to Flexibility of Enterprises

To evaluate how countries progressing in KBE, The World Bank elaborated KAM methodology (Knowledge Assessment Methodology), used to assess changes in individual economies (countries), in the process of transition to a Knowledge-Based Economy. The KAM methodology uses 148 indicators which are ultimately aggregated in four KBE pillars: Economic Incentive and Institutional Regime, Education and Training, Information and Communications Technologies (ICT) Infrastructure, and Innovation and Technological Adoption.

The values of the 148 indicators of the KBE, when compared in time, presents the changes in the business environment. Therefore they are treated as first degree independent variables (IV-1) describing the environment in which the enterprises act. From the list of 148 variables a set of 53 independent variables was chosen that have potential influence on enterprises' agility. Their value were standardized end expressed in sten scale[4] Eight of them refers to flexibility of the enterprises. They were grouped into two second degree independent variables (IV-2). Each of these two fulfils the conditions of reliable scale for measuring the change of situations in KBE potentially important to enterprises' flexibility. The reliability was tested by alpha Cronbach test. The independent variables of first and second degree are presented in Table 1.

2.2 Identification of Changes of Flexibility of Enterprises

To identify if the enterprises adjusted themselves to the changes of KBE a questioner consisted of 383 questions was elaborated. The questions refer to the state that existed in the enterprises in 2007, 2011, and to changes in the period in following four research areas: strategy of business agility, human capital of enterprise, information and communications technologies, and changes of organizational structures. The study was conducted in 2012 in 150 enterprises throughout Poland, including 45 large, 60 medium and 45 small enterprises. The questions are treated as dependent variables of first degree (DV-1). The values of the variables were transposed on a scale from (−5, 0) to (5, 0), since the value of individual DV-1 were not comparable. As a general rule of the transposition assumed that if all the surveyed companies evaluate a given DV-1 positively, its value would be (+5, 0); if all companies evaluate it negatively, its value would be (−5, 0); the balance of negative and positive assessments gives result (0, 0).

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[4] Sten scale or sten scores consist of 10 units (stens), have a mean of 5.5 and a standard deviation of 2.

Table 1 Independent variables affecting flexibility of enterprises

Second degree independent variable (IV-2)		Reliability		First degree independent variable (IV-1)		Standarized value							Change	
Symbol	Name	Crobnach's alpha	Assessment	No. in KBE	Name	2007	2008	2009	2010	2011	2007	2011		
IV-F1	Situations potentially important for financial flexibility of enterprise	0.7963	Good	1	Average annual gross domestic product (GDP)	8.00	6.00	2,00	4.00	5.00	30.00	17.00	−13.00	1.00
				9	Gross capital formation as % of GDP (Average)	8.00	4.00	4,00	4.00	6.00				
				44	Availability of venture capital (1-7)	8.00	6.00	4,00	4.00	3.00				
				49	Firm-level technology absorption (1-7)	6.00	7.00	6,00	3.00	3.00				
IV-F2	Situations potentially important for social flexibility of enterprise	0.585	Poor	2	Gross domestic product (GDP) per capita	3.00	7.00	3,00	5.00	7.00	14.00	28.00	14	
				61	Life expectancy at Birth	2.00	5.50	5,50	5.50	8.00				
				80	Unemployment rate (% of total labor force)	6.00	2.00	4,00	6.00	6.00				
				90	Pay and productivity (1-7)	3.00	3.00	6,00	6.00	7.00				

From all dependent variables a set of 67 variables that refer to changes of flexibility of enterprises was selected. They were clustered in second degree (DV-2) and next in third degree dependent variables (DV-3). Using the Cronbach's alpha test the DV-3 were checked for being reliable scales for measuring the changes of flexibility in the enterprises. In results, 10 for small and 12 for medium-sized enterprises, second degree dependent variables that make up reliable measuring scales were disclosed (Table 2). The different number of variables for small and medium-sized enterprises is an effect of testing the DV-3 for being reliable measuring scale of flexibility. To get the reliable Cronbach's alpha measure, in some cases, different DV-2 for small and medium-sized enterprises were selected from the third degree dependent variables. These DV-2 that fulfill the conditions of reliable scale have got the ordinal number. In consequence in several cases the same variable DV-2 has different symbol for small and medium-sized enterprises. Example can be "Change of importance of competencies" that has symbol DV-F2-VC-2 for small and DV-F4-VC-1 for medium-sized enterprises. However in both cases it consists form exactly the same first degree dependent variables.

Table 2 Dependent variables describing flexibility of enterprises

Small sized enterprises		Medium sized enterprises		Name
Second degree dependent variable (DV-2)				
Symbol	Change of value	Symbol	Change of value	
		DV-F1-VC-1	3.75	Change of employment
DV-F1-VC-1	5.67			Change of number of tasks done by teams and forms of managerial contracts
DV-F1-VC-2	4.78	DV-F1-VC-2	5.92	Change of: spending for external trainings, number of computers, and variety of operational systems and applications
		DV-F2-VC-1	2.42	Change of dimensions and flexibility of orgnizational structure
		DV-F2-VC-2	2	Change of importance of candidates' competencies and use of tools of competence management
DV-F2-VC-1	1.44	DV-F3-VC-1	3.17	Change of tools for competencies management and features of competencies
		DV-F3-VC-2	3.58	Change of flexibility of organizational structures in: R&D, marketing, sales, and procurement

(continued)

Table 2 (continued)

Small sized enterprises		Medium sized enterprises		Name
Second degree dependent variable (DV-2)				
Symbol	Change of value	Symbol	Change of value	
DV-F2-VC-2	2.44	DV-F4-VC-1	4.08	Change of importance of competencies
		DV-F4-VC-2	3	Change of flexibility of organizational structures in: Operations, Administration, and importance of issues on organizational structure
DV-F3-VC-1	0.44	DV-F5-VC-1	0.92	Change of number of departments and forms of organization for making strategic decisions
DV-F3-VC-2	1.78			Change of: configuration and formalization of organizational structure, number of employees with flexible working time, and managers' knowledge about designing organizational structures
DV-F4-VC-1	1.56	DV-F5-VC-2	0.67	Change of share of strategic and operational tasks performed in different forms of work organization
		DV-F6-VC-1	2.25	Change of: number of low value contracts, variety of used technology, and way of staff recruitments
DV-F4-VC-2	1.78	DV-F6-VC-2	1.33	Change of: recruitment by top management, importance of HRM, and policy of employment
DV-F5-VC-1	0.78			Change of: number of task and project teams, number of customers sectors, number of short term contracts with suppliers, and territorial scope of competition
DV-F5-VC-2	2.78			Change of: specialization of administrative staff, participation in relatively stable cooperative networks, importance of initiatives of top management about strategy and structure, and number of subcontractors

The symbols mean: *DV*—Dependent Variable; *F*—Flexibility preceding the number of third degree dependent variable; *VC*—Value Change preceding the ordinal number of DV-2 in DV-3

Table 3 Correlation of flexibility of small-sized enterprises

Zmiennna	DV-F1-VC-1	DV-F1-VC-2	DV-F2-VC-1	DV-F2-VC-2	DV-F3-VC-1	DV-F3-VC-2	DV-F4-VC-1	DV-F4-VC-2	DV-F5-VC-1	DV-F5-VC-2
IV-F1-VC	−0.94	−0.74	−1.00	−0.35	−0.69	−0.93	0.84	0.87	−0.20	−0.13
IV-F2-VC	−0.94	−0.74	−1.00	−0.35	−0.69	−0.93	0.84	0.87	−0.20	−0.13

2.3 Correlation Between Changes of KBE and Changes in Enterprises

To check if the changes of flexibility of enterprises follow the changes of these variables of KBE that refer to flexibility, a correlation between independent and dependent variables analyzed. From the point of view of the essence of correlation, the term independent and dependent variable is not appropriate because basing on the correlation coefficient it cannot be concluded about the cause and effect relation. However, when interpreting the correlation it was assumed that changes in the macro-environment of companies (independent variables), and this is the environment that is the subject of analysis of Knowledge Based Economy, are primary to changes in enterprises (dependent variables). This is also accepted on the basis of strategic management and is the logical consequence of assumption that the economic policy of countries and economic groups should cause such acting of enterprises that is desired for social and economic objectives. The correlations are presented in Tables 3 and 4.

3 Discussion of Results

3.1 Changes in Business Environment Important to Flexibility of Enterprises

The changes in the business environment are calculated as the difference between values of the independent variables in 2011 and 2007. These values have been standardized and are expressed on a sten scale, ranging from 1 to 10. Therefore the maximal absolute value of the change for a single first degree variable (IV-1) can be 9 and for the second degree variable (IV-2) that groups four IV-1 may be 36. The maximal change is treated as a reference point to assess the scale of changes of the independent variables [3].

The values of the independent variables and their changes are presented in Table 1. The situation potentially important for financial flexibility of enterprises was essentially deteriorated. The value of the variable achieved −13. Each IV-1 that consists on that IV-F1-VC got worse. The probably reason for that had been the financial crisis from 2008. The second IV-2 “situation potentially important for social flexibility of enterprise was improved and got the value +14. This is 39 % of

Table 4 Correlation of flexibility of medium-sized enterprises

Variable	DV-F1-VC-1	DV-F1-VC-2	DV-F2-VC-1	DV-F2-VC-2	DV-F3-VC-1	DV-F3-VC-2	DV-F4-VC-1	DV-F4-VC-2	DV-F5-VC-1	DV-F5-VC-2	DV-F6-VC-1	DV-F6-VC-2
IV-F1-VC	0.65	−0.94	0.7.	0.2.	−0.99	−0.53	−0.43	−0.87	−0.94	−0.65	0.98	1.00
IV-F2-VC	0.65	−0.94	0.7.	0.2.	−0.99	−0.53	−0.43	−0.87	−0.94	−0.65	0.98	1.00

Table 5 Statistically significant correlation

Independent variable Symbol	Enterprise	Second degree dependent variable DV-2			
Name	Small medium				
Value		Symbol	Change of value	Name	Correlation
IV-F1-VC	S	DV-F1-VC-2	4.78	Change of: spending for external trainings, number of computers, and variety of operational systems and applications	−0.74
Situations potentially important for financial flexibility of enterprise	M	DV-F1-VC-2	5.92		−0.94
	S	DV-F2-VC-1	1.44	Change of tools for competencies management and features of competencies	−1.00
	M	DV-F3-VC-1	3.17		−0.99
−13.00	S	DV-F3-VC-1	0.44	Change of number of departments and forms of organization for making strategic decisions	−0.69
IV-F2	M	DV-F5-VC-1	0.92		−0.94
Situations potentially important for social flexibility of enterprise	S	DV-F4-VC-1	1.56	Change of share of strategic and operational tasks performed in different forms of work organization	0.84
	M	DV-F5-VC-2	0.67		−0.65
	S	DV-F4-VC-2	1.78	Change of: recruitment by top management, importance of HRM, and policy of employment	0.87
14.00	M	DV-F6-VC-2	1.33		1.00

the maximal possible change. In result the changes in segments of the environment that are described by eight IV-1 of the KBE (Table 1) was slightly positive and got the value +1. It covers only 1.4 % of the maximal possible value.

3.2 Changes of Flexibility of Enterprises

The maximal possible absolute value of change of single DV-2 that consists of four DV-1 is 20 (each DV-1 can get a maximal absolute value of 5). This is the reference point for estimating the scope of changes of the DV-2. The scope is calculated as share of the particular DV-2 change of value in its maximal possible change.

Each DV-2 describing the changes of flexibility of both small and medium-sized enterprises got positive value (Table 2). This confirms a positive trend of changes of flexibility in the enterprises. The scope of changes is relatively high. The average DV-1 covers 46.9 and 55.2 % appropriately in case of small and medium-sized enterprises. Among the variables IV-2 that contribute the most to increase of flexibility are following: spending for external trainings, number of computers, tools to manage the competencies, importance of competencies, recruitment by top managers, and importance of HRM.

3.3 Correlation Between Environment and Flexibility of Enterprises

Seven dependent variables DV-2 of small-sized and ten DV-2 of medium-sized enterprises are statistically significant correlated with independent variables (Tables 3 and 4). In these two sets five variables are common (Table 5).

Three of the common variables are negatively correlated, one is correlated positively with both independent variables, and one is positively correlated for small and negatively for medium-sized enterprises. The negative correlation is surprising. The explanation of it lies on managerial decisions when the situation in the environment gets better. The attempt of explanation is in Conclusion chapter.

4 Conclusions

In the period covered by the research two opposing trends in the business environment, significant from the point of view of the flexibility of firms, did emerge. The trend expressed by indicators of KBE describing situations relevant to the financial flexibility of enterprises was negative. There was a deterioration in the environment. This deterioration was reflected in declines in the following ratios: average annual GDP, gross capital formation, availability of venture capital, and firm level technology absorption. The aggregate value of these indicators covers 36.1 % of the smallest possible value. The second trend is positive and is expressed by indicators of KBE relating to the social flexibility of enterprises. All indicators expressing it, such as GDP per capita, life expectancy, unemployment rate, and pay and productivity, were improved. Their aggregate value covers 38.8 % of the maximal possible value. Related absolute values of the two opposite trends gave a picture of seemingly stable part of the environment, which affects the flexibility of companies. In fact, the environment was very turbulent. It seems that the weight of the negative impact on the financial flexibility of companies is greater than the positive impact on the social flexibility. It is this negative trend that caused that most of the variables describing the change in firms' flexibility are correlated negatively. The deterioration of conditions in the environment which are significant for financial flexibility of enterprises led to slow down of management activities that require involving financial resources in the development of social potential and flexibility of human resources [10] as well as networking [11] and reduction the wastes [12]. This process was mitigated by changes in the environment, supporting the increase of social flexibility of enterprises.

Flexibility is one of the four characteristics of enterprise's agility. This article does not discuss the changes of other features, which are brightness, intelligence and shrewdness. Some results relating to these characteristics are presented in works [3, 9, 13, 14]. They allow to conclude that agility of enterprises was improved, although not to the extent that was potentially possible.

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Part VII
Human-Oriented Design of Production Systems

Effects of Macro-ergonomic Compatibility of Work Demands on Manufacturing Systems' Organizational Performance

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Abstract High work demands (WDs) usually have negative effects on employees such as exhaustion and absenteeism, whereas moderate WDs have positive effects that include work enjoyment and creativity. However, effects of WDs on clients, production processes and organizational performance are scarcely studied. This paper analyzes the effects of macro-ergonomic compatibility of work demands of employees (MCWDs), as independent variable on manufacturing system with respect to production processes, clients, and organizational performance as dependent variables. As methods, a macro-ergonomic compatibility questionnaire (MCQ) is developed and statistically validated, and a Structural Equations Model (SEM) is created to find the effects of MCWDs on the dependent variables, and also the effects among them. Results indicate that MCWDs do not have a direct effect on organizational performance, but on production processes and clients; and significant indirect effect on organizational performance. As conclusion, MCWDs represents a source of clients' satisfaction, production processes' reliability, and organizational performance.

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1 Introduction

According to [1], “Ergonomics and human factors use knowledge of human abilities and limitations to the design of systems, organizations, jobs, machines, tools, and consumer products for safe, efficient, and comfortable use”. The objective of ergonomics is to improve both performance and health and safety of employees [1]. Ergonomics is divided into two sub-disciplines: Micro-ergonomics and Macro-ergonomics. Macro-ergonomics is the part of this science, that is aimed to study work systems in order to achieve fully harmonize of their elements at both micro-ergonomic and macro-ergonomic level [2].

According to [1] work systems design can impose work demands (WDs), which in turn may produce negative or positive effects on employees. Negative effects usually appears when WDs are high [3]. Such effects may include exhaustion, negative work attitudes [3], absenteeism, health impairment and cynism [4]. On other hand, positive effects may appear when tasks represent a challenge for employees [5]. Such positive effects may include work enjoyment and organizational commitment [3]. Most of literature is related to direct effects of WDs on employees. However, the effects of WDs on work systems performance has not been explored sufficiently. Macro-ergonomic compatibility of work demands (MCWDs) refers to the requirement level of a set of tasks when they can be performed on a comfortable, challenging and creative way. In this paper we present a structural equation model (SEM) about the effects of MCWDs on manufacturing systems with respect the production processes, clients, and organizational performance.

According to [2], macro-ergonomic compatibility is a construct based on the theory of Karwowski [6], and it exists when in a work system there is an appropriate interaction between the personnel subsystem and the technological subsystem, including the relationship with the external environment. About the variable of organizational performance, it is stated that it is a construct difficult to measure, and according to [7], it refers to whether a company does well in discharging the administrative and operational functions pursuant to the mission and whether this company actually produces the actions and outputs pursuant to the mission or the institutional mandate.

In this paper, MCWDs is based on the execution of tasks that relatively demand little mental workload, time, attention and pressure, and also require of the employees’ creativity. Whereas organizational performance refers to whether a company does well in discharging the administrative and operational functions pursuant to the mission and whether this company actually produces the actions and outputs pursuant to the mission or the institutional mandate.

The rest of the paper is structured as follows: Sect. 2 presents some theoretical backgrounds on which the SEM is based. Section 3 shows the methodology applied to gather data and analyze them, Sect. 4 aims to the results, and Sect. 5 includes conclusions of the research.

2 Literature Review

2.1 Effects of Work Demands on Production Processes

Work demands (WDs) can be the root cause of success or failure on manufacturing systems according to their level of requirement. WDs are defined as psychological stressors that are present in the work environment or work load [8], while production processes refer to a relevant procedure for adding value to an organization [2]. Several studies have found a negative indirect relation between WDs and production processes. For example, some authors state that high WDs cause burnout on employees, which takes them to get a depression and a low occupational engagement [9]. Also, there are studies that show that high WDs may cause high emotional exhaustion and work stress [8], and reduced availability of adequate supervision [10]. However, there are also studies showing that adequate levels of WDs may produce well-being and improve the learning of employees [8].

All of these effects impact on employees' performance, which in turn impacts on the production processes. This fact was considered into this macro-ergonomic approach and we propose the following hypothesis H_1: Macro-ergonomic compatibility of WDs has a direct and positive effect on reliability of production processes on manufacturing systems.

2.2 Effects of Work Demands on Clients

The level of WDs plays a critical role on clients' satisfaction on manufacturing systems, since the interaction between employees and clients may be influenced by WDs. According to [11], the Lobbying Disclosure Act (LDA) defines client as "any person or entity that employs or retains another person for financial or other compensation to conduct lobbying activities on behalf of that person or entity". There are several studies that present evidence on the effects of WDs on different types of clients. For example, [12] states that high WDs are strongly related to work family conflicts (husband vs. wife, which can be seen as mutual clients according to the definition given above). Moreover, [13] points out that high WDs may cause burnout, which can be manifested through a reduced personal accomplishment marked by a tendency to evaluate oneself negatively, particularly with regard to work with clients. Another study also suggests that workers with high emotional

WDs may have a depersonalized attitudes with their clients [14]. All of these effects may cause a state of dissatisfaction on clients. Therefore, based on these backgrounds and from a macro-ergonomic perspective, we propose the hypothesis H_2: Macro-ergonomic compatibility of WDs has a direct and positive effect on satisfaction of clients of manufacturing systems.

2.3 Effects of Work Demands on Organizational Performance

The main objective of companies is to improve their competitiveness on the global market. To achieve this, such companies have to improve their organizational performance. Organizational performance is a construct difficult to measure, and according to [7], organizational performance refers to whether a company does well in discharging the administrative and operational functions pursuant to the mission and whether this company actually produces the actions and outputs pursuant to the mission or the institutional mandate.

Researches have shown high WDs can impact individual and organizational performance. For example, [15] state that WDs cause stress, which in turn affects organizational performance. Other study found that WDs are positively related to emotional exhaustion and negatively to vigor and dedication [16], impacting negatively on organizational performance. Moreover, [17] point out that stress caused by WDs may affect performance by means of a poor employee's commitment, motivation to invest effort, and motivation to maintain personal discipline.

Based on these previous antecedents we propose the hypothesis H_3: Macro-ergonomic compatibility of WDs has a direct and positive effect on organizational performance on manufacturing systems.

2.4 Effects of Production Processes on Organizational Performance

On manufacturing systems, reliability of production processes is one of the most significant aspects to improve the organizational performance. Several studies have stated that different organizational processes may have an effect on organizational performance. For instance, [18] mention that types of innovation (service, technological and administrative process) have a positive effect on organizational performance in service companies, while [19] state that innovations are an indispensable component of corporate strategies since they help apply more reliable production processes to improve organizational performance in manufacturing companies. Moreover, studies have shown that reliable production processes have positive effect on organizational performance on manufacturing systems [2]. That is the case of [20], who illustrated the effects of a reliable production process in a manufacturing company. For this reason, we propose the hypothesis H_4: Reliable production processes have a direct and positive effect on organizational performance in manufacturing systems.

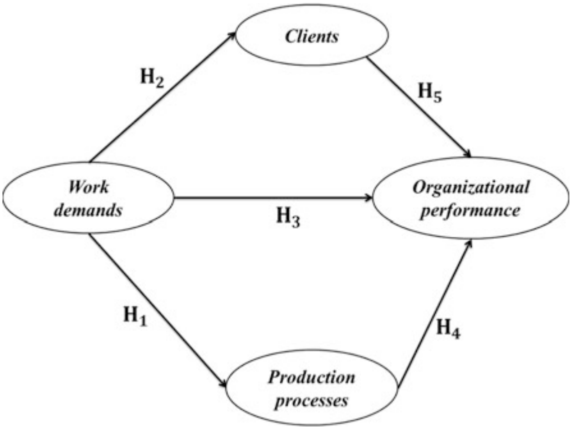
2.5 Effects of Clients on Organizational Performance

Clients are the most significant mediator of the success of a company. Several researches have pointed out that clients have effects on organizational performance of companies. For instance, it has been stated that satisfied clients are the major source of employment [21], and the most significant power for competitiveness of companies. In fact, [21, 22] argue that when companies understand better the needs of clients, they increase their competitive advantage.

However, researches have also found that clients can improve other aspects of organizations. Oyedele and Tham [21] indicate that evaluations made by clients on the performance of companies can improve abilities and responsibilities of employees and therefore organizational performance. Likewise, [23] state that when clients lack of knowledge and experience, projects developed by companies may fail or generate poor quality products. All these findings have allowed for the proposal of hypothesis H_5: Satisfied clients have a direct and positive effect on organizational performance in manufacturing systems.

Figure 1 shows the hypothetical model for this research.

Fig. 1 Hypothetical causal model



3 Methodology

Methodology applied in this research basically comprises four stages: (1) the development of the macro-ergonomic compatibility questionnaire (MCQ), (2) the application of the MQC, (3) the statistical validation of the MCQ, and (4) the analysis of the structural model. Each of these stages is explained below.

3.1 Macro-ergonomic Compatibility Questionnaire (MCQ) Development

Developing the MCQ requires an extensive literature review in order to define the most frequent and concise macro-ergonomic compatibility variables. Five general variables are selected and named macro-ergonomic factors, which in turn are divided in more specific variables called macro-ergonomic elements. Macro-ergonomic factors include: (1) person (human capital), (2) organization, (3) tools and technology, (4) tasks, and (5) physical environment. On this research we focus only on the macro-ergonomic factor of tasks.

The macro-ergonomic factor of tasks includes four macro-ergonomic elements named: (1) variety of tasks; (2) work content, challenge and use of skills; (3), autonomy, job control and participation; and (4) work demands (WDs). This research is focused only on the macro-ergonomic element of WDs.

The section of the MCQ corresponding to the macro-ergonomic element (dimension) of WDs includes six items (statements). These items are answered on the 5-point Likert scale: (1) Totally disagree, (2) Disagree, (3) Neither agree or disagree, (4) Agree, (5) Totally agree. This scale is used since it has been applied in recent and similar researches [24]. Items on the MCQ corresponding to the macro-ergonomic element of WDS are showed below:

1. Tasks are designed in order to employees perform one task at a time.
2. Tasks performed are simple and uncomplicated.
3. Employees process/monitor a small amount of information during the execution of their tasks.
4. Tasks require solving problems whose answer is obvious.
5. Tasks require creativity of workers.
6. Tasks are evaluated periodically on the workload

Items corresponding to the dimensions of Production processes, Clients, and Organizational performance are answered on the same 5-point Likert scale. These items are shown below.

Items corresponding to the dimension of Production processes:

1. The number of Clients' complaints on a year is very low.
2. The number of defects is very low.

3. The productivity level shows a positive trend (increasing) since the beginning of operation of the company.
4. Inventory levels are low.

Items corresponding to the dimension of Clients:

1. The needs and expectations of Clients are taken into account.
2. Clients are satisfied with the products they receive from the company.
3. Clients have remained loyal to the company.
4. The number of Clients of the company has shown a positive trend (increasing) from the beginning of its operations.

Items corresponding to the dimension of Organizational performance:

1. The number of employees has grown due to high Clients' demands.
2. Since its beginnings of operation, the company has increased the variety of products it offers to its Clients.
3. The turnover is very high.

3.2 *Procedure of Application of the MCQ*

The application of the MCQ is carried on manufacturing systems of Ciudad Juarez, Chihuahua, México. Surveyed people include employees of middle and senior management (managers, supervisors, and team leaders). The procedure for applying the MCQ basically consists of the two steps described below:

1. Contact a manager of a company. Contact information about manufacturing companies is obtained by means of databases provides by the National Institute of Statistics, Geography and Informatics (Instituto Nacional de Estadística, Geografía e Informática, INEGI) [25], and the Association of Maquiladoras, Civil Association-Index Juarez (Asociación de Maquiladoras, Asociación Civil, AMAC-Index Juarez) [26]. Then a manager of a specific company is contacted and invited to participate on the research project. The manager is informed about the research project, the MCQ, the objectives of the project, and the benefits for the company. After the manager accept participate we proceed with the step 2.
2. Application of the MCQ. As at this step the manager has already informed his colleagues about the research project, a date and hour is defined for the application of the MCQ.

The application of the MCQ comprises data of 188 surveyed employees of four manufacturing systems. With these data we proceed to perform the MCQ statistical validation.

3.3 MCQ Statistical Validation

A database is made introducing the 188 data on the SPSS® software [27]. Then a data screening is performed by replacing the outliers and missing values by the median, due to data are on a ordinal scale (Likert scale) [24]. Once all outliers and missing values are replaced, the statistical validation of the MCQ is performed for each dimension using the Cronbach's alpha coefficient, and considering a minimum cutoff value of 0.7, since when a Cronbach's alpha value is ≥0.7, the dimension is considered to be important for the questionnaire's purposes [24]. Then, all dimensions with a Cronbach's alpha value ≥0.7 are preserved in the MCQ. For those dimensions that do not meet this condition, a process of removal of items is performed considering the corrected item-total correlation and the new Cronbach's alpha value when an item is removed, and that a dimension must have at least two items. Items with a corrected item-total correlation lower than 3.0 are removed.

Dimensions that do not meet with the Cronbach's alpha cutoff value even after removing items are deleted of the MCQ.

Another important coefficient is the average variance extracted (AVE), which is used as indicator of discriminant validity and convergent validity. For discriminant and convergent validity it is recommended to set a minimum value of 0.5 for each item, and the *p* value has to be significant, it means $p \leq 0.05$ [24]. The index of variance inflation factors (VIFs) is useful to detect collinearity between latent variables. Collinearity is satisfying when the VIFs value is below 3.3 in every dimension or latent variable [24]. Moreover, Q-squared is used as a nonparametric measure of predictive validity when data are expressed in an ordinal scale. Predictive validity is achieved when Q-squared is higher than zero [24].

3.4 Analysis of Structural Model

Relationships between dimensions are analyzed by using the technique of structural equation model (SEM), since this technique is the best one to find relationships when the analysis includes several independent or dependent variables, as in this research [24, 28]. This analysis is performed with the aid of the software WarpPLS 5.0® to detect the relations among the dimensions to test the hypotheses defined in Fig. 1.

The model fit and quality indices used are the average path coefficient (APC), average R-squared (ARS), and average variance inflation factor (AVIF), since they are highly recommended to evaluate the model [24]. For the APC and ARS, the *p* value is the general criterion to accept or reject a relation between dimensions. Relations with $p < 0.05$ are considered significant, since the analysis is performed at a confidence interval of 95 %. Otherwise, relations are considered insignificant and are removed. Once significant relations are detected, the load values are analyzed. If in item possesses a greater load value in one dimension different from where it belongs, this item is removed.

For the APC and ARS, acceptable values are those different to zero, meanwhile for the AVIF, 5 is set as the maximum acceptable value [24].

Direct effects are used to validate hypotheses shown in Fig. 1. Indirect effects are obtained through other dimensions or latent variables, and they can also be due to two or more segments. The sum of direct effects and indirect effects provided a total effect [24].

4 Results and Discussions

This section presents the results of applying the methodology described in the Sect. 3. It comprises the results of MCQ statistical validation and the analysis of the structural model.

4.1 MCQ Statistical Validation

Table 1 shows the statistical validation of the MCQ for the dimension of WDs, Production processes, Clients, Organizational performance and their items.

None of the dimensions was removed according to the criteria established in Sect. 3.3. However, items 5 and 6 included in the dimension of Work demands (see Sect. 3.1) were removed since they had corrected item-total correlation values of 0.275 and 0.294, respectively. Then, these items were not included in the analysis of the structural model.

According to the results on Table 1, it can be stated that MCQ is reliable, since the Cronbach's alpha value is greater than 0.7 in all dimensions analyzed.

Table 2 presents the results of MCQ regarding the discriminant and convergent validity, collinearity between latent variables, and predictive validity. The AVE values are greater than the minimum cutoff value of 0.5 in all dimensions; thus, the MCQ has discriminant and convergent validity. The VIF values are lower than 3.3, then it can be stated that there are no problems of collinearity between latent variables. Finally, every Q-squared value for each dependent variable is higher than zero; hence, nonparametric predictive validation is achieved.

Table 1 MCQ statistical validation

Dimension (Cronbach's alpha)	Items and their corrected item-total correlation					
	1	2	3	4	5	6
Work demands (α = 0.757)	0.516	0.616	0.596	0.489	0.275	0.294
Production processes (α = 0.774)	0.709	0.690	0.522	0.404		
Clients (α = 0.818)	0.550	0.684	0.742	0.609		
Organizational performance (α = 0.781)	0.568	0.660	0.632			

Table 2 Validity of the MCQ

Index	Work demands	Production process	Clients	Organizational performance
AVE	0.578	0.600	0.654	0.697
Full VIF	1.182	1.633	1.825	1.565
Q-squared		0.146	0.102	0.392

4.2 Analysis of Structural Model

Model Fit and Quality Indices. The APC value was 0.355, with a $p < 0.001$, while the ARS value was 0.221, with a $p = 0.001$. Then relations with continuous lines depicted in Fig. 2 are significant. Additionally, the AVIF value was 1.482. With these values the model is efficient and predictive [29].

Direct Effects (Hypotheses Test). Figure 2 shows all of the direct effects. The values expressed in β are dependence measurement values and represent standardized values. *p* values are the values for the significance hypothesis test. Note that most of the $p \leq 0.001$, which means that the relations are significant. Only the *p* value for the relation between Work demands and Organizational performance was higher than 0.05, meaning that this relation is not significant and can be rejected.

In Fig. 2 significant direct effects are those with continuous lines, whereas insignificant direct effects are marked with discontinuous lines.

Indirect Effects. The only indirect effect was between Work demands and Organizational performance. The value of this indirect effect was 0.240, with a $p < 0.001$, which means that Work demands has a significant indirect effect on

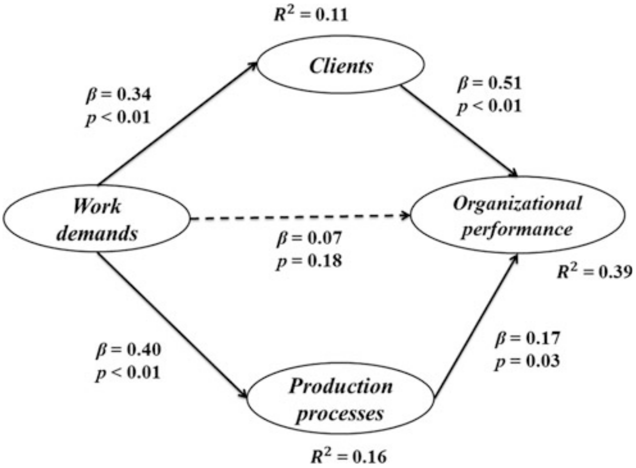


Fig. 2 Significant direct effects (*continuous lines*) and insignificant direct effects (*discontinuous lines*)

Table 3 Total effects

To	From		
	Work demands	Production processes	Clients
Production processes	0.40*		
Clients	0.34*		
Organizational performance	0.24*	0.17**	0.51*

*Significant at the 99.9 % confidence level, **significant at the 95 % confidence level

Organizational performance, since when Work demands increases its standard deviation by one unit, Organizational performance increases by 0.240.

Total Effects. Table 3 introduces the total effects among the dimensions analyzed. Most impacts are significant at the 99.9 % confidence level. Total effects have the same interpretation as indirect effects. As there was only one indirect effect, most of the significant direct effects and total effects are the same.

5 Conclusions

This section presents the conclusions derived from the results regarding the development of the MCQ and the hypotheses stated.

5.1 Conclusions Related to the MQC

In this research we only presented and used the section of the MCQ related to the Work demands and the indicators of Production processes, Clients, and Organizational performance. However, and based on the Cronbach's alpha values for each dimension, we can conclude that this section of the MCQ is reliable, it means, it measures what it has to measure.

5.2 Conclusions Related to Hypotheses

According to results shown in Fig. 2 it can be concluded that there is not enough statistical evidence to reject hypotheses H_1, H_2, H_4, and H_5, meanwhile there is enough statistical evidence to reject hypothesis H_3. Then we can conclude the following:

1. Macro-ergonomic compatibility of WDs is required for reliable production processes.
2. Macro-ergonomic compatibility of WDs is required for satisfied clients.

3. Reliable production processes are required for improvement of Organizational performance.
4. Satisfied Clients are required for improvement of Organizational performance.

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Approaches for the Efficient Use of Range Sensors-Based Ergonomic Assessment Results in the Ergonomic Intervention Process of Awkward Working Postures

Christopher Brandl, Tobias Hellig, Alexander Mertens and Christopher M. Schlick

Abstract In occupational practice the majority of health-related sick leave and early retirements in industrial nations is caused by musculoskeletal disorders and awkward working postures are known as whose major risk factor. In the past, many methods for identifying and assessing working postures were developed and applied in companies. The purpose of this paper is to address the ergonomic intervention process, which is also part of an ergonomic improvement of work systems. Therefore a general process for the ergonomic improvement with a range sensor-based approach and an approach to adapt the ergonomic intervention process on range sensor-based ergonomic assessment results was developed. These approaches are able to combine a digital ergonomic analysis process with a digital ergonomic intervention process in order to achieve a holistic ergonomic improvement process. The advantages and limitations of these approaches for the prevention of musculoskeletal disorders are discussed.

Keywords Cyber physical systems · Ergonomics · Intervention process · Working postures

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1 Introduction

With the bid for cyber physical systems, in future much data will be available in real-time. For ergonomic purposes the increase of data has a high potential in redesigning better work systems. The technical innovation related to sensors, e.g. the use of range sensors in observational methods [1] will decrease the effort of sampling data. However the effort in post-processing will increase disproportionate. For this reason it is important to consider this part of the ergonomic improvement process more detailed.

In occupational practice the majority of health-related sick leave and early retirements in industrial nations is caused by musculoskeletal disorders and awkward working postures are known as whose major risk factor. For this reason we chose awkward working postures as the example for developing a process for an ergonomic improvement process. The reasons and effects of awkward working postures are known widely. In the past, many methods for identifying and assessing working postures were developed and applied in companies, e.g. the Ovako Working Posture Analysing System [2]. The scientific research is still focusing on issues of ergonomic analysis of working postures—meaning for example to correctly assess the interaction between body postures or to give correct recommended limits for intensity, duration and frequency of working postures [3]. But research seems to miss completely to address the ergonomic intervention process, which is also part of an ergonomic improvement of work systems. Methodic assistance detached from ergonomic assessment methods or assistance for the ergonomic intervention process of working postures to create technological requirements through automation is essentially nonexistent. It's not a question that this phase is at least as important as the ergonomic analysis as without developing and implementing corrective measures the efforts by then are useless. Neither the German standard handbook for "Industrial Engineering" [4] nor internationally established handbooks, such as "Evaluation of Human Work" [5], "Handbook on Standards and Guidelines in Ergonomics and Human Factors" [6], "Handbook of Human Factors and Ergonomics" [7], "Handbook of Human Factors and Ergonomics Methods" [8], "Maynard's Industrial Engineering Handbook" [9], "The Occupational Ergonomics Handbook—Fundamentals and Assessment Tools for Occupational Ergonomics" [10], "The Occupational Ergonomics Handbook—Interventions, Controls, and Applications in Occupational Ergonomics" [11] and "Working Postures and Movements—Tools for Evaluation and Engineering" [12]. The ergonomic intervention process is currently a highly individual, knowledge-based process without an ergonomic-focused methodical procedure. Moreover, a methodical connection of the ergonomic analysis and the ergonomic intervention of working postures could not be established, until now.

Thus the aim of this paper is (1) to present a general process for the ergonomic improvement with a range sensor-based approach and (2) to develop approaches to adapt the ergonomic intervention process on range sensor-based ergonomic assessment results, i.e. investigating the possibility of a holistic digital ergonomic improvement process.

2 General Process for the Ergonomic Improvement of Existing Work Systems

Before the range sensor-based improvement of working postures can be conducted, an observation-based method for data collecting by using range sensors has to be selected. A large number of such observational methods are available. Selecting a method is depending on the objectives of its use, the characteristics of the work, the individuals who will use the method and the resources available for collecting and analyzing data [3]. Usually such methods determine parameters which affect work load mostly, e.g. working postures of persons, force and time characteristics of the load [13]. In the present work we have used the Ovako working posture assessment system (OWAS).

As Fig. 1 shows, the ergonomic improvement process comprises two sub processes: the ergonomic analysis and the ergonomic intervention process. The ergonomic analysis targets at collecting data—in our case of working postures—by using range sensors. Afterwards the ergonomic intervention process uses the collected data for improving working postures.

The ergonomic analysis comprises two steps, (i) identifying and (ii) assessing stress on the musculoskeletal system of working persons. Therefore range sensors with an implemented observation-based method for identifying and assessing stress on the musculoskeletal system of the working person can be used [1].

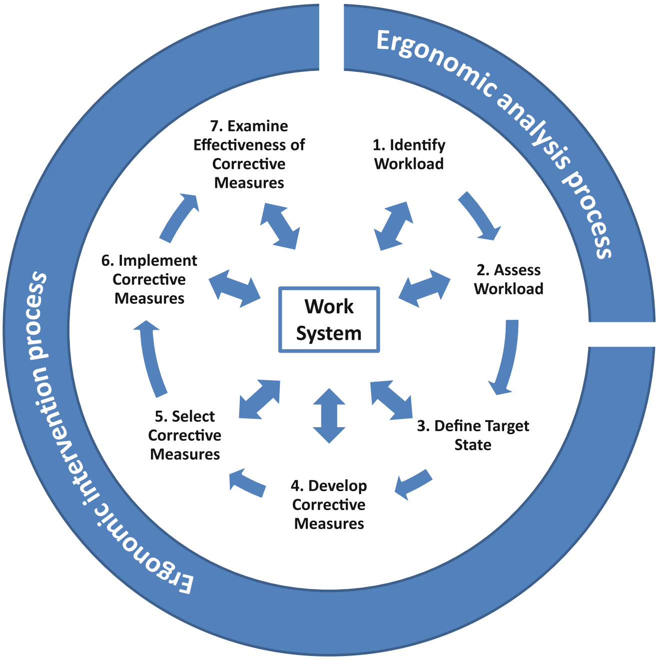


Fig. 1 Flowchart of ergonomic improvement process

After identifying and assessing working postures, an ergonomic intervention process is necessary. This ergonomic intervention process mostly targets at improving work systems through reducing stress by using the collected data of range sensors during the ergonomic analysis. Therefore five steps have to be conducted: (i) target states have to be defined, (ii) corrective measures for attaining defined target states have to be developed, (iii) corrective measures have to be selected, (iv) corrective measures have to be implemented in existing work systems and (v) effectiveness of implemented corrective measures has to be examined.

Usually, target state would be a decrease in stress on the musculoskeletal system of working persons. Depending on identified and assessed working postures corrective measures have to be developed. In the following this paper focuses on presenting two approaches for post-processing of ergonomic data obtained through range sensors for defining target states (iii), developing corrective measures (iv) and selecting an appropriate corrective measure (v). The first approach considers the methodical background of OWAS for developing technical measures, such as workplace design. The second approach comprises organizational measures.

3 Approaches to Support the Ergonomic Intervention Process

The following two approaches are described with the understanding that the results respectively the data of a range sensor-based ergonomic analysis using the Ovako Working Posture Analysing System (OWAS) has to be used as an input for the pos-processing during the ergonomic improvement process.

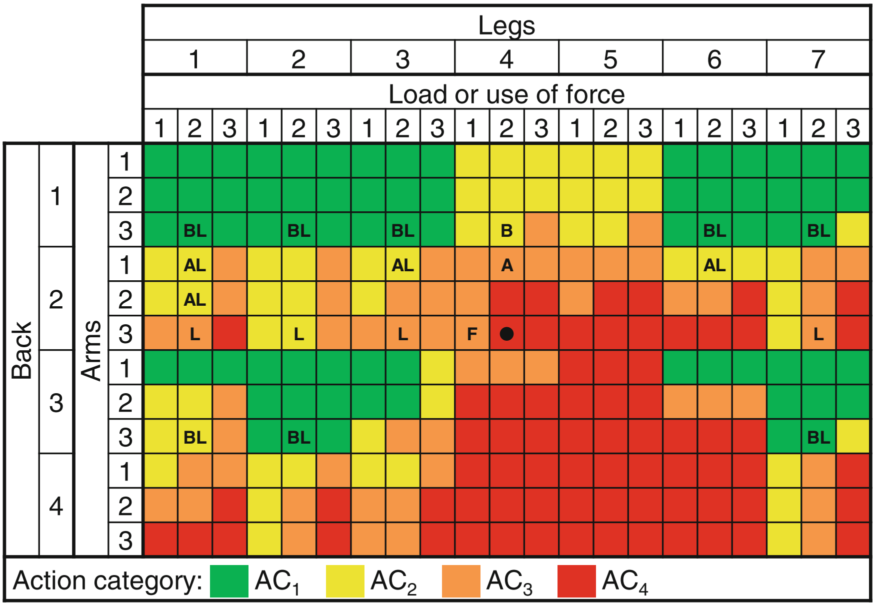
3.1 Approach to Develop Measures for an Ergonomic Improvement

The proposed concept for supporting the ergonomic intervention process of awkward postures compromises the following steps,

1. to define target states, first a search algorithm has to identify and prioritize target postures with less postural load than the awkward posture,
2. to develop corrective measures, second drafts of corrective measures to realize target postures with less postural load has to be found and/or conceived and
3. to select an appropriate corrective measure, third the drafts as to be compared due to requirements.

For the improvement of awkward working postures target postures should be identified first. Therefore, in accordance with the ergonomic assessment of working postures defined by OWAS an algorithm was developed. The algorithm is searching target postures with better action categories (AC) as defined by OWAS in comparison to the awkward posture to be changed. This procedure begins by changing one digit of the numerical code, which is called first-order change and will continue with second- and third-order changes. The procedure is briefly explained by using the example of the working posture “2342”. This working posture indicates an awkward posture (AC4) with back bent forward, both arms above shoulder level, standing with both legs bent and a load of 12 kg (indicated in Fig. 2 as “●”). Identifying target postures with less postural load than “2342” requires changes in the numerical code. For example, changing the first digit of the numerical code “2342” into “4” will lead to the numerical code “4342”, which indicates a working posture assigned to AC4. As the postural load is not decreased by this change, this working posture is not identified as target posture. Changing the first digit of the numerical code “2342” into “1” will lead to the numerical code “1342”, which indicates a working posture assigned to AC2. As the postural load is decreased by this change, this working posture is identified as a target posture. This procedure is performed for each possible first-order change to identify the solution space of first-order target postures and will continue with the higher-order changes. The software-based post-processing enables practitioner to handle to the huge amount of data.

The target postures are classified according to the action category and the order of change in the numerical code in order to prioritize them. To support finding



		Legs																				
		1			2			3			4			5			6			7		
		Load or use of force																				
Back	Arms	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩
	2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩
	3	🟩	🟩 BL	🟩	🟩	🟩 BL	🟩	🟩	🟩 BL	🟩	🟨	🟨 B	🟧	🟨	🟨	🟧	🟩	🟩 BL	🟩	🟩	🟩 BL	🟨
2	1	🟨	🟨 AL	🟧	🟨	🟨	🟧	🟨	🟨 AL	🟧	🟧	🟧 A	🟧	🟧	🟧	🟧	🟨	🟨 AL	🟨	🟨	🟧	🟧
	2	🟨	🟨 AL	🟧	🟨	🟨	🟧	🟨	🟧	🟧	🟧	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟥	🟨	🟧	🟥
	3	🟧	🟧 L	🟥	🟨	🟨 L	🟧	🟧	🟧 L	🟧	🟧 F	🟥 ●	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟧 L	🟥
3	1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟧	🟧	🟧	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	2	🟨	🟨	🟧	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟩	🟩	🟩
	3	🟨	🟨 BL	🟧	🟩	🟩 BL	🟩	🟨	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩 BL	🟨
4	1	🟨	🟧	🟧	🟨	🟨	🟧	🟨	🟨	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟧	🟥
	2	🟧	🟧	🟥	🟨	🟧	🟥	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟧	🟥
	3	🟥	🟥	🟥	🟨	🟧	🟥	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟧	🟥

Action category: 🟩 AC_1 🟨 AC_2 🟧 AC_3 🟥 AC_4

Fig. 2 Identifying target postures on the example of “2342” (●) by changing the numerical code according to OWAS (*B* = change of back posture; *A* = change of arm posture; *L* = change of leg posture; *F* = change of load class; *one letter* = first-order change; *two letters* = second-order change) and/or conceiving drafts of corrective measures, for each first-order change generic interventions were developed and therefore are available in the process. As support for the procedure a software-based variable knowledge database was developed. This database will contain generic intervention examples for each first-order change and will be extendable by already implemented corrective measures. By using such a methodical procedure, the continuous ergonomic intervention process is supported by a systematic conceiving with existing drafts, which can be extended countless. Similar awkward working postures, requiring an ergonomic intervention, will be found automatically within in the documented interventions. Selecting one draft of a corrective measure due its ergonomic effectivity can be done with a working posture prediction model. A detailed description of the previous research can be found in [14].

3.2 Approach to Develop an Optimized Model for the Assignment of Employees

The data of a range sensor-based ergonomic analysis can also be used to improve the assignment of employees aimed to reduce work-related risk factors, such as awkward working postures. Therefore, ergonomic analysis results, at least differentiated by work place, better by individual are required. In general the assignment of employees can be done by the linear assignment problem [15], which can be formulated with the optimization function F for the optimization criteria o_{ij} and assignment options z_{ij} according to Eq. 1 under the additional conditions of Eqs. 2 and 3.

$$F(z) = min \sum_{i=1}^{x} \sum_{j=1}^{y} \left(o_{ij} \cdot z_{ij} \right) \tag{1}$$

$$1 = \sum_{i=1}^{x} z_{ij} \quad z_{ij} \in \{0, 1\} \ \forall i \tag{2}$$

$$1 = \sum_{j=1}^{y} z_{ij} \quad z_{ij} \in \{0, 1\} \ \forall j \tag{3}$$

This was tested for several criteria, such as the energy expenditure, the job severity index and the European Assembly Worksheet, and for small scales of usually four employees and four work activities [16–19]. With the help of the linear assignment problem, the criterion that needs to be optimized is minimized. For work-related working postures this appears to be constructive because the present state of knowledge only allows partially quantitative assessments. For this reason DIN EN 1005-4 strongly recommends striving for a maximal improvement of the working postures, even if the assessment result already is “acceptable”. However, the linear assignment problem only minimizes the stress of the group and therefore ignores the goal of the equal distribution of the stress on the employees. For an equal distribution of the stress on the employees a distribution exponent e can be introduced for the product of the optimization criteria and the assignment options. The distribution of risk factors in a work group requires a consideration of the time respectively the number of assignments n.

4 Discussion

Prior work has documented the process of identifying and assessing stress on the musculoskeletal system of working persons, for example observation-based assessment of working postures according to OWAS [2]. However, these methods have not focused on the ergonomic intervention process which is an integral part of the ergonomic improvement process. Previous studies have analyzed the ability of range sensors for identifying and assessing stress on the musculoskeletal system of working persons [1]. In this article we found a general process for the ergonomic improvement of existing work systems. Furthermore, two approaches were presented. These approaches are able to combine a digital ergonomic analysis process with a digital ergonomic intervention process in order to achieve a holistic ergonomic improvement process. Furthermore, the approaches enable software-based post-processing of the huge amount of data, are easy to use and do not require the employment of highly trained and skilled staff in each step. In addition, the use of range sensors does not require calibration processes and does not affect the work process [1]. These findings extend the feasibility of the ergonomic intervention process contrary to prior approaches. However, some limitations are worth noting. The software-based variable knowledge database contains generic intervention examples. These examples are not always realizable due to determining factors of the product or production process. Furthermore the optimized model for the assignment of employees does only minimize the stress of the group and therefore ignores the goal of the equal distribution of the stress on the employees.

5 Conclusion and Outlook

The increasing digitalism in production systems generates a high potential in ergonomics. Using range sensors in observational methods, e.g. for the ergonomic analysis of working postures, will reduce the effort of data sampling. The connection between this digital ergonomic analysis and new post-processing algorithms or existing approaches of a digital ergonomic intervention process can lead to a holistic ergonomic improvement process.

Further developments of algorithms for supporting the ergonomic intervention process should focus on the individual optimum of stress on the employees as with range sensors the sampling of ergonomic data is less extensive. Implementing such procedures or algorithms in existing work systems would help decrease stress on the musculoskeletal system of working persons and could contribute to a decrease in the prevalence of musculoskeletal disorders. Further work has to be done in order to develop software tools. Furthermore, digital support or post-processing during the implementation and the examination process of corrective measures should be focused in scientific research.

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An Activity Centered Design Framework for Determining Design Decision Levels in Production Systems

Cecilia Berlin and Lars-Ola Bligård

Abstract This paper presents the ACD^3-Production framework—a two-dimensional model whose purpose is to visualize and clarify the scope, impact and organizational position of design decisions. The abbreviation stands for Activity-Centered Design Decision Determination and is based on a similar framework for product development that supports design decision-making in product design. The framework characterizes design problems along the two dimensions of *Abstraction levels* and *Design perspectives*; it is postulated that design decisions are made at the intersection of these, and that the production system's overarching purposes will propagate coherently down to the physical detailed design level if the design work follows the top-down process indicated in the framework. ACD^3-Production is visually represented in the form of a matrix that can facilitate discussions between design change agents, in order to determine where in the production system there are problems, where specific effects are desired, and where to implement a design change.

Keywords Activity-Centered design · Production systems · Production development Framework · Systematic design process

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1 Introduction

This paper is a short communication to introduce the ACD^3-Production framework—a two-dimensional model whose purpose is to visualize and clarify the scope, organizational position and impact of design decisions in a production system. The abbreviation stands for *Activity-Centered* (AC) *Design Decision Determination* (D^3) and is based on a similar framework for product development that supports design decision-making in product design [1, 2]. The framework is meant to enable organizations to address problem solving at the right level of detail, leading to design solutions that address the desired system performance outcomes at the right design detail level. The framework maps and reveals whether the design decisions and desirable outcomes are identified and addressed at the intersection of congruent organizational levels and design perspectives. This helps decision-makers to avoid costly implementations that end up not supporting the original intent.

1.1 Background

By necessity, most production systems [3] include a mix of humans, tasks, organization and technology—i.e., they are *sociotechnical systems* displaying high levels of complexity [4] that require a top-down approach that is capable of designing not just the physical human-machine interfaces, but also the design of work itself and the organizational structure that will make production possible [5, 6]. According to Clegg [6], sociotechnical principles to guide system design state (among other things) that "design is systemic" (p. 465), involves making choices (p. 466), entails "multiple task allocations between and amongst humans and machines" (p. 468), and that systems components should be congruent. Furthermore, Davis et al. [7, p. 3] propose in their framework that sociotechnical systems must form a balance of considerations between Goals, People, Buildings/Infrastructure, Technology, Processes/Procedures and Culture, under the external influence of Stakeholders, Financial/Economic Circumstances, and Regulatory frameworks.

Needless to say, optimizing such a complex system is a formidable task that requires a systems view while it acknowledges the process-oriented knowledge base that is at the heart of design and product development research [8]. This top-down view may appear easy to accept as being the appropriate approach, and yet, many tangible, intentional design decisions are commonly associated with the lowest levels of technical detail. According to Zink et al. [9], many change management processes end up unsuccessful because of a lack of choosing approaches that are congruent with policy and strategy (called vertical harmonization) and a lack of "logical fit between the single concepts (horizontal harmonization)" (p. 530). The question is, with all these threats to successful design change, how can the necessary multi-level systemic view be supported in the production system design process?

Edwards and Jensen [10] have suggested guidelines for “system designers”, but the focus was organization-, stakeholder- and knowledge-management oriented rather than design-oriented. When it comes to problem solving from a design perspective, such models may not always provide sufficient detail to guide production system designers towards graspable design changes of a physical or concrete nature. In light of the above, extending a design process framework for product development to the requirements of a production systems setting appears promising, to address many of the above concerns.

1.2 Theoretical Foundation of ACD^3-Production

In light of the above, adapting the ACD^3 framework for product development [1, 2] to be applicable to a production systems setting appears promising, to address many of the above concerns. The *ACD^3-Production* framework described in this paper draws from a “sibling” framework specifically developed for product development (ACD^3, described in [1], which in turn draws on [11] and B [12]). Originating from a sociotechnical systems-, human factors and design process perspective, the framework draws from the authors’ experiences of teaching and carrying out industrial product development design projects, the framework emerged as a tool for increasing the understanding of design processes and design outcomes. The theoretical basis draws on activity theory [13], systems engineering [14], product development [8], and human factors [15], and is combined with a production systems framework [3] that transfers the question of “where and how are design decisions made?” from the product realm to the production systems realm. Particularly, the framework places the problem-solving focus on *Use*-centered design [16]. This emphasizes the interaction between humans and the system as a whole, regardless of who the user is (in coherence with the Activity Theory basis), rather than *User*-centered design, which focuses on the adaptation of systems to the characteristic needs and requirements of specific individual users.

The point of using the ACD^3-Production framework is to first *design the intentions and effects of the change*, before finding the correct level at which the design decision has the most impact. The design decision in turn determines the solution principle (which may range from a comprehensive change of mission or strategy, all the way down to a simple tool purchase or redesign). The point made by the framework is that every design decision, regardless of whether it is made intentionally or not, results in a tangible (physical or procedural) manifestation in the final production system.

2 The ACD^3-Production Framework

The key elements of the ACD^3-Production framework are the *Abstraction levels* and the *Design perspectives.* When determining the appropriate level of re-design and/or problem solving in a production system, it can be valuable for the involved stakeholders to reach consensus on the desired outcomes or effects of the design chance, as well as the scope and nature of the proposed solution.

2.1 Abstraction Levels

The dimension of *abstraction level*s addresses the "system resolution" at which the production system is viewed—in other words, is the production system viewed as a "black box" that inputs are entered into to generate outputs [3], or are the sub-system levels and their components made explicit? This captures the nature of the problem to be solved—is the issue a strategic, high-level question that requires organization-wide implementation and has repercussions throughout the production system? Or is the issue a low-level "quick-fix" to solve a system inefficiency that can be addressed with the purchase or design of a technical solution? To cover this spectrum, the Abstraction level dimension (Table 1) is divided into five levels:

Table 1 The Abstraction Levels of the ACD^3 framework, with examples of design decisions

Abstraction level	Core question	Design decision examples
Effect	What kind of impact should the production system achieve?	Produce higher quality at the same cost
Operation	How should the production perform its functions in order to achieve desired effects?	Principles used: kitting and parallel assembly flows
Architecture	How should resources (humans, machines and support structures) be distributed spatially to achieve the technical functionality that enables performance?	Layout of the factory and flow of material will be on two floors
Work	How should the resources (machines and operators) of the production system carry out work, and how should machines respond to operators and the environment?	Mix of manual assembly and human-robot collaboration
Tool/Information	What detailed, concrete support do the resources (primarily operators) need to fulfill partial tasks that have been decided in the overarching design levels?	Hand tools are designed for all hand sizes and fixtures guide the product assembly

This division makes it easier to identify at which level a problem is situated, an effect is desired, and/or where a design change should be implemented.

2.2 Design Perspectives

The *design perspectives* dimension addresses which conceptual view or detail level that the production system is viewed at when the decision is made. This aids decision-makers in determining the appropriate approach for problem solving to fulfill the system's overarching purposes. This dimension is divided into five levels (Table 2):

2.3 The ACD^3-Production Matrix

Combining the two dimensions *Abstraction levels* and *Design perspectives* in a matrix (Fig. 1) presents a powerful visual representation for discussion of where and how to specify, plan and implement a design change. Figure 1 shows this representation with the added nuance of a top-down system design process, indicated by the darker arrows. The arrows indicate a flow where working top-down through each column leads to a coherent *Goal Specification* (grey boxes) for the Abstraction level, which becomes the input to the next abstraction level, moving the process towards a higher degree of concretization of the design decisions.

Table 2 The Design Perspectives of the ACD^3 framework, with examples of the range of "design space" that the designers must find solution options for

Design perspective	Core question	"Design space" examples (ranging across abstraction levels)
Problem	The desired outcome(s) that drive(s) the process forward	*From:* The main purpose of the production system *To:* Problems with hand tools
Structure	The sub-components of the production system and how they are related to each other, physically and organizationally	*From:* Industry stakeholders *To:* mechanical parts of a hand tool
Function	The affordances and capabilities the system needs to offer	*From:* Industry values *To:* Functions in a hand tool
Activity	The tasks carried out by the system's human actors	*From:* Intended production tasks *To:* How to use the hand tool
Realization	How the system is concretized in terms of technology and personnel	*From:* Industry options and limitations *To:* Physical design of a hand tool

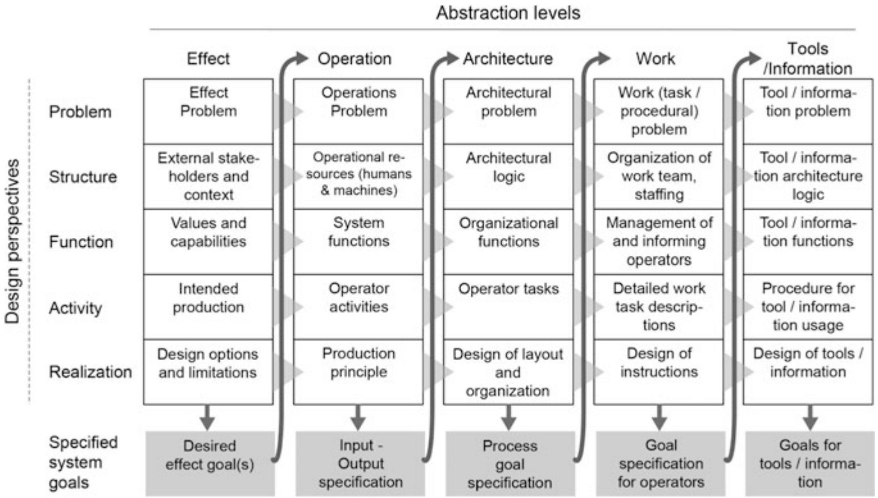

Fig. 1 The ACD^3-Production matrix in detail, with type of design decisions to be made at the intersection of each abstraction level and design perspective. The *dark arrows* indicate a flow indicating how each abstraction level's specified system goal(s) becomes the input to the problem perspective of the next abstraction level (to the *right*)

Within each Abstraction level (vertical column), the design decision contained in each cell is a consequence of the ones above it, regardless of whether a design decision has been actively taken or not. This reflects the increasing degree of concretization and level of detail as the systems designers progress through the different design levels. Within each Design perspective (horizontal row) each cell becomes more and more highly specified for each design level moving from left to right, i.e. they contain the same type of decisions, but for different abstraction levels.

The benefit of the matrix is that it helps to visualize the necessary work to be done in specifying what is wanted from the production system as well as what options there are for deciding on a solution; the degree of concretization and number of design constraints increase from top to bottom and left to right, respectively.

2.4 *Using the Matrix*

The way to use the framework in the most coherent way from a systems design perspective is to start at the top left in the *Effects* cell and work downwards through each column (abstraction level) to arrive at a specification of the system's *goal(s)*. The specified goal(s) is then an input to the next abstraction level. As stated in [1], this specification narrows down the design space to the range of possible solutions accessible to the design team. Continuing the design decision-making in this manner leads to a "cascade" of systemically coherent design decisions that propagate from an overall desired effect down to detailed physical design manifestations.

However, it is also possible for analysts to start at any cell in the matrix (for example, if a minor adjustment to technical equipment is determined to be the problem, it is not necessary to start questioning the organization's overall goals). From the starting point of any design decision, looking "upwards" in the matrix reveals the overarching driver for the change, and what boundaries have been set by earlier decisions on higher levels. Doing this allows a design team to determine whether the available design space is wide enough to find a solution, or if an adjustment at a higher level of purpose needs to be altered to enable the right range of solution possibilities.

3 Discussion

The ACD^3-Production framework addresses many of the requirements proposed by [6, 7, 9] regarding the design of sociotechnical systems. The framework is systemic; emphasizes the necessity of choices and design decision-making; addresses task allocations between humans and machines; strives for a coherent propagation (vertical and horizontal harmonization) from purpose (desired effects) down to technical detail-level design; and covers Goals, People, Buildings/Infrastructure, Technology and Processes/Procedures.

Another benefit of the ACD^3-Production framework is that it can serve as a "map" or mediating object [13, 17, 18] for dialogue where the impact of different stakeholders can be made explicit to everyone in the design team. The discussion can then facilitated for the design team to determine where there are problems, where specific effects are desired, and where to implement a design change. From this perspective, the framework is suitable to combine with an initial phase of stakeholder analysis, e.g. the CHAI method [19], where the actors that are most crucial to involve in the change process are identified and invited to participate in the design decisions—again, at the right abstraction level and design perspective. Some recent macroergonomics literature [20–22] emphasizes that in cross-disciplinary design endeavors, the extent of certain stakeholders' influence and power is limited, particularly that of ergonomics change agents [20, 22, 23]. In order for their knowledge to reach and influence workplace design changes, they must be involved from a design- rather than a health and safety perspective, and thus be given appropriate information, access and mandates to influence the design decisions.

As indicated by [20, 21, 23], the access to participation in a change project may be different for e.g. ergonomists and industrial engineers, and hence they may (by virtue of their profession and the expectations placed upon them by other stakeholders) be expected to solve certain types of workplace improvement problems, but may not always have the trust, mandate or authority to make design decisions. This is an issue that the ACD^3-Production framework could help to address, e.g. by mapping out the "extent of influence" of different stakeholders in the matrix cells.

Toward this end, the framework can greatly aid the involvement of stakeholders at the most effective levels, and facilitate that they are given an appropriate mandate to make decisions. For example, in some cases it may become apparent that a lower-level design change is not possible to carry out, because the mandate of the stakeholder at that level is limited—if changes are needed at a higher level first, a new stakeholder may need to be engaged. Reaching consensus about this in a design team is crucial to ensure that team members are not "talking past" each other as a result of viewing the problem at different abstraction levels, and that problems cannot be solved because different change agents have insufficient mandates to make decisions.

4 Conclusions

This paper has presented the basic elements and work procedure that together make up the ACD^3-Production framework for production system design change. When the abstraction level and the design perspective are combined, a powerful tool for visualization and decision support emerges for design team stakeholders, to help determine the appropriate solution level and approach.

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Effects of Human Factors in Planning and Production Control Activities in Remanufacturing Companies

Karina Cecilia Arredondo Soto, Humberto Híjar Rivera, Jorge de la Riva Rodríguez and Rosa María Reyes Martínez

Abstract Due to the scarcity of natural resources, the high competitiveness between companies and the need to create new business opportunities, some manufacturers are becoming interested in activities that involve more complexity than conventional manufacturing of its products. This is the case of companies being the original manufacturers of a product, engaged in reverse logistics to recover it at the end of its useful life and apply remanufacturing. The main objective of this research is to identify how human factors influence the activities of planning and production control, specifically in the remanufacturing process. However, it is interesting to note that it is not possible to establish a fair comparison between the conventional manufacturing process and remanufacturing in this regard. Remanufacturing is a process with greater uncertainty, so that establishing relationships with influential human factors allows: first, to make a more realistic approach to the situation in the company; second, determine the manner in which the staff makes decisions about the process and; third, develop a strategy allowing the company to improve its key performance indicators. Remanufacturing, is a relatively new process, the papers found with this approach are scarce. So conducting exploratory, descriptive and explanatory research was considered. To start this research, a study was conducted including employees of seven companies in the auto parts remanufacturing industry. In the first place, semi-structured interviews were applied; thereby the basic information to design the survey was

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obtained, which prior to its implementation was validated. After collecting the data, a confirmatory factor analysis was developed. Subsequently, we proceeded with the design and implementation of a SEM (Structural Equations Modelling). This allowed proposing a theoretical model to interpret the information provided by employees in the implementation phase of interviews and surveys. The model is convincing in demonstrating that the activities of planning and production control in remanufacturing are strongly affected by the human factor and has a significant impact on its key performance indicators.

Keywords Remanufacturing · Human factors · Planning and production control activities

1 Introduction

Remanufacturing is and end of life strategy for products (EOL). There are been identified economical, ecological and social drivers in its implementation [1]. With regard to social benefits, it has been identified that remanufacturing requires personnel with technical knowledge, highly specialized. This allows them to develop a better paying job than conventional industrial activities that require basic assembly, being remanufacturing activities more rewarding than production line jobs. There are very well-defined positive effects of remanufacturing in production staff. However, it is clear that there are effects in both directions. Some of the planning and production control activities in remanufacturing are affected by the human factors. According to Guide et al. [2], Guide [3], Gungor and Gupta [4], Ferrer and Whybark [5] and Junior and Filho [6] the major complicating characteristics of PPC in remanufacturing are as follows:

Activities occupying the base of the pyramid are considered external, remanufacturers and production staff has no relation with these and are out of its reach. Regarding the first three activities identified in the top of the pyramid, are internal activities performed in the production plant, so the staff is directly related to them (See Fig. 1).

- Disassembly of returned products: products that were not designed to be disassembled allow staff to propose techniques for disassembly or recovery operations development.
- Highly variable processing times: It is due to different conditions in the parts returned; two identical parts may require a different degree of treatment for each remanufacturing operation. Another factor is the worker who performs the activity as well as their acceptance or rejection criteria based on their experience.
- Stochastic routings for materials for remanufacturing operations: it is too much related with the previous activity.

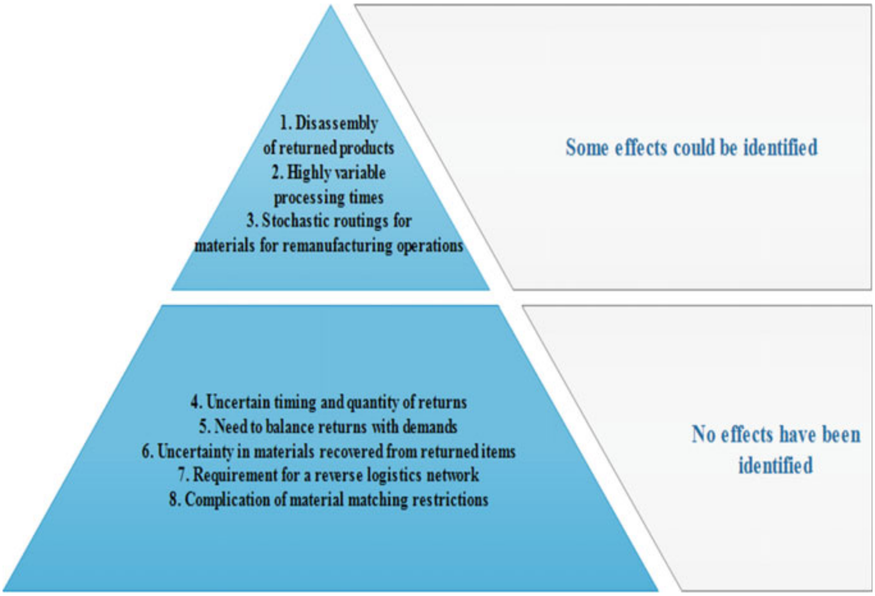

Fig. 1 PPC activities in remanufacturing

Remanufacturing is a process with high variability, so that establishing relationships with influential human factors allows: first, to make a more realistic approach to the situation in the company; second, determine the manner in which the staff makes decisions about the process and; third, develop a strategy allowing the company to improve its key performance indicators. Therefore, it is interesting to know how affects the production staff in the internal PPC activities.

2 Literature Review

It is well known there is a relation and influence between the human factor and the organizations' performance [7, 8]. The human factor is present at every stage of the production process. The worker contributes knowledge, attitudes, technical skills, human and conceptual skills, physical effort and management in the production process [9]. The company enables the individual to joining the organization (induction, training and development, evaluation and reward). However, the worker is collecting experience, incorporating skills and knowledge acquired individual, each worker acquiring it very personally.

Graham et al. [10] select ten general production engineering KPIs as follows: Work In Progress (WIP), Overall Equipment Effectiveness (OEE), Lead Time (LT), Cycle Time (CT), Hours Per Unit (HPU), Product Margin (PM), Quotation Accuracy (QA), Number of Concessions (NC), Number of managed BOMs (BOM), and Personnel Saturation (PS). However it was not easy to quantify the effects. Even though this evaluation method is considered good, it does not explain the results obtained. It does not explain how the human factor exerted influence on the final performance of the process.

Seifert et al. [11] identifies the following human factors affecting key performance indicators in remanufacturing operations: great effort in coordination activities (internal), very variable criteria for acceptance and rejection of products, level of experience based knowledge, broad qualifications/skills are necessary, complex knowledge management, increased error rate, perceived complexity of the product. In measuring the performance of an organization they are used key indicators for the company to obtain a numerical value for each given indicator.

Null, Marvel and Rodriguez [9], identifies other variables related with human factors and productivity: job satisfaction, participation, emphasis of achievement, motivation, cohesion, conflict, moral, consensus, control, stability, information management and communication, interpersonal skills management, training and development, flexibility, planning and accident (ergonomics).

2.1 Structural Equation Modeling

Subjective methods of measurement have been used, such as the Delphi Method, Likert Scale and Confirmatory Factor Analysis, in order to apply multidimensional scaling. Propose a model of multivariable measurement that considers human factors requires advanced statistical techniques such as SEM (Structural Equation Modeling). Starting from a construct to explain the observed behavior. The constructs are latent variables or factors cannot be observed directly [12], to be defined require indicators or other variables that are observable. By causal analysis it is possible to discover causal relationships between variables, using empirical research. These models do not prove causality but helps the researcher in making decisions.

The hypothesis is shown in Fig. 2, where unidirectional arrows involve direct relation and bidirectional arrows correlation. Assuming: HF_IND = Individual Human Factors, HF_PROD = Human Factors associated with the product, HF_PROC = Human Factors associated with the process and HF_ORG = Human Factors associated with the organization.

According to the problem statement, PPC_ACT is a dependent variable HF_IND, HF_PROD, HFPROC and HF_ORG. The latter are latent variables defined by the observed variables shown in Table 1.

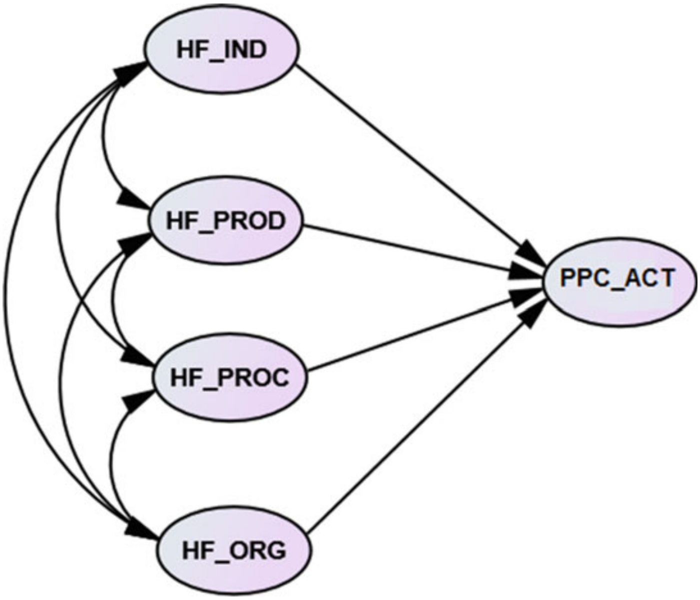

Fig. 2 Relations model PPC activities and human factors

Table 1 Model specification

Latent variables	Observed variables	Structural model equation	Measurement model equations
HF_IND (ξ_1)	Experience EXP (X_1)		$X_1 = \lambda^x_{11}\xi_1 + \delta_1$
	Attitud ATT (X_2)	–	$X_2 = \lambda^x_{21}\xi_1 + \delta_2$
	Job satisfaction JS (X_3)		$X_3 = \lambda^x_{31}\xi_1 + \delta_3$
HF_PROD (ξ_2)	Pollution CO1 (X_4)		$X_4 = \lambda^x_{42}\xi_2 + \delta_4$
	Corrosion CO2 (X_5)	–	$X_5 = \lambda^x_{52}\xi_2 + \delta_5$
	Wear CO3 (X_6)		$X_6 = \lambda^x_{62}\xi_2 + \delta_6$
HF_PROC (ξ_3)	Machine availability MD (X_7)		$X_7 = \lambda^x_{73}\xi_3 + \delta_7$
	Security PS (X_8)	–	$X_8 = \lambda^x_{83}\xi_3 + \delta_8$
	Perceived Complexity PPC (X_9)		$X_9 = \lambda^x_{93}\xi_3 + \delta_9$
HF_ORG (ξ_4)	Training TRA (X_{10})		$X_{10} = \lambda^x_{104}\xi_4 + \delta_{10}$
	Information management and communication IMC (X_{11})	–	$X_{11} = \lambda^x_{114}\xi_4 + \delta_{11}$
	Ergonomics ERG (X_{12})		$X_{12} = \lambda^x_{125}\xi_4 + \delta_{12}$
PPC_ACT (η_1)	Time process variability VAR_TIME (Y_1)	$\eta_1 = \gamma_{11}\ \xi_1 + \gamma_{12}\ \xi_2 + \gamma_{13}\ \xi_3 + \gamma_{14}\ \xi_4 + \xi_1$	$Y_1 = \lambda^y_{11}\eta_1 + \varepsilon_1$
	Routes variability VAR_ROUT(Y_2)		$Y_2 = \lambda^y_{21}\eta_1 + \varepsilon_2$

3 Methods

The instrument was applied to 206 employees working in remanufacturers companies specifically metalworking industry. Previous factor analysis was applied to verify the presence of latent variables and possible relationships. With the method of principal components analysis, factors were extracted applying Varimax rotation.

The proposed theoretical model was validated with quantitative analysis technique SEM (Structural Equation Modeling), applying multivariate statistical. This technique allows finding an estimate of multiple dependency relations, may represent not observed concepts in these relations and estimate the error rate in the measurement process. For data analysis was used software SPSS Statistics version 20 and AMOS version 23.

4 Results

Conducting a comprehensive study of the theoretical framework were defined five factors, four related to human behavior (the individual or personal, regarding the product, the process and organization) and a factor of indicators (variability in processing time and operating routes) activities associated with planning and production control.

Evaluating the data, factor analysis was considered relevant. This because KMO (the measure of sampling adequacy for Kaiser-Meyer-Olkin) is acceptable (0.811). The determinant of the correlation matrix was 3.173E-005, indicating the existence of very high correlations between variables. Five factors were extracted by Varimax rotation which explains the 85.57 % of the variance of the data. The results are visible in Tables 2 and 3.

Table 2 Rotated component matrix

Component					
	1	2	3	4	5
EXP	0.80				
ATT	0.83				
JS	0.89				
CO1		0.88			
CO2		0.93			
CO3		0.89			
MD			0.83		
PS			0.88		
PCC			0.89		
TRA				0.88	
IMC				0.92	
ERG				0.88	
VAR_TIME					0.90
VAR_ROUT					0.91

Table 3 Total variance explained

Component	Initial eigenvalues			Sums saturations squared extraction			Sum saturations squared rotation		
	Total	% variance	% accumulated	Total	% variance	% accumulated	Total	% variance	% accumulated
1	5.257	37.548	37.548	5.257	37.548	37.548	2.736	19.544	19.544
2	2.318	16.556	54.104	2.318	16.556	54.104	2.584	18.456	38.000
3	1.727	12.335	66.439	1.727	12.335	66.439	2.514	17.960	55.960
4	1.625	11.608	78.048	1.625	11.608	78.048	2.480	17.711	73.671
5	1.054	7.532	85.579	1.054	7.532	85.579	1.667	11.908	85.579
6	0.340	2.429	88.009						
7	0.317	2.262	90.271						
8	0.278	1.983	92.254						
9	0.264	1.883	94.136						
10	0.212	1.515	95.651						
11	0.173	1.236	96.887						
12	0.160	1.141	98.028						
13	0.140	0.997	99.025						
14	0.137	0.975	100.000						

Extraction method principal component analysis

Fourteen variables with significant loads were found. The first factor (component 1) is integrated with three variables: level of experience, attitude and job satisfaction. These variables are related to internal factors of the individual, the perception of their environment and how they react to it. In the second factor (component 2) are loaded three variables: criteria operator regarding the condition of origin of the product regarding the level of (a) corrosion, (b) pollution and (c) mechanical wear. In the third factor (component 3) are grouped: machine availability, process security, perceived process complexity. This factor considers subjective variables that show the perception of the skilled operator, concerning the process. In the factor four (component 4) loaded: level of training, information management and communication, and ergonomics. This factor considers variables related to the organization but affect the performance of the individual. Finally, the fifth factor (component 5) is composed of two variables: variability in process times and routes operations, wich strongly affect PPC activities. When there is proof of the relationships identified theoretically, we proceeded with the analysis of causal relationships. The standardized solution is shown in Fig. 3.

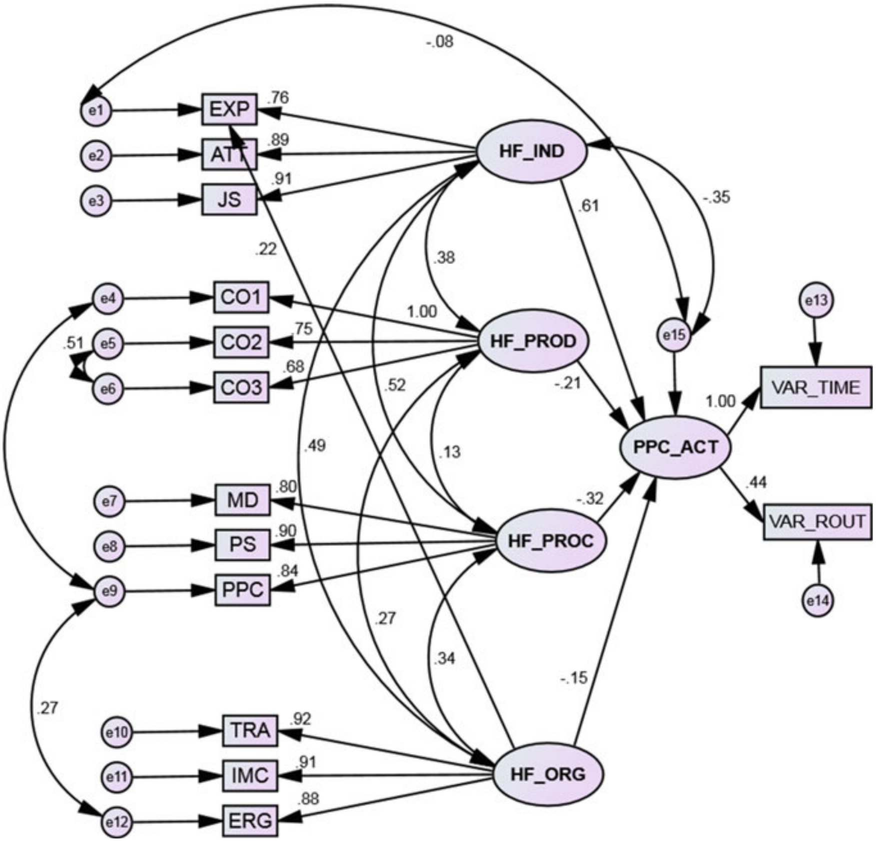

Fig. 3 Standardized solution of the proposed model

Table 4 Model fits

Statistical	Acceptance value	Model value	Decision
χ^2	$p > 0.05$	$\chi^2 = 73.132$ ($p = 0.158$)	Acceptance
Ratio χ^2/gl	<2	1.179	Acceptance
RMSEA (Root Mean Square Error of Approximation)	<0.05	0.030	Acceptance
NFI (Normed Fit Index)	>0.95	0.966	Acceptance
RFI (Relative Dit Index)	>0.90	0.949	Acceptance
CFI (Comparative Fit Index)	>0.95	0.995	Acceptance
IFI (Incremental Fit Index)	>0.95	0.995	Acceptance
TLI (Tucker-Lewis Index)	>0.90	0.992	Acceptance
GFI (Goodness of Fit Index)	>0.90	0.954	Acceptance
AGFI (Adjusted Goodness of Fit Index)	>0.90	0.923	Acceptance
PGFI (Parsimony Goodness of Fit Index)	>0.90	0.563	Rejection

Table 4 shows the adjustment level in the model. The global fit indices indicate a reasonable fit of the model, except for PGFI pointing a poor fit. However, it is considered that the adjustment is still good, as most indicators support the model.

5 Conclusions

In the literature review were identified the involved variables related to human factors that affect PPC activities. Conducting an analysis with direct staff in remanufacturers companies, the most appropriate variables considered were identified. These were used for the design of the instrument. These variables were grouped into five factors. These factors were called human factors related to (a) the individual, (b) the product, (c) the process, (d) the organization and (e) indicators that affect the activities of planning and production control.

It was found that HF_IND component exerts greater influence on PPC_ACT, considering the degree of experience, attitude and job satisfaction. This indicate that, even when the factors of complexity of the product, the process and the type of company strongly affect the activities of planning and production control, in the end, the individual factors of the worker are those that increase or decrease the indicators of the company. Correlation was found between measurement errors of some variables. This is logical in all cases. For example, the correlation between: error measurement in the perceived complexity of the process and the application of ergonomic principles by the company. The worker also associates the complexity of the process with the level of the product corrosion when the process starts. The worker identifies a link between the level of product contamination and mechanical wear.

The companies considered in the study, remanufacture of metalworking products sector, have a workshop type production system. Most workers involved in the process are men. Analyzing the results of the model, the companies studied need to develop a strategy that allows them to improve their key performance indicators. The model is robust to demonstrate that the key is to develop the individual. According to global indexes, incremental and parsimony fit the model is accepted.

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Relevant Aspects of Human Error and Its Effect on the Quality of the Product. Study in the Maquiladora Industry

Teresa Carrillo-Gutierrez, Rosa María Reyes Martínez,
Jorge de la Riva Rodríguez and Jaime Sanchez-Leal

Abstract This document presents a study of human factors that influence human errors from the perspective of cognitive ergonomics. The purpose of the research is to determine the root of human errors from the perspective of the human factors that affect the quality of the product. The study of took place in the context of the Maquiladora Industry. The scientific methodology used is located in Cognitive anthropology, through the application of the theory of the Cultural consensus. The methodological approach of the study corresponds to the mixed methods. The design of the study was cross-sectional, descriptive and analytical. The population studied was that of multifunctional operators, existing in the company's two modalities: those in manufacturing support and those in quality inspection support. With this research, it is possible to move closer to a classification of the causes root of human errors that affect the product quality in the industry maquiladora in Tijuana, Mexico. With this knowledge it is possible to propose preventive actions in Maquiladora improvement projects.

Keywords Cognitive ergonomics · Human error · Product quality · Cultural consensus

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1 Introduction

This article exhibits the partial results of a study of documentary and field research in progress; same which objective is to identify the analysis methodologies and quality evaluation of the product currently used in the maquiladora industry of Tijuana, in conjunction with their approaches and if they incorporate the analysis and evaluation of human error. Human error is considered as a possible cause of failures and defects in the products. First of all, a brief reference framework of the maquiladora industry is presented and afterwards a reference framework of Ergonomics is shown, and ends with the presentation of the partial data obtained of the study in the maquiladora industry within the city of Tijuana in Baja California, Mexico.

Consensus Cultural Theory is a collection of techniques and analytical models that can be used to estimate cultural beliefs and the degree to which individuals know and report these beliefs. This theory considers the culturally correct answers to a series of questions and simultaneously knowledge of each informer or degree to which the answers are shared, the accuracy of responses is measured the degree of reliability and validity [1]. The researchers assume that the correspondence between the responses of two informants is a function of the extent to which each is correlated with beliefs about truth possessed by members of culture [2].

2 Literature Review

According with Douglas and Hansen [3] the Maquiladora Industry has become one of the characteristics elements of the Mexican northern frontier due to the increasing changes that its presence has brought in terms of population growth, subsidiaries or supplier industries, trade and services. The term “maquiladora” comes from the word “maquila” of Arab origin; word that in its beginnings was used related to the activity of milling every time that it refers to the portion of grain that belong to the miller in exchange of his service, the meaning of the term evolved to designate “any particular activity in an industrial process—for example, assembly or packing—that is on one hand not executed by its original manufacturer” [4]. Based on this definition, the word maquiladora refers to a wide industry that covers a great variety of goods and services. Modern maquiladoras perform product assembly operations that, once processed, are re-exported to the United States and other countries. There are 896 establishments registered in Baja California, according to the National Council of the Maquiladora Industry and Export Manufacturing Industry [5].

2.1 Human Reliability and Quality

In regard to the term ergonomics, it comes from the Greek ergos (work) and nomos (natural laws), being a discipline oriented to the systems, which nowadays is applied to all aspects of human activity. Reyes [6] mentions that ergonomics aims to create a work system that helps to improve human being interactions and other components. However, it needs to be done at a total work level system and not only in one of the elements. As a result, human reliability is within the knowledge field of ergonomics.

On the other hand, there exist many definitions of human reliability. For this work it is considered the definition presented by Arquer and Nogareda [7] of the Centro Nacional de Condiciones de Trabajo en España (National Center for Working Conditions in Spain); it is defined as "the body of knowledge relating to the prediction, analysis and human error reduction, focusing on the role of the individual in design operations, maintenance, use and management of a socio-technical system". Therefore, human reliability aims to study human error.

Moreover, the dominant definition of human error is set out by Reason who defines it as "a generic term that accompanies all those occasions in which a consequence of physical or mental activities, fails to achieve its desired goal and when these failures cannot be attributed to the intervention of any opportunity" [8]. According to Reyes [6], human error is human error is a complex construct that has received constant attention among scholars of human factors in dynamic and complex systems. Likewise, human error is defined as the specific behavior of people that exceeds the tolerance limit defined for a particular task [8]. Generally, researchers define it as: the cause of an action, like something that was made wrongly, or something that went wrong [8, 9–11]. According to Cañas and Waerns [12] the study of human error has been boarded from three different approaches: Engineering, Cognitive Psychology and Cognitive Ergonomics.

In the study of Reyes [6] it is mentioned that the engineering approach has developed a number of techniques known by the generic name of analysis techniques of human reliability; which start from the basic assumption that the actions of a person in the workplace can be related to the operation of a machine. Its goal is to predict the probability of a human error and evaluate how the whole work system is degraded as a result of the error alone or in connection with the operation of the machines, the characteristics of the task or of the person and the design of the work system. These techniques have been criticized as inadequate, although it is recognized their contributions to the efforts in order to predict the occurrence of human error.

The approach of cognitive psychology seeks to know which are the mental processes responsible for which a person commits an error [8, 13]. These authors state that mistakes are not irresponsible behavior; nor that they occur by a defective mental functioning; they could be a consequence of ignoring during the design of the work system; how a person perceives, attends, remembers and makes decisions.

In this approach the causes of human errors are investigated by analyzing the characteristics of human information processing.

Following Reyes [6], the cognitive ergonomic approach consists in the combination of the human reliability analysis, developed by the engineers and the cognitive models. This approach departs from two basic assumptions:

1. Human errors cannot be explained only from the cognitive models. The person and the system where he or she works, must be seen as a joint cognitive system where the interaction between them can take place.
2. The conduct of a person is determined by the context in which it occurs. The work system creates dynamic situations that change continuously. Therefore, it is necessary to bear in mind the context of the task when considering the behavior. It is not enough to evaluate the errors from the perspective of the human information process.

The human reliability knowledge field has bestowed through time multiple applications. Among them safety engineering stands out with its studies focused on fatal accidents; characterized by a great number of human and economic losses. In this context, the nuclear industry, aviation and military navy have made significant contributions with their studies of human reliability. Between other knowledge fields there appears medicine, transit and software development. The methodological approaches addressed in the studies have been quantitative, qualitative and mixed type (quantitative and qualitative). Hereafter are some studies that have identified the human errors that contribute to the defects or failures in processes or products within the context of the manufacturing industry in the production and quality fields.

Within the work of Fan-Jang and other authors the assembly process of an initiator device of a missile is studied [14]. In order to guarantee the safety of the operators and to update the quality and reliability of the product the Human Error Critical Analysis was applied to identify the critical human tasks, critical modes of human error and the information of human reliability concerning the assembly tasks of the initiator device. Additionally, to ensure human safety and increase the quality and reliability missile's initiator device, the Standard Assembly Process will evaluate from the point of view of an analysis method of human reliability to determine potential critical problems in the product assembly process. The SAP provides a tasks analysis of the assembly task which can be divided in 14 sub-tasks. This procedure leads the workers into how to carry out these tasks, from the raw material up to the final product.

The following study was conducted in India [15] and aims to enable analysts, managers, professionals and engineers analyze the failure system behavior; making use of the diffuse methodology. It is used as an example an industrial case of a paper factory. The diffuse methodology within the failure engineering system helps the system to: analyze the failure behavior of the industry systems in a more realistic manner, since subjective judgments are often made.

Myszewski [16] describes the development of a probabilistic model of human error. In the industrial processes, the special causes of errors are closely related to the allocation of an inadequate amount of time to correctly carry out the operations. In his work, he mentions that there are three general types of human error mechanisms: the ones generated by factors to small to be controlled, that represents the systemic and inherent fund; the common causes are related to human beings. The second type is the special mechanisms generated by factors that are represented by the curve of the bathtub and they are characterized by the presence of human beings in the manufacturing process. This should be taken into consideration when planning daily work schedules; otherwise reengineering should be considered. Lastly, there are the special mechanisms generated by factors related with the system that represents the processes of dominating new operations and the accumulation of tasks.

Miralles et al. [17] present in their study a case that demonstrates the use of Poka-Yoke in a protected workplace for people with disabilities. They emphasize the way in which they are useful to improve accessibility to work, this by means of the fulfillment of the principles of universal design. The article focuses on the benefit of using the tools of slender manufacturing towards people with disabilities. Likewise, Paun et al. [18] present a theoretical research on the prevention of errors involved in the manufacturing flow of products through Poka Yoke techniques. These techniques are designed to prevent failures, which represents a concept of quality management. The authors used the methodology called integrative Engineering, which is the methodology that allows to realize an integrated design of products and processes of associate production or maintenance. Its goal is to eliminate all errors, regardless of type; that is to say, obtaining a product with zero failures, of high quality at low prices.

Rigolin and Quartucci [19] provide a process improvement approach of the structuring and execution of the process of Requirement Engineering. They study the possible correlation between human errors and problems that may arise in the process of requirements engineering. The Human Error Theories can help the understanding of the problems in the process and the adoption of controls and methods for prevention and detection.

In the opinion of Yang et al. [20], human error is one of the most important reasons for quality defects in manufacturing systems because 70–90 % of the quality defects on the production systems are directly or indirectly due to human error. The study has the intention of demonstrating and of providing a new method that offers a theoretical basis and practical guidance for the evaluation and control of quality defects induced by human error. The new analysis method of the quality of accident due to human error in the engine assembly line was obtained through a combination of CREAM (Cognitive Reliability Analysis Method) and fault tree analysis. The traditional method CREAM was improved in order to adapt itself to detect the root causes of quality incidents in the engine assembly line; also the fault tree analysis was applied to assess the relative importance of the fundamental causes. This method was applied in a case study to analyze the accident, and the result showed a series of fundamental causes, such as impatient operation, inadequate training, poor safety awareness, regulating escapes and quality were the top four causes of quality human errors in the engine assembly. The results provide a theoretical basis and practical guidance for quality analysis of accidents due to human error in the production line of engines.

3 Method

Due to the lack of statistics within the maquiladora industry in Tijuana, a staff survey in the quality area of the maquiladora industry was applied. The aim is to identify which are the human errors that occur more frequently and cause defects in its products, as well as to know their possible causes. A sample by convenience was realized because the aims were of sounding and not of generalization. To the moment, 34 factories have answered the survey of which twelve are of the medical area, ten of the electronic branch, four of plastics, three of the aerospace branch, three of the automotive branch, a factory of the metal mechanics branch and 1 of furniture. The description of the variables was performed by an aggregation or a simple selection of the responses, the highest frequencies for each variable were sought.

4 Results

The survey instrument is structured with open questions and questions with selection answer selection. As shown in Fig. 1, in the first open question thirty-two factories answer that inspection methods are the way they detect quality defects in the sample of thirty-four factories.

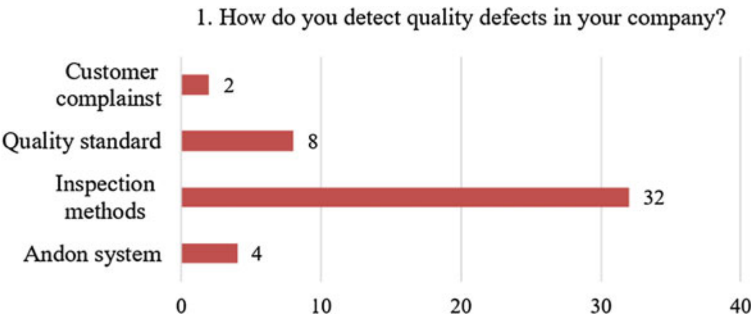

Fig. 1 Results to question 1 of questionnaire

Figure 2 shows that the Poka Yoke techniques, training, documentation and process flow, as well as corrective and preventive actions (CAPA) are the most commonly used strategies to reduce the incidence of defects caused by human error.

In the third question the statistical techniques, inspection and 8D are the most frequent responses; which confirms the engineering reliability analysis approach of the surveyed factories. See Fig. 3.

It can be seen on Fig. 4 the factor corresponding to the experience, also called the learning curve, in the first place there is the frequency; followed by training. In descending frequency follows communication problems and the use of unsuitable tools or in poor condition. Followed subsequently by work overload; bad detection of errors in pilot runs that escape into mass production to the line of production,

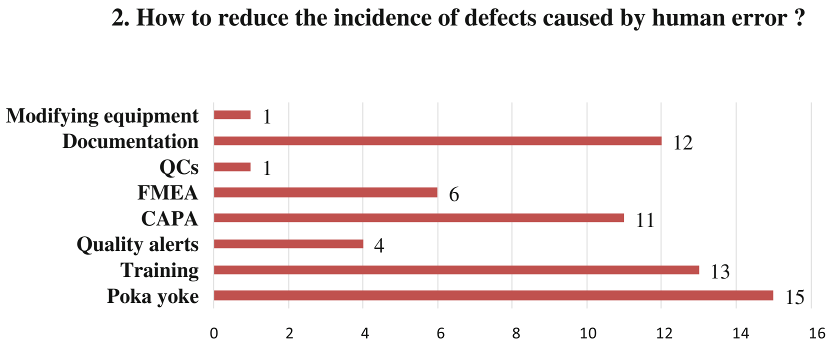

Fig. 2 Results to question 2 of the questionnaire

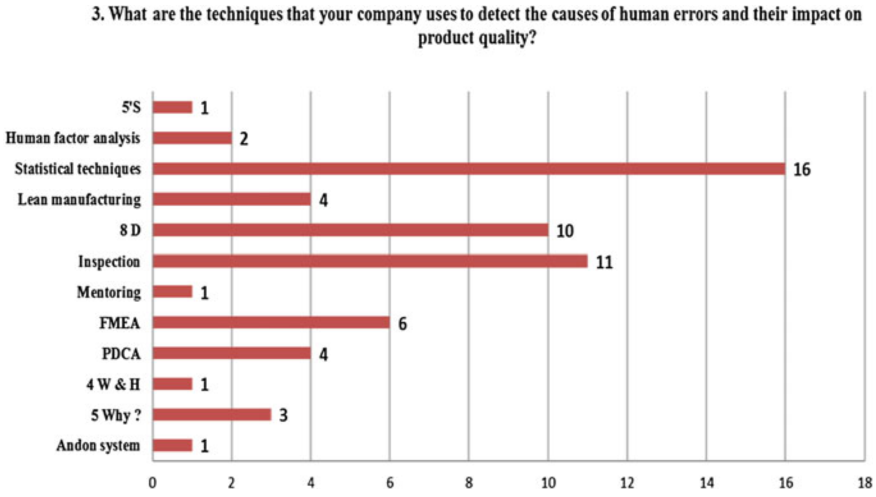

Fig. 3 Results to question 3 of the questionnaire

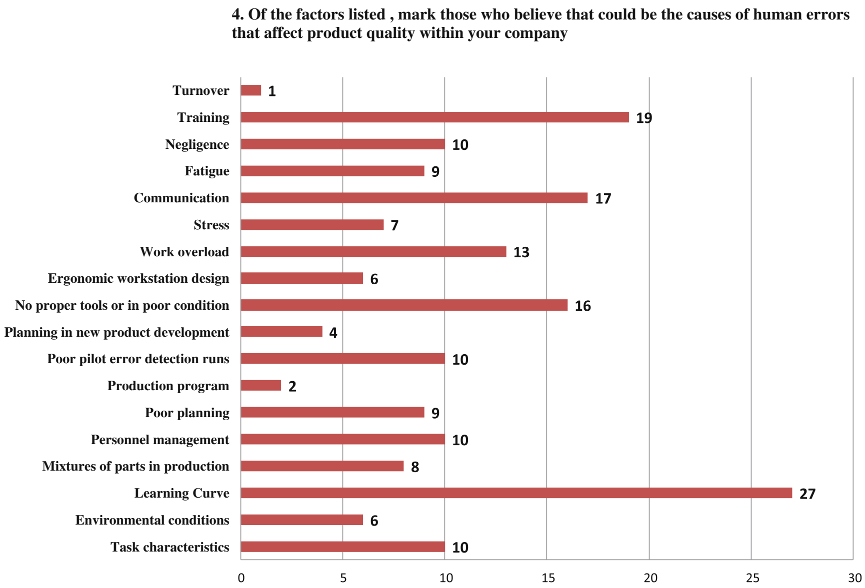

Fig. 4 Question 4 of the questionnaire. Frequency response for the causal factors of human errors that affect the quality of a product, according the opinion of those in charge of the quality area

tasks characteristics, that is difficulty performing production operations, and negligence can be found in an equal frequency.

Twelve fabrics of the universe of thirty-four answer in an affirmative manner to the fifth question. It is asked to them if they consider human error as a very important causal factor of the product defects. For reasons of space the graph is not included. Figure 5 shows the results obtained in the survey who by consensus agree that the most frequent errors are caused by procedural omissions, lack of experience of the operator on a par for distraction, followed by and inadequate entertainment.

The seventh open question was “Does your company use any methodology to analyze and evaluate human error related to failures or defects in product quality?” The 60 % of the companies answered affirmatively. Also, it is asked which one is this utilized method. Only sixteen of the companies recognize that the methods used are from an engineering approach. In Fig. 6 are shown the results.

Also it was included in the poll survey, an approximation regarding possible causes of quality defects that occur in the company. A list with ten causes is provided to them and according to the opinion of the participants, they show a predominance of Machines, followed by Training of the worker, and by lack of visual aids and unclear or very long procedures. On question nine it is asked the following question: In your company, Which of the following actions applies at the moment to eliminate or to reduce the human errors that cause quality defects in the product? The most frequency answer was Poka Yoke followed by Automatization in congruence with the result of question two.

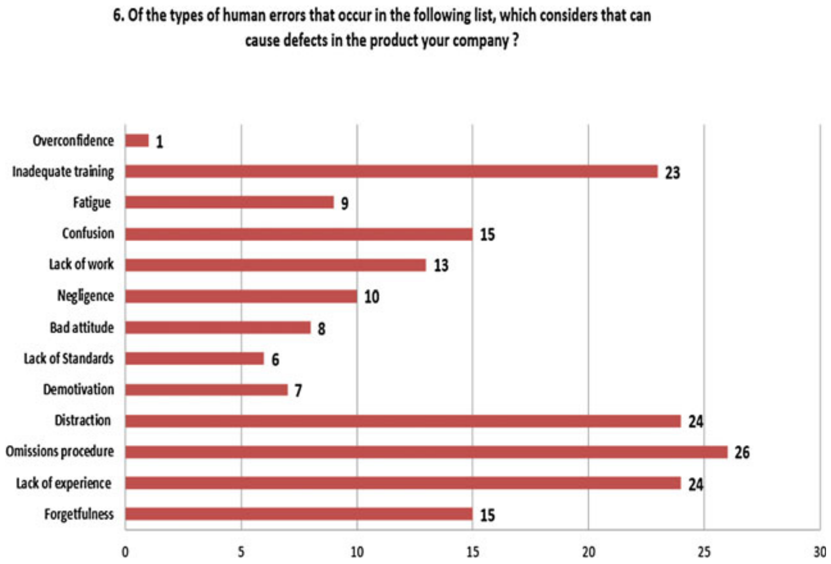

Fig. 5 Results to question 6 of questionnaire

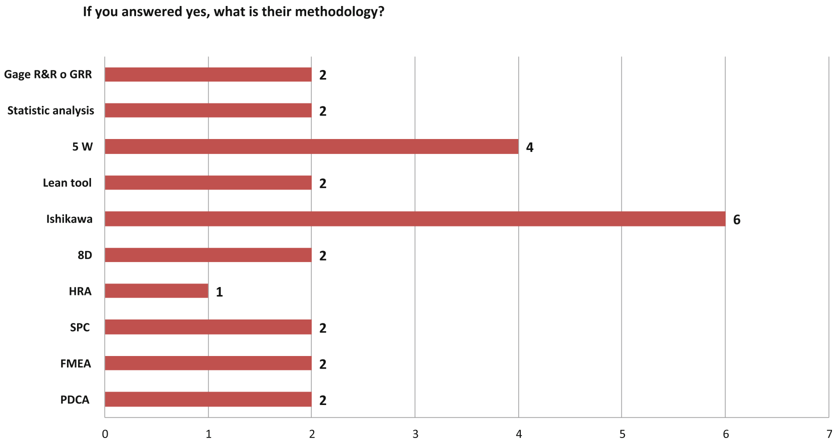

Fig. 6 Results of the second part to question 7

5 Conclusions

Most of the companies surveyed detect defects in the quality of the product through inspection methods. Poka Yoke, corrective and preventive actions (CAPA), documentation and process flow, and training are the strategies used to reduce the incidence of defects caused by human error. The three techniques most used to detect the causes of human errors and their impact on product quality are statistical techniques, inspection and FMEA.

The information presented in relation to the state that shows the defects in the quality of products, allows to visualize the need to incorporate the human factors approach and human error, from a cognitive ergonomic perspective in the analysis and evaluation of the defects of the products in the maquiladora industry; since the explanation of this phenomenon will provide more elements for the design of better techniques and strategies of prevention of product defects. This research continues in progress.

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Part VIII

Integrated Design of Flexible Production Systems

Age-Differentiated Modeling and Prediction of the Learning Time of Sensorimotor Tasks

Francoise Kuhlenbäumer, Sönke Duckwitz and Christopher Marc Schlick

Abstract A model to predict learning time for young people was developed by Jeske. In this paper, we extended Jeske's model by analyzing and modeling the learning time of older people. Therefore, a replication of Jeske's study on the influence of task descriptions on the learning time was conducted. Sixty participants took part in this study. Their experimental task was a tenfold repeated assembly of a carburetor. In each trial the execution time and the number of errors were measured and analyzed with respect to the age of the participants and the task description. Furthermore, it was investigated how well Jeske's model can be fitted to the acquired data. The results show a significant influence of the age on the learning time. Furthermore, a significant deviation between the data and Jeske's model is revealed. Thus, a power function model fits the data of older participants in the most appropriate way.

Keywords Age-differentiated · Learning time · Prediction method

1 Introduction

Access to global sales and procurement markets as well as an increase in requests from customers for individualization contributes to a rising number of product variants, while the duration of product-life-cycles decreases simultaneously. For working persons, this results in frequently changing working tasks. In the case of assembly areas, these tasks often demand sensorimotor skills that have to be learned

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and trained task-specifically [1]. The period a working person needs to become acquainted with the altered task and the time need to practice said task until a reference performance is reached is referred to as learning time [2]. The related changes in performance can be described mathematically by learning curves. In the context of industrial use, the first learning curve can be traced to the work of Wright [3]. He described the increasing performance due to repeated execution as a power function with a constant exponent. For the reason that this function has a limiting value of zero for infinite repetitions, his model was criticized and a lot of alternative learning curves were developed. A survey of learning curves can be found in [4] or [5], for example. But it is not only of interest to describe the learning time ex post but also to predict it, e.g. to avoid inaccuracy in the assignment of working persons in serial assembly. Previous prediction methods necessitated a large amount of effort and until the development of a useful model [6, 7] done by Jeske, the results were mostly inaccurate. However, the development of Jeske's model is solely based on a sample of subjects between 20 and 35 years. Consequently the goodness of fit of this model is not implied for older working persons. Against the background of demographic change in Germany though, planning tools have to take elder into account, too.

2 Prediction of Learning Times—Jeske's Model

The development of Jeske's learning time prediction model [6, 7] is based on three empirical laboratory studies. In these studies participants aged between 20 and 35 years had to assemble technical parts repeatedly. In each repetition the execution time and the number of assembly errors were measured to investigate the changes in performance. To analyze the influence of different factors on learning sensorimotor working tasks, some characteristics of the participants were collected and the assembling object as well as the learning method was varied in the different studies.

On this basis, Jeske modeled a learning curve, which represents an extension of the model of de Jong [8]. According to de Jong's model, the time t_n needed for the nth execution can be described by a power function with an exponent $-k$ and a limiting value c:

$$t_n = c + (t_1 - c) \cdot n^{-k}. \tag{1}$$

Against the model of de Jong Jeske ascertained that learning pace is not constant and takes the changeable learning pace into consideration with the exponential structure of Levy's learning curve [9]. Thus, Jeske's learning curve contains a power and an exponential term. Jeske assumes that the exponential term descripts the initial reception of knowledge whereas the power term characterizes the long-term evolution of sensorimotor skills [6].

According to Jeske's learning curve model, the time t_n needed for the nth execution can be described by the use of three parameters: (1) the long-term limit c,

(2) a parameter λ that represents in combination with the long-term limit c the time t_1 for the first execution and (3) the learning rate k. Jeske's learning curve is:

$$t_n = c + \left(\underbrace{c \cdot \lambda}_{=t_1} - c \right) \cdot n^{-k} \cdot n^{-k \cdot e^{-\frac{k}{2} \cdot (n-1)}}. \tag{2}$$

While Jeske's method provides to determine the long-term limit c by Methods-Time Measurement Universal Analyzing System (MTM-UAS) the prediction of the parameters λ and k results from information about the working person, the working task and the learning method. In this regard Jeske formulated an equation for each parameter by regression analyses. So, the prediction of λ depends on four independent parameters, which are:

- the task complexity H_{UAS}, which can be calculated by the first order entropy of parts and movements according to MTM-UAS combined by using the Euclidean norm [2]
- the self-reported experience with assembly $E_{Assembly}$ of the working person on a four-stage scale (none/1, little/2, medium/3, much/4)
- the task description D, which form of representation can be sorted according to Media Richness Model [10] by their informational richness (textual/1, text- and figure-based/2, graphical/3, animated/4)
- the gender G: (m/1, f/2).

The regression model for λ is:

$$\lambda = 2.256 + 0.978 \cdot H_{UAS} - 0.755 \cdot E_{Assembly} - 0.45 \cdot D + 0.87 \cdot G. \tag{3}$$

For the prediction of k, λ and additional information about the working person are necessary, these are:

- two (FF_1 and FF_6) of the six factors of Fleishman [11, 12] that describe the fine motor skills of a working person
- the age A of the working person.

Thus, the learning rate k can be predicted based the following regression model:

$$k = 0.141 + 0.073 \cdot \lambda - 0.008 \cdot FF_1 + FF_6 + 0.013 \cdot A. \tag{4}$$

3 Method

To validate Jeske's prediction model [6, 7] for working persons aged 52–67 years (AG II), a replication of Jeske's study concerning the influence of task descriptions [13] was conducted with an enlarged sample.

3.1 Participants

Sixty participants (gender-balanced) took part in the replication study. Half of them were between the ages of 20 and 35 years (age group: AG I) and the other half were aged 52–67 years (age group: AG II). All participants were right-handed, had normal or corrected to normal vision and had no restrictions of motor skills of their hands or arms due to illness or injury. Against the research done by Jeske [13], there was no grouping regarding to previous engineering knowledge caused by academic studies due to the fact that no significant difference could been proven.

3.2 Experimental Task

The experimental task was a tenfold repeated assembly of a carburetor (type Stromberg 175 CD-2) with the help of one of three task descriptions, which were already used in the original study by Jeske [13]. However, two small modifications were conducted: a correction of a representation mistake and a highlighting of two positional marks to reduce the risk of material damages, which occur if these marks are disregarded. The investigated task descriptions were (1) a textual, (2) a text- and figure-based and (3) an animated task description. All task descriptions represented the necessary steps to assemble the carburetor in three independent sections.

According to MTM-UAS the standard time for the carburetor assembly is 146.2 s. However, the participants got no time constraint, but they were asked to assemble as fast as they could do so accurately. According to the measurement of complexity [2], the task complexity H_{UAS} is 4.682.

3.3 Experimental Variables

The independent variables are the age group with two levels (AG I, AGII) and the type of task description with three levels (textual, text- and figure-based, animated). The dependent variables are the execution time and the number of assembly errors in each trial as well as the subjective work load at the end of all trials.

3.4 Procedure

Initially, the participants were asked about their demographic data and their experience with assembly. Due to the fact, that there was no grouping regarding previous engineering knowledge caused by academic studies as in Jeske's study [13], the technical comprehension of the participants was surveyed in a pretest. For this purpose a subtest of the AZUBI-TH ("Arbeitsprobe zur berufsbezogenen Intelligenz – Technische und handwerkliche Tätigkeiten" [14] freely translated: work sample of occupational intelligence—technical and mechanical jobs) was used. In this paper-based test, the task of the participants was to solve sixteen technical problems in a time limit of 10 min. In further pretests the fine motor skills and the retentiveness of the participants were evaluated. The fine motor skills were evaluated with the Motor Performance Series [15, 16] and the retentiveness with a subtest of the German version of the Intelligence Structure Test IST-2000R ("Intelligenz-Struktur-Test 2000R" [17]).

After that, the main test started. Thereby, the participants had to assembly a carburetor ten times. The necessary information was provided by one out of the three task descriptions (see Sect. 3.2). The execution times and the assembly errors were measured for each trial.

Finally, the participants were asked about their perceived workload by means of the NASA Task Load Index (NASA-TLX, [18]).

3.5 Statistical Analyses

With the exception of curve fitting (executed with The MathWorks MATLAB R2013a), all statistical analyses were executed with IBM SPSS Statistics 21. The analyses of execution times and assembly errors were carried out by non-parametric Scheirer-Ray-Hare test (SRH [19]) with the extension of Mayer [20] for repeated measures designs.

For analyses relating to Jeske's method, the model parameters λ and k were first approximated to the learning curve of Jeske with non-linear least square fit for each individual participant. Afterwards regression analyses were carried out. Thereby, a hierarchical procedure was used that comprises a forced entry regression analysis of the predictors of Jeske (see Eqs. 2 and 3) and a subsequent stepwise regression analysis of new predictors. For all statistical analyses $\alpha = 0.05$ was chosen [21].

4 Results and Discussion

The results presented in this section, include only 59 participants. One participant was excluded due to the reason that an analysis concerning abnormalities revealed that his individual approximated λ-value differs from the mean by more than four standard deviations. Following the criterion of Jeske [6] such a deviation represents an outlier that is not considered in further analyses. The excluded participant is male and used the textual work description during the assembly.

4.1 Characteristics of Study Participants

The participants' characteristics are shown divided into the two age groups in Table 1. Most participants had no or little experience with assembly. However, some participants of AG II declared, that they have much experience with assembly whereas almost all participants of AG I appraised their experience at most medium. The average values of both factors of Fleishman [11, 12] indicated normal (value within the range of 50 ± 10) fine motor skills for both age groups. In average, the participants of AG I answered slightly more technical questions correctly compared to participants of AG II. Furthermore, the participants of AG I achieved a higher average percentile rank concerning their retentiveness than participants of AG II. However, there was no significant difference between the both age groups concerning the technical comprehension and the retentiveness.

4.2 Statistical Analyses of the Actual Laboratory Study

Execution Times. Figure 1 shows the average execution times and 95 %-confidence intervals for the participants of both age groups (AG I and II) depending on the different task descriptions. It is obvious that the execution times of all participants decrease from the beginning up to about the seventh trial where an almost constant level is reached. This observation indicates a learning effect that can be statistically proven by SRH (SS = 8735886.97; df = 9; H = 370.02; p = 0.000) and was also noted by Jeske [13]. In a pairwise comparison with Bonferroni correction

Table 1 Characteristics of participants divided into the age groups AG I and AG II (shown as mean and standard deviation)

	AG I	AG II
Predictors of Jeske		
Gender	Balanced	29 m/30 f
Age [years]	25.17 (±3.696)	59.45 (±4.657)
Experience with assembly (none/1, little/2, medium/3, much/4)	Little 2.00 (±0.947)	Little 2.28 (±1.162)
Fleishman 1 [T-value] (descripts accuracy of target-oriented movement)	51.6 (±6.701)	54.89 (±3.404)
Fleishman 6 [T-Value] (descripts speed of wrist—finger movement)	54.8 (±8.542)	50.66 (±10.217)
New potential predictors		
Technical comprehension [number of correct answers]	10.63 (±2.526)	9.07 (±3.515)
Retentiveness [percentile ranks]	69.50 (±24.776)	57.66 (±24.530)

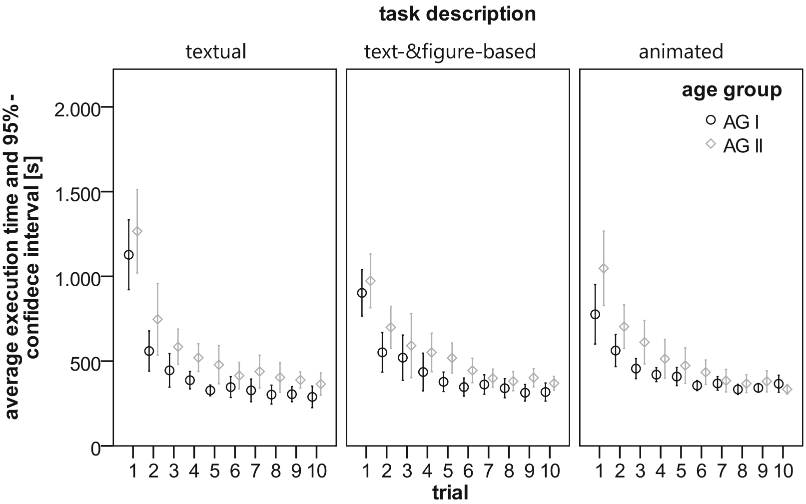

Fig. 1 Execution times of both age groups depending on task description

the learning effect becomes apparent by means of decreasing mean differences between one execution time to the following. Thereby, significant differences exist until the seventh trial. According to this, a constant level appears not till then the eighth trial.

A comparison of execution times between the different age groups shows the participants of AG I needing less time than the participants of AG II for most trials. This is statistically confirmed by a significant major effect ($SS = 1191544.75$; $df = 1$; $H = 13.35$; $p = 0.000$) of the age group on the execution time. Further significant effects cannot be proven in the SHR analysis. In particular, no interactions between the executions' repetition and the task description can be ascertained as it was observed by Jeske [13]. A comparison between the first execution times of AG I shows a decrease of these times proportional to the increasing informational richness of the task descriptions. This relation can be proven statistically ($r = -0.505$; $p = 0.004$) and was also noted by Jeske [13]. Unlike the result for participants of AG I the participants of AG II needed the least amount of time while being given the text- and figure-based work description, which has a medium informational richness. Therefore there no correlation between the informational richness of the task description and the first execution time for AG II was found. In the last trial there are no significant differences in execution times concerning the task descriptions or the age group.

Assembly Errors. The average numbers of errors for the participants of both age groups (AG I and II) are shown depending on the different work descriptions in Fig. 2.

The learning effect is clearly visible due to decreasing numbers of errors with rising number of trial. This effect is statistically significant ($SS = 6381951.008$; $df = 9$; $H = 318.3452343$; $p = 0.000$) and was also proven by Jeske [13]. In

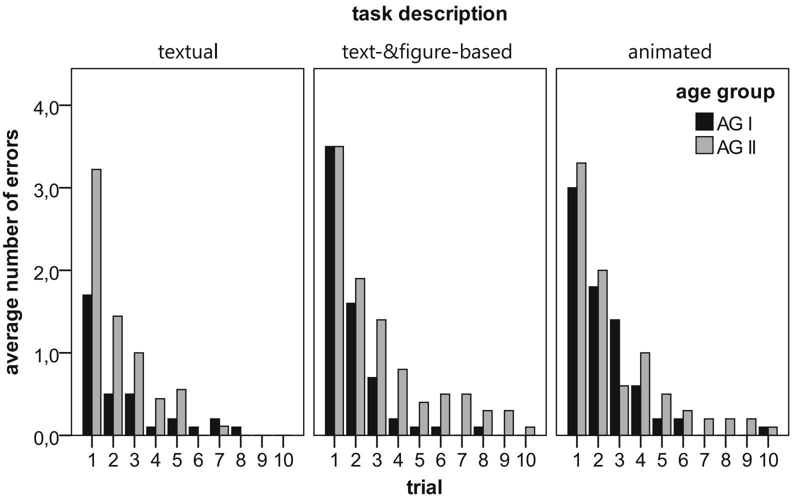

Fig. 2 Average number of assembly errors of both age groups

pairwise comparisons no more significant reduction of error can be found for trial numbers lager than six. Concerning to differences between the age groups, it can be seen that in no trial the participants of AG I made more errors than participants of AG II. This difference can be proven as a significant main effect (SS = 190531.440; df = 1; H = 5.375118292; p = 0.0204). In this regard, Table 2 summarized the average numbers of errors of both age groups depending on task description. It can be seen, that the lowest numbers of errors occur in each age group when the textual task description was used. For AG I the numbers of errors rise with rising informational richness. Such a correlation was also observed by Jeske [13] for participants without engineering knowledge. For participants with engineering knowledge Jeske found that they made as well as participants of AG II in the actual study the most errors by using the text- and figure-based task description. However, in agreement with Jeske [13], the statistical analysis indicates no significant influences of task descriptions on numbers of errors.

Subjective Workload. Table 3 shows the results of the NASA-TLX for both age groups depending on task description. Hence, the subjective workload of participants of AG I decreases with rising informational richness. Unlike

Table 2 Number of assembly errors of both age groups depending on task description (shown as mean and standard deviation)

Task description			
Age group	Textual	Text- and figure-based	Animated
AG I	3.40 (±1.897)	6.30 (±2.710)	7.30 (±3.368)
AG II	7.50 (±4.528)	9.40 (±9.228)	8.40 (±5.700)

Table 3 Subject perceived workload of both age groups depending on task description (shown as mean and standard deviation)

Task description			
Age group	Textual	Text- and figure-based	Animated
AG I	8.0250 (±1.520)	7.4100 (±2.065)	7.3850 (±2.438)
AG II	5.7800 (±2.308)	8.0650 (±2.159)	6.3950 (±2.697)

No workload 0…15 max. workload

participants of AG II who feel the least demand by using the textual task description and the most demand by using the text- and figure-based task description.

Concerning to the results of the analysis of execution times and assembly errors, it can be noted that participants of AG I perceived higher workload with increasing time whereas a rising workload of participants of AG II can be linked to a rising number of errors.

4.3 Goodness of Fit of Jeske's Model to Data

Learning Curve. To investigate the goodness of fit between the collected data and Jeske's model [6, 7] for both age groups, the data was first fitted to Jeske's formulation of a learning curve. Thereby, the parameters λ and k were approximated assuming that the long-term limit is given at $c = 142.6$ s according to MTM UAS.

Due to the coefficient of determination R^2 reaches merely 61.7 %, Jeske's learning curve fits just moderately. For a detailed investigation, age-group-divided fits to (1) Jeske's learning curve and to (2) de Jong's power function-based learning curve were analyzed. To enable a better comparability, the time for the first execution t_1 in de Jong's model was described as $c \cdot \lambda$. The parameters as well as the coefficient of determination R^2 are given in Table 4 for each fit and the best fittings are shown in Fig. 3. It became apparent that the highest coefficient of determination R^2 (bolt print in Table 4) for all participants (R^2 = 62.5 %) and for participants of AG II (R^2 = 65.2 %) can be reached with the power function whereas the best fit for participants of AG I (R^2 = 66.8 %) can be achieved with Jeske's learning curve.

Table 4 Parameters and explanation of variances for each fit (shown as mean and standard deviation)

Function	Age group	λ		k		R^2	
Power	AG I	6.223 (±0.291)	6.787 (±0.244)	0.729 (±0.057)	0.684 (±0.041)	0.662	**0.625**
	AG II	7.378 (±0.356)		0.649 (±0.053)		**0.652**	
Jeske	AG I	6.452 (±0.305)	7.012 (±0.262)	0.586 (±0.055)	0.540 (±0.040)	**0.668**	0.617
	AG II	7.590 (±0.391)		0.504 (±0.053)		0.631	

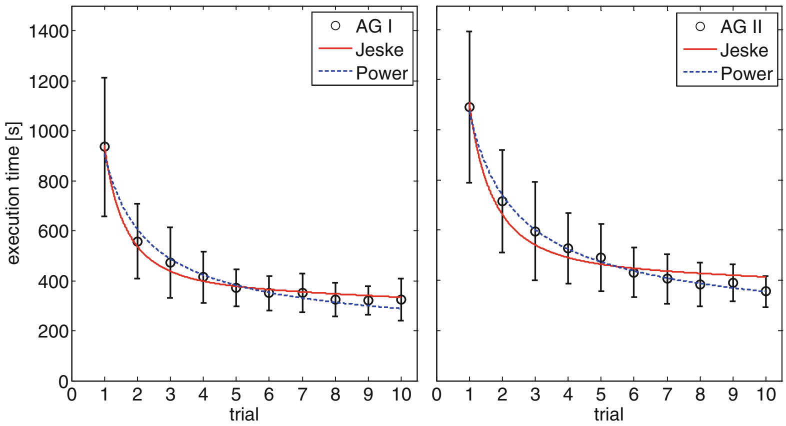

Fig. 3 Best fitting of execution times to the learning curve of Jeske [6, 7] and a power function for both age groups

Parameter Prediction. To evaluate the conformity between the collected data and Jeske's parameter prediction equations on the one hand and to investigate new potential parameters on the other hand, hierarchical regression analyses were carried out to determinate λ and k (see Tables 5 and 6). In both analyses, model 1 includes, all predictors of Jeske [6, 7] with an entre procedure. However, the meaningful assumed factor task complexity $H_{UAS} = 4.682$ is constant, because there was no variation of the task in the actual study. Model 2 additionally considers the two potential predictors *technical comprehension* and *retentiveness* in a stepwise procedure. Thereby, the analyses done without age group divided examination due to the consideration of age as predictor for k [see Eq. (3)].

Table 5 Regression analysis to predict λ

	B	*BE*	β	ΔR^2	R^2 (adjusted)
Model 1 [*entre regression: predictors of Jeske* (2013)]				0.180^a	0.180 (0.135)
Constant	7.659	1.300			
$E_{Assembly}$	−0.229	0.260	−0.121		
Gender	0.730	0.545	0.184		
Task description	−0.528	0.195	−0.330^a		
Model 2 [*additional stepwise regression: new predictors*]				0.142^a	0.322 (0.271)
Constant	11.063	1.566			
$E_{Assembly}$	−0.203	0.239	−0.107		
Gender	0.071	0.538	0.018		
Task description	−0.454	0.180	−0.284^a		
Techn. comprehension	−0.267	0.080	−0.417^a		

^{a}Significant at the 5 %-level

Table 6 Regression analysis to predict k

	B	BE	β	ΔR^2	R^2 (adjusted)
Model 1 [*entre regression: predictors of Jeske* (2013)]				0.319[a]	0.319 (0.240)
Constant	1.084	0.307			
$\mathrm{E}_{\mathrm{Assembly}}$	−0.048	0.027	−0.237		
Gender	−0.067	0.063	−0.158		
Task description	−0.076	0.019	−0.449[a]		
Age	−0.003	0.002	−0.212		
Fleishman factor 1	−0.001	0.005	−0.033		
Fleishman factor 6	0.000	0.003	0.015		
Model 2 [*additional stepwise regression: new predictors*]				0.057[a]	0.375 (0.289)
Constant	1.281	0.311			
$\mathrm{E}_{\mathrm{Assembly}}$	−0.045	0.026	−0.222		
Gender	−0.113	0.065	−0.267		
Task description	−0.071	0.019	−0.422[a]		
Age	−0.003	0.002	−0.283[a]		
Fleishman factor 1	0.000	0.005	−0.003		
Fleishman factor 6	0.001	0.003	0.027		
Techn. comprehension	−0.019	0.009	−0.275[a]		

[a] Significant at the 5 %-level

Model 1 explains a large percentage of the variance in the value of λ ($F_{(3;58)} = 4.028$, $p = 0.012$, $R^2 = 0.180$). However, the analysis shows that only the parameter task description does significantly predict λ ($B = -0.528$, $p = 0.009$). Nevertheless, in comparison with Jeske, it can be noted that the relationships between each predictor and λ have the same sign in the actual analysis and in Jeske's formula for λ [see Eq. (2)].

Using the additional stepwise regression analysis a model was found that leads to a significant improvement in the coefficient of determination ($\Delta R^2 = 0.142$). This model 2 is able to account for 32.2 % of the variance in the value of λ ($F_{(4;58)} = 6.403$), $p < 0.001$). In model 2 it became apparent that the technical comprehension ($B = -0.267$; $p = 0.001$) is another significant predictor of λ. Thus, a rising informational richness of the task description as well as a better technical comprehension tends to result in a reduction of the value of λ.

The six predictor model 1 was able to account for 31.9 % of the variance in the value of the learning rate k ($F_{(6;58)} = 4.052$; $p = 0.002$). Though the analysis shows that only the predictor task description ($B = -0.076$, $p < 0.001$) significantly predicts k. As against the findings in regression analysis to predict λ, the relationships between the predictors and k have not the same signs as in Jeske's formula [see formula (3)].

The result of the additional stepwise regression analysis indicates a significant improvement in the coefficient of determination ($\Delta R^2 = 0.057$). It was found that besides the task description ($B = -0.071$, $p < 0.001$) also the age ($B = -0.003$,

$p = 0.029$) and the technical comprehension ($B = -0.019$, $p = 0.036$) significantly predict k. Due to the fact that age is not a significant predictor in model 1, the technical comprehension seems to be a suppressor variable [21]. Suppressor variables are usually uncorrelated with the output, but they increase the coefficient of determination of a model by reducing the irrelevant amount of variance of another variable [22]. Since the technical comprehension is uncorrelated to the learning rate k, it is assumed that the different technical comprehension of the participants is a result of the different employment histories that leads to **a** suppression of the influence of the age.

5 Conclusion and Outlook

The results of the replication study under consideration of participants in the ages of 52–67 years (AG II) show that age group significantly influences the learning time of sensorimotor tasks. This is indicated by both longer execution times and significant more assembly errors for participants of AG II. Whilst the increase in performance due to repeated execution of the task can be best fitted to the learning curve of Jeske [6, 7] for participants of AG I, a power function leads to better predictions of the learning process of participants of AG II. In regression analyses it was established that technical comprehension is an additional predictor of Jeske's learning curve parameters. However, not all predictors of Jeske could be proven as significant for the acquired data. This is probably because of the small sample size of 59 participants [21], so as in further investigations the sample size has to be extended. Furthermore, it is important to conduct further research on the influence of age and modify the model accordingly. Therefore, more influential factors must be regarded and further statistical methods, e.g. vector autoregressive models, should be consulted.

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Employee Data Model for Flexible and Intelligent Assistance Systems in Smart Factories

Alexander Arndt and Reiner Anderl

Abstract By implementing solutions and approaches of the Industrie 4.0 the role of employee's in-house production environments underlie a significant change. This paper begins with an introduction and basics about Industrie 4.0 and the research project "Effiziente Fabrik 4.0". Thereafter requirements for the employee data model are presented for use in intelligent and flexible worker assistance systems. Then a concept for the employee data model is developed and described by using Unified Modeling Language (UML). The model consists of various partial models, including a newly developed qualification matrix. These partial models are all presented. Based on this, there will be a prototypical implementation of the employee data model. Thus the employee and his supervisor, for example, for human resources planning, the necessary information is always at hand ready on a tablet. Finally, an outlook on further work is given.

Keywords Industrie 4.0 · Assistance systems · Employee data model · Smart factory · Efficient factory · UML · Assembly assistance

1 Introduction

Industrie 4.0 refers to the computerization of manufacturing technology and logistics for the machine-to-machine communication. The term comes from a future project in the field of high-tech strategy of the German government and industry [1]. Here, these developments are to be primarily driven. Industrie 4.0 aims at improving value chains and value-added networks in industry. Industrie 4.0 is pursued as a goal to give the customer individual product variants in the form of

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batch size 1. This presents challenges for manual operations such as the assembly in production. Because, in addition to intelligent machines, equipment and components or products, the employees must also understand all the available information and announce information about itself. The ever-increasing number of variants in the assembly requires implicit knowledge of the workers. This can lead to increased search efforts and increased logistics costs regarding the availability of components. Consequently, there are changing conditions for assembly and higher requirements and potential for greater personal responsibility of the workers. To assist the assembler in his complex working environment, flexible and intelligent worker assistance systems are being developed as a part of Industrie 4.0. This paper focuses on the development of an assistance system for implementation in the field of Industrie 4.0. The goal is independence of the skills of the worker to ensure the quality standards of assembly and to carry out the worker-oriented situation. This requires a bidirectional communication between the system and the employee. On the one hand, the system adapts to the employees and presents user-centered installation information. On the other hand, the employee passes on his own knowledge of the system that learns from it. But, in order to be able to generate user-friendly assembly information, the worker assistance system requires a variety of information about the employee. This may relate to ergonomic parameters such as the body height, but also skills such as knowledge and craft skills. The aim of this paper is the development of an employee data model that the worker assistance system can use to provide this information. Here, the benefits of such data must be pointed out to the employee and the company. The data collection and storage must also consider questions about data protection and employee acceptance due to the sensitive topic in Germany.

1.1 Industrie 4.0

The definition of Industrie 4.0 refers to the introduction of the fourth industrial revolution [2]. The first industrial revolution was based on the use of hydropower and steam power. The second industrial revolution was influenced by electricity. Moreover, mass production was introduced. The introduction of information technology in industrial processes characterizes the third industrial revolution. All industrial revolutions have had a major impact on industrial structures, business models, processes and employee qualifications. By Industrie 4.0, similar effects are expected. For this purpose, the term Industrie 4.0 was created, also called fourth industrial revolution.

As an important basis and innovation driver in the Industrie 4.0 Cyber-Physical Systems (CPS) are seen. The approach of CPS integrated embedded systems in physical products. This results in intelligent products. Each embedded system is associated with an internet address. Thus, the physical products are capable of communication. With the introduction of GPS, innovations are expected in many industries. A major advantage is expected through so-called vertical and horizontal integration. Horizontal integration means the integration of IT systems for the various process steps of production and corporate planning. This applies to processes between which a material flow, energy flow and information flow runs. But both within the company and across company boundaries. Vertical integration is the integration of IT systems at the various levels of the hierarchy to an integrated solution [3].

The global target is to improve the value process chains through the operation of communicating smart systems. Target areas of communicating smart systems comprise e.g. smart products, smart factories, smart plants, smart logistics, and smart grids. To achieve the goals different technology approaches come into use:

- Cyber-physical systems,
- Internet,
- Components as information carriers and
- Holistic concept for safety, security, privacy and knowledge protection.

In addition, an appropriate IT-infrastructure is necessary. For more details about the technology approaches we refer to Anderl [4].

1.2 Project "Effiziente Fabrik 4.0"

The aim of the project "Effiziente Fabrik 4.0" is the analysis, development and implementation of information and communication technologies and their linkage with advanced production technologies for the realization of a resource-efficient process learning factory. The "Effiziente Fabrik 4.0" is a research project funded by the Hessian Ministry of Economics, Energy, Transport and Regional Development (HMWEVL). The fund is granted under the operational program for the funding of regional competitiveness and employment in Hessen and comes from European Union funding for regional development (EFRE). This factory will be able to demonstrate and provide an experience of the potentials that are offered by the solutions of Industrie 4.0 not only for user companies and suppliers but also employee's associations and corporate networks.

The special feature is that there is no need to create a new production environment. The project builds on the existing process learning factory "Center for Industrial Productivity", that is placed at the Technische Universität Darmstadt. Based on the project results various Industrie 4.0 use cases were developed. These use cases are implemented gradually on the software side and the hardware side. Overall, developed four use cases and a central backbone, see Fig. 1.

For the present publication Use Case 4, the flexible and intelligent worker assistance system, is of relevance.

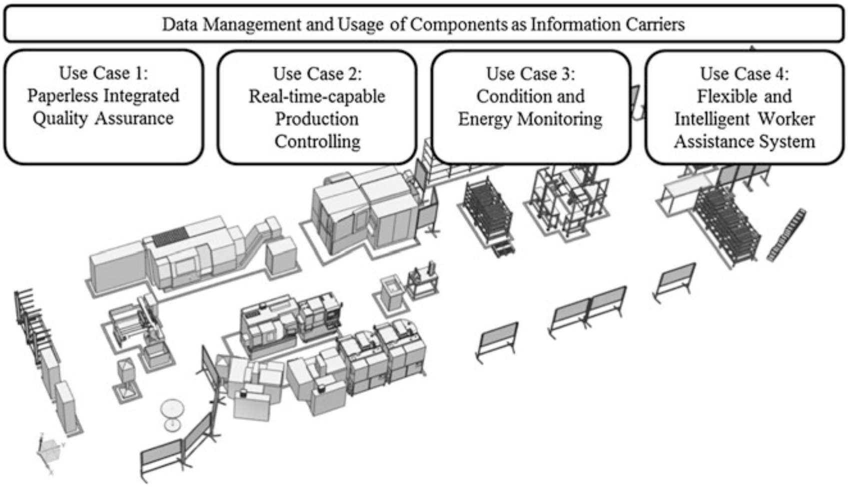


Fig. 1 Use cases "Effiziente Fabrik 4.0" overview

2 Requirements for Intelligent Worker Assistance Systems

The requirements for an intelligent worker assistance system vary. They differ greatly depending on the task area and ambient conditions. Therefore, in Table 1 general requirements are presented on assistance systems. This must be considered depending on the company.

The human with his individual qualities has been up to now hardly looked at in the development by assistance systems. Accordingly, no data models are available yet, in which personal data may be stored. For a conceptual design of an employee data model therefore these requirements are described. Because every company has different requirements and starting points for the introduction of assistance systems, the requirements may vary on employee data model. The illustrated basic requirements must therefore be considered company-specific, see Table 1. The assembly information is an important input for the worker assistance system. For completeness, these requirements are obtained also in Table 1. Focus of this paper is on the requirements for the employee data model.

Based on the requirements that developed concept will be presented in the next chapter.

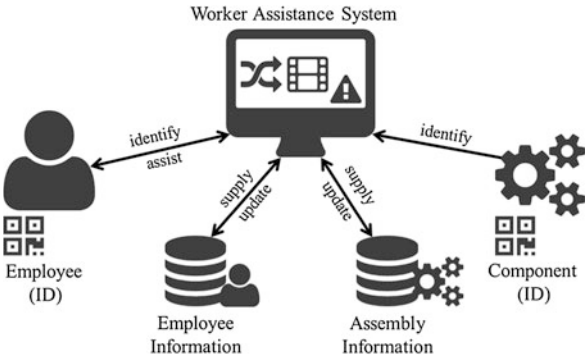
Table 1 Requirements for intelligent worker assistance systems

Requirement	Description
General requirements	
Design of the assistance system as a bidirectional learning system	– Reducing training times – Diverse learning functions – Self-learning system
Supporting quality assurance	– Reduction of assembly errors
Situation oriented system	– Adaptation to selected range of information – Adjustment component and tool availability
Ergonomically oriented system	– Improve the ergonomics – Reducing searching times
Human oriented system	– Age-based work organization – Enabling new activities
Employee ID	– Identify employees – Storage and use of employee profiles
Requirements for the employee data model	
Open source employee data model	– Open design, assistance system must be adaptable – Expandable/shortened – Regular updating of data
Recording of all useful data	– Personal data and ergonomics parameters – Assistance systems data – Qualification data
User-oriented presentation	– Differentiated evaluation (of qualifications) – Personal influence by employees
Data security and protection	– Assign rights for data model – Protection against misuse
Requirements for the employee data model	
Display of assembly information	– Digital – Meaningful illustration through animations/videos
Whole relevant assembly information	– All you need to know – Provide background knowledge – Adequate information depth
User-related assembly information	– Adapted to knowledge of the employee – Situational information
Generating assembly information	– If possible, automated – Media break free, digital

3 Concept of an Intelligent Worker Assistance System

Subsequently, the concept will be presented for the implementation in the "Effiziente Fabrik 4.0". This provides improved and interactive assistance in the assembly. Basis of the concept is to firstly register and process the employee data and then to provide the assembly information. Figure 2 shows the schematic

Fig. 2 Concept of an intelligent worker assistance system in the project "Effiziente Fabrik 4.0"



structure of the overall concept for a flexible and intelligent worker assistance system.

Each employee has an identification number (ID). In the present case it has been decided in favor of the easy way of user name and password. However, more possibilities, such as registration by QR Code are conceivable. By using the employee's ID, the employee information is provided. As already described, the development of the employee data model is a primary component of the concept, due to the active participation. Therefore the employee data model will be in detail presented in the next section. If the information about the employee is known, the employee can identify the component to be mounted in the workplace in the next step. The component as an information carrier has a unique identifier which can be read by RFID. Then, the associated assembly information will be accessed. Now the assistance system is capable of using the component information and installation information. The knowledge of the employee's level of qualification is crucial to assist these needs. The demanded preparation is also shown again in the chapter on prototype implementation.

3.1 Concept of an Employee Data Model

An employee data model contains a lot of data about the employee. One approach to this delivers [5]. In the featured employee data model for the digital factory, the ergonomic profile of the employee will be expanded to include a skills profile and an authentication profile. These partial models allow the virtual representation of each employee. In the authentication profile the employee's ID, the role in the production environment and granted rights and privileges are included. The competency profile contains rudimentary hard skills and soft skills, such as experience, leadership skills and expertise. In the ergonomic profile informations such as height, weight or physical limitations are included. For the implementation of an intelligent worker assistance system that works personable, an expanded employee data model is needed. In such a data model all employee-specific data can be stored,

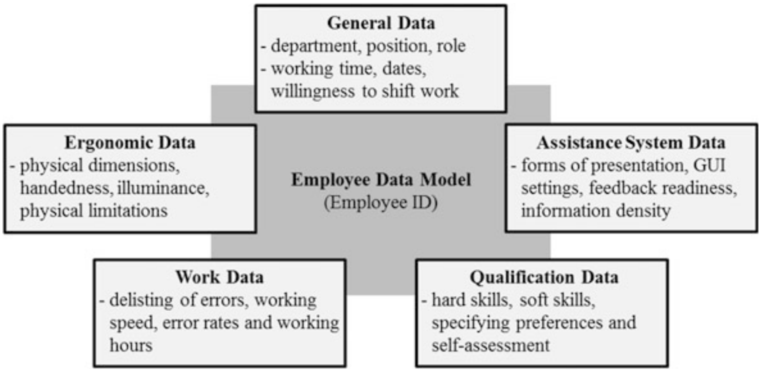


Fig. 3 Schematic employee data model

so that the assistance system, the supervisor and the employee have access to this. The concept development begins first with the consideration of all the data that are possible in principle. Following the acceptance by the employees of such data collection were discussed and ways to increase acceptance were presented. As an acceptance-encouraging measure an advanced qualification matrix was developed. This matrix captures the skills and competencies of an employee better than classic qualification matrixes do it. Finally, the employee data was structured. This gives a schematic overview of employee data model, which is finally represented in the Unified Modelling Language (UML) as a class diagram.

Figure 3 shows the developed structured schematically represented employee data model. The developed data model consists of five partial models. In these all necessary data about the employee are included. General data is defined as the personal data and coordination data. These are particularly important for the human resources departments and the time operational planning. The relevant settings of workplace ergonomics data will not be stored in the form of body measurements, but as a set of parameters. Accordingly, the employee is measured directly. The necessary parameters are instead in the initial setup of a workplace recorded and stored. The parameters include e.g. the seat height, table height and other important dimensions. Likewise, special settings are taken (for example, the optimum light intensity). To interact with the assistance system data must be collected. This relates to the language and the settings of the graphical user interface. Also, the feedback that gives the employee the completed work instructions, are stored. Which working data are recorded and the extent to which the various actors are available, must be decided company-specific. The employee data must be protected from abuse.

The qualification data must also be part of the employee data model. The classic qualification matrix is extended to soft skills and self-assessment of the employee and his preferences. Humans qualify not only with hard skills for a job, but also with soft skills, personality and with preferences and interests. The qualification matrix must therefore be extended to these areas. This allows the assistance system a more personalized and to extend the user interaction further and also enables the team leader to a more sensible employee management. The advanced qualification matrix consists of the areas “assessment by the team leader”, “self-assessment by the employee” and “preferences of employee” together. For the evaluation of competencies, differentiated classification is introduced. The assessment and classification of individual skills and preferences therefore will be performed by using numerical values from zero to five. The corresponding scales are listed in Table 2, see also [6, 7].

The three ratings “assessment by the team leader”, “self-assessment by the employee” and “preferences of employee” will be for each competency to a numerical value, the expertise value, merged. The competence value is calculated based on the technical quality according to VDI 2225 Sheet 3 [8]. For the present employee data model the expertise value W_K is defined as follows. p_f, p_s, and p_p are the points rating for each evaluation criteria. This can be between 0 and 5, see Table 2. Thus not all summands are valued equally strong, there are the weighting factors g_f, g_s, and g_p. For the weighting ratio p_f:p_s:p_p in this case 3:2:1 is selected.

$$W_K = p_f * g_f + p_s * g_s + p_p * g_p. \tag{1}$$

Table 3 shows a brief example of the advanced qualification matrix of the employee 1, see also [7]. Besides the evaluation of hard skills and soft skills by the

Table 2 Requirements for intelligent worker assistance systems

Points	Scale hard skills	Scale soft skills	Scale preferences
0	No information	No information	No information
1	In education	Badly	Not like to
2	Work independent	Moderately	Acceptable
3	Work in required quality	Passable	Neutral
4	Work in required quality and quantity	Good	With pleasure
5	Mastered all skills and communicates this to team	Very good	Very happy

Table 3 Qualification matrix of the employee 1

		Assessment by team leader p_f	Self-assessment p_s	Preferences p_p	W_K
Hard skills	Welding	3	4	5	3.67
	Screwing	1	3	4	2.17
	…	…	…	…	…
Soft skills	Lead employees	2	2	3	2.17
	Ability to work in a team	1	2	1	1.33
	…	…	…	…	…
	Weighting ratio	3	2	1	$\Sigma = 6$
	Weighting factors	$g_f = 0.5$	$g_s = 0.33$	$g_p = 0.17$	$\Sigma = 1$

team leader, the self-assessment and preferences of the employee are applied. From the registered scores of current qualification level of the employee is visible.

The qualification matrix of an employee can be visualized by means of a three-dimensional bar chart. Figure 4 shows the visualization of the created in Table 3 extended qualification matrix.

Such an advanced qualification matrix is established for each employee. It is not only the advanced skills level visible, but also the motivation. It is an individual and situation-adapted evaluation possible to derive employee-customized resource planning and skills training.

With regard to the implementation of the employee data model can be represented as a class diagram in the Unified Modeling Language (UML). The schematic employee data model of Fig. 3 is already largely structured so that it lends itself to the implementation in such a diagram.

The UML class diagram of the employee data model is shown in Fig. 5. The core model is the class Employee_Data_Model. Through the employee ID the data will be assigned to a specific employee. Employee_Data, Ergonomic_Parameter, Assistance_Data, Working_Data, and the Qualification_Matrix form the five partial models. The partial models consist of several classes with attributes. Depending on the design of the assistance system and demands on the employee data model, it may be useful and necessary to remove, change or add individual attributes, classes or entire partial models. Through this, the employee data model can be individually adapted to the given conditions, so that it can meet the requirements in the best possible way.

Based on this concept a prototypical implementation has been worked out, which takes place in the next chapter.

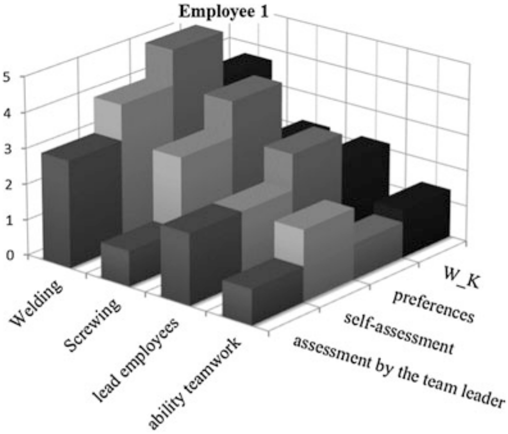


Fig. 4 Visualized qualification matrix for employee 1

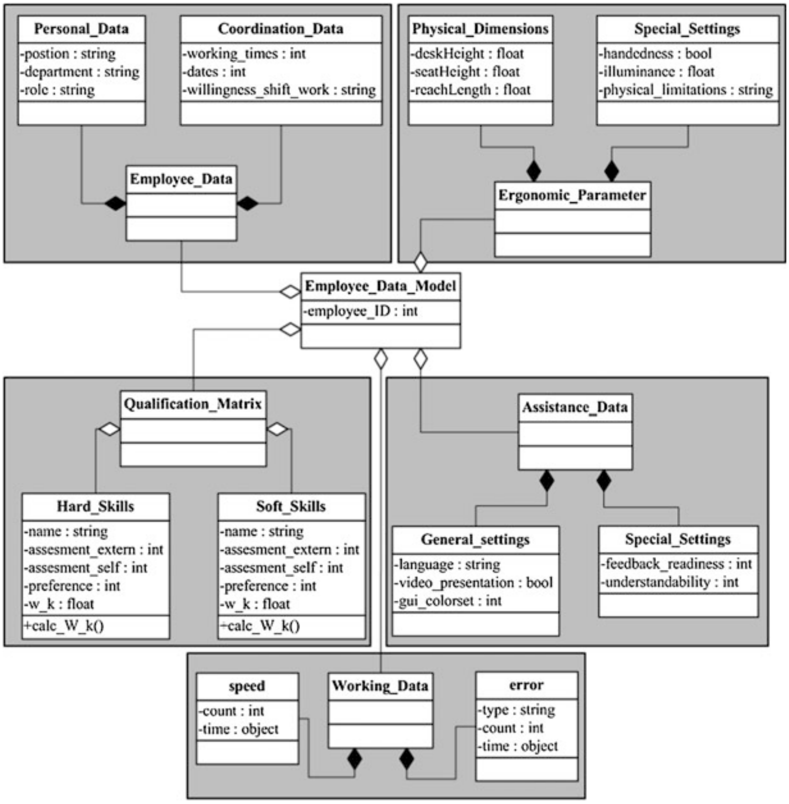


Fig. 5 UML class diagram of the employee data model

4 Prototype Implementation

In the implementation of the employee data model, it is sufficient to develop a relational database as a stand-alone solution in a first step. The integration into an overall system can be carried out in a similar way and is dependent on the system used in the company environment. As a user interface a Windows application was used and implemented. In Fig. 6 images are shown to illustrate the implementation. The first picture shows the physical structure of the worker assistance system, at the top of the tablet for employee communications can be seen (A). When the employee logs on the GUI is displayed to him (B). He will now be visualized to him where he must read how the component is to be mounted. After this the assembly assistant starts. Depending on the application, the assembly information can be created virtually directly from the CAD system or by means of real video recordings and provide instructions, based on the components as information carriers (C). In order to keep the effort involved in assembly smaller batch sizes small, here an

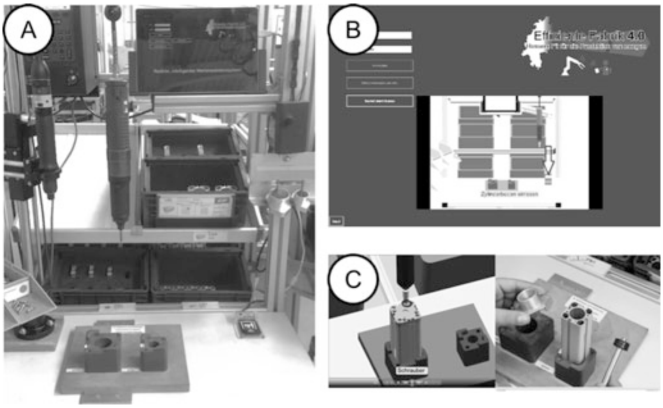


Fig. 6 Prototype implementation of the worker assistance system. **a** physical build of the system; **b** visualization of the GUI; **c** visualization of assembly information

algorithm-based semi-automated method of creation from the CAD system was conceived. In contrast is the creation of real assembly information, which e.g. brings with it the advantage that ergonomic instructions, such as the hand position can be taken into account.

By linking the employee information, the assembly information can be provided as needed. Needs-based means in this case based on the employee model. Important in the implementation is to involve the employees, so he should decide for example on the cycle time and the amount of information. Figure 7 shows an example of the

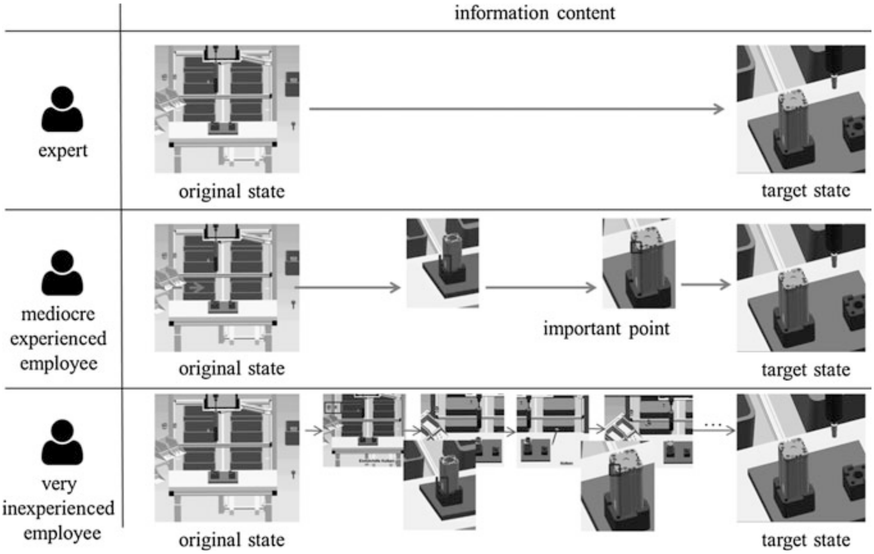


Fig. 7 Needs-based assembly information

needs-based assembly assistant. Here is an example divided into three types, an expert, a mediocre experienced employee and a very inexperienced employee.

The expert is sufficient here only the objective condition of the assembled product to fulfill its task. At mediocre experienced employee only important points are shown in the assembly. The inexperienced employee has for the first time installation, a step by step instruction, so the quality of the assembly is guaranteed. Based on the employee information, these types are derived by the system and submitted by employees. The employee can then finally again even customize their desired information content.

5 Conclusion and Outlook

The prototypical implementation confirms the functionality of the developed concept. The development fulfills the identified requirements. The employee data model made it possible, by the advanced qualification matrix recently developed, to get a needs-based delivering of information for the employee. The qualification matrix allows to embed the perspective of the employee. This deals with the view of the team leader and the employee. In the implementation, it is necessary to ensure that it is always handled company specific. Every company has a different philosophy in dealing with assistance systems and employee data. Building on the concept of employee data model is the next step the executable implementation on the software side. Another important aspect is data security. Both the programmer and the IT structures of companies must protect the stored data against unauthorized access and abuse. Thus for example a certified data system where employees can store data, although these are not visible for the supervisor, provide a basis for employee data storage. By introducing intelligent worker assistance systems as well as other Industrie 4.0 innovations, both the working environment and the job content of company staff changes. To advance from this current human-centered work organization the physical and the mental load must be investigated, to bring further innovations. After [9], this aspect is not yet adequately addressed and must be included as further field of action in the research.

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Dynamic, Adaptive Worker Allocation for the Integration of Human Factors in Cyber-Physical Production Systems

Daniel Strang, Nadia Galaske and Reiner Anderl

Abstract In this paper an adaptive, dynamic, and individualized worker allocation method is presented. The developed method is based on individual worker information, the new flexible cyber-physical production system, and the communication between the participants of such a production system. According to a communication scenario demands of a manufacturing step and a manufacturing station are compared with employee information. This provides the basis for a decision of the worker allocation. Workers are only allocated to manufacturing stations that match their qualifications and personal characteristics. For a better integration of human factors in CPPS, the job satisfaction of each worker also has to be taken into account. Therefore a satisfaction value for each manufacturing operation and manufacturing station is defined and part of the worker information. The aim of the research is to increase the productivity in the production system and the satisfaction of each individual worker.

Keywords Industrie 4.0 · Cyber-physical production systems · Profile data model · Worker allocation · Discrete-event simulation

1 Introduction

To encounter the challenges presented by globalized markets, shorter product life cycles, and increasing demands for individualized products, the initiative "Industrie 4.0" was started by the German Federal Government. This initiative aims to achieve

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a highly flexible production, especially in high-wage countries. In this scope, researches in cyber-physical production systems (CPPS) are conducted, in which cyber-physical systems (CPS) consisting of sensors, actors, and communication interfaces are implemented in production systems.

The main focus of CPPS is to enable the manufacturing of high product variety in small lot sizes. In order to facilitate a highly flexible production process, a combination of automated and manual manufacturing operations is needed. Manual manufacturing operations, however, are heavily influenced by individual expertise and qualification of each worker.

To anticipate a fluctuating order situation and a large product variety, workforce management needs to be more flexible. Instead of a static prescheduling, a dynamic worker allocation that considers several different factors, such as individual qualifications and personal characteristics of each worker, is required. For a better integration of human factors in CPPS, the job satisfaction of each worker also has to be taken into account.

In this paper, an adaptive, dynamic, and individualized worker allocation method based on the individual profile data model for each worker is developed to integrate human factors in CPPS and guarantee a worker-friendly and productivity-enhancing production. For this purpose, relevant attributes of the profile data model are defined and instanced for each worker. Additionally, because productivity is strongly linked to the job satisfaction level the preference of each worker for each manufacturing station is specified in the profile data model.

For the execution of the adaptive worker allocation in CPPS, a model-based communication scenario is developed. This communication scenario illustrates the necessary communication between product components, manufacturing stations, and production workers. Using information about the availability and ability of manufacturing stations, current product components, required process steps, and characteristics of each worker, the worker allocation is executed by matching the requirement of the manufacturing station with the qualification of the worker.

2 State of the Art

2.1 Cyber-Physical Production Systems

The foundation for modern manufacturing systems are cyber-physical systems. The principles of cyber-physical systems defined by LEE are *cyberizing the physical* and *physicalizing the cyber* [1]. Everything that is existent physically is represented in the virtual world, and everything that is represented virtually exists in the physical world.

Cyber-physical systems are systems with embedded software [2]. Thus, they are an advancement of the embedded systems [3]. These cyber-physical systems use sensors to record data and affect physical processes by actors, evaluate and save data, interact with the physical and virtual world, connect with each other, communicate via interfaces, use global data, and use human machine interfaces [2].

In the domain of production the application of cyber-physical systems are called cyber-physical production systems. They are used to equip manufacturing participants to get smart machines, storage systems, and production facilities, that are able to exchange information autonomously, trigger actions, and control each other [4]. In this context Internet of Things and Big Data are two research areas that result from the development of cyber-physical systems. The Internet of Things represents the networking of all objects in a smart factory based on cyber-physical systems. Further information can be found in Kopetz [5]. The Big Data research treats the high amount of data by cyber-physical systems. Therefore, an approach for data management in cyber-physical production systems is necessary [6].

In an ideal cyber-physical production systems all participants are the carrier of their own information. All manufacturing stations, workers, and components in the production system are equipped with a structured information storage. The information of each participant can be exchanged using the communication interfaces of the cyber-physical systems and can be used for autonomous decisions in the production process. The communication in a cyber-physical production system can be executed via a central server or directly between the participants [7].

Two approaches for a structured information representation for individual components in cyber-physical production systems are presented as the focus in recent research. The first approach is the semantic product memory. It offers the continuous collection of individual component data [8, 9] and the contextual retrieval of information of each individual component [10] with the use of ontologies [11]. Information on the semantic product memory is limited to the information of one specific component and the information that was generated during the manufacturing and utilization phase of the specific component [9, 12, 13].

The second approach is the component data model. It was developed in regards to the product data model concept as a data model for individual components [14]. It integrates the information of all components of a product (product data) and the information of the semantic product memory [15, 16]. Thus, it extends the approaches of the product data model on the one hand and the semantic product memory on the other hand. In addition, it enables the active use of product and component information in the product manufacturing, e.g. in the assembling of a component [17].

Possibilities to provide the manufacturing process with individual information of each component are the use of web services [18] or the application of the Extensible Markup Language (XML) [15].

2.2 *Profile Data Model*

In order to anticipate a fluctuating order situation and a large product variety, an adaptive and dynamic workforce allocation that considers several different factors, such as individual qualification and personal characteristics of each worker, is required. For this purpose, the integration of individual worker information in the CPPS is indispensable.

As mentioned in the previous chapter, every object in CPPS is a carrier of its own individual information. For individual components, this function is provided by the component data model [14]. Similar to the concept of component data model, the profile data model for production workers offers a solution for the virtual representation and the integration of worker-related profile data in CPPS [19]. It enables the exchange of individual worker information with other objects of CPPS. Individual information, such as qualifications, skills, and experiences of each worker, can be represented in a profile data model. The profile data model consists of a worker profile model as the core element and three partial profile models: authentication profile, competence profile, and ergonomic profile [19, 20]. Figure 1 shows the basic structure of the profile data model.

The worker profile contains the identification attribute *workerID* and serves as integration module for the three partial models. The authentication profile consists of basic personal information of each worker, e.g. name and address, as well as organizational information, e.g. job descriptions, availability status, and access rights. The competence profile includes both hard and soft skills of the worker, such as qualification, knowledge, and experience [19]. This information needs to be quantified and digitally represented in order to determine, whether the worker satisfies the requirement of the manufacturing operation or the manufacturing station [21]. The ergonomic profile contains information about physical characteristics of the worker and essential attributes for the ergonomic assessment, e.g. limitations or restrictions [19]. Preferences of each worker can be integrated also in the ergonomic profile. By using the profile data model as foundation for the individual worker allocation, qualification and ergonomic factors can be taken into account.

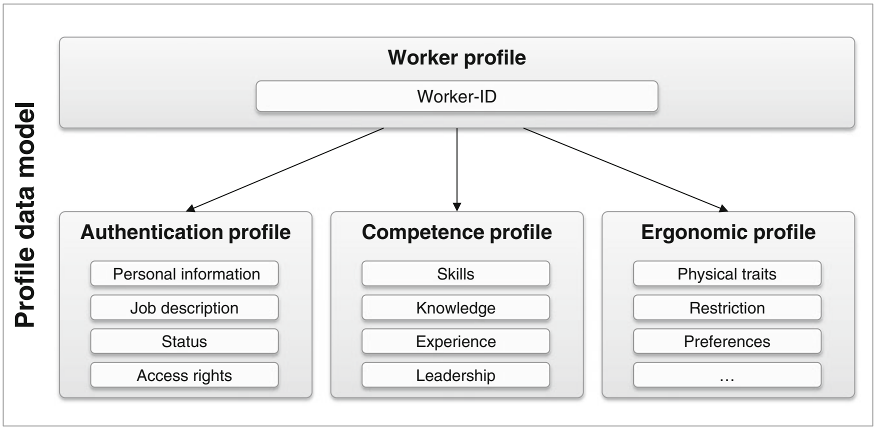

Fig. 1 Profile data model, adapted from [19]

2.3 Worker Allocation

The aim of the dynamic worker allocation in the context of this paper is an ideal allocation of employees to manufacturing stations in a cyber-physical production system. This is consistent with the goal of the procedure model for a worker allocation defined by Scherf [22]. A worker allocation to a manufacturing step is based on an optimized consensus between the demands to perform a manufacturing operation or to operate the manufacturing station and the qualifications and characteristics of each worker of a production system.

To guarantee an adequate allocation of every worker, mathematical models and simulation models have been presented in various publications. Due to the implementation and validation, this paper will only focus on the simulation models.

The effect of a qualification-based worker allocation in the production can be observed using computer-aided simulation models. An approach for the modelling of qualification can be found in Zülch and Becker [23]. In this approach, the workforce allocation to work functions and workplaces is performed using the factors feasibility, authorization, and ability. A worker must possess these factors in order to be able to perform a certain activity on a certain manufacturing station. This approach is similar to the qualification matrix approach [24], in which a qualification matrix is used as a mathematical model to classify and select the suitable worker for each job.

Another approach for a simulation-based worker allocation can be found in Denkena et al. [25]. The worker allocation for the production planning is executed by matching the requirement of the manufacturing station and the competence profile of each worker, resulting in a machine occupancy plan with one best suitable worker as the first priority and other workers as alternatives in the order of priority. However, this approach does not satisfy the dynamic requirement of a CPPS as it is based on a predefined machine occupancy plans. Furthermore, the existing approaches do not consider the preference and job satisfaction level of the worker.

3 Dynamic and Adaptive Worker Allocation

Cyber-physical production systems enable a new automatic form of worker allocation, which is dynamic and adaptive. The dynamic worker-allocation is demand-based. This means that the manufacturing station only calls for a worker if needed. The dynamic character of the worker allocation implies that all workers do not stay at one manufacturing station during the whole shift, but are reallocated dynamically according to the requests of queueing manufacturing operations.

To explain the concept of the dynamic worker allocation in CPPS a communication scenario is developed. This communication scenario is presented in Fig. 2. It is developed with a UML sequence diagram, which defines the participants, the communication and the activity sequences of each participants. In CPPS the

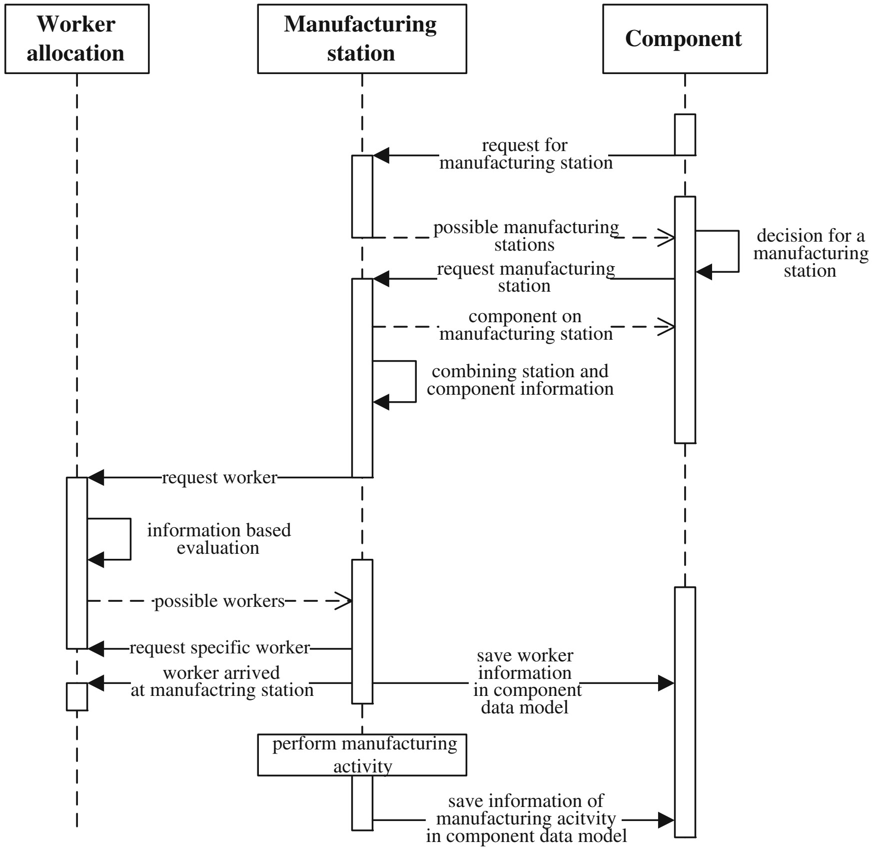

Fig. 2 Communication scenario for dynamic worker allocation

components and manufacturing stations negotiate about the execution of a manufacturing operation based on the individual information of the participants. Components are the carrier of a process plan, which specifies all manufacturing operations. Every manufacturing operation has different requirements for a manufacturing station. Based on these requirements and the negotiation between components and manufacturing stations a matching station is automatically chosen.

For the specification of the requirements for a worker at the manufacturing station, the information of the component and the manufacturing station is combined. The requirements are derived from this information. The manufacturing station requests a worker that satisfies the requirements. For the dynamic worker allocation the requirements are evaluated and possible workers are selected and informed to the manufacturing station. The manufacturing station picks one of the suitable workers. As soon as the requested worker arrives at the manufacturing station, the manufacturing operation is executed.

All communication activities in the communication scenario in Fig. 2 needs to be represented in a data model. This is important to retrace the reasons for an autonomous decision, to optimize the communication process, to update the information of each worker, manufacturing station and component, and to deliver a detailed service and customer documentation.

An approach for the representation of the communication and the autonomous decisions during the manufacturing process is the component data model. The component data model consists of a core model and several partial models. For the representation of the dynamic worker allocation a new partial model is defined. It contain information about the possible workers, the actual worker at the manufacturing station, and the performed manufacturing operations of each worker and each manufacturing step.

The stored data on the component data model can be presented completely for internal issues and can be displayed with limited information for users. A limitation of information is necessary to maintain the privacy of the workers in the CPPS.

4 Use Cases for the Simulation

The use cases for the simulation of the dynamic worker allocation are based on a sample product. The pneumatic cylinder production of the center of competence learning factory[1] at TU Darmstadt is chosen. The assembly process of the product consists of 6 different assembly operations that can be performed in 6 manufacturing stations with 5 or less workers. For the simulation use cases a variety of workers with different qualifications is taken into consideration.

For the implementation and validation of the dynamic and adaptive worker allocation, four use cases are defined. The first use case is a fixed worker allocation. The other use cases are defined to demonstrate the dynamic worker allocation with different objectives. The principles of the fixed and dynamic worker allocation are illustrated in Fig. 3.

The workers in the production system in Fig. 3 are classified by their qualification. The *trainee* is a new worker in the CPPS. He is not used to any of the manufacturing stations. The *workers* are average workers who already worked for some time in the CPPS. They are familiar with some of the manufacturing stations and operations. The *foreman* is the person in charge of the assembly line. Thus, he has a good knowledge of all manufacturing stations and manufacturing operations.

Use Case 1. The first use case is defined to compare the fixed worker allocation to the new dynamic worker allocation of CPPS. In this use case each worker is allocated to a specific manufacturing station and stay there during the whole shift. Hence, the utility of the fixed worker allocation is strongly dependent on the

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[1] For further information: www.prozesslernfabrik.de.

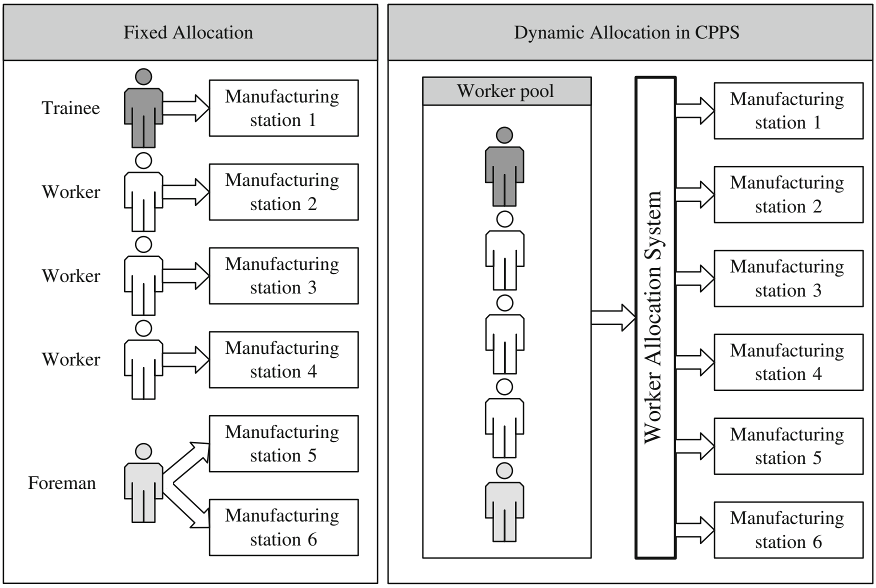

Fig. 3 Fixed and dynamic worker allocation

experience and qualification of the staff planer. It is not ensured that the workers are allocated optimally regarding their qualifications and personal preferences.

Use cases 2 to 4 are defined for a dynamic worker allocation in CPPS. The allocation method regards the experience and the satisfaction of each worker. Therefore, an experience level (EL) and satisfaction level (SL) is introduced as parameters. Both parameters represent accumulated values, which are calculated from worker attributes taken from the individual profile data model. To take both parameters into consideration, the dynamic worker allocation defines an allocation value (AV), which is calculated with Formula 1:

$$\mathrm{AV} = \omega_{\mathrm{EL}} * \mathrm{EL} + \omega_{\mathrm{SL}} * \mathrm{SL}. \tag{1}$$

A high EL has positive influence on the productivity of the CPPS, while a high SL leads to satisfied workers. In the Formula 1 it is possible to focus more on the productivity or on the satisfaction using the weighting factors (ω). The sum of the weighting factors is one (Formula 2):

$$\omega_{\mathrm{EL}} + \omega_{\mathrm{SL}} = 1. \tag{2}$$

Use Case 2. The second use case aims for a maximum productivity. Formula 3 expresses this by defining the weighting factors for use case 2:

$$\omega_{\mathrm{EL}} = 1, \quad \omega_{\mathrm{SL}} = 0. \tag{3}$$

Use Case 3. The third use case maximizes the satisfaction of the workers. Formula 4 expresses this by defining the weighting factors for use case 3:

$$\omega_{\mathrm{EL}} = 1, \quad \omega_{\mathrm{SL}} = 0. \tag{4}$$

Use Case 4. The last use case for the dynamic worker allocation in CPPS takes experience and satisfaction equally into consideration. Formula 5 expresses the forth use case by defining the weighting factors as follows:

$$\omega_{\mathrm{EL}} = 0.5, \quad \omega_{\mathrm{SL}} = 0.5. \tag{5}$$

5 Simulation of the Dynamic Worker Allocation

The developed method is implemented in a discrete-event simulation model of a production system. Furthermore, an add-on is programmed to provide the simulation with intelligent, communicating product components. The processing time is simulated and the satisfaction level for each worker is calculated using the preference attribute and the frequency of assignments to preferred manufacturing stations.

5.1 Implementation

The implementation of the simulation is done with the software tools Tecnomatix Plant Simulation and NetBeans. Tecnomatix Plant simulation is used for the material flow simulation. NetBeans is used to develop add-ons, which are necessary for the simulation of CPPS.

One of the add-ons is the integration of intelligent components. These components possess information about themselves and are able to communicate with the manufacturing stations in a material flow simulation. To build up a connection for communication purposes between the intelligent components and the material flow simulation a socket interface is implemented. This interface simulates a network connection between the components and the manufacturing stations.

For the dynamic worker allocation a worker pool has to be defined. The workers that were introduced in Fig. 3 are added to the worker pool. Their experience levels (EL) and satisfaction levels (SL) for each manufacturing step at the corresponding manufacturing stations (MS) are stored as parameters. The chosen values for the parameters are presented in Table 1. All parameters range between 0 (low level) and 2 (high level). A worker with zero experience level at a specific manufacturing

Table 1 Implemented experience and satisfaction levels of the workers

Worker	Parameter	MS1	MS2	MS3	MS4	MS5	MS6
Trainee	EL	0.2	0	1.5	0	0	0
	SL	2	0	0.3	0	0	0
Worker 1	EL	2	0.4	0.4	0.1	0.2	0.2
	SL	0.2	0.5	0.4	1.9	0.6	0.6
Worker 2	EL	0.6	2	0.3	0.4	0.4	0.4
	SL	0.4	0.3	0.5	0.7	1.7	1.7
Worker 3	EL	0.5	0.2	0.1	1.8	0.6	0.6
	SL	0.6	1.8	0.7	0.1	0.4	0.4
Foreman	EL	0.3	0.3	0.2	0.6	1.9	1.9
	SL	0.3	0.4	1.9	0.3	0.2	0.2

station will not be allocated to that station. To illustrate the significance of the results the values of the parameters in Table 1 are exaggerated.

The communication scenario presented in Fig. 2 is implemented to apply these parameters in a dynamic worker allocation. The manufacturing station demands a worker from the worker pool. The dynamic worker allocation system evaluates the experience and satisfaction levels of the available workers and defines an allocation value (Formula 1). The weighting factors for the calculation are dependent on the use cases defined in Sect. 4. A worker is allocated to the requested manufacturing station according to the allocation value (AV).

As the goal is to display the advantages of the dynamic worker allocation method, a simulation with fixed worker allocation is also executed. The total production time and the average satisfaction of the workers are selected as simulation results to illustrate the advantages of the dynamic worker allocation to the fixed allocation.

5.2 Simulation Results

The simulation results show a positive effect of the dynamic worker allocation on the overall productivity of the production and on the satisfaction level compared to a fixed worker allocation.

To validate the positive effects of the dynamic worker allocation the simulation is executed using a production batch of 5, 10, 20, 50, and 100 equal components. Due to the limitations, only the simulations with 5 and 10 components are presented in this paper. The other simulations show comparable results.

Simulation with 5 Components. The results of the simulation of the use cases with 5 components show the results of the fixed location and a time improvement in the dynamic allocation. The best production time is achieved with the optimization for the experience level (Use Case 2). The average satisfaction of the workers is

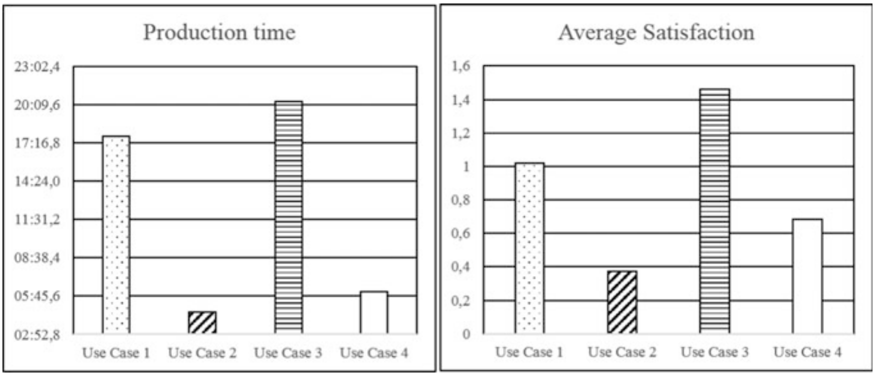

Fig. 4 Results of the simulation of the use cases with 5 components

highest when the simulation is optimized for the satisfaction level (Use Case 3). Use Case 4 shows a compromise between satisfaction and productivity. The results are shown in the diagrams in Fig. 4.

Simulation with 10 Components. The simulation with 10 components confirm the results of the simulation with 5 components. The results are shown in Fig. 5.

The dynamic worker allocation guarantees a higher satisfaction of the workers and a higher productivity. With the variation of the weighting factors the focus of the production can be varied between productivity and satisfaction.

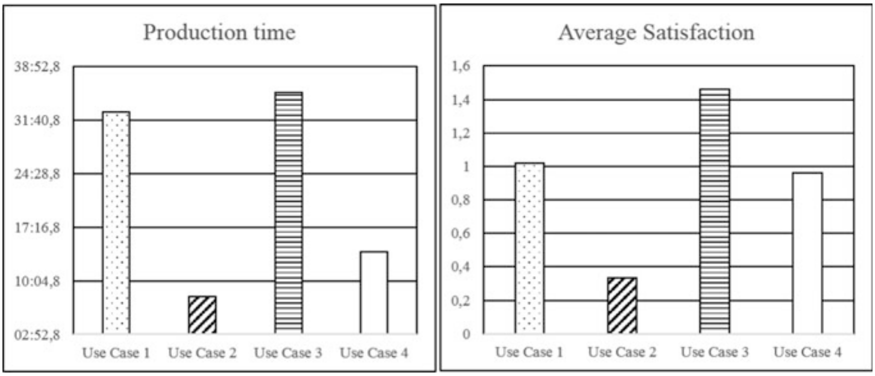

Fig. 5 Results of the simulation of the use cases with 10 components

6 Conclusion and Future Work

The dynamic worker allocation for CPPS provides an approach to increase the productivity and the satisfaction of the workers by using the individual profile data model. Due to the consideration of individual profile data the production time and the satisfaction level can be optimized. The ideal solution is dependent on the manufacturing company and lies somewhere between a maximum productivity and maximum satisfaction. To test the different solutions, a weighting factor for the experience and satisfaction level is introduced and implemented in the material flow simulation. The simulation provides good first results, which can be optimized with further research.

The experience and satisfaction levels are estimated values in this paper. Based on the information of the profile data model, the values have been provided to show the effects of a dynamic worker allocation. With a more detailed individual data model and a calculation algorithm these values can be determined more correctly. Nevertheless, the algorithm should take the experience and satisfaction level as well as the weighting factors into consideration. Other parameters can be supplemented, such as the influence of physical limitations of the worker or the frequency of mistakes made during a manufacturing operation.

Finally, the dynamic worker allocation needs to be tested in a productive environment. The provision of individual profile data of each worker is currently not yet part of any production facility, but it is the basis for the dynamic worker allocation. Therefore, the dynamic worker allocation can currently only be tested in research environments.

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Systematic Dimensioning of Personnel Flexibility in Manufacturing

Moritz Hämmerle, Wilhelm Bauer, Dieter Spath and Stefan Gerlach

Abstract In addition to customized products and eroding delivery times, todays volatile markets are a major challenge for manufacturing companies. Stronger and more short-term fluctuations in sales require lean production structures and, more and more frequently, the flexible use of manufacturing resources. In high-wage countries like Germany in particular, the flexible use of well-qualified manufacturing employees is a competitive advantage for manufacturing companies. This paper describes the challenges of manufacturing companies in the field of volatile markets and introduces a new method to dimension personnel-flexibility systematically.

Keywords Volatile markets · Human resources flexibility · Human resources management · Manufacturing systems engineering · Advanced manufacturing

1 Introduction

Manufacturing companies are subject to ever-larger fluctuations in customer orders, which cannot reliably be predicted at an early stage with today tools [1]. Next to these volatile market conditions there are still challenging goals in high delivery rates with short delivery times at low stocks and a high utilization rate of the manufacturing capacities. Especially companies, which add a high part of value in manual manufacturing and assembly areas, are forced to use their personnel flexibility higher to react against the volatility of customer markets [2]. To avoid losses

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due to insufficient flexibility of resources and to increase the delivery rates a proactive and systematic planning and control of personnel flexibility through personnel flexibility tools is needed in addition to a high system flexibility and reactive supply chains.

The German manufacturing companies can already use a high variation of personnel flexibility tools. A systematic selection and dimensioning of these tools enables companies to have the right flexibility tools at the correct scale available at any time. This paper describes the design of the new method and first initial findings.

2 Factors Involved in the Volatile Markets of Manufacturing Companies

Various drivers for fluctuations influence the market volatility of manufacturing companies. Short-term flexibility interferes with long-term volatility.

Short-term flexibility challenges order-oriented manufacturing companies through orders with minimum delivery times at an increasing number of product variants. In addition to these increasingly individualized products, the numbers of big orders from individual customers increase. In manufacturing these orders are processed as project or tender order [3]. If customers' orders such big orders, companies must be able to provide a high amount of short-term personnel capacity. The other way round, if orders are cancelled, material is missing or if other disruption happens, the personnel capacities have to be reduced very fast [4].

Medium- and long-term volatility result for manufacturing companies by seasonal influences, due to product life cycles and through economic changes. Here effects arise that are valid to the fiscal year, such as reducing the goods in stock at specific dates or plan budgets for specific periods of time. These effects create seasonal fluctuations with are supplemented with seasonal effects. The company holidays of customers or suppliers can be mentioned here as well as product-specific effects [5]. This volatility interferes with the product life cycle. In contrast to former times, today's product life cycles are much shorter and contain strongly pronounced up- and downswing phases. Furthermore, economic-based effects are added, which typically produce very strong fluctuations over a longer period. Here the global economic crisis in 2008 can be exemplified in which there was a strong and rapid economic collapse because of the close proximity of the financial markets and the manufacturing industries. The sales index of the German manufacturing sector collapsed during the crisis by almost 30 % in 2008 [6].

The individual fluctuation mentioned overlap to volatile markets. Therefore it is important for manufacturing companies to control the resulting effective flexibility, which especially challenges the companies in the management of manufacturing capacities. In such turbulent market environments companies must adjust their capacity more quickly to the changing market trends, to be able to operate successfully in future too [7]. To establish a systematic volatility management in the planning processes of the companies is thus a central point to increase the resilience against volatile markets. Because of this the companies must firstly create the conditions for high personnel flexibility in the operative areas of manufacturing.

3 Basic Strategies of Personnel Flexibility

For the labour-intensive sectors of manufacturing work, which have more than 7.7 million directly dependent employees in Germany, high personnel flexibility is an ever more important competitive environment factor. To develop a quick adaptability of their personnel capacities to the required market fluctuations is an important approach for successful companies in volatile markets.

In order to adjust their manufacturing volumes, and therefore to adjust its manufacturing capacity to the volatile market demand, companies can follow different basic strategies (see Fig. 1). If the produced quantities and the necessary personnel capacity are closely linked, it can be assumed that the basic strategies of emancipation, synchronization and partial emancipation also apply to the flexible personnel capacities as basic patterns.

In the *emancipation strategy* the produced quantity is decoupled from the demand quantity. A constant utilization of manufacturing capacity results in a constant manufacturing volume in this case. If market demand and manufacturing volumes differ, it is smoothed over the temporal distribution during scheduling of orders. In good order situations this can lead to longer delivery times. Moreover, stocks can be used as a buffer. However, this usually leads to high stock costs. Another disadvantage is the adaptation weakness of the factory to new products. However, the other side of the disadvantages is a constant high utilization of manufacturing equipment [8].

The *synchronization strategy* adjusts the manufacturing quantity or the available capacity to the demand needed by the markets at any time. That's why expensive stocks can be avoided. A synchronous manufacturing is geared very

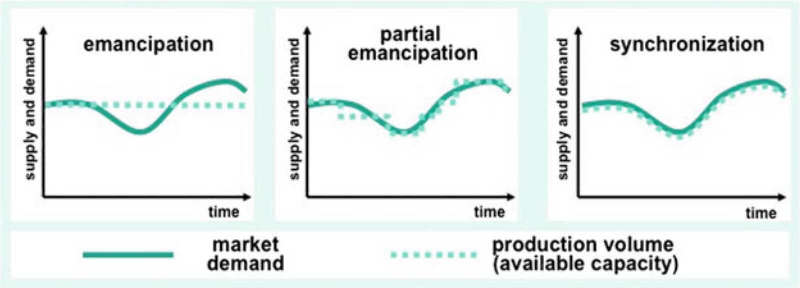


Fig. 1 Basic strategies of capacity flexibility for manufacturing companies [8]

customer-oriented, which usually leads to high delivery reliability. However, high capacity flexibility is required to productively follow the strong fluctuating utilization [8].

The *partial emancipation strategy* lies between the emancipation and the synchronization principle. It adjusts the manufacturing quantity to the demand in certain levels [8]. The advantage of this strategy is that the capacity utilization may be higher than in the synchronization strategy. However, manufacturing units can't be scaled in infinitesimal levels. That's the reason why the partial emancipation with particularly small adaptations levels is very similar to the synchronization strategy. To realize a particularly fine adjustment of manufacturing capacities, companies are required to use different dimensions of personnel flexibility jointly and parallel. The combination of different flexibility instruments such as the setting of a full-time employee should be enriched with fine acting instruments to realize, for example, adjustments in the minute range (e.g. through extension of a certain shift).

Which of these strategies matches best to a company must be determined on the basis of company-specific market volatility and the requirements of the manufacturing system. Moreover, the cost of flexible manufacturing capacity and idle time costs need to be considered for a constant manufacturing. It is necessary to find the ideal point in regarding of efficiency and flexibility between customer-oriented synchronization and emancipation working closely with the company.

4 Application of Flexibility Instruments

The widespread distribution of instruments of personnel flexibility in the German industry is shown in many current studies. In 2010 the project FlexPro surveyed more than 1200 companies on the application of different flexibility instruments in Germany. More than 2/3 of these companies do business in the manufacturing industry [9]. The results demonstrate the wide range of personnel flexibility instruments, which are regularly used in manufacturing (see Fig. 2). Instruments that are quickly available, such as overtime and extra work or internal personnel shifts are highly prioritized by the companies surveyed. Furthermore, part-time and temporary workers are used strongly. The working time of these employees can be adjusted flexibly to the short-term changes in capacity requirements of volatile markets.

On behalf of Randstad Germany GmbH & Co. KG the Ifo Institute quarterly surveys HR Managers from different sectors of the economy according to the importance of flexibility in personnel deployment. From these replies indicators are calculated for each flexibility instrument, which represents their respective importance. Thus, the survey examines the role of appropriate flexibility measures in the economic cycle and in the long term. In addition to the evaluation of each flexibility instrument the HR Managers were asked which of these instruments were applied in their company [10]. Based on the results of the survey the personnel capacity of

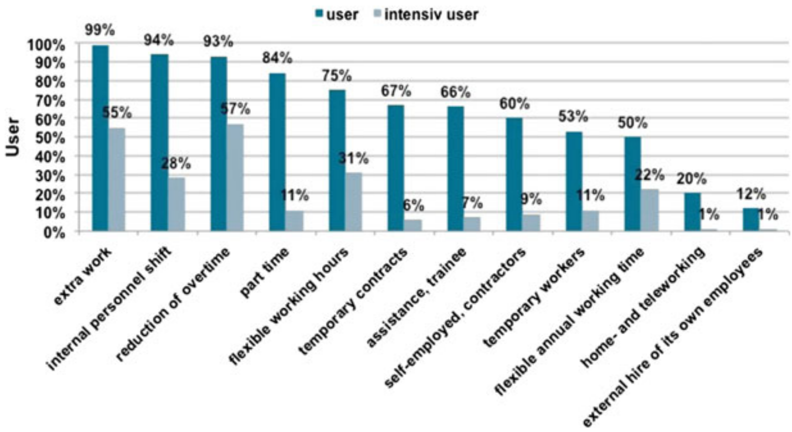


Fig. 2 Spread of personnel flexibility instruments in Germany [9]

nearly every company is heavily adapted by the ramp up and compensation of overtime (98 %). Very frequently companies use working time accounts (90 %), temporary contracts (86 %) internal transfers (86 %), as well as mini-jobs (81 %). A little more rarely the instruments of temporary work (69 %), outsourcing (59 %) and free collaboration (58 %) are applied.

In comparing the economic sectors and company size classes there were no major differences from the average values. In addition, an analysis of the data for the eight quarters of the years 2013 and 2014 produced no significant differences or sequence changes in the frequency of use of the shown flexibility instruments in Fig. 3. Elder analysis from the second quarter of 2012 came to the result that more than 70 % of German manufacturing companies provide their employees with working time accounts (see Fig. 4).

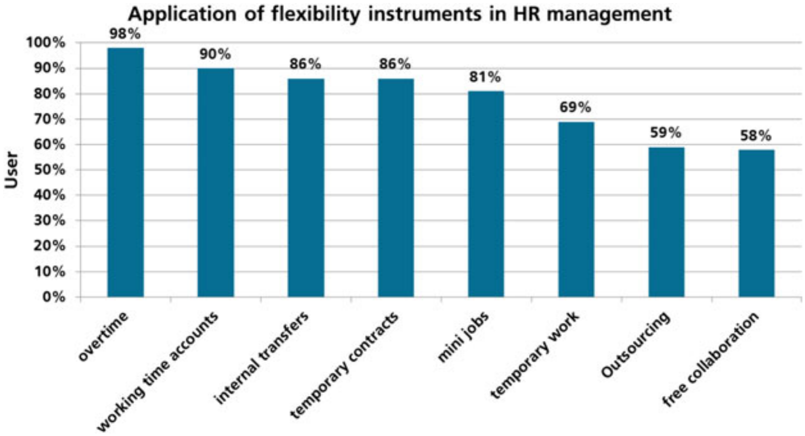


Fig. 3 Application of personnel flexibility instruments (Q4 2014) [10]

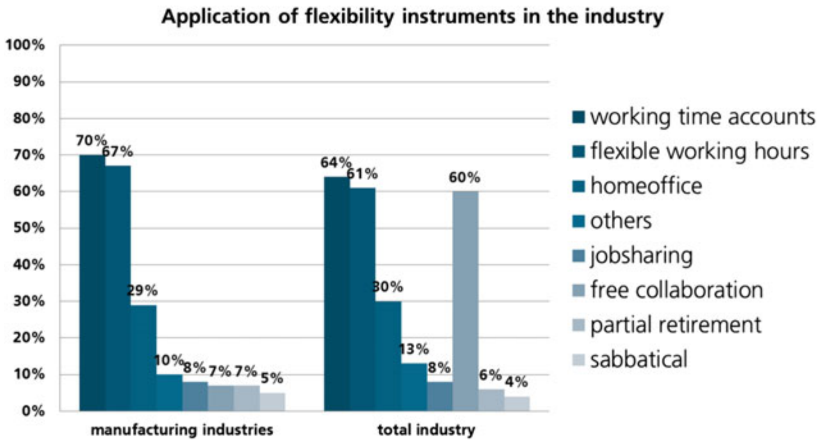


Fig. 4 Spread of personnel flexibility instruments in the manufacturing industry [11]

A very important flexibility instrument for the manufacturing is temporary work (even known as temporary employment, employee leasing or supply of temporary workers). In 2011, the temporary work reached to its employment peak with nearly 900,000 temporary workers in Germany [12]. The employment in temporary work has been continuously increasing with annual growth rates of about 10 % for years (see Fig. 5). In the last years in Germany temporary work was discussed differently and learned strong changes like new regulations on surcharges dependent on industry branches.

The main benefit of temporary work for companies is the high availability of workers. These can be applied at the company quickly and demand driven. On the other side the low employment security in temporary work is often a challenge to

Fig. 5 Development of temporary work in Germany [12]

the employees. The recent developments in the area of regulations on minimum wages and minimum employment periods may change this situation. A study conducted by the German Federal Statistical Office shows that almost 50 % of temporary workers operate in the manufacturing industry in Germany. Another quarter comes from manufacturing-related activities, such as logistics [13].

In order to continue to manage the increasingly volatile markets efficiently German manufacturing companies will use the large variety of existing personnel flexibility instruments stronger in the future. In the study “Manufacturing Work of the Future Industry 4.0” the Fraunhofer IAO indicates that more than 72 % of the 600 companies involved state that they extend their company regulations for flexible work assignments in future [4]. They especially highlight instruments for short-term adaption of work assignments in the field of manufacturing.

Nearly 2/3 of the companies believe that a faster personnel deployment provides a significant competitive advantage for them. Furthermore, they want to expand this advantage in the future.

5 Challenges in the Application of Personnel Flexibility Instruments

To ensure the competitiveness even in volatile markets continuously an increasingly more extensive application of personnel flexibility instruments will be necessary in manufacturing [14]. As depicted already there is a large number of personnel flexibility instruments, such as flexible working hours, part-time or temporary workers is available for German companies.

Despite a large number of personnel flexibility instruments in Germany exist, German companies do not systematically use these today [4, 15]. Companies often use a general flexibility buffer, like temporary work or contracts for certain services. The application of instruments is typically aligned to the short-term and reactive needs [4]. Currently the personnel flexibility is not configured on the basis of the individual volatility requirements of the companies. In most of the cases it doesn’t come to a proactive and forward-looking application of personnel flexibility instruments.

As an example of this is the great dissemination of short-time work can be seen in the economic crisis of 2008–2011 in Germany. In 2009, German companies paid more than 6 billion euros for the use of short-time work [16]. In contrast, they paid more than 44 billion euros for overtime to their employees in the previous year 2008 [17]. If the companies had built up the working time accounts intensively with the accrued overtime before the crisis, they could have largely relinquished to the intensive and expensive use of short-time work in 2009. Therefore their cost situation would have been improved significantly over the two years.

For a forward-looking application of basically suitable personnel flexibility instruments a dimensioning is required for the companies. This dimensioning must make sure that all necessary flexibility instruments are available for an efficient organisation of flexible work assignments. Only in doing so, the right personnel flexibility instrument can be organized appropriately at the right time and for the specific operational volatility situation.

6 Systematic Dimensioning of Personnel Flexibility with KapaStar

KapaStar is a new method that enables companies to make their flexible personnel deployment in the manufacturing more efficient. It makes different combinations of personnel flexibility instruments comparable and supports in selecting the correct specific instruments for a company.

For this KapaStar dimensions the necessary extent of use of the personnel flexibility instruments and evaluates the consequences of the use of each instrument (see Fig. 6). In this case different alternatives of combined flexibility instruments, so-called flexibility alternatives, compensate for one or more strategic sales scenarios. For any flexibility—alternative the individual extent of use and the intensity and duration of the instruments used is determined based on a simulation. The simulation is structured in a spreadsheet. So it can be easily adapted to new conditions of different companies. Further to the dimensioning KapaStar enables the company to evaluate each of the flexibility alternatives based on quantitative and qualitative indicators. This makes it possible to identify the companies matching, prioritized and dimensioned flexibility instruments.

After one or more market or sales scenarios have been defined, the basic flexibility alternatives are formed by the method. This works by using a flexibility

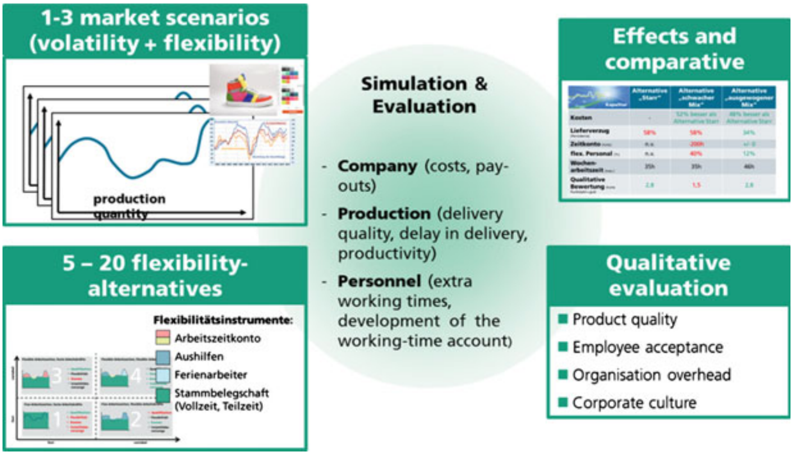


Fig. 6 Overview of the method for the strategic dimensioning of personnel flexibility

matrix, which represents different concepts of personnel flexibility. It includes numerical (e.g. temporary work), temporal (e.g. shift extension) and financial (e.g. short-time working) personnel flexibility instruments. Different instruments can be combined from the dimensions described, to create specific flexibility alternatives. So the method determines which instruments can be used and how intensively they can be used in a flexibility alternative.

The scenario-specific application of the instruments is furthermore determined by the simulation. In this step, the dimensioning of the personnel flexibility instruments takes place. Here he simulation determines the duration and intensity of the application of the different flexibility instruments in an combined application-scenario.

The structure of the dimensioning model, which is used in the simulation, can be understood as a control circuit. The control variable in this control circuit is the productive usable personnel capacity of all employees in a manufacturing area. The reference variable, which is compared to this value in capacity levelling, is the market-side capacity need. When both values differ, then the one provided by available personnel capacity is adjusted to the required value by the scenario needs. For this purpose the intensity or period of use, of the instruments of flexibility can be adjusted individually or in combination. If the applied flexibility instruments cannot cover the required capacity needs of the scenario, KapaStar transmits the remaining capacity in future periods. In practice, this is the effect of increasing delivery times.

In the simulation model, the instruments are always dimensioned for defined periods (e.g. day, week, month). Through a step-by-step approach, the instruments are dimensioned gradually for all planning periods. Simultaneously to the dimensioning, the evaluation of the instruments application is done by the simulation model. Figure 7 shows a part of the simulation results exemplarily.

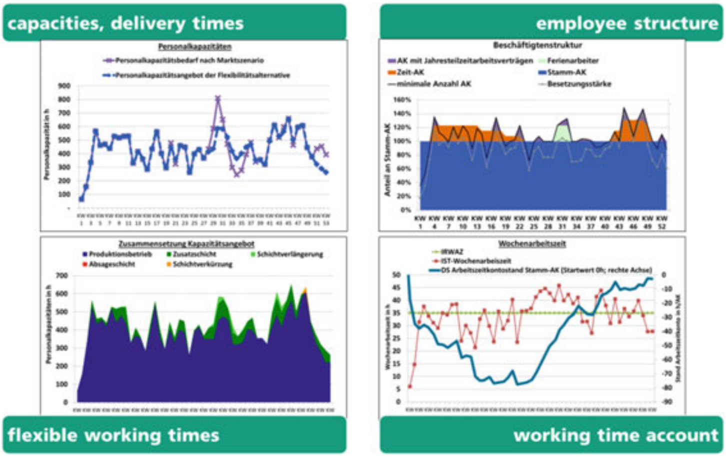


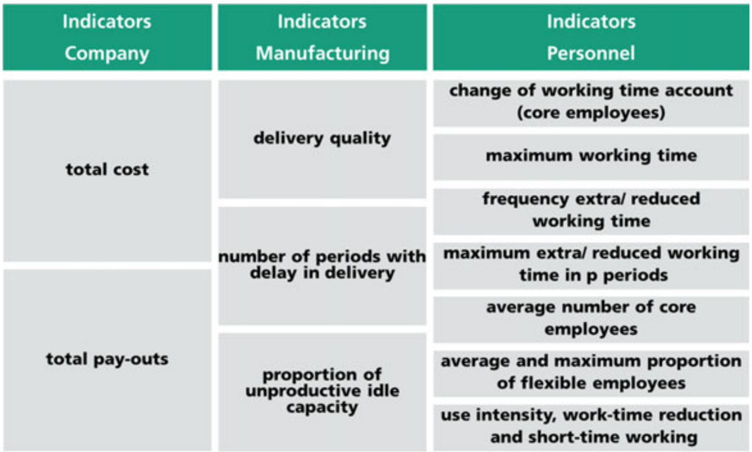
Fig. 7 Part of a result from the simulation with KapaStar (Example)

To evaluate the flexibility alternatives, the simulation model determines quantitative indicators for the perspectives of the company, for manufacturing and for the personnel. Company indicators show the total costs and pay-outs, which are generated by the application of the instruments. The determined indicators for manufacturing show the delivery quality, the delivery delay and the proportion of unproductive idle capacities. In the personnel area KapaStar calculated the proportion of flexible workers (e.g. temporary work and temporary employees), maximum and minimum working hours, and what the development of the working time accounts of the employees. An overview of the calculated indicators of KapaStar shows Fig. 8.

To allow non-quantifiable manufacturing and operation-specific criteria to be included in the evaluation of the personnel flexibility alternatives, a qualitative assessment takes place even after the performance-based one. For this purpose, a list of criteria was developed, from which appropriate criteria should be selected for the company in a first step. These criteria are weighted and toped up in a value-benefit analysis with performance values. In the benefit analysis the total amount of the performance shows the adjustment of the flexibility alternatives in respect of the selected qualitative criteria.

The quantitative and qualitative evaluation is performed for each flexibility alternative. If the dimensioning and rating result unsatisfactory or other combinations of personnel flexibility instruments should be examined, the steps can be run repeatedly from the definition of the alternatives to the evaluation step.

A total evaluation combines the quantitative and qualitative assessment. Through this it becomes transparent, what impact the various flexibility alternatives have for each market scenario. Figure 9 shows an example of a result for three different flexibility alternatives. These differ in the used personnel flexibility



Indicators Company	Indicators Manufacturing	Indicators Personnel
total cost	delivery quality	change of working time account (core employees)
		maximum working time
	number of periods with delay in delivery	frequency extra/ reduced working time
total pay-outs		maximum extra/ reduced working time in p periods
	proportion of unproductive idle capacity	average number of core employees
		average and maximum proportion of flexible employees
		use intensity, work-time reduction and short-time working

Fig. 8 Key figures for evaluating flexibility alternatives in KapaStar

KapaStar	Alternative „fixed “	Alternative „weak mix“	Alternative „balanced Mix“
cost	-	52% better than alternative fixed	48% better than alternative fixed
delay in delivery[periods/a]	58%	58%	34%
Working time account[h/Ak]	not available	-200h	+/- 0
flex. personnel[%]	not available	40%	12%
weekly working time(max.)	35h	35h	46h
qualitative evaluation (high score = good)	2,8	1,5	2,8

Fig. 9 Extract from the comparison of results of different flexibility alternatives

alternatives and their application intensity. In the “fix-alternative” fixed weekly working hours and a fixed number of employees limit the personnel flexibility. In the “mix alternatives” flexible weekly working hours and flexible forms of employment are applied in addition to the company’s core workers. In the “weak mix” the possible intensity of use of these flexibility instruments is less pronounced than in the “balanced mix” [e.g. max. working week of 35 h (weak) to 46 h (balanced)].

For the market scenario analysed, the simulation results show large differences in the cost impact. Through the flexible forms of employment the idle capacities are reduced intensively. This makes the company avoiding idle capacity costs here. However, the large proportion of flexible personnel resulting to limitations in the qualitative evaluation because with this personnel structure the company’s product quality can no longer be provided. By increasing the range in the temporal flexibility the delay in delivery could be reduced and the proportion of flexible personnel could be reduced to an acceptable level (12 %) for the company of this use case. This also leads to a good qualitative evaluation (2.8).

It shows that with the help of KapaStar for operational market scenarios suitable personnel flexibility instruments can be identified and dimensioned. No new flexibility instruments have to be created by the method, but known and established flexibility instruments are newly combined and dimensioned as required. The results of the dimensioning can be written into the consequence in the company’s work agreements. So they become operationally for manufacturing management. For the required operational negotiations with the works council the systematic procedure is transparent and based on real data.

The dimensioned personnel flexibility instruments by using KapaStar offers a greater flexibility to efficiently and effectively manage of the prevailing market volatility for the company. This improves the initial situation for them significantly and represents an important contribution to securing the future of businesses and jobs in the volatile market environment.

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Approach for the Development of an Adaptive Worker Assistance System Based on an Individualized Profile Data Model

Nadia Galaske and Reiner Anderl

Abstract For the purpose of manufacturing a high product variety in small production batches at low costs, cyber-physical production systems are being developed, in which cyber-physical systems consisting of sensors, actors, and communication interfaces are implemented in production systems. In order to facilitate a highly adaptive assembly process in cyber-physical production systems, an individualized worker assistance system is required. This has to take into account the different roles, qualifications, and personal characteristics of each individual worker. In this paper, a profile data model for the integration of individual worker information and the modeling of human aspects in cyber-physical production systems is developed. Based on the profile data model, an approach for the development of adaptive and individualized worker assistance systems is presented with the focus on shop-floor workers and foremen with operative planning tasks.

Keywords Industrie 4.0 · Cyber-physical production systems · Profile data model · Worker assistance system · Human factor integration

1 Introduction

Global markets, shorter product life cycles, and rapidly advancing technologies are challenges that manufacturing companies nowadays have to face. Especially in high-wage countries, the cost pressure for the production of individualized products is increasing. To encounter these challenges, the German Federal Government leads the initiative Industrie 4.0 [1] aiming to achieve a highly flexible production system and to ensure the competitiveness of manufacturing companies in high-wage

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countries. The main focus is to research and develop new production systems based on cyber-physical systems which enable the manufacturing of a high product variety in small production lot sizes and similar costs to those of mass production.

The flexibility of cyber-physical production systems (CPPS) leads to an ever-changing working environment, which in turn presents additional challenges for the human factors in this context. In order to facilitate highly adaptive production processes as well as to support workers in learning new work tasks in short time, an individualized worker assistance system is required. This has to take into account the different roles, qualifications, and personal characteristics of each individual worker. A worker assistance system can offer support for the worker especially during manual assembly processes by displaying required assembly steps and can also be used to teach new workers or to familiarize workers with new manufacturing processes. In regards of planning and coordination tasks, the worker assistance system can provide the required information, thus acting as a decision support. Due to the flexibility of cyber-physical production systems, the worker assistance system in this context must also be adaptive and able to adjust to the changing work situation, worker roles and qualifications.

For the development of such an adaptive worker assistance system, a systematic acquisition, storage, and exchange of worker's information regarding his/her qualifications, skills, and experiences is needed. This information must be quantified and formally represented in a computer-aided data model. In addition, information regarding the availability of assembly stations and the required assembly steps needs to be captured and linked with the information of each worker.

In this paper, a concept for the development of an adaptive worker assistance system based on the profile data model for the integration of individual worker information and the modeling of human aspects in cyber-physical production systems is developed. The profile data model enables the integration of individual worker profile data with other objects in cyber-physical production systems, such as single components, machines, and assembly stations, through communication interfaces. It allows a formalized computer-aided representation of worker information using the three modules authentication profile, competence profile, and ergonomic profile. Based on the individual qualification information stored in profile data model, each worker can be classified in different categories. This provides the basis for the decision of the content design and the level of detail of assembly instructions for the worker assistance system.

2 State of the Art

2.1 Industrie 4.0 and Cyber-Physical Production Systems

Cyber-physical systems are the foundation for future manufacturing systems. The basic principles of cyber-physical systems are "*cyberizing the physical*" and "*physicalizing the cyber*" [2]. This means that every object that exists physically has to be represented in the virtual world and every virtual object has to exist in the physical world. Cyber-physical systems are systems with embedded software that record data using sensors, influence physical processes using actors, evaluate and save data using globally connected services, possess human-machine interfaces, and interact with other systems using digital communication facilities [3].

The application of cyber-physical systems in the domain of production leads to cyber-physical production systems (CPPS). Manufacturing stations, storage systems, and production facilities, as well as manufactured components and products in CPPS are equipped with cyber-physical systems consisting of sensors, actors, and communication interfaces. Consequently, all production elements are digitally networked and can exchange information autonomously, trigger actions, and monitor each other during the production process [4]. In this context, each manufacturing object is the carrier of its individual information [5]. Through an information exchange using the equipped communication interfaces, these manufacturing objects can make autonomous decisions to steer the production process by comparing the requirements of manufacturing steps and manufacturing stations and negotiating the ideal allocation of production resources [6].

2.2 Integration of Human Factors in Cyber-Physical Production Process

Although cyber-physical production systems establish digitalization and automation to optimize the processes and quality in manufacturing, this does not equal a full automation [7]. As the main focus of CPPS is to enable the manufacturing of a high product variety in small lot sizes, a combination of automated and manual manufacturing operations is needed to achieve this flexibility. This means that human factors will still be an integral part of the production process in CPPS, for example during manual assembly operations [8].

Nevertheless, CPPS will lead to a considerable change for workers in the production. The complexity of job tasks is increasing considerably, immediate reaction and ad-hoc decisions are becoming more important, and a high degree of autonomy and flexibility of the workers are required. The role of workers in CPPS will shift from merely a machine operator to a planner and coordinator of the production process [9]. Consequently, the demands for the shop-floor workers are changing. The workers need to have competencies in the application of new digital technologies. They are also required to be trained accordingly to be able to deal with the complex processes in CPPS [10]. CPPS also offer a paradigm shift that human resources should not adapt to machines but instead the other way around—machines should adapt to the needs, speed, and capabilities of human resources [4].

Manual manufacturing and assembly operations are heavily influenced by individual expertise and qualification of the worker. Therefore, in this paper a great emphasis is placed in cyber-physical assembly process as a subdomain of the cyber-physical production system. In order to increase productivity, the production control in CPPS needs to be able to plan the production capacity and allocate the human resources properly so that individual workers receive individual job tasks that are specifically suitable [8]. However, in most cases the qualification and experience level of shop-floor workers is not mapped within the IT system. In this case, production foremen have to manually allocate the workers to the manufacturing stations or decide whether substitute resources are required [11]. This process can be supported by assistance systems to increase efficiency.

2.3 Information-Based Assistance Systems for Industrie 4.0

Due to the flexibility of cyber-physical production systems as well as the changing role and working environment, there is the need for intelligent assistance systems to support workers during their activities in CPPS. The application of information technology within the production will also continue to rise. New digital technologies, mobile devices, and connected services offer new possibilities for the development of such an intelligent assistance system for the workers in Industrie 4.0.

Industrial assistance systems are software and hardware systems that provide support for the workers in learning new processes or systems and accompany them in carrying out the tasks at the later stage. The main tasks of such assistance systems are to aggregate available information, filter them according to defined criteria, and provide the information to the user as required in a user-friendly way [12]. These systems also have to enable a lifelong-learning process and a fast reaction to the changing working environment due to order situations.

In manual assembly processes in CPPS, in which a significant ratio of the operations are performed by the workers, adaptive assistance systems are required to guide the worker through the assembly process and manage the complexity and heterogeneity of small lot sizes. These systems can also be used to alert workers, thus reducing errors and mistakes [7, 13].

Information-based assistance systems can generally be divided in five types: assistance systems for raising awareness, for guiding the workers, for monitoring the processes, for ensuring quality standards, and for documentation purposes [13]. The spectrum of possible application of assistance systems in the production is very large. The assistance systems range from simple software applications that provide necessary context-based information for the user to applications that consist of interaction between several highly complex technical systems, for example using simulation or virtual reality [12]. Current researches for the development of intelligent information assistance systems and automated activity tracking for assembly processes for shop-floor workers can be found in [13–15]. In this context, a gamification approach is seen as promising to increase the acceptance of the system [16].

As the amount of assistance systems in the production will increase remarkably, workers are required to deal with the new systems and learn how to use them. New training concepts are required for dealing with these systems as to not overstrain the workers.

3 Profile Data Model

For the integration of human factors in CPPS and the development of worker assistance systems, an excellent information basis is needed. A worker assistance system must be able to access information about all manufacturing participants, such as workers, product components, and assembly stations.

One of the main concepts of Industrie 4.0 is the integration of product information along the entire product life cycle using individual objects as information carrier. For product components the component data model is developed for the specification of the semantic representation of individual component and the integration of product, process, resource, and component data, as well as the corresponding behavior [17]. However, the digital representation of individual worker profiles is currently not yet sufficiently advanced. For this purpose, the profile data model is developed as the foundation for the development of worker assistance systems. The aim is to enable a systematic acquisition, storage, exchange, and representation of individual worker information.

3.1 Definition of Profile Data Model

The first approach for the development of the profile data model was presented in previous work [18]. The profile data model is part of the information models developed specifically for the integration of worker-related individual information in cyber physical production systems. It consists of a core model and several partial models. The core model is schema-based and serves as a central integration platform, in which the fundamental data structure, logic, and interfaces are defined. The partial models, in which the factual information is stored, complement the core model. The core model defines the access right to the information of the partial models and provides the interfaces to other systems, such as CPPS, worker assistance systems, or ergonomic assessment tools. Through the instantiation, the individual profile data model with the three partial models enables a virtual representation of each individual worker.

Figure 1 shows the integration of the profile data model and the assistance systems as additional packages with interfaces to CPPS. The model for CPPS can be found in detailed form in [6]. The assistance systems in this context are divided into four target groups: assistance systems for shop-floor workers, foremen, production planners, and technicians for repair and maintenance.

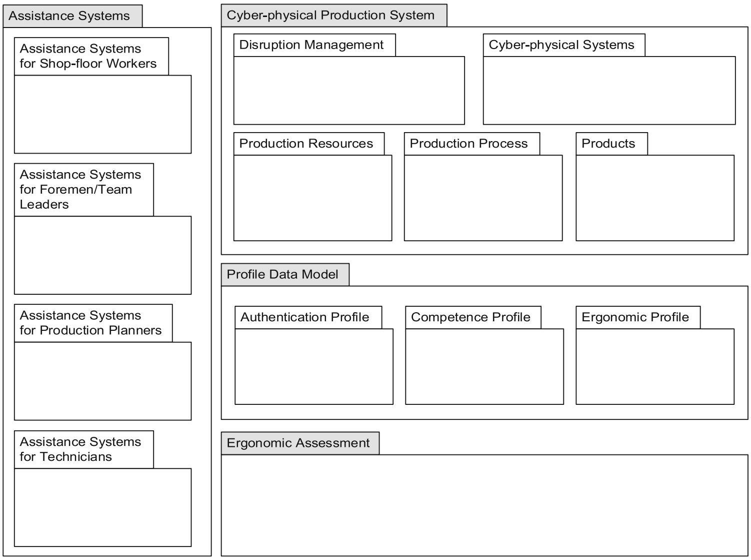


Fig. 1 Integration of profile data model and assistance systems in cyber-physical production system as UML package diagram

3.2 *Profile Specification*

The profile data model is divided into one superclass as the core element and three partial models: authentication profile, competence profile, and ergonomic profile. The structure of the profile data model enables the extension of additional partial models if required. Relevant information is stored and managed within the corresponding partial models. This information has to be collected using consistent methodological support and formally represented for each partial model. By instantiating the information recorded in the profile data model, individual profile model can be assigned to each individual worker and used for example in the process and resource planning in cyber-physical production systems or for the configuration of the worker assistance system. The information can be exchanged directly between the systems as well as through a central server.

Figure 2 shows the detailed structure of the profile data model and its specification as UML class diagram. The superclass *workerProfile* as the core element contains the attribute *workerID*, which serves as identification for each profile instance. This means that every individual worker in the system can be identified by his worker ID. The communication between the systems in CPPS and the profile data model take place via the *workerProfile* class. Using the worker ID, the assistance systems should recognize the worker automatically and retrieve his individual profile information according to the defined access rights of the system. The three partial models inherit the attribute from the core element. In this way, the

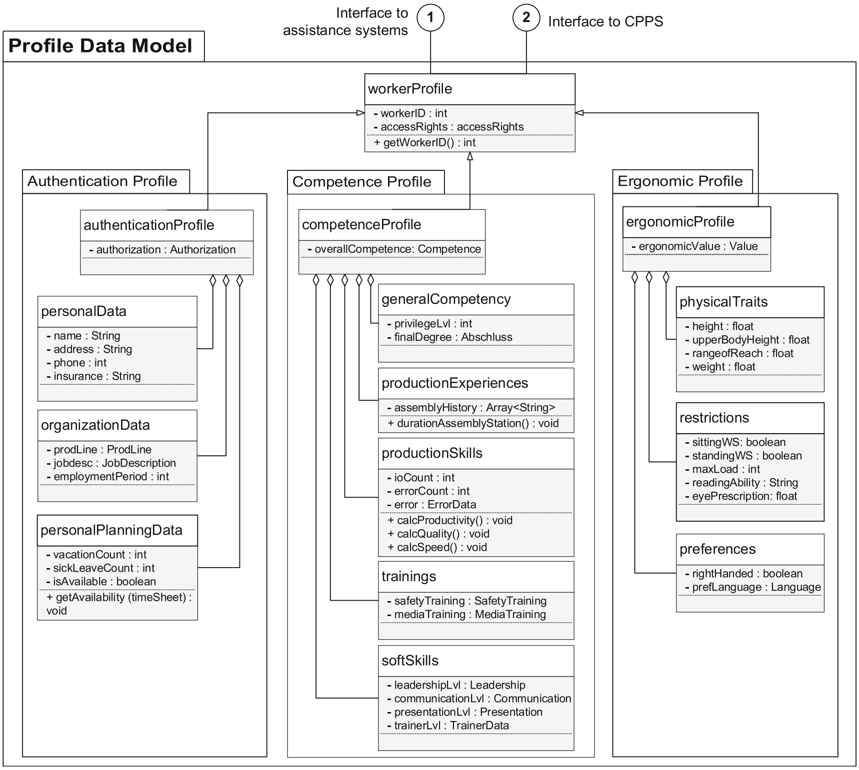


Fig. 2 Metamodeling of the specifications of the profile data model in UML class diagram

concept supports protecting data privacy because each profile specification can be stored in different databases and the access rights to these data can be regulated.

Authentication Profile. The authentication profile consists of personal data, organizational data, and personal planning data. The personal data includes the name, address, phone number, and insurance number of the worker. The organization data consists of the job description and current production line of the worker and how long the worker has been employed in the company. The personal planning data includes the information required for the workforce scheduling system, for example whether the worker is present or absent. This information can be obtained either via shift planning system or automatically when the worker logs on to the assistance system.

Competence Profile. The competence profile is the main focus of the profile data model. In this partial model, information regarding the competence, qualification, expertise, and experience of each individual worker is stored. This includes both hard skills and soft skills as well as additional trainings and courses. The production skills of the worker can be detailed for each production line or product variant and includes the count and type of errors that the worker has made. This information can be used to assess the worker regarding his productivity, quality, and speed. As this data is highly sensitive, the access rights should be restricted only to the required information and the worker should be involved in defining which persons and which systems can have access to this data.

Ergonomic Profile. The ergonomic profile contains information about physical traits, capacity and restrictions, as well as preferences of the worker. The physical traits information, such as height, weight, and range of reach of the worker, can be used to configure the workplace of the worker. The restriction data contains information that is important for the allocation of job tasks to the worker, for example the maximum load that the worker can carry. The preference information includes information that can be used to configure the user interface of the assistance system, such as language or font size.

3.3 Application of Profile Data Model

The profile data model enables the integration of human factors with other systems in the cyber-physical production systems. The application of profile data model allows a context-specific use and evaluation of individual worker information. For example, the ergonomic profile information can be used as input variable for the digital human models (DHM). This leads to an individualized digital human model that can be used in a digital simulation of an assembly process. As a consequence, ergonomic assessment or load analysis can be automatically performed for each worker.

The profile data model can also be used for a dynamic worker allocation that considers individual qualification and assign each worker to a manufacturing station according to his individual skills and abilities [19]. The worker allocation can also be done using the ergonomic profile information and the requirement for physical strength for each job task. By matching the required physical strength and the limit of each individual worker, the worker, whom the load exceed his exposure limit or who does not possess the required ability, can be removed from the worker selection. This ensures an ergonomic working environment [8]. Another use for the profile data model is for the development of adaptive worker assistance systems, which will be explained in the next chapter.

4 Approach for Adaptive Worker Assistance Systems

In this paper, concepts for the development adaptive worker assistance systems for CPPS based on individual profile data model are presented. The aim is to support different target groups in the production process using adaptive assistance systems and intelligent teaching methods. The main focus of such adaptive worker assistance systems is to provide users with relevant information in suitable form. Beside a user-friendly human-system-interaction and an optimal visual presentation of information, the worker assistance system has to take into account the individual cognitive processing skills and different learning abilities of the user. Furthermore, technical specifications and usability factors, such as font size and screen resolution, have a great influence for the acceptance of the assistance system. In the following sections, concepts for the development of assistance systems for shop-floor workers on the one hand and for foremen on the other hand are presented.

4.1 Assistance System for Shop-Floor Workers

The constantly changing working environment due to the high product variety results in increasing needs for support for shop-floor workers. The worker guidance system presents the central element of assistance systems for shop-floor workers in this context. Figure 3 shows the metamodeling of a worker guidance system. The main function is to guide workers during manual assembly operations and show (step-by-step) assembly instructions if required. In this way, workers can overcome difficulties in dealing with complex assembly processes and learn the process for new product variants. At the same time, the system can prevent error and improve the quality performance of standard process steps.

Using the interface to profile data model, the system is able to recognize the profile of the currently logged-in worker and obtain the required information from his individual profile data. The general settings, content design, and level of details of the provided assembly instructions are adapted based on the individual profile data of the current worker. The information source for the assembly instructions of the worker guidance system can be for example instructional videos, 3D models, or

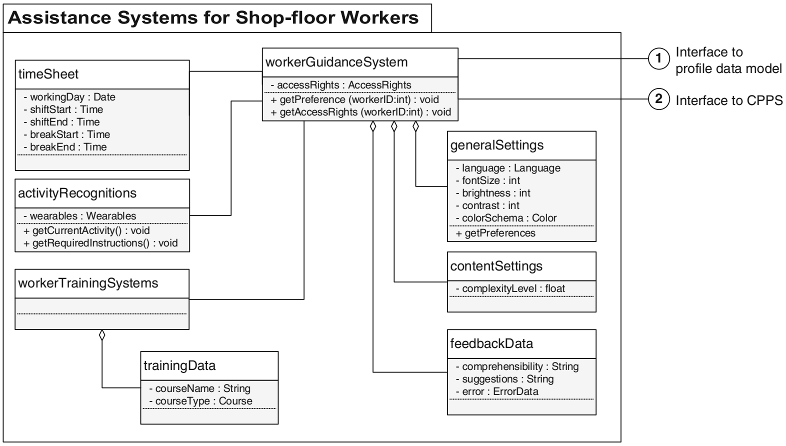


Fig. 3 Metamodeling of assistance systems for shop-floor workers as UML class diagram

technical documentation. Through the interface to CPPS, the system can also retrieve the required assembly steps from the component data model. The individual assembly steps stored on each component can also be further detailed in assembly process descriptions for the worker guidance system.

In order to work properly, the worker guidance systems has to be connected to other supporting systems, such as training systems or activity recognition systems. For example, if the worker does not have previous experience with the product variant, the worker guidance system can retrieve information from the training database to teach the worker the required assembly steps. RFID readers can be implemented to identify the assembly component and read the stored assembly steps. The progress of the assembly process can be tracked using sensors. The worker guidance system can also communicate with a pick-by-light system, which then indicates which components and materials the worker needs to use. This can also help to identify whether the worker has completed the current assembly step so the next assembly step can be displayed.

As the worker also needs to be able to influence the content information and level of detail of the assembly instructions provided by the worker guidance system according to his qualification and experience, the attribute *privilegeLvl* is included in the competence profile. This defines the privileges of the worker, whether he has the access right to reduce the level of detail of the instructions or even to skip certain assembly steps. A more experienced worker who already worked in the assembly line for a certain period of time usually already knows the assembly steps and might feel obstructed by the worker guidance system. In this case, the worker only needs to be advised in steps where errors frequently occur. This attribute can be determined using the assembly activity history and the skills of the worker (Table 1). This has to be calculated for each production line and product variant.

Based on the parameters and the weighting factors defined in Table 1, the attribute *privilegeLvl* can be derived. Table 2 shows the category for access rights

Table 1 Parameters for the calculation of the attribute *privilegeLvl*

Attributes	Parameters	Weighting factor parameters	Weighting factors attributes
Production experience	Period of employment	0.2	0.4
	Previous assignment in assembly line	0.4	
	Previous assignment in product variant	0.4	
Production skills	Speed	0.2	0.4
	Error count	0.3	
	Error type	0.5	
Ergonomic capability	Age	0.1	0.2
	Reading speed	0.4	
	Digital media knowledge	0.5	

Table 2 Derived category for access rights and the impact on worker assistance system

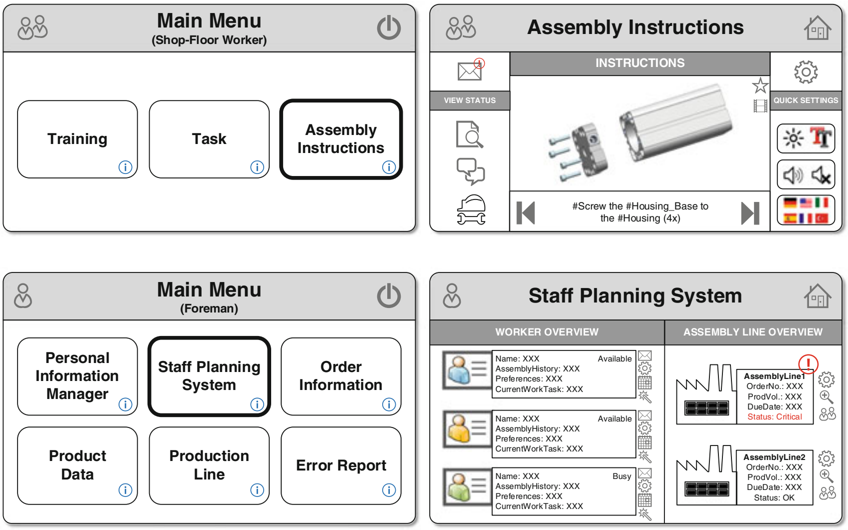
Access rights level	Value	Definition
0	$0 \leq privilegeLvl < 1$	No skipping of instruction allowed
1	$1 \leq privilegeLvl < 2$	Level of detail can be reduced
2	$2 \leq privilegeLvl < 3$	Individual steps can be skipped
3	$privilegeLvl \geq 3$	Worker can freely decide

based on the attribute privilege level and the influence on the worker assistance system.

4.2 Assistance System for Foremen/Team Leaders

The profile data model can also be applied and used for the development of assistance systems for foremen and team leader. Due to their additional tasks and responsibilities, the assistance system in this context has to offer support, for example for operative planning tasks, and the required information must be provided in the assistance system. Figure 4 shows the difference between assistance systems for shop-floor workers and foremen.

As the shop-floor workers are primarily supported by the system during the execution of assembly operations, the visualization of assembly instructions should be the main focus. The shop-floor workers only need information regarding his



#Screw the #Housing_Base to the #Housing (4x)

Name: XXX Available
AssemblyHistory: XXX
Preferences: XXX
CurrentWorkTask: XXX

Name: XXX Available
AssemblyHistory: XXX
Preferences: XXX
CurrentWorkTask: XXX

Name: XXX Busy
AssemblyHistory: XXX
Preferences: XXX
CurrentWorkTask: XXX

AssemblyLine1
OrderNo.: XXX
ProdVol.: XXX
DueDate: XXX
Status: Critical

AssemblyLine2
OrderNo.: XXX
ProdVol.: XXX
DueDate: XXX
Status: OK

Fig. 4 User interfaces and system functions for shop-floor workers (*top*) and foremen (*below*) current activity or assembly station. In order to not distract the worker from his main task, the information content should be restricted and symbols should be used instead of text. Furthermore, the assistance system should offers shortcuts for essential functions, such as settings, status, or message. On the contrary, the foremen need additional support for the planning and organizational activities. The main menu of the assistance system for the foremen should therefore offer more options. For supporting planning tasks, the foreman will need aggregated information from several assembly stations and the current status of the production of several assembly lines. The information content in this case should be more detailed. Another example of assistance system developed for foremen can also be found in [20].

5 Conclusion and Future Work

In this paper, the profile data model for the integration of individual worker information and the modeling of human aspects in CPPS is presented. Based on the profile data model, an approach for the development of adaptive and individualized worker assistance systems for shop-floor workers and foremen with operative planning tasks is introduced. The developed model in this paper provides a solution for the provision and exchange of individual profile information in the future production systems. Using the developed model, adaptive teaching concepts can be developed that satisfy the needs of each individual worker.

From the legal perspective, data protection issues need to be considered. They are omitted in this paper due to the conceptual nature of the proposed design. Data encryption and access rights regulation in this context are subject of current research. In addition to the technical and legal restrictions, particular user-factors, such as age, media consumption habits, and prior experience with assistance systems influence the acceptance of worker assistance systems. This should be gathered using questionnaires and stored in the profile data model in order to improve the continuous development of worker assistance systems. An example of such a questionnaire is shown in Fig. 5.

I am very experienced in dealing with assistance systems	Strongly agree					Strongly disagree
	1	2	3	4	5	6
I am familiar with the use of related digital technologies, such as tablets or smartphones	Strongly agree					Strongly disagree
	1	2	3	4	5	6
I have a good overview at anytime which of my personal information is stored and who can access them	Strongly agree					Strongly disagree
	1	2	3	4	5	6

Fig. 5 Excerpt of the feedback questionnaire

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A Competence Based Approach to Support the Working Force Within Assembly Lines

Christiane Dollinger and Gunther Reinhart

Abstract An increasing diversification and customization of products, lead to a broad product mix within assembly lines. These mixed-model assembly lines challenge the production planning, because of a varying capacity utilization depending on the specific mixture of variants. To prevent quality defects and productivity losses, companies implement different strategies to support their workforce—such as the integration of auxiliary workers. The paper presents an approach, which increases the coordination efficiency of auxiliary workers by using competence profiles. The changing production environment also raises the cognitive load of workers. Therefore companies need to think of new strategies to support them while learning new operations or product variants. The described approach also introduces a concept that allows qualifying people on the job by using a specific type of auxiliary worker. The question whether this concept has a positive impact on learning curves, has been examined in an empirical research study.

Keywords Assembly system · Competency · Qualification

1 Introduction and Need for Action

Global competition as well as the growing importance of customer demands lead to a higher diversification of products [1]. To assemble these products, the assembly lines need to be sufficiently flexible and adaptable to handle an extensive product mix [2]. Especially balanced mixed-model assembly lines raise problems for the production planning. These lines are characterized by a one-piece-flow of different variants running through the same assembly process [3]. Due to the variants the number of assembly operations as well as the needed time at one assembly station

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can vary. Depending on the available capacity, the worker will exceed the cycle time of the process at worst. This has a negative impact on the productivity of the entire assembly system. To counteract this problem, some companies use auxiliary workers, so-called jumpers [4] or floaters [5]. These kind of workers are not directly integrated in the assembly process, they just step in on demand, for example when a capacity peak is reached at a workstation or when a worker needs a short pause. Two types of jumpers can be distinguished. In the following, a jumper that assists another worker is designated as "assistance jumper" and a jumper that replaces someone is hereafter defined as "replacement jumper". Because of higher labor costs for jumpers and a higher fluctuation in their assignments, existing approaches try to minimize their number and to maximize their utilization [6]. This optimization will be achieved by planning approaches which are based on various line-balancing-models that mostly focus on process parameters (e.g. cycle time, variants and quantity) [7]. Individual skills of jumpers as well as the requirements of workstations are neglected. Furthermore, it is assumed that all jumpers have the same ability to perform all operations in line. Under real conditions this presumption is not applicable, though. The potential of a competence based allocation of jumpers is not taken into account yet. Although it would help avoiding inefficient allocations, caused by missing competences as well as the integration of jumpers with different competence profiles in line. Consequentially, a competence based approach increases both the efficiency in the utilization of jumpers and the quality of work. Chapter 2 describes an initial approach that enables a competence based matching of jumpers and workstations, to support the working force within assembly lines.

The changing environment, as described before in this chapter, also has an impact on the workload of the assembly workers. A higher product variety as well as shorter life cycles of products and technologies raise the cognitive load [8]. Workers have to learn various operations within shorter periods and with less practice possibilities, because of the decreasing frequency of similar operations [9]. This has an enormous impact on learning curves, which are based on the principle that jobs are performed more efficiently as greater experience is gained [10]. Experience can be measured by the fact, that the more time a task has been performed, the less time is required on each subsequent iteration [11]. Besides the time aspect, costs or defective workpieces can also be used as experience indicators [12]. Relating to a higher product variety as well as customer individualized products, the assembly of similar products in a subsequent iteration will no longer be possible. So, the experience provoked through assembling the same products, on which the effect of learning curves is based on, can no be achieved by working on the job anymore. In order to compensate this deficit, companies need to help their workers to gain the knowledge and experience they need, by providing fundamental pre-trainings and assistance systems in the assembly line [13]. Against the background of the fast progression and changing product mix, the content of trainings and assistance systems becomes rapidly obsolete. Therefore more frequent trainings are needed. Both, the planning and the execution of trainings are very cost- and time-consuming [14]. In this context the question arises whether conventional trainings are still efficient and economical enough to qualify people. As an alternative to trainings, this paper presents a new strategy of qualification. The idea is to use jumpers as coaches on the job, which can be requested from the worker on demand. This concept follows the idea of the HANCHO Principle, originated in the LEAN Production System [15].

Whether the integration of jumpers is a valid method for qualification, has been examined by an empirical research study. The setup and results of the study are outlined in Chap. 3. Chapter 2 demonstrates a competence based approach to support workers within assembly lines as well as the idea of integrating jumpers as coaches. In the following, this type of jumper is defined as "coach-jumper".

2 A Competence Based Approach

Existing approaches of coordinating jumpers neglect competences (Chap. 1), which can result in incorrect matches (mismatches) of jumpers and stations. The presented approach enables a more efficient utilization of jumpers, because of considering competences. There are two reasons for an efficiency increase. First, mismatches of jumpers and workstations can be avoided by a transparent knowledge of existing skills and requirements, which ensures the working ability at the station. Second, tracking the frequency and types of requested jumpers depending on the product mix, the worker and workstation, helps to predeterminate an efficient constellation of the jumper group. The jumper group consists of three types of jumpers (assistance jumper, replacement jumper and coach jumper) in varying numbers. Due to high labor costs, the aim is to minimize the number of jumpers. Analyzing the tracked data enables the production planning to forecast a more precise demand on jumpers, made on the basis of past experience. This paper constitutes the preparatory work required to develop an efficient constellation of jumper groups.

The coordination of jumpers and workstations is based on competences. This means, all required competences caused by the assembly operations in line and by the type of jumper that is assigned to the workstation, need to be recorded in competence profiles. In case a worker initiates a jumper request from his station, the required competences will be compared to the existing skills of available jumpers within the group. The most suitable jumper (because of competences and availability) will be selected and send to the workstation. Figure 1 illustrates this process exemplarily.

At workstation 1, the worker struggles with his given task and needs support from a jumper. In this example a smart watch is provided, with which the worker can initiate the request to the jumper group. To enhance the efficiency the smart watch includes an application, which provides him three options of jumper requests—replacement jumper, assistance jumper or coach jumper. The display of the smart watch is shown in Fig. 2 exemplarily. Furthermore the watch communicates with the product and workstation, why the transmitted order also contents the information of the workstation's profile (Fig. 1). The content of this profile may be seen as the

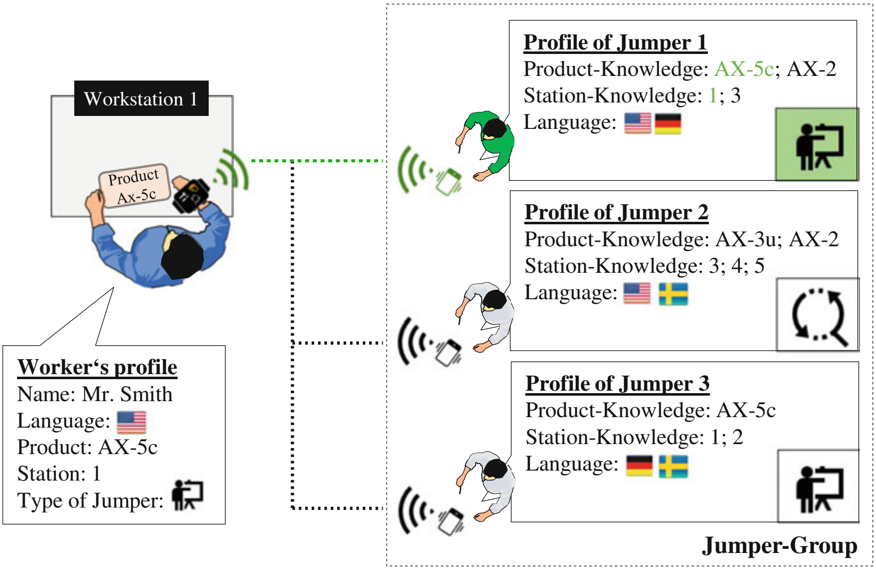

Fig. 1 Process of requesting a jumper

Fig. 2 Jumper icons on the smart watch

requirements of the workstation including data of the worker (e.g. name, language), which will be compared to the profiles of the jumper group. In this example the jumper group consists of two coach-jumpers and one replacement-jumper. The worker on station 1 requests a coach-jumper, which can be recognized by the small icon in the workstation's profile. Due to the selected type of jumper and existing profile, the competence match is at its highest with the profile of Jumper 1 (product, language, workstation and jumper type suit). That is why the outstanding request is sent to the smart phone of Jumper 1.

For the establishment of such a coordination systematic, a method that enables the modeling of profiles is required. There are two different types of profiles, which

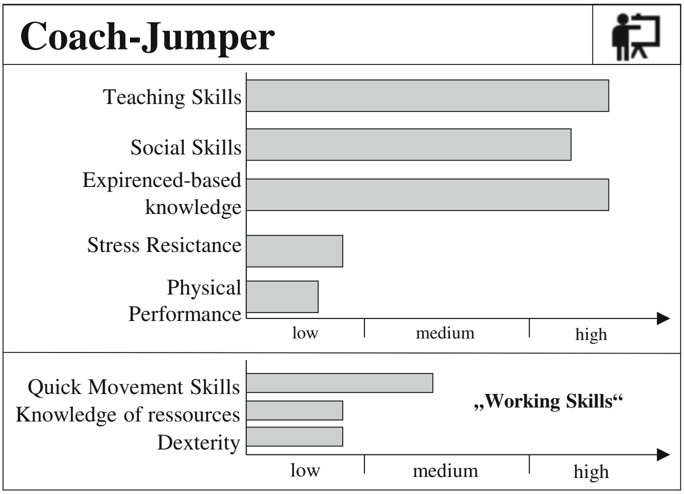

Fig. 3 Profile of a Coach-Jumper

have to be designed: *Profiles of the jumpers* and *profiles of the workstations*. Each of the three jumper types has its own profile, which is divided into two sections, first, the required competences for the type of jumper and second, the "working skills". The profiles of the workstations also consist of two parts. The first part includes personal information of the worker and the second part the category "working skills", resulting from the assembly task. Figure 3 shows the structure of a *coach-jumper*'*s profile* exemplarily.

Generally, the y-axis contents relevant competences and the x-axis shows the level of these competences. The level can reach three different grades: low, medium and high. "High" signifies, that an expert grade for this competence is necessary and "Low" implicates an amateur grade. The competences for a certain type of jumper can be defined universally, but the "working-skills" depend on the respective assembly operations in line. This part presents the knowledge of assembly operations, needed by a worker for a specific workstation. Depending on the manufacturing system and its parameters, the operations' level of difficulty can vary and thus the required skills of the jumpers, too. These "working-skills" are also part of the workstations' profile, which is explained in the following.

The *workstations*' *profiles* have to be created for each workstation. Their design needs to be individually adaptable to the constraints of the respective production system. The impact of the circumstances on the working skills varies, depending on process-, product- and environment-related parameters (e.g. number of operations, cycle time). There are several existing and practiced methods which had been developed for the designing of such profiles. One of the most known are for example the GENFER Scheme [16] or the REFA [17] job evaluation. These profiles are described by specified requirements on the worker's qualifications. Thereby the description level is very universal and does not allow a direct relation to relevant

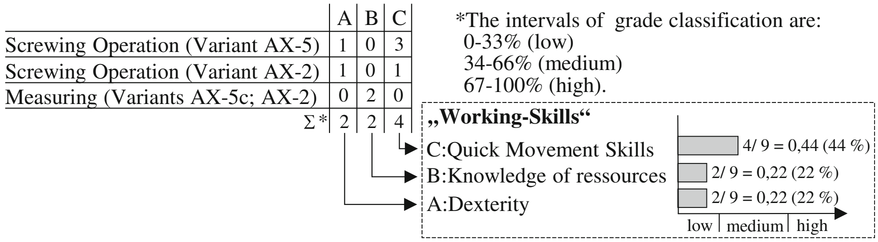

Fig. 4 Profile of a workstation

competences. This is due to their original use case, which refers to the determination of wages and not to the assignment of workers to stations [18]. For the here presented approach, the existing methods are not sufficient enough. Therefore a new procedure of modeling job profiles has to be developed. The aim is to generate a standardized model, which allows to generate competence based profiles, adjustable to individual circumstances of a production system. Figure 4 illustrates an example, how competences can be derived from the operations on a workstation.

The first column contents all assembly tasks, operated on one station, and the first line of the matrix states assembly relevant competences. The numbers within the matrix show the weight factors of the relations between the assembly task and a competence. The weight factor has a range from 0 (= no impact) to 3 (= high impact) and therefore considers the impact of different product, process and environment parameters. To extract the grade of a certain competence, all weight factors in a column have to be added up and translated into the three grades of competences (low, medium and high) (Fig. 4). In this scenario, for example the competence “A: Dexterity” gets a total weight factor of 2. This factor has to be divided by the maximal possible value of the weight factors per column, in order to get a percentage for the grade classification (2/9 = 0.22). The result of this ratio is 22 %, which refers to the “low” grade classification.

3 A Study on Learning Processes Caused Through the Integration of Coach Jumpers into Assembly Lines

In Chap. 1 the question was raised, whether the integration of jumpers is a valid method for qualifying workers. The presented research study examines the influence of jumpers as coaches on learning processes. Thereby the following hypothesis shall be validated: *The integration of coach jumpers into assembly lines has an adequate impact on learning curves compared to pre-training sessions.*

The hypothesis becomes valid, whenever it is validated that efficient learning curves can be reached by using coach jumpers. Efficient means that the curves are comparable to those generated by trainings. Therefore some fundamental questions arise: Is it possible to teach unexperienced or new workers through the usage of coach jumpers? Do they learn quickly enough, to start adding value directly without being pre-trained? How long does it take to keep a given target time? In order to answer these questions, an empirical research study has been carried out. The Institute for Machine Tools and Industrial Management (*iwb*) has built up a so called Future Factory Lab (FFL) to conduct empirical studies in a laboratory environment. The FFL is a semi-realistic assembly environment that is set up with standard assembly tables which are broadly used in real assembly lines. All elements within the Lab are mobile and have a modular structure so that highly flexible and dynamic compositions are possible. The purpose of this Lab is to test and confirm theoretical hypotheses for research projects.

To validate the hypothesis of this study, the following key questions need to be examined:

- How long does the assembly of one product take, after having a pre-training?
- How many products need to be assembled until a given target time is reached, under the conditions of pre-training?
- How long does the assembly of one product take, under the conditions of requesting a coach jumper?
- How many products need to be assembled until a given target time is reached, under the conditions of requesting a coach jumper?
- How often a coach jumper will be called, while assembling the products?

3.1 Setup and Assembly Scenario

In order to examine the above key questions, 40 test subjects, split into two groups, conduct the defined assembly tasks. 20 of them, were pre-trained and the other 20 could request coach jumpers instead. The group of probands consists of students of the Technical University of Munich (Mechanical Engineering Department). So it can be assumed that every participant has a fundamental knowledge of assembly systems and operations, but still different physical and cognitive skills, which secures inhomogeneity on the study results. In order to ensure, that all probands are not experienced at the given task, they had to fill in a self-evaluation of their skill level (range between 1 and 10). "1" signifies non pre-experience and "10" a long-term experience as professional worker. The average of the testing group stated a 2.2, which confirms low experience. The assembled product (a dummy gear box) and task (assembling parts of the gear box) were the same for both groups. The target time for the given assembly operations was 40 s. The learning curve of the pre-training is used as benchmark, in order to confirm, that the learning curves, caused by the coach jumper approach, are at least similar to their effects. While the probands were assembling, a supervisor observed them and stopped the time for each fully assembled product. Following, the procedure of the research study is described, separated into two scenarios:

- *Scenario* 1: Pre-Training
  20 test subjects got a fundamental pre-training, where the coach explained the assembly process by showing them the assembly operation step-by-step. After having the instructions, the probands got the chance to exercise the assembly steps by themselves for a few minutes. The pre-training session took 15 min in total for all probands. Following this, the probands assembled six gear boxes at the prepared workstation, one-by-one, and the supervisor took notes of their consumed time per gear box.
- *Scenario* 2: Coach-Jumpers
  The procedure is similar to scenario 1, except the beginning. Here the other 20 test subjects started directly with the assembly of six gear boxes at the prepared workstation. Every proband was allowed to request a coach jumper via a provided smart watch. The coach jumper was the same person as the coach in scenario 1. While the jumper was giving advice to the test person, the supervisor continued timing. He also noted the amount of jumper requests per gear box.

3.2 Results of the Study and Interpretation

Figure 5 shows two graphs about the course of the average target times consumed in each scenario. The third line in the figure illustrates a constant of 40 s, which is the benchmark time for both scenarios. The values of the consumed target times display the average time of all 20 probands noted for one gear box. For example, in scenario 1, the average time to assemble the first gear box was 42.9 s, with a maximum of 45.2 s and minimum of 41 s.

Analyzing the learning curve of scenario 1, it can be stated, that the pre-training helped the probands gaining experience. There is just a slight gap between the reached target time (42.9 s) and the cycle time (40 s). Nevertheless it lasted five gear boxes until the cycle time was met. Comparing the beginning of the other learning curve (scenario 2), a very significant increase of the target time can be revealed. The average target time for the first gear box in scenario 2 was 80.1 s. This is a plus of 37.3 s compared to the curve of scenario 1. But after only assembling three gear boxes, the learning curves of both scenarios started merging.

Figure 6 lines out the frequency of jumper requests, which helps to interpret the learning curve of scenario 2. Both curves have a similar shape, which implies a coherence (Fig. 6). Figure 6 shows, that all 20 probands requested a jumper for instructions, while assembling the first gear box. While the need of advice decreases with the amount of assembled gear boxes, the target times also approximate to the cycle time. Apparently the time increase is due to the presence of a coach jumper, which interrupts the regular work flow of the worker. The worker needs to pay attention to the instruction of the jumper, which keeps him off working. But after a while, the utilization of coach jumpers reaches a similar learning curve as pre-trainings (Fig. 5). The learning process caused by coach jumpers is even more

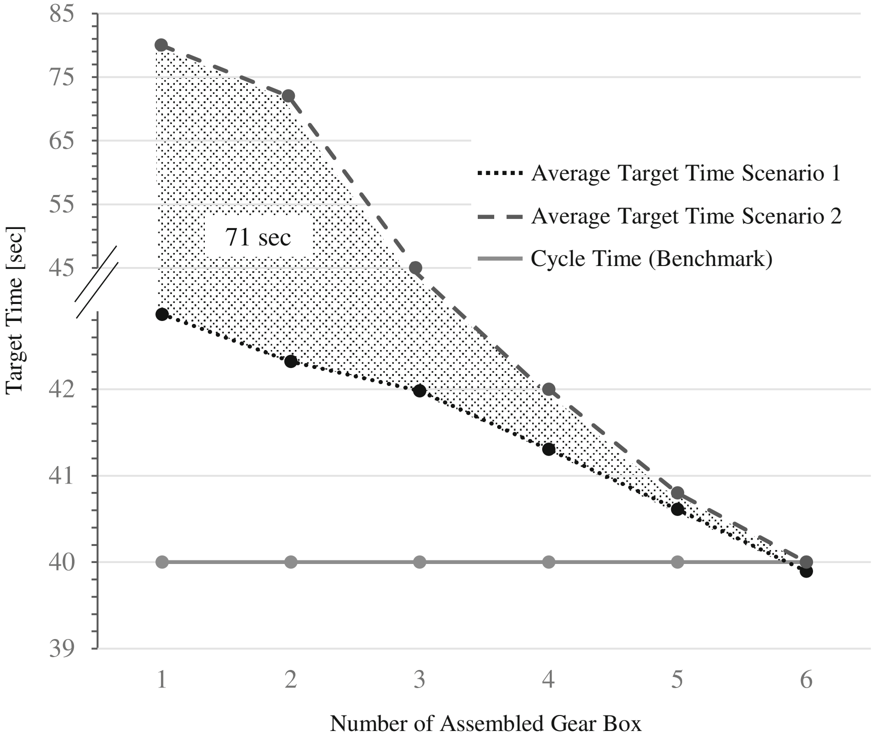

Fig. 5 Learning curves—scenario 1 and scenario 2

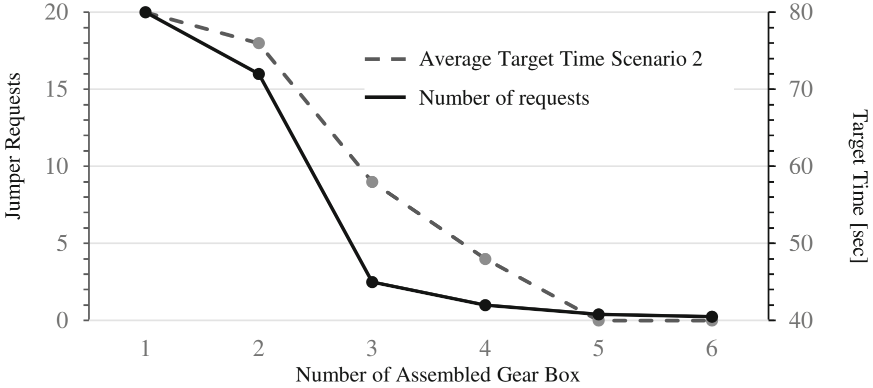

Fig. 6 Number of jumper requests—scenario 2

efficient, if the time for the fundamental pre-training in scenario 1 is additionally taken into account. The pre-training in scenario 1 took 15 min. Compared to that, the time difference of both scenarios, which is the integral between the curves of scenario 1 and 2, is only 71 s (Fig. 5). These results validate the pre-postulated hypothesis: *The integration of "coach-jumpers" into assembly lines has an adequate impact on learning curves compared to pre-training sessions*.

3.3 Critical Reflection of the Study Results

To conclude this chapter, some critical aspects of the study will be analyzed and their impact on the results discussed. The target group included probands between the age of 20 and 27, so it focused on younger people, who still have a high cognitive receptivity [19]. Furthermore all of them are students at University, which implies a certain level of education and advanced learning skills. They are used to solve unknown problems and to memorize new information. Memorizing as well as learning skills could differ by older or lower educated people. To proof the general validly of the postulated hypothesis, the study will be executed within a realistic production environment. But nevertheless, the achieved results give enough evidence to proof a positive impact on learning process by utilizing coach jumpers. Therefore the relevance of this research project becomes significantly more important.

4 Summary and Outlook

The first part of the paper presents a competence based approach to support workers within assembly lines as well as the idea of integrating jumpers as coaches. The aim is an efficient coordination of jumpers to stations as well as the minimization of the jumper group in order to cut costs. That is why the capacities of jumpers shall be correctly utilized as well as their skills and competences. To realize a competence based coordination, relevant competences and skills for the profiles need to be identified and validated. The results will be discussed in several interviews with experts and project partners. The second part of the paper describes the results of a study concerning learning curves under two different conditions—pre-trainings versus coach jumper requests. Due to the group of probands, a similar study will be carried out in a real production environment, provided by the project partner. Thus a general validity of the first results can be proofed. Additionally, the economic efficiency of providing coach jumpers has to be examined within further research work.

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The Role of Human Motivation in Quality Inspection of Production Processes

Agnieszka Kujawińska, Katarzyna Vogt and Adam Hamrol

Abstract Despite fast technological progress, machine-oriented production solutions and more demanding customer needs still human presence in production is evident, important and needed. In quality inspection human uses own senses when deciding about products quality. Decisive step is then the most complex part of inspection with regard to big number of product attributes, variable attributes and often limited possibility to measure product characteristics. Attribute inspection is much more difficult than control based on measurements and figures. Effectiveness of attribute inspection is always lower than based on measurements due to risk of human mistake during inspection. It can appear two types of failures during inspection: defects overlooking, improper classification. Human is unreliable part of inspection. One of key factors influencing on inspection performance is motivation. Motivation types differs people. With regard to that fact it is stated that human motives investigation needs to be carried out already on personnel selection phase.

Keywords Motivation · Quality control · Effectiveness · Production process

1 Introduction

The main goal of any production process is to deliver products that fulfill customer demands and expectations. Nevertheless, production processes are not 100 % reliable and some nonconformities (defects) may occur. The consequences of

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nonconformities include, among others, disruptions in the process rhythm, additional costs, and reduced product value. It is therefore necessary to introduce sufficient and effective quality control tools and systems. Quality control should as quickly as possible detect any defects in processes. The best methods include the use of automatic quality control systems. However, automatic control systems are frequently too expensive or not reliable enough, and therefore quality control must be conducted manually. This is especially necessary when quality control concerns the so-called attribute features, like damages, scratches, lack of solder, paint, etc. The most popular method of examining these features and detecting possible nonconformities is the so called visual control [1–4].

One of the major advantages of visual inspection consists in its relatively low costs, because in general, no specialized technical equipment is required. Human senses, usually sight, are the measurement tool. Unfortunately, such inspection does not guarantee a correct assessment. This is due to the fact that human senses cannot be considered completely reliable. There are numerous factors which may affect a man's ability to assess the process quality properly. An important group includes individual and social factors referring to physical, mental, and personal characteristics such as age, intelligence, extraversion and type of motivation etc. [3, 4].

During the visual control two types of errors may occur: on the one hand, good products may be classified as defective, and on the other, faulty items may be incorrectly classified as good. The probability of these two types of errors was selected as an indicator of control process effectiveness. The paper describes the results of a broad research, conducted in an automotive company in electronics manufacturing process. Individual factors, such as motivation of inspectors, have been extensively investigated in an attempt to identify the traits of the "perfect" inspector and to develop personnel selection.

2 Quality Control—Term and Classification

Quality control is very important in businesses. The established experts of management [5–7] recognize its role and refer to controlling as the fourth function of management, next to planning, organizing and leading. The aim of controlling is to compare the achieved process results with the intended target. There are different manners in which control may be manifested and exercised. For example, it may be institutionalized and formalized. Due to a predetermined phase or phases which comprise the job process, controlling may be exercised as preliminary control, ongoing control, ad hoc control, or final control [5].

Among the different types of controlling in production companies, quality control is of particular importance, as it aims at checking process or product compliance with the requirements of an internal or external customer [5]. Most often, it consists in the evaluation of one or more features of the product, and comparing the result with the expectations.

Quality control may be divided into different types, one of them being the division into the control of measurable (quantitative) and unmeasurable (qualitative) features [5, 8]. Alternative product assessment is used when a direct or indirect measurement of a given product feature, expressed with a numerical value, is either impossible, difficult, or cost ineffective. The outcome of an alternative assessment does not provide information on the extent to which the examined feature complies with requirements; it is only the basis for a decision whether a given product may be considered "good" or if it should be rejected and regarded as poorly made, "bad" (defective). Therefore, the decision whether a product meets or fails to meet the specific requirements most often leads to the product being classified to one of the two (rarely more) conditions.

Alternative control may be performed using specialized equipment, which classifies products automatically (e.g. pattern-recognizing machines which verify PCBs and the quality of soldered joints, devices evaluating the location and orientation of components etc.), or it may be performed with the use of human senses only. The other method is usually called organoleptic control. Visual inspection is a particular example of such control.

It is believed that visual inspection is economically viable, for it does not require the use of any expensive equipment. Also, it is a non-destructive method, which means that it does not cause any damage to the inspected product. However, while using visual inspection and keeping in mind its strengths, one may not disregard the weakness of the method: it is unreliable, and does not guarantee 100 % correct assessment [1].

There is a number of factors which affect both the efficiency and effectiveness of visual inspection. They include technical and organizational factors, aspects related to the work environment, and issues concerning the man [1, 2, 4, 6, 9, 10].

The technical factors are related to the physical performance of the inspection. They include, for example, product features subject to inspection (e.g. their accessibility for visual inspection), the standards, according to which the product is controlled, or the availability of tools used during the inspection. The organizational factors include, among others, the type and number of inspections to be performed, support in the decision-making during the inspection, or the availability of information about the efficiency and effectiveness of inspections. Workplace environment conditions are associated with the workplace, where the inspection takes place. These include physical factors, such as lighting, noise, temperature, as well as the organization of the workstation itself. The last group comprises factors related to the man. They are often referred to as the psychophysical factors, which are associated with mental and physical features of inspectors [2, 3, 6, 8–10]. The factors include age, sex, intelligence, temperament, health condition, and the type of motivation influencing the employee.

3 Motivation as Determinant of Quality Control Efficiency

Motivation for work is a process taking place between superiors and subordinates, where the behaviour of the latter is influenced for their actions to allow for the achievement of previously established goals. Motivation is a complex issue, and it is one of the most difficult functions of management. Although there are many theories of motivation, in practice it is difficult to develop a universal motivating system which could be successfully applied in any conditions [11, 12].

What is more, there is a plethora of definitions of motivation, which does not facilitate the understanding of the process [9]. According to literature motivation may be understood, among others, as a set of factors that direct human energy and behaviour (or preparedness) toward particular action [11–13].

Haber [12] defines motivation as manager's personal approach to an employee, investigating the employee's hierarchy of needs and expectations, which leads to providing proper conditions of work and the achievement of goals.

Armstrong, in turn, sees motivation as goal-oriented behaviour. People feel motivated when they expect that their actions will lead them to achieve their goals and bring the reward, which will satisfy their needs. He believes that highly motivated people will always strive for clearly defined goals. They can motivate themselves, but most need, to a greater or lesser extent, the motivation that comes from the outside [12].

The analysis of literature shows that motivation is the inner strength of man that drives and shapes his behaviour aimed at achieving his objectives. Such a condition may be caused by urges, instincts, needs and states of tension. Many researchers believe that the underlying causes of motivation include needs, which condition human behavior aiming at satisfying the needs, as well as tasks, which the individual assigns himself or which are imposed from the outside [7, 12, 14].

There are different types of motivation for work. Researchers divide motivation into external, internal, and hubristic [13]. The criterion for this classification is the kind of values that a man follows. In the case of external motivation, activity results most often from external motivators, both positive and negative, e.g. from a system of rewards and punishments (such as bonuses, job loss etc.). For internal motivation, the factors which make a man behave in a given way include: opportunity for personal development, responsibility, challenges at work, life values, etc. Hubristic motivation is often described as the motivation for the pursuit of "perfection", i.e. employees seek to confirm and increase their value (importance). According to Kozielecki, the desire results from the need to "boost one's self-esteem", be satisfied with one's performance and recognize one's own merits displayed in action. The hubristic aspirations are never satisfied. People who want to satisfy them frequently get involved innovative actions, which not only improve their self-esteem, or give meaning to their lives, but also serve the society well [14].

Given the diverse approaches to life and methods of solving problems in both private and professional life, subjecting employees to identical stimuli may result in different reactions. The diversity among people may be caused not only by the differences in temperament, personality traits, skills, abilities and physical or psychological limitations; it may also be related to different perceptions of the surrounding world or current events, and to people's different desires, aspirations and needs. Hence, experts claim that motivation, together with interpersonal communication, is one of the most difficult challenges faced by managers. There is no ready formula, or procedure describing how to recognize attributes of motivation in people recruited for a given job, and there are no guidelines on how to effectively trigger motivation and maintain it [8, 13, 14].

Managers and quality engineers, who often have to select quality controllers from their operational staff, have to deal with similar problems. An applicant for the position of a quality controller must meet a number of requirements. The first is having relevant abilities and specialized knowledge. A quality controller must demonstrate specific psychophysical predispositions, particularly when the inspections are conducted with the use of senses (e.g. visual inspection). The candidate must therefore have good sight and memory, must be able to multitask, and be systematic and patient.

The authors of this paper believe that the selection of a quality controller may be facilitated by the identification of the candidate's motivation. In the case of a quality controller it is important that the person be motivated to perform their work right, and to self-improve.

The aim of this study was to analyze and evaluate the impact of various types of motivation driving quality controllers and operational staff who perform the so-called self-control on the effectiveness of their work.

4 Research Methodology

In order to verify the relationship between the type of motivation and effectiveness of quality control operations, research was carried out in an automotive industry company, in the area of electronics production. The study was divided into three stages (Fig. 1). The first stage involved the identification of the type of motivation among 26 employees working as quality controllers and visual inspection staff. In the second stage, the authors evaluated the effectiveness of visual inspection performed by 19 operators selected from 26 employees representing different process jobs (component assembly, soldering, application of protective coating, functional

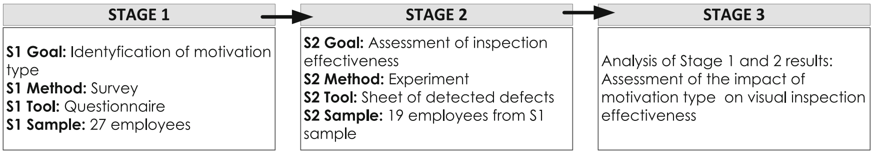


Fig. 1 Stages of the study [own work]

test of the product) and control positions (Fig. 3). The selection was determined by an experiment performed for a specific sequence of operations—a part of the technological process. Three technological operations and four quality control operations were chosen for the experiment. During the third stage we analyzed how the given type of motivation affects the effectiveness of control and self-control processes performed by the selected 19 employees.

During stage 1 a questionnaire was used as a research tool. The questionnaire consisted of 32 questions, which were divided into three groups. The first group of questions (1–10) referred to the external motivation, the second one (questions 11–21)—to internal motivation, and the third (questions 22–32) to hubristic motivation. For each statement the tested employee used a five-point Likert scale to indicate the extent to which he/she agreed with the statement. The grading scale began with a strong affirmative "definitely yes", through "yes", "neither agree nor disagree", "no", to a final negation "definitely no". At this stage of coding, the statements and responses were assigned to an ordinal scale {1, 2, 3, 4, 5}. An average grade was calculated for each respondent in each of the three groups of questions. The motivation type most relevant for the respondent was the one with the highest average grade.

5 Research Results

The first stage of the study was participated in by 27 persons. The subjects worked in a three-shift operation system. Figure 2 shows the sample structure according to age, professional experience, education and number of positions on which the employee may potentially work (according to his/her skills). The majority of respondents were 35 years old or younger with secondary education.

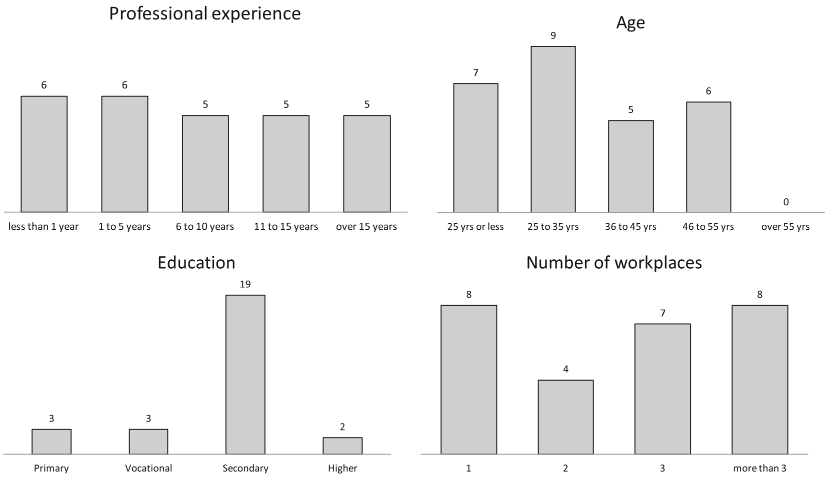


Fig. 2 Sample structure [own work]

In the second stage of the study 18 operators were selected from the 26 operators analyzed in stage 1. Four of them were quality controllers in the analyzed operation sequence, others were operators and controllers (Fig. 3). Next, the researchers evaluated the effectiveness of visual inspection performed at various stages of the process shown in Fig. 4.

Three operations took place in the examined production process (Fig. 3):

- operation 1: assembly and soldering of through-hole components,
- operation 2: application of protective coating on the PCB,
- operation 3: functional test.

For a given process, five control operations have been distinguished (Fig. 3):

- inspection 1 (self-control): performed by the operator during the assembly and soldering of components—on-line;
- inspection 2: performed in an separate location by the inspector—inter-operational off-line;
- inspection 3 (self-control): performed by the operator during the application of the protective coating—on-line;
- inspection 4 (self-control): performed during the functional test operation—on-line;
- inspection 5: final control, performed in a separate location by the inspector—off-line.

The sources of possible defects in the process include operation 1, and operation 2. The defects which occur in the process of assembly and soldering of components (operation 1) included, among others: lack of component, incorrect assembly of a component, component not lead through outside the assembly hole, excess of

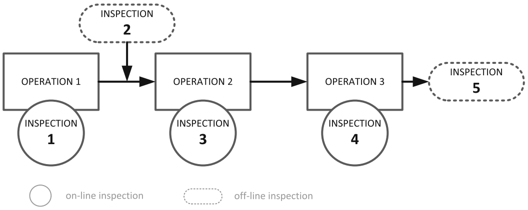
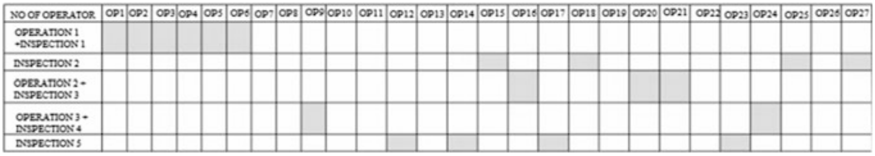


Fig. 3 Location of visual control in the production process [own work]



NO OF OPERATOR	OP1	OP2	OP3	OP4	OP5	OP6	OP7	OP8	OP9	OP10	OP11	OP12	OP13	OP14	OP15	OP16	OP17	OP18	OP19	OP20	OP21	OP22	OP23	OP24	OP25	OP26	OP27
OPERATION 1 +INSPECTION 1	▨	▨	▨	▨	▨	▨																					
INSPECTION 2															▨			▨							▨		▨
OPERATION 2 + INSPECTION 3																▨				▨	▨						
OPERATION 3 + INSPECTION 4									▨															▨			
INSPECTION 5												▨		▨			▨						▨				

Fig. 4 Operators who participated in the evaluation of inspection effectiveness and their location in the process [own work]

solder, lack of solder. It was assumed that the defects should be first detected at inspection 1 and inspection 2. They are also detected by inspection 4 and 5.

Defects which occur in the application of protective coating may include: coating in prohibited area of the circuit, and lack of coating. It was assumed that the defects should be detected during inspection 3, i.e. by the operator applying the coating. Defects originating in this operation are also detected in inspection 4 and 5 (final inspection).

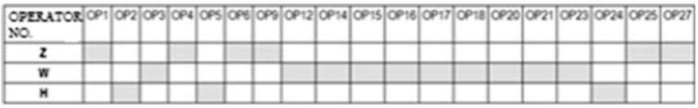
Defects related to impurities of protective coating originate during the application of the coating. It was assumed that the defects should be detected at inspection 3, 4 and 5. In the experiment we identified 6324 defects, including 328 defects associated with assembly errors, 3586 defects related to soldering, 1175 defects resulting from the application of coating, and 1235 defects associated with impurities.

One hundred percent of PCBs were inspected. The operator verified objects at 4x magnification, and in uncertain cases, at 10x magnification. An identified defect was qualified and sent for destruction (irreparable defective products) or to repair (repairable defects). The operators working at the position of assembly, soldering, functional test and final inspection performed self-control.

For all control operations and predetermined defect categories we also calculated the percentage of detected defects (the so-called control efficiency, CE) in relation to all defects which occurred at the entry to the inspection process performed by the given operator. It should be noted that for inspection 1 and 2, the basis for determining the fraction of defects detected was the number of defects related to two categories, while for inspection 3, 4 and 5 it was the total of defects that were not detected in previous inspections and defects concerning the coating which appeared in operation 3. The operators participating in the experiment were assigned to the operations according to the diagram in Fig. 4 (their affiliation to the given process stages is marked with grey).

Figure 5 shows the results of the motivation assessment of the operator. The majority was driven by internal motivation, three of them—by hubristic motivation, and six needed external motivation.

The control operation no.5 was participated in by four operators: no. 12, 14, 17, and 23. The results of the questionnaire showed they had a high level of internal motivation. For each of them the average effectiveness of inspection was 100 %. This was mainly due to the fact that their job consisted only in the inspection activities, and they were aware that they conducted the final inspection. Therefore



OPERATOR NO.	OP1	OP2	OP3	OP4	OP5	OP6	OP9	OP12	OP14	OP15	OP16	OP17	OP18	OP20	OP21	OP23	OP24	OP25	OP27
Z	▨			▨		▨	▨											▨	▨
W			▨					▨	▨	▨	▨	▨	▨	▨	▨	▨			
H		▨			▨												▨		

Fig. 5 Type of motivation driving the operators [own work]; Symbols: Z—external motivation, W—internal motivation, H—hubristic motivation [own work]

the authors of this paper excluded the result of this group of controllers from further analysis, as it was a special case.

The results of employees participating in operation 2—applying protective coating on the PCB (operator 16, 20, and 21) turned out to be interesting. It was recognized that in this case the effectiveness of control operations was on average equal to 1 %. An in-depth analysis of such low result revealed that the operators were not able to perform and supervise the process of applying the protective coating in the time allocated for the operation. Too short cycle of the operation forced the employees to focus on grave defects of coating operations (e.g. complete lack of protective coating), overlooking the inspection actions based strictly on the criteria described in the manual of applying protective coating. Reduction of time necessary to inspect the circuit after the application of the coating could have had the biggest impact on the effectiveness of the inspection. The time parameter was recognized as a distorting factor. Therefore, the results of these operators were also rejected as distorted and resulting from the conditions of the experiment.

For these reasons, further analysis of the impact of motivation type on the effectiveness of inspection involved a group of 12 operators. Normalized values of indices for all the types of motivation for each operator and the achieved level of inspection effectiveness is shown in Fig. 6.

The analyzed experiment shows that high effectiveness of inspection, and self-control in particular, was reached by employees who displayed a high level of hubristic and internal motivation. The above is confirmed by the results achieved by operators 5, 6, 24, 2, and 15, for whom the percentage of detected defects was 100, 100, 92, 84 and 82 %, respectively. The group of operators was related to the operation of assembly and soldering of through-hole components and inter-operational inspection (2). The analysis of results achieved by them in the group of statements related to a given type of motivation shows that they are mainly driven by hubristic motivation (Fig. 6c).

Low effectiveness of inspection and self-control was found in employees 9, 4, and 6, associated with the operation of assembly and functional test. Their average

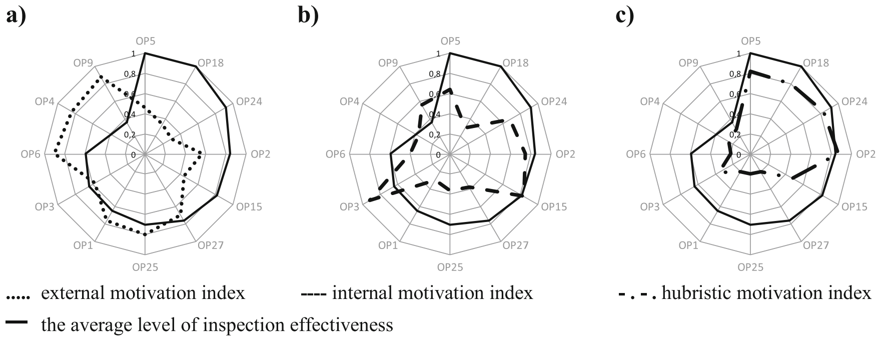


Fig. 6 Graphical interpretation of motivation indices and effectiveness of inspection for each operator [own work]

score, for both internal and hubristic motivation, was rather low (Fig. 6b, c). Their responses given in all three groups of statements classify them as persons who are driven to action by external factors.

6 Conclusions

It is often emphasized that due to the individual nature of visual inspection, which is often carried out as self-control, it is difficult to assess its impact on the effectiveness of the inspection, or to evaluate the correlation (or its lack) with other factors affecting the efficiency and effectiveness of the operator.

Definitely, the factor which greatly affects the effectiveness of self-control is the operator's understanding of the purpose of the control actions, clear definition of control methods and criteria, as well as appropriate time-planning and organization of the workplace. The research suggests that it is important to know the type of motivation which drives persons employed as controllers, as the motivation has a direct impact on the effectiveness of their work.

The results of this research show that employees who are motivated only by external needs have a lesser tendency to self-control their actions (as proven by the low rate of defects detected in the experiment). In turn, employees who seek self-realization and development tend to continuously control the results of their work.

The types of motivation may be identified e.g. using the surveys which served as the basis for this study. Moreover, motivation should be assessed periodically, to allow for appropriate reaction and the use relevant motivation tools. It is not easy to determine the type of motivation which drives a person, and maintaining the level of motivation is a very challenging task.

It should be noted, however, that the crucial point of motivation efforts lies in appropriate organization of control. When organizing the control process, one should take into account many issues, including the structure of the workplace according to the guidelines of ergonomics, through the access to appropriate tools, documents, measurement and control devices, relevant employee training, to control methods and well organized work time. Whatever the type of motivation that drives an employee is, if any workflow parameter is not fulfilled, the efficiency of control will still be low.

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Improving and Embedding Project Management Practices in Organizations—The Human Perspective

Gabriela Fernandes and Madalena Araújo

Abstract A conceptual framework of the factors that facilitate embedding useful project management improvement initiatives (PMIIs) was developed from an exploratory study. This paper aims to make some contribution to theory as well as to practice by exploring the human perspective of the framework conceptualization. The framework resulted in 15 key PMIIs and in 26 key embedding factors, that can act as levers to be used by organizations in devising strategies to promote embedding PMIIs into their systems. Almost half of each, seven PMIIS and twelve embedding factors, are directly related to Human aspects.

Keywords Improving · Embedding · Project management · Human perspective

1 Introduction

PM is a well-developed and accepted organizational science that has been shown to deliver tangible and intangible benefits to organizations [1–3]. Nevertheless, PM remains a highly problematical endeavor. Projects still fail to live up to the expectations of stakeholders as they continue to be disappointed by projects' results [4]. The Standish Group International Chaos Manifesto 2013 [5] shows that, in the information and technology (IT) sector of activity, in 2012, only 39 % of all the projects surveyed succeeded (i.e. were delivered on time, on budget, with the required features and functions); 43 % were challenged (late, over budget and/or with less than the required features and functions) and 18 % failed (cancelled prior to completion or delivered and never used). These results highlight the importance of improving PM practice in organizations. Geraldi et al. [6] raised the question *how to better develop and apply the knowledge of PM in projects?* As argued by

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Shi [7] how to implement and improve PM in the “right way” is still a relevant topic to study. One important issue in all these questions is that PM is highly contingent on the organizational context, such as structure of business or industry sector, size, and its environment [8, 9]. In a research study: “Researching the value of project management”, sponsored by Project Management Institute, Thomas and Mullaly [10] concluded that there is no unique way being adopted when PM practice is improved in organizations; there are several different PM initiatives for improving PM practice present in organizations. The implementation of PM methodologies varies considerably, from the very ad hoc and informal to methodologies that are formally defined and consistently adhered to.

While the literature on PM provides some advice, organizations need guidance on which project management improvement initiatives (PMIIs) they should concentrate their efforts. A related issue is how to facilitate the embedment of PMIIs in organizations. A conceptual framework of the factors that facilitate embedding useful project PMIIs was developed from an exploratory study. The framework is conceptualized into two constructs: improving PM practice and embedding PMIIs, although the two concepts are linked, since an organization engaged in embedding a PMII is consequently improving PM practice. However, in this research improving is seen as the identification and selection of useful PMIIs for embedding into the organization. In respect of the embedding construct, the research was particularly focused on identifying factors contributing to the successful embeddedness of PMIIs. The assumption is that if an organization is aware of these factors and addresses them during the stages of the embedment process of a PMII, then the embeddedness is more likely to be achieved.

The research described in this paper aims to make some contribution to theory as well as to practice exploring the human perspective of the framework conceptualization, by detailing the key PMIIs and key embedding factors related to human aspects.

2 Relation to Existing Theories and Work

Based on a review of the literature, a first attempt to construct a conceptual framework, listing the PMIIs regarded as most useful and the key factors that can facilitate the embedding of the PMIIs into PM practice, drew largely from three main theoretical foundations:

1. The Value Adding Path Map (VAPM) framework from Shi [7], which identifies several improvement initiatives, identifying them as ‘hard’ and ‘soft’ PM system implementations, and inclusively gives the step by step indication of how to introduce them in the organization in a better way.
2. The conceptual model for the spread and sustainability of innovation in service delivery and organization from Greenhalgh et al. [11], which is the result of one of the most comprehensive reviews of research on innovations, and had as the

unit of adoption the organization and not just individuals, which it is the focus of the framework conceptualization. Greenhalgh's model identifies several factors for the spread and sustainability of innovation grouped into six main themes: (i) PMII (innovation) attributes; (ii) adopter and adoption process by individuals; (iii) communication and influence (diffusion/dissemination); (iv) inner context; (v) outer context; and (vi) implementation.

3. The technology acceptance model3 (TAM3) from Venkatesh and Bala [12], which is a combination of the model of the determinants of 'perceived ease of use' from Venkatesh [13] and TAM2, which presents the determinants of 'perceived usefulness' [14].

These works were selected for reasons associated with the similarity of objectives, robustness, empirical evidence obtained, multidisciplinary teams and multitude of organizational contexts, but also due to the relevance of the variables being used, namely 'perceived usefulness' and 'perceived ease of use' (TAM3).

3 Research Methodology

An exploratory research was undertaken, which aimed to identify key PMIIs and key embedding factors, based upon the circumstances encountered in different organizations. A first attempt at framework conceptualization based on a literature review was used as a skeleton support for the exploratory study. A series of thirty semi-structured interviews with PM professionals sought to identify additional PMIIs and embedding factors and check the salience of the PMIIs and embedding factors identified from literature review. Analysis of the interviews data led to a modified set of pertinent PMIIs and embedding factors resulting in a revised framework [15]. In a subsequent phase of the research, an online questionnaire survey was undertaken to obtain a wider set of views and it was answered by 793 PM professionals from about 75 different countries. Analysis of the questionnaire responses largely confirmed the revised framework for embedding useful PMIIs [16], which resulted in the framework presented in Fig. 1.

The framework highlights the need for organizations to focus on key PMIIs, beyond the specific PM 'processes, tools and techniques' and gives some guidance on other priority areas, such as 'people and organizational learning' and 'general management system'. The framework also lists a number of facilitating factors that can lead the embedding of PMIIs. While adopter features are an important group of factors to consider [12], organizations should not neglect a broader perspective which considers 'inner context'-related factors, 'outer context'-related factors, 'communication and influence'-related factors, 'implementation'-related factors, and 'routinization'-related factors.

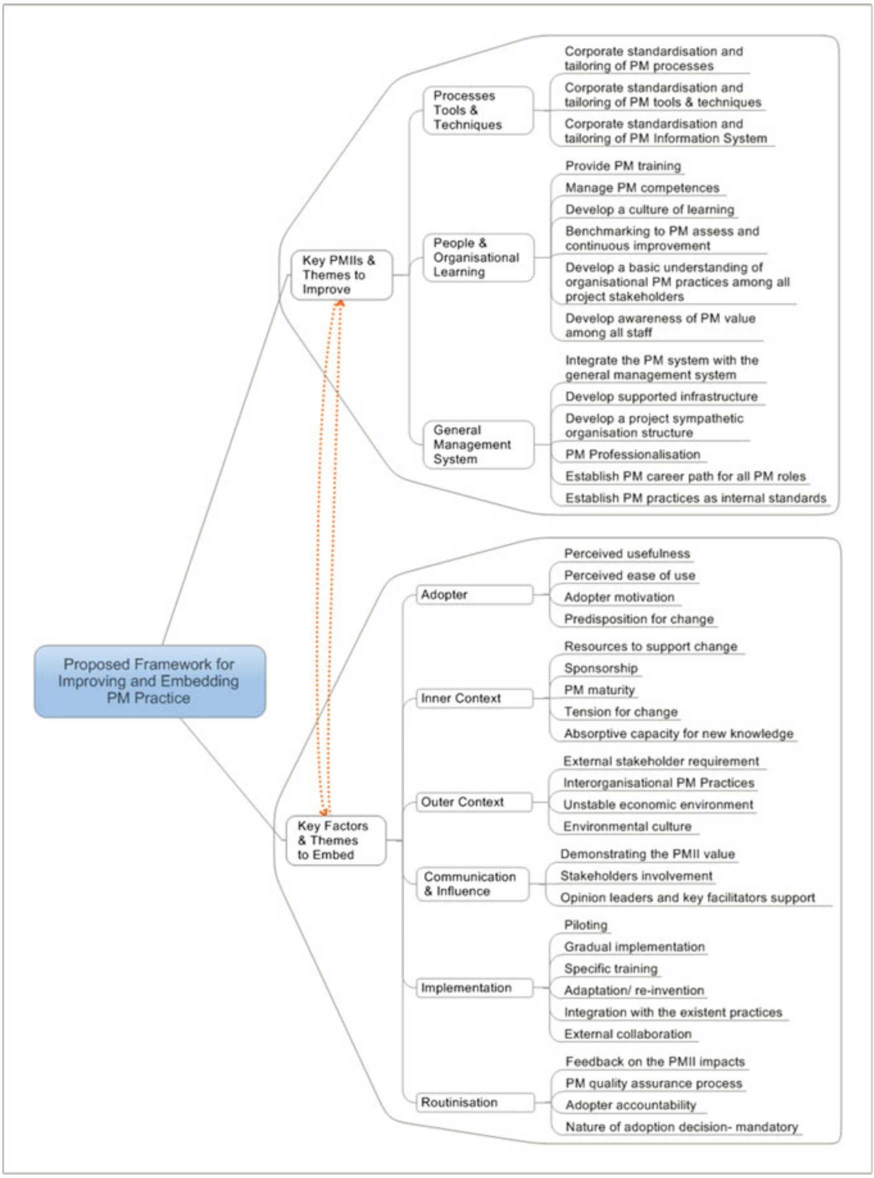

Fig. 1 Framework for improving and embedding PM Practice [16]

4 Framework for Improving Project Management Practice—Human Aspects

The framework resulted in fifteen key PMIIs (see Fig. 1), seven of them (almost half) are related to human aspects. As argued by Cooke-Davies [17, p. 89] “*when it comes to project management, it’s the people that count*”. Some of these PMIIs are strongly related. For example, an organization that has a PM career path established motivates their PM staff to develop their PM competences in order to ascend in the career path. An organization that has a culture of learning facilitates the development of the staff’s PM competences. The PMIIs are categorized into ‘process, tools and techniques’, ‘people and organizational learning’ and ‘general management system’. None of the PMIIs in the category ‘process, tools and techniques’ are directly related to human aspects, as expected by the given name category.

4.1 Human Related PMIIs Under People and Organizational Learning Category

Five of the six PMIIs in the category ‘people and organizational learning’ are related to human aspects.

Provide PM Training. Several studies had pointed it as one of the most important areas for improving PM practice. For example, Loo [18] had identified the need for PM training and education, particularly, training in planning tools. Thomas and Mullaly [10] have identified PM training as one of the most important improvements that had the greatest impact on project performance. Andersen and Vaagaasar [19], based on just three case studies, conducted in Norway, as part of the research project “Researching the value of project management”, have identified the creation of internal PM schools as one of the two more important efforts to improve PM practice. Shi [7] argues that organizations should make training budget of PM aligned with the needs of PM development competences and that the training plan should involve people from top management to team members.

Manage PM Competences. Human resource competences development is a critical discipline in the PM world [20]. As argued by Suikki et al. [21, pp. 724] “competence development is becoming more and more critical in today’s turbulent business environment”. Winter and Smith [22] argue that is important to recognize and nurture the diversity of professional capabilities required in project work. Therefore, and based on the premise that competences have a direct effect on PM performance, it is important for organizations to manage their staff PM competences. For example, through the development of a system to identify the core PM competencies for the organization’s projects and assess these competencies on the organization’s PM staff.

However, there is no agreement among educators and training program directors of many leading institutions on what competencies are required to make a good project manager [23]. Although, some efforts have been made, for example, the Standard Project Manager Competency Development Framework (PMCDF) from the Project Management Institute [24] or the IPMA Competency Baseline (ICB3.0) [25].

Develop a Culture of Learning. Learning and knowledge management contributes to PM in different ways, for example by the availability of repositories of data from past projects which are crucial to the quality of estimates [26]. Sense [27] argues that activities directed towards enabling and promoting learning activity within project oriented organizations are essential, and certainly not considered 'optional' or simply as something 'nice to do'. In fact, projects can create barriers to organizational learning, by privileging short-term task performance over long-term knowledge accumulation [28]. Organizations might develop a culture of learning, for example through the development of a knowledge management system including a learning system to improve the effectiveness of the PM professionals [7].

Develop a Basic Understanding of Organizational PM Practices among All Project Stakeholders. Unfortunately, many people still have the perception that PM is something that project managers do, rather than a discipline in which the whole organization is involved. The development of a basic understanding of the institutionalized PM processes, tools and techniques, its purposes, and its benefits, among all staff involved in project activities is important to improve PM practice and create a culture of PM [7]. People that are better informed and more aware of what is happening in their organization, would become more involved and committed to what is happening [29]. Develop a basic understanding of organizational PM practices among all project stakeholders can be, for example easily facilitated by organizations through the availability of easily, customized, PM documentation.

Develop Awareness of PM Value among All Staff. Only if organizations are fully aware of the value of PM they will make further efforts to improve PM practice [2]. Organizations investing in PM need to be confident of a return on the effort invested. Therefore, it is crucial for an organization to increase awareness of both perceived and actual benefits of PM, for example through more effective communication [30]. All the people in the organization, especially the top managers, should highly recognize that PM contributes to the success of the organization [7, 31].

PM value has been explained differently from different authors, for example Ibbs and Reginato [32] demonstrated the value of PM by measuring the financial ratio return on investment. However, only considering the monetary return of PM is obviously not enough, since PM also brings intangible benefits to corporate culture, organization efficiency, and the satisfaction of clients [3, 19, 33].

4.2 Human Related PMIIs Under General Management System Category

Only two of the six PMIIs in the category 'general management system' are related to human aspects.

PM Professionalization. The need for PM professionalization was perceived since many project managers act as such but do not have conscious of being PM professionals. Probably they were technical managers that were "upgraded" to project managers by the top management, without a clear assumption of added value and responsibility. Their main concern remains technical and management issues are seen as bureaucratic. Therefore, it is proposed PM professionalization, i.e., the project managers who dedicate almost 100 % of his/her work to PM activities.

Established PM Career Path for All PM Roles. Many project managers do not feel adequately respected and compensated for their work. They often see their role as a temporary one and focus more on their advancement in traditional leadership career paths [34]. Shi [7] argues that organizations should establish a clear career path in the organization to PM professionals, in order to motivate them to improve in their PM practice to climb the PM career path. In some organizations professionals did not want to become project managers because did not see how they could progress in the career. The development of a PM career path is also an important issue for an organization to ensure that it has enough people with the right level of expertise to deliver the project work [8].

5 Framework for Embedding Project Management Practice—Human Aspects

Almost half (twelve) of the twenty six key embedding factors (see Fig. 1), that can act as levers to be used by organizations in devising strategies to promote embedding PMIIs into their systems, are related to human aspects. As mentioned in Sect. 3, these embedding factors are categorized into factors related to adopter, inner context, outer context, communication and influence, implementation and routinization.

5.1 Human Related Embedding Factors Under Adopter Category

All the four embedding factors identified placed in the category 'adopter', as expected, are related to human aspects.

Perceived Usefulness. The Technology Acceptance Model (TAM3) posits that adopter acceptance is determined by two key beliefs, namely perceived usefulness and perceived ease of use [12]. Perceived usefulness is the person believing that a particular technology will enhance her/ his job performance. As argued by Greenhalgh et al. [11] a new practice is more likely to be adopted if adopters are aware of the new practice, have sufficient information about what it does and how to use it, and are clear about how the new practice would affect them personally. Mengel et al. [3] argue that it is necessary to be aware of people's sense of satisfaction (and dissatisfaction) in PM implementations, since it is a crucial factor when it comes to the (perceived) value of PM to organizations. Therefore, perceived usefulness maybe strongly influenced by the capacity of the organization to demonstrate the PMII value.

Perceived Ease of Use. It is defined as the degree to which a person believes that using a technology will be free from effort [12, 13]. In the case of PMIIs, a new PM practice is more likely to be adopted if adopters perceive that a new practice is easy to use.

Adopter Motivation. The adoption and continued usage of new practices (innovations) by adopters depend on their motivation [11, 35]. Adopters need to be convinced that the new practice will help them to meet their own objectives in a cost effective manner, both directly and indirectly through enhanced organization performance [36]. The lack of motivation may result in passivity, feigned acceptance, sabotage, or outright rejection in the use of new practice.

Adopter Predisposition for Change. This embedding factor emerged from interviews analysis. The aversion to change can be explained by individuals wishing to retain their own identity and do things 'their way' rather than conform to an imposed standard [37]. As argued by Ward [36] the parochial self-interest of individuals in maintaining the *status quo*. Ward [36] points other individual issues (also related to resistance to change), such as: the inability to perceive a need for change; concerns that they will be unable to carry out the new practices (lack of skills); and the uncertainty and suspicion about the nature of the change. As argued by Loo [18] some managers and staff are simply not prepared to change or do not seeing a need to change. The individualism can be managed and its effects harnessed, namely, through the encouragement of employee participation, and the development of an understanding of organizational PM practices among all project stakeholders [38].

5.2 Human Related Embedding Factors Under Inner Context Category

Only the embedding factor—sponsorship in the category 'inner context' is related to human aspects. Sponsorship was identified during the interviews research phase. Interviewees affirmed that top management should have the perception of what is involved in the systematic use of certain PM practices, namely the efforts needed, in order to support with the necessary resources. Top management should value if the project team follow the established PM practices in the organization. Top management should indeed benefit from, or use the information generated by the established PM practices. Interestingly, one interviewee observed 'local sponsorship', i.e. the managers responsible for the people that will use the practice must agree that this is the 'way' and support the change.

5.3 Human Related Embedding Factors Under Communication and Influence Category

The three embedding factors identified in the category 'communication and influence' are related to human aspects.

Demonstrating the PMII Value. It was discussed above the importance of the PMII 'develop awareness of PM value' in general to improve PM practice. Here as an embedding factor, it is discussed the importance of the effective communication of the value of a particular PMII across the structural boundaries within the organization prior to its implementation, namely, as argued by Englund and Bucero [31] the positive bottom-line impact on the organization. Several studies have demonstrated the benefits of investing in PM, for example, the study—"Researching the Value of PM" [10]. However, it is important that organizations evaluate project and organizational performance impact of a particular PMII to the organization. The advantages of new practices must be recognized and acknowledge by key people involved in the process [39]. The costs associated with not applying the specific PMII, should also be described and evaluated. Showing adopters the value of a PMII would increase the 'perceived usefulness' by the user, which is, as discussed above, crucial to the adoption of innovations [12].

Stakeholders Involvement. Early and widespread involvement of adopters in the implementation process of a new practice enhances the success of embedment of the new practice in the organization [11, 39]. Involvement is seen as a key process for achieving behavioral change [40]. As argued by Eskerod and Riis [33] project managers should have a high level of involvement in the implementation of PM methodologies.

Opinion Leaders and Key Facilitators Support. Certain individuals have particular influence on the beliefs and actions of their colleagues. Opinion leadership is the degree to which an individual is able to influence informally other individuals' attitudes and behavior [41]. It is important the existence of opinion leaders, influencers who will encourage the adoption of new practices, who could have active local networks to spread new practices [11, 39]. As argued by Loo [18] the inexistence of influencers of PM principles in the organization is a potential barrier for achieving PM improvements. However, it is important to realize that opinion leaders can have either a positive or negative influence on the adoption of innovations [42]. Therefore, organizations should determine and nurture individuals who already support PM practice [31], in order to help overcoming the skepticism and resistance among key individuals. These individuals (near-pears) would serve as role models, whose innovation behavior tends to be imitated by others in their system. The existence of key facilitators to support the change, who can encourage the take up and embedment of PMIIs, namely to provide some coaching during the implementation and routinization process, is also important.

5.4 Human Related Embedding Factors Under Implementation Category

Only the embedding factor—specific training in the category 'implementation' is related to human aspects. Training is associated to new PM tasks and new working methods (particular PMII). This embedding factor is closely related to the PMII—provide PM training. However, as a PMII, in the framework, is indicating the necessity for organizations to provide PM training, in order to guarantee the PM competences necessary to manage their projects, whereas an embedding factor, in the framework, is indicating that when organizations are implementing a new PM practice they should give the necessary specific training to their human resources to become able to its effective use.

5.5 Human Related Embedding Factors Under Routinization Category

Three of the four embedding factors identified in the category 'routinization' are related to human aspects.

Feedback on the PMII Impacts. Accurate and timely information about the impact of the implementation of the new practice (through efficient data collection and review systems) in the project and organization performance increases the chance of successful embedment [11]. Giving feedback on the PMII impacts the organization is demonstrating the PMII value after its implementation. These two embedding factors are strongly correlated, both were intensely emphasized by interviewees, highlighting the two distinct phases of the embedding process.

Adopter Accountability. It was a new embedding factor identified during the interviews research phase. Interviewees emphasized that it should occur consequences, being them positive—rewards or negative—penalties, if project staff are complying or not with the standardized PM practices.

Nature of Adoption Decision—Mandatory. Greenhalgh et al. [11] argued that generally, authoritative (mandatory) decisions for adoption may reduce in the long term the chance that the innovation is successfully implemented and routinized. Interviewees asserted the importance of the 'imposition' for the use of the new practice. However, when mentioned this factor, some interviewees followed with some assertions about the importance of demonstrating the benefits of the new PM practice to adopters. Important to note, that if the nature of adoption decision of a PMII is mandatory as opposed to optional, it demonstrates sponsorship.

Table 1 Human related key PMIIs and embedding factors

Key PMIIs	Key embedding factors
1. Provide PM training	1. Perceived usefulness
2. Manage PM competences	2. Perceived ease of use
3. Develop a culture of learning	3. Adopter motivation
4. Develop a basic understanding of organizational PM practices among all project stakeholders	4. Opinion leaders and key facilitators support
5. Develop awareness of PM value among all staff members	5. Nature of adoption decision—mandatory
6. PM professionalization	6. Adopter predisposition for change
7. Established PM career path for all PM roles	7. Demonstrating the PMII value
	8. Stakeholders involvement
	9. Specific training
	10. Feedback on PMII impacts
	11. Adopter accountability
	12. Sponsorship

6 Conclusions

This paper aims to make some contribution to theory as well as to practice by exploring the human perspective of a developed framework for improving and embedding PM practice in organizations. The framework resulted in 15 key PMIIs and 26 key embedding factors, and nearly half of them—seven PMIIs and twelve embedding factors are related to human aspects. They are presented in Table 1.

Further research will be conducted to understand how organizations can enhance the effect of the human related embedding factors. In identifying pertinent embedding factors it was necessary to make judgments about how far to distinguish different factors. For example, in the key embedding factor—perceived ease of use, the framework does not detail the components of perceived ease of use. However, it may be useful for organizations to understand how this factor and the others can be enhanced when embedding a particular PMII, by acting upon each of its components, differently.

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Group Support Systems Features and Their Contribution to Technology Strategy Decision-Making: A Review and Analysis

Cláudio Santos, Madalena Araújo and Nuno Correia

Abstract Collective decision-making processes require careful design considerations in organizations. On one hand, the inclusion of a greater number of actors contribute to a wider knowledge base, on the other, it can become a diffuse process and be distorted from the principles initially established. This paper observes a specific collective decision making process in organizations—technology strategy formulation—and, through a critical review of the literature, analyzes how the advances in features of group support systems support improvements in different stages of this process. This paper also discusses the implications of GSS appropriation in group dynamics.

Keywords Technology strategy · Group support systems · Review · Decision-Making

1 Introduction

The growing globalization of businesses is driving important changes in the many ways people communicate. Large corporations have to deal with the particularities, be them geographical, economic and cultural, of business units of various locations. This issue is also faced, to a certain degree, by Small and Medium Enterprises

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(SMEs) which have, for example, to accommodate divergent requirements of several customers and manage suppliers with different capabilities.

With respect to group decision-making that requires the analysis of sensitive topics, such as the role of leadership and aspects of organizational culture, the approach chosen may have a determinant role in the effectiveness of group meetings. In an attempt to overcome these issues, Group Support Systems (GSS) are making unprecedented contributions to improve the communications between and within organizations and thus, in collaborative decision-making.

In the specific case of decisions involved in the formulation of a technology strategy, these may be compromised by: (1) divergent opinions arising from the functional areas involved in the process (technical, marketing, production departments and others) (2) different cultural backgrounds and (3) uncertainty and ambiguity. Despite its undeniable importance for the exchange of ideas and problem solving, the dynamics imposed in group meetings may lead to job dissatisfaction [1] and higher costs derived from excessive time devoted to meetings [2]. In this paper, we explore how different features of GSS have been contributing to improve strategic decision-making in organizations.

The remainder of this paper is structured as follows: Sect. 2 presents the literature review on the topics of technology strategy and group support system. Section 3 describes the research methods used in this study. Section 4 discusses the potential contribution to the technology strategy formulation process and Sect. 5 presents the conclusions.

2 Literature Review

2.1 Technology Strategy: Stages and Tools

The management of technology is understood as a fundamental cornerstone of the competiveness of companies. As an integral process of managing technology [3] technology strategy is defined as the process through which organizations develop and leverage technological resources to exploit market opportunities [4, 5].

The enactment of a technology strategy is a complex task for organizations for a variety of reasons, one of them being the relative irreversibility of technological investments. Such investments are made in a context of high uncertainty, as it is considered a period of strategic positioning for organizations, when considerable financial commitments have already been made [6].

The content of technology strategy concerns the required decisions that constitute a technology strategy program [7]. A review of the most prominent decisions is summarized in Table 1.

A large number of frameworks have been proposed to support the formulation of a technology strategy in business environments [7–13], which in essence characterize a structured methodology to conduct the process. Technology strategy

Table 1 A review of technology strategy decisions

Decisions	[8]	[10]	[12]	[16]	[7]
Selection of technologies	X	X	X	X	X
Technology acquisition mode		X	X	X	X
Timing of introduction		X	X		X
Organization and management approach of technology and innovation		X			X
Organization of technology intelligence efforts		X			
Identification and exploitation of technological interrelationships		X			
Selection, evaluation, resource allocation and control of projects		X			
Technology availability and feasibility				X	
Process to ensure best return of investment				X	
Required technological competences and capabilities					X
Investment level in technological developments					X

frameworks consists of two basic elements [14]: *activities* and *tools*. Through an extensive review of proposed frameworks, Santos [15] argues that the technology strategy formulation is consolidated in five core activities, each of them supported by a wide range of tools and techniques: *internal analysis*, *external analysis*, *generation*, *selection* and *monitoring*.

The internal analysis activity concerns the identification and assessment of the technological competences and capabilities inside the organization. The external analysis is related with the process aimed at identifying possible technological trajectories, their impacts in the industry and in events that may influence these patterns. The generation activity is related to the activities involved in generating technology project ideas, based upon the findings from the internal and external analysis and in specific pieces of information required in the ideas generation process (patents, technology suppliers, etc.). Selection activity addresses how the generated technology project ideas are going to be selected for implementation within technology investment budgets. This should also consider how technology is going to be sourced (developed in-house, in collaboration or acquired externally). Finally, the monitoring activity is related to the control and oversight of the project and the learning from theses *vis-a-vis* the initial goals set, turning the enactment of a strategy a cyclical process in the long-term.

The tools and techniques used in each activity play an important role in supporting the definition, evaluation and decision-making process. The complexity inherent in the requirement of studying several areas of knowledge to define a technology strategy may favor the integration of different tools and techniques to grasp the best features of each one and thus support the development of a more robust framework [3]. On another aspect, the exchange of ideas and communication of guidelines offers a good opportunity for the development of group support systems (GSS) that support the development of a technology strategy inside organizations.

2.2 Group Support Systems

Group meetings are often arranged so that a group of individuals can share ideas, make decisions, solve problems and communicate within organizations. It has been defined as a "*a focused interaction of cognitive attention*, *planned or chance*, *where people agree to come together for a common purpose*, *whether at the same time and same place*, *or at different times in different places*" [17]. Their existence is based on the principle that collective knowledge supports improved decision-making [18, 19].

The contribution of group meetings to decision-making has been extensively discussed in the literature. Its overuse may lead to unproductive group meetings [20], job dissatisfaction [1] and high costs, either due to the time directly devoted to the meetings, or to opportunity costs, i.e. time wasted that could be used in more productive activities [2, 21]. On the other hand, an excessive reduction of the number of meetings limit access to needed information and may also cause employees' job dissatisfaction [2].

The most frequent mode for conducting group meetings is face-to-face. Despite enabling a comprehensive media for exchanging non-verbal communications, face-to-face meeting have numerous problems [22]: obtaining meaningful responses deriving from the inability of some individuals to express their ideas publicly and because of time limitations; limitations with group size, which normally reduces the opportunity of an individual to make his/her contribution and costs associated with the time and resources required in the schedule, coordination and realization of group meetings.

The advent of advanced information and communication technologies (ICT) is having a considerable impact in the way people communicate inside organizations. In this domain, Group Support Systems (GSS) is an electronic meetings system technology consisted of a network of computers connected to support group meetings and collaborative work [23, 24].

GSS may include a number of tools and techniques designed to facilitate several tasks in group discussions, such as problem definition, explorations of issues, consensus building, group writing, activity coordination, knowledge sharing and accumulation, data and decision analysis [25]. GSS may also use a divergent information gathering software in order to collect a large number of ideas quickly [26].

Three basic features characterize GSS: asynchronous communication, anonymity and collective memory - the access to previous participants' inputs [27]. GSS are expected to benefit group meetings in the sense it may free individuals from group conformity and scrutiny [28]. Despite such advantages, some studies indicate that GSS may have lower performance in particular issues, namely in decision speed [29] and effectiveness of leadership and coordination competence over time [30] and group cohesion [31]. GSS may also be embedded with group management techniques such as the Delphi method and Nominal Group Technique (NGT) to improve the coordination and effectiveness of group meetings [32].

Nowadays, GSS are having a significant impact in the socio-technical designs of organizations, especially in larger groups, where GSS has proved to be most effective [33]. There is also an increasing usage of the structure of social networking in GSS [34, 35].

The objective of this study is to analyze the contribution of GSS in technology strategy formulation. This paper differs from the study developed by Torkkeli and Tuominen [36] which examined the role of technology selection in managing core competencies and identified several characteristics of GSS that may contribute to fulfill the requirements of this process. In this study, a further level of analysis is included in the sense that inherent characteristics of activities involved in an organization process—technology strategy formulation—are analyzed and contrasted with the potential contributions from the adoption of GSS.

3 Research Methods

The research method used in this paper is based on the review of existing literature about GSS with focus on a specific organizational process—technology strategy formulation. A technology strategy framework composed of a number of activities is used as lens for analyzing potential contributions from GSS features.

4 GSS in Technology Strategy Formulation

This section presents a review and analysis of the use of GSS in different stages of the technology strategy formulation process, as evidenced in the literature review section. It highlights specific features of GSS and their potential contribution to each of the aforementioned activity.

4.1 Activities and Applications of GSS

GSS are primarily useful for quickly gathering inputs from multiple participants, disseminating this information and in providing structure for collective decision-making. Table 2 presents a review of applications of GSS in different activities of technology strategy formulation. A discussion on each of the activity is provided below.

The activity of assessing internal capabilities deals not only with technical competencies, but also with management skills, and often involves the discussion of sensitive issues such as those related with the leadership exerted by top management. This discussion may lead to internal divisions and biased assessments. Anonymity enabled by GSS may exempt employees from social pressures and dominant personalities, thus contributing with more engagement and more accurate assessments of internal capabilities. In terms of tools, internal audits have been used

Table 2 Technology strategy activities and GSS applications

Technology strategy activities	Examples of applications	GSS features
Internal analysis	[37]	Asynchronous communication, anonymity, group memory.
External analysis	[38–42]	Consensus building, collaboration, electronic documentation, moderation/facilitation, asynchronous communication, descriptive statistics.
Generation	[43, 44]	Group memory, asynchronous communication, moderation/facilitation, proposal submission.
Selection	[45–47]	Group memory, consensus building, and asynchronous communication.
Monitoring	[48]	Group memory.

as tools for organizations to self-assess their technological capabilities and to analyze whether the conditions for managing technological innovation are present in the organization. The technological innovation audit proposed by Santos et al. [37] is embedded with the Real Time Delphi method [49] and enables the anonymous participation of employees involved in an organization's technological innovation process in the internal capabilities evaluation. Additionally, group memory is accessible in the sense that participants of the audit can visualize and reply to comments from others, which can contribute to the convergence of judgments towards consensus building.

The external analysis is being increasingly supported by ICT tools. In fact, the results from a survey with foresight experts points to a greater use of ICT in foresight processes and a transition from standard information gathering functionalities to the interpretation of this information for strategy making [50].

The *context-based* or *open foresight* [51] is an emerging foresight paradigm that puts more emphasis in communication and creativity among relevant stakeholders inside organizations. In line with this paradigm, GSS may contribute with greater collaboration among a larger number of actors with different perspectives, for raising a higher number of ideas and validating them [40], thus supporting communication and gathering of anonymous feedback and their aggregation in collective insights about technological, economic and societal developments [38] and in the establishment of rules of order in decisions through facilitated group discussions [39]. The web-based system proposed by Spithourakis et al. [42] combines features of forecasting, such as descriptive statistics, with the "soft" factors of foresight to improve user experience and gather a better knowledge about a problem.

The generation activity is, perhaps, the most dependent on the creativity of involved actors. Through enabling group memory, a repository of ideas is continuously and collectively created for proposal submission [43] and concepts generation [44]. When coupled with *technology intelligence systems* [52, 53], the generation activity can benefit with greater analytical content by keeping an extensive database that gathers, analyzes and disseminates relevant information about new technologies, patents, standards, regulations, trends and others to participants in the innovation process of an organization.

The selection activity is typically a GSS embedded with a decision-making procedure, however, GSS which merges external analysis and selection activities have also been proposed [39]. According to Bozdağ and colleagues [54], the selection of technology projects is a multi-dimensional and complex task which involves considerable uncertainty, and therefore should include non-quantifiable, intangible criteria, in which human reasoning is critical and GSS can leverage this through intensive group interaction. The model proposed by Zandi and Tavana [46] also include subjective criteria and considers the interdependencies between information technology (IT) projects. An organizational decision support system (ODSS) is proposed by Tian et al. [45] to address two particularities of typical R&D project selection: as a typical multi-stage decision-making process and the involvement of groups of people from different organizational units. On the other hand, Choudhury et al. [47] highlights the disadvantages of asynchronous communication in building consensus and adopts the concept of consensus measure to improve on the group interaction process and replace the role of a moderator.

Compared to the previous activity, monitoring has received less attention for GSS development, which can be partially explained by being often performed by management control groups instead of being a bottom-up process. Dennis et al. [48???] has recalled the importance of group memory for retrieving information about past decisions and goals initially set to compare with performance of the strategy under implementation.

4.2 Contributions for Group Dynamics

Besides removing geographical and time restrictions in communications (through asynchronicity and group memory), GSS provide a number of features that improve the way groups of people can interact towards a common goal. In a review of various studies that compares asynchronous GSS and face-to-face group meetings, Tung and Turban [55] identified a number of implications of adopting GSS in group dynamics: increased *choice shift* among participants which contributed to achieving consensus; improved *conflict management* where disagreements and conflicts were more easily overcome in GSS meetings, *focus of participants*, with respect to task orientation and productivity and *performance*, more specifically concerning the quality of ideas generated by groups of people.

In a longitudinal study aimed to offset likely biases in the evaluation of GSS, Reinig and Shin [56] selected three issues commonly associated with face-to-face meetings—production blocking, free riding and sucker effect—and found that the adoption of GSS improves group cohesion, self-reported learning and affective reward, although they could not conclude on the individual level of influence of each of the analyzed features of GSS (anonymity and simultaneity).

The nature of the tasks being performed has natural implications in the use of GSS. If consensus building is the ultimate goal of the process, GSS should be not be used in stages when factual information is exchanged, but only when decision options are being analyzed and selected [57]. Concerning the information being shared in regular and non-regular or role-assigned GSS meetings, Vathanophas and Liang [58] found that in the first, participants tend to use more commonly shared information while in the latter unique or individually held information are more shared to support collective knowledge homogenization of groups with different fields and levels of expertise. Minorities tend to experience greater uncertainty, greater conformity, lower satisfaction and produce lower quality decisions in groups that share common perceptions and beliefs and when non-anonymous communications are enabled [59].

Over a decade ago, Shim et al. [60] provided a research agenda for GSS in which they highlighted the need to address incomplete data and qualitative insights from participants through the infusion of intelligence systems and methods in GSS. Now, with the emergence of advanced artificial intelligence, there are several opportunities for GSS in organizations. On the other hand, Ackerman and Eden [61] warn about the dangers of technological opportunism and argues that mixed techniques which incorporate single user and manual methods should be promoted as to complement divergent thinking—through the rapid generation and proposal of ideas supported by GSS technologies—with human facilitated convergent thinking for adequate and inclusive decision-making. This aligns with the findings of Limayem et al. [62] which indicated that the assimilation of GSS structure should be accompanied by tailored training and decisional guidance.

5 Conclusions

The socio-technical design of organizations has been strongly influenced by advances in GSS. The massive use of social networking is an evidence that GSS has the potential of drastically changing how groups of people make decisions [34, 35]. This paper presents an extensive review and an analysis of GSS literature, with emphasis on GSS applications in different stages of the technology strategy making process.

In literature, while much focus is being put in observing the determinants of information sharing and adoption of GSS, much has been left untreated with respect to implications in different organizational settings and task specificities. In this paper, we expect to fill this latter gap by relating features of GSS, derived from literature, with the activities and stages of a specific decision-making process in organizations—technology strategy formulation. The characteristics of such activities are analyzed in order to specify how groups of people analyze information and make decisions collectively, and thus relate such issues to the potential contributions from the implementation of GSS. Additionally, the way GSS influence group dynamics towards achieving greater meetings' results were also highlighted.

We expect that, with this study, some design principles for GSS for technology strategy formulation in organizations can be identified. Further work needs to be done to generalize these findings, by analyzing other organizational decision-making practices.

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Projecting Efficacy and Use of Business Simulation Games in the Production Domain Using Technology Acceptance Models

Philipp Brauner, Ralf Philipsen and Martina Ziefle

Abstract Globalized markets, product complexity, and increased requirements on quality lead to growing complexity of business and manufacturing processes. Game-Based learning environments and business simulation games offer great potential to prepare employees the increasing complexity. As it is unclear who profits most from these learning environments, we did a study with 66 participants on a game for conveying Production Planning and Control and Quality Management. In our research model we combined personality attributes and two common technology acceptance models to determine factors projecting performance in the game and projected later use of business simulation games in general. We found that main drivers for usage are performance expectancy and transfer of skill, i.e., the perceived applicability of the learned knowledge and skills for the later work. The attained performance is unrelated to the projected use. The article concludes with guidelines to increase the likelihood for the later use of business simulation games and for increasing their overall efficacy.

Keywords Serious game · Game-based learning · Business simulation game · Production planning and control · Quality management · UTAUT2 · Supply chain management · Technology acceptance · Human factor · System thinking

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1 Introduction

Today's globalized markets are characterized by increasing complexity of cross-national supply chains, growing variant diversity, and rising pace. In order to sustain at the market, manufacturing companies must enhance their competitiveness. Methods to increase the competitiveness include novel products and services, increased efficiency in production and administration, but also smarter personnel that handle the complexity of todays' world more efficiently. One specific area of interest is production planning and control and quality management: While most aspects are rather easy to comprehend when considered individually, the true complexity unfolds in the conjunction of all aspects to be considered.

One necessary skill of tomorrow's decision makers is "*Systems Thinking*": The ability to understand that systems are more than the sum of their parts and that the systems' behavior emerges from the dynamic connections and feedback loops between its parts. Peter Senge defines this as a "*way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of systems. This discipline helps us to see how to change systems more effectively, and to act more in tune with the natural processes of the natural and economic world.*" [1]. In fact, Forrester used this methodology to describe the complexity and relationships in production processes using System Dynamics modeling [2].

The important question is, how Systems Thinking can be conveyed to scholars, such as, university students from mechanical engineering and prospective managers in this domain. A prominent methodology is the use of business simulation and serious games. Beyond traditional transmission of knowledge, these environments allow the active exploration of cause-and-effect relationships of complex and interconnected systems in simulated and safe environments. However, it is not sufficiently understood yet, if serious games are preferred over conventional knowledge dissemination forms and which user and system characteristics of serious games contribute to an increased acceptance.

To explore if serious games are appropriate to convey Systems Thinking and to identify the factors that contribute to an increased acceptance of game-based learning, we applied the technology acceptance research methodology on a business simulation game that conveys knowledge of material disposition and quality management.

This article is structured as follows. Section 2 outlines related work in regard to technology acceptance models and serious games. Section 3 presents our experimental approach and the sample of our study. Section 4 presents the findings of this research endeavor. Section 5 discusses the results and their implications for implementing serious games as a teaching method and for developing further serious games. Finally, Sect. 6 addresses the limitations of this study and outlines the future research agenda.

2 Related Work

The following paragraphs introduce technology acceptance research and its models. Afterwards serious games and their application domain are outlined. Finally, serious games from the domain of production engineering are presented.

2.1 Technology Acceptance Models

The goal of technology acceptance research is to predict the active adoption of a technology as well as the likelihood of a technology to be used by people. What is central here is to identify the learners' personality as well as supportive and impeding system factors that govern this adoption, to address these factors through adopted designs, improved training materials, or optimized dissemination strategies.

Many empirical technology acceptance models are rooted in Fishbein and Ajzen's *Theory of Reasoned Action (TRA)* [3] that postulates a strong relationship between the *intention* to do something and the actual *doing*. In this model, as well as in the subsequent technology acceptance models, the intention to use is governed by the attitudes of an individual. In TRA the *intention* to do something is related to the *attitude* and the *subjective norm* of an individual towards the behavior. For example, an individual can like playing games (attitude), which might increase the intention towards serious games, but may consider playing as socially undesirable (*subjective norm*), which would dampen the intention to use serious games.

Based on this model the *Technology Acceptance Model (TAM)* [4] suggests that the intention to use software at the workplace is largely controlled by the *perceived usefulness* and the *perceived ease of use* of the software. The perceived usefulness refers to the perceived benefits of using the software to achieve better results or to achieve results in shorter time. The perceived ease of use captures how usable and how learnable the software is evaluated by an individual. Using this model, about 51 % of the variance in actual use of software could be predicted in advance. The original TAM and many of its successors (e.g., [5, 6]) primarily addressed business software used in work contexts.

A model that specifically aims at predicting the adoption of consumer products with voluntary usage is the *Unified Theory of Acceptance and Use of Technology 2 (UTAUT2)* [7]. It postulates that intention to use is controlled by the seven dimensions *performance expectancy (PE)*, *effort expectancy (EE)*, *social-influence (SI)*, *price-value (PV)*, *hedonic motivation (HM)*, *facilitating conditions (FC),* as well as *habit (HA)*: *Performance expectancy* refers the individual's perceived benefits of using the technology (cf. perceived usefulness in TAM). The *effort expectancy* addresses the perceived effort for learning or using the technology (cf. perceived ease of use). The *social influence* comprises how an individual perceives the reaction of his/her peers regarding the technology. That is, a technology might be judged as beneficial for doing something (*PE*) and easy to use (*EE*), but through negative expectations regarding the social environment (*SI*) it might still not be indented to use. The *price-value* dimension captures that a technology might be perceived as useful, but not worth the money. The *hedonic motivation* addresses that a technology ought to be fun to use, especially when the use of the technology is voluntarily. The *facilitating conditions* capture the environmental and contextual aspects that support or diminish the usage of a technology. For example, the technology must be compatible with other technologies in use or help should be available if difficulties emerge. The last dimension *habit* refers to the individual's perception of integrating the use of the technology in the daily routine.

Another model that specifically addresses serious games is the Serious Games Technology Acceptance Models (SG-TAM) [8]. Despite being still in its infancy, the model builds on the theoretically sound dimensions *Transfer of Skills (TOS)*, *Learner Control (LC)*, *Situated Learning (SL)*, and *Reward (REW)*. *Transfer of Skills* refers to perceived abilities to apply the learned knowledge to other tasks or to a later job. *Learner control* addresses the player's perception of adjusting the game to his or her own pace. *Situated Learning* describes the player's perception of a similarity between the game environment and the real life. Finally, *Reward* records if the players feel that the feedback and positive reinforcement encourages further interaction with the game.

2.2 Serious Games

Michael and Chen [9] define a serious game as "*a game in which education […] is the primary goal rather than entertainment*". They build on the famous Premack principle [10] to link undesired activities—such as learning, exercising, change attitudes, or behaviors—to pleasant activities—in this case playing. They are very successful in the medical domain, for example for conveying knowledge about a disease [11], for supporting a rehabilitation [12], or for enhancing cognitive control of elderly [13].

Prensky argues that game-based learning environments are a necessity to address the knowledge dissemination needs of Digital Natives, Millennials, and the Generation Y [14]. These generations grew up with ubiquitous information and communication technologies they are not easily attracted by conventional didactical approaches.

2.3 Serious Games for Production Systems

A prominent example for a serious game in production engineering is Forrester's Beer Distribution Game [15, 16] that aims at sensitizing dispatchers and schedulers for the "Bullwhip effect" in supply chains, i.e. that order quantities can quickly escalate along multiple tiers and that sharing point-of-sale information across the supply chain can reduce this effect. Multiple players form a multi-tier market driven supply chain, ordering information flows upstream from the customer, to subsequent tiers, to the factory, whereas the produced goods flow downstream from factory to customer.

Goldratt introduced variances to this kind of business simulation game [17]. In his hypothetical game orders are not fulfilled completely, but capped by a dice toss. He concludes that variances in a supply chain limit their overall performance.

Stiller et al. [7] combined material disposition from the Beer Distribution Game with variances in production quality into the game model *Quality Intelligence Game* (aka. *QI-Game*). In contrast to previous games, players need to balance investments for managing the inventory, incoming goods inspection, as well as investments in the own production quality. Broken and undetected bought-in parts cannot be fixed during the production and the customer detects all defective parts. Thus, missing one of the three key aspects (stock management, quality of incoming goods, own production quality) yields in disastrous performance. Figure 1 illustrates the game's user interface.

In a recent article we compiled four basic methods for using game-based learning environments and business simulation games as empirical and interactive research environments [19]: The various in-game metrics (e.g., company's profit, stock levels, and customer complaints) can be related to gaps in knowledge and identify learning potentials, classify the task fit of job applicants, isolate underlying human-factors relating to performance, and help to critically benchmark user-interface aspects [18]. Serious games are rarely evaluated using formal technology acceptance models. Two of the few examples are the evaluation of a physical exercising game [20] and a game for cognitive functioning [21] in technology-augmented habitats using the before-mentioned UTAUT2 technology acceptance model.

To address this void and to identify factors that are crucial for the use of serious games for knowledge dissemination in quality management, mechanical engineering,

Incoming Parts

Delivered parts: 103
Rejected parts: 7
Quality of sample: 93%

Warehouse and Logistics

Price / part: 100 €
Storage costs / part: 50 €
Contract penalty / part: 500 €
Stock: 385
Demand: 106

Production and Sales

Price / product: 500 €
Sold products: 94
Rejected products: 22
Product quality: 77%

Production planning and control for the upcoming month

Investments into part inspection: 9400 €
Component order at the supplier: 103 Parts
Investments into production quality: 14400 €

Fig. 1 Illustration of the quality intelligence game (see [18] for details) and production engineering we applied technology acceptance research on the Quality Intelligence Game in a formal user study. The next section presents our approach.

3 Method

To investigate if business simulation games will be used and which specific aspects promote or undermine the use we conducted a formal experiment using the before mentioned *QI-Game* (see Fig. 1). The following sections describe (1) the experimental procedure, (2) the experimental variables, and (3) the sample's characteristics.

3.1 Experimental Procedure

The interaction with the *QI-Game* is accompanied by a proceeding survey to assess demographics and personality attributes and a subsequent survey to measure the evaluation of the game. Both surveys and the in-game metrics (e.g., attained performance, number of interactions) are linked using a hidden unique identifier. The game is presented in a rather easy setup, meaning that no sudden changes in the supplier's delivery quality or the internal production quality occur (contrary to [18]). The link to the study was distributed through regular and computer-mediated social networks among our students. Hence, we assume that we have addressed mostly university students.

3.2 Investigated Variables

Independent Variables. As independent variables we captured the *age* and *sex* of the participants, as well as three personality traits and states:

Self-efficacy in Interacting with Technology (SET). This construct captures the individual's believe to be able to master technology and to solve technical problems [22]. It is a key variable to predict efficacy, efficiency, and user-satisfaction in interacting with technology. It could therefore relate to the evaluation of and the attained performance in computer-mediated serious games and that people with lower SET scores achieve lower scores and are less inclined towards the game (e.g., [20]).

Attitude Towards Serious Games (ASG). We measured an individuals' attitude towards Serious Games to convey knowledge through four items. This new scale achieved an outstanding internal reliability [Cronbach's $\alpha = 0.917$, 4 items, $n = 66$].

Need for Achievement (NA). This trait refers to the desire and the continuous efforts to achieve difficult goals [23]. We suspect, that NA influences the performance and the intention to use the game to gain a competitive advantage in this domain.

Dependent Variables (Subjective). We measured the seven dimensions from UTAUT2 (see Sect. 2.1). We further included the four dimensions of SG-TAM *Reward*, *Learner Control*, *Transfer of Skills*, and *Situated Learning*. We assume that using serious games is perceived as fun and entertaining, but potentially as less efficient than listening to lectures or reading a reference book. Hence, we also assess the perceived *Time-Value (TV)* tradeoff.

Four items capture the *Intention to Use* serious games ($\underline{\text{BI}}$) [Cronbach's $\alpha = 0.737$]. This construct is divided into items that address this specific game and serious games for knowledge dissemination in general.

Dependent Variables (Objective). In addition to the subjective measures from above, the game captured several objective metrics through log-files of the game environment: We investigated the influence of the attaint overall performance and the number of changes to the three controllers in the game's user interface (incoming goods inspection, procurement, internal production quality).

Methods. All subjective measures were captured through six-point Likert scales. The data is analyzed with parametrical and non-parametrical methods, using bivariate correlations and multiple linear regressions. The STEPWISE method is used in the multiple linear regressions and models with high variance inflation (VIF $\gg$ 1) are excluded. The type I error rate (level of significance) is set to $\alpha = 0.05$ and findings $0.05 < p < 0.1$ are reported as marginally significant.

3.3 Description of the Sample

66 people aged 20 to 56 years (median 24 years) participated in the experiment (8 female, 57 male, 1 unspecified). Sex was neither associated with Self-efficacy in interacting with technology (SET) [$\rho_{n=64-2} = -0.081$, $p > 0.1$], Need for Achievement (NA) [$\rho_{n=65-2} = -0.084$, $p > 0.1$], nor the Attitude Towards Serious Games (ASG) [$\rho_{n=62-2} = -0.133$, $p > 0.1$]. However, SET is strongly associated with NA [$\rho_{n=65-2} = 0.519$, $p < 0.001$] and weakly associated with ASG [$\rho_{n=62-2} = 0.262$, $p = 0.042 < 0.05$]. Finally, ASG is positively related to NA [$\rho_{n=63-2} = 0.421$, $p < 0.001$].

30 participants dropped out during the study (45 %, sic!): 5 during the pre-questionnaire, 18 during the game, and 7 during the post questionnaire. The dropout rate during the pre-questionnaire is negatively associated with the gaming motivation [$\rho_{n=62-2} = -0.281$, $p = 0.026 < 0.05$] and the dropout rate at the post questionnaire is negatively linked with the learning motivation [$\rho_{n=61-2} = -0.254$, $p = 0.048 < 0.05$]. The results section is based on the completed sets and single missing times were deleted on a per-test basis.

4 Results

This section is structured as follows: We first present the determinants for an increased interaction with the game. Second we show the determinants for performance in the game. Third, we explore the components for an increased acceptance. Fourth, we complement the study by reporting verbal feedback of the study's participants.

4.1 Determinants for Increased Game Interaction

The number of changes to the controls in the game varied from 3 to 39 (mean 22.6 ± 10.6, median 22). The single explanatory variable influencing the number of changes is self-efficacy in interacting with technology. People with higher SET did significantly more changes [$\rho_{n=36-2} = 0.367$, $p = 0.028 < 0.05$].

Considering the three levers individually, we find that changes to the incoming goods inspection as well as the procurement [$\rho_{n=36-2} = 0.545$, $p < 0.001$], procurement and own production quality [$\rho_{n=36-2} = 0.560$, $p < 0.001$], and incoming goods inspection and own production quality [$\rho_{n=36-2} = 0.787$, $p < 0.001$] are positively related. This indicates that some people explore the game environment more thoroughly than others. Specifically, we found that people with higher SET experimented with the controls for the incoming goods inspection more often [$\rho_{n=36-2} = 0.465$, $p = 0.004$] and NA also seems to affect this measure [$\rho_{n=36-2} = 0.282$, $p = 0.096 < 0.1$].

4.2 Determinants for Performance

As the *Performance* is not normally distributed [$Z = 0.961$, $p = 0.314 > 0.05$], we refrain from investigating the contributing factors with parametrical methods and report Spearman ρ-coefficients instead. Outcomes are depicted in Table 1. Most independent variables did not relate to the achieved *Performance* in the game. In fact, the only significant relationships are the attitude towards serious games ASG [$\rho_{n=36-2} = -0.327$, $p = 0.051 < 0.1$] and the need for achievement NA [$\rho_{n=36-2} = -0.329$, $p = 0.050 < 0.1$]. Both had a negative influence on performance. Yet, *Performance* is strongly associated with the subjective relative performance [$\rho_{n=36-2} = 0.528$, $p < 0.001$] and the individual's satisfaction with his or her result [$\rho_{=36-2} = 0.672$, $p < 0.001$]. Surprisingly, the number of interactions within the game (see previous section) is also not related to performance [$\rho_{n=36-2} = 0.235$, $p = 0.135 > 0.1$].

Table 1 Spearman's ρ-correlation coefficients for the user factors and the UTAUT2/SGTAM model dimensions (listed if $p < 0.1$, *<0.05, **<0.001)

	EE	PE	HE	FC	SI	PV	TV	REW	LC	TOS	SL	BI
EE	–	0.732^{**}	0.780^{**}	0.447^{**}		0.466^{**}	0.601^{**}	0.693^{**}	0.698^{**}	0.684^{**}	0.434^{*}	0.603^{**}
PE		–	0.671^{**}	0.502^{**}		0.630^{**}	0.516^{**}	0.733^{**}	0.372^{*}	0.834^{**}		0.790^{**}
HE			–	0.497^{**}		0.419^{*}	0.309	0.782^{**}	0.495^{**}	0.720^{**}	0.289	0.619^{**}
FC				–	0.280	0.357^{*}	0.365^{*}	0.498^{**}	0.463^{**}	0.548^{**}		
SI					–							
PV						–	0.717^{**}	0.417^{*}		0.633^{**}	0.317	0.415^{*}
TV							–			0.594^{**}		0.359^{*}
REW								–	0.417^{*}	0.745^{**}		0.595^{**}
LC									–	0.354^{*}	0.432^{**}	
TOS										–		0.747^{**}
SL											–	
SET	0.588^{**}	0.410^{*}	0.574^{**}	0.399^{*}		0.419^{**}	0.472^{**}	0.486^{**}	0.372^{*}	0.534^{**}	0.407^{*}	0.401^{*}
ASG	0.398^{*}	0.477^{**}					0.357^{*}	0.309		0.491^{**}		0.682^{**}
AM	0.319	0.334^{*}	0.349*	0.441*				0.480^{*}		0.470^{**}		0.405^{*}

4.3 Determinants for Acceptance

The overall intention to use the game as a tool for exam preparation is governed by SET [$\rho_{n=36-2} = 0.401$, $p = 0.015 < 0.05$], ASG [$\rho_{n=36-2} = 0.682$, $p < 0.001$], and the NA [$\rho_{n=36-2} = 0.405$, $p = 0.014 < 0.05$].

Performance did neither influence the overall intention to use the game [$\rho_{n=35-2} = -0.155$, $p = 0.373$], nor the individual dimensions from UTAUT2 or SGTAM ($\rho_{max} = 0.224$).

However, there is some evidence that the number of changes to the game environment relates to the usage intention [$\rho_{n=36-2} = 0.293$, $p = 0.088 < 0.1$].

From the perspective of the UTAUT2 and SGTAM models the results indicate a strong positive relationship of most variables on the intention to use the game BI and a strong interconnection between the model's variables (Table 1 summarizes the results). The three strongest influencing factors are Performance Expectancy PE [$\rho_{n=36-2} = 0.790$], Transfer of Skills TOS [$\rho_{n=36-2} = 0.747$], and Hedonic Motivation HE [$\rho_{n=36-2} = 0.619$]. Within the sample, neither Facilitating Conditions FC, Social Influence SI, Learner Control LC, nor Situated Learning SL significantly influence BI.

As most of the constructs are closely interwoven, the usual procedure would be the application of multiple linear regressions with the user factors and/or the models' factors as independent variables and BI as a dependent variable to untangle this complex net of intercorrelations (cf. [21]). However, due to the small sample, this method yielded only in a single significant model for the user factors and for the models' factors: The model based on the user factors identifies attitude towards serious games ASG as the single predictor for intention to use the game, explaining 61.7 % of the variance in BI ($r^2 = 0.617$, $\beta = 0.792$). From the perspective of the UTAUT2 and SGTAM variables, the model with the single predictor PE explains 59.2 % ($r^2 = 0.592$, $\beta = 0.778$) of the variance in BI. However, we suspect that a larger sample size will reveal multifactorial relationships between user and model factors on BI.

4.4 Qualitative Findings

The participants expressed mostly positive feedback on the overall game. One participant expressed the overall suitability of the game to convey knowledge about production planning and control PPC: "*[…]is really good and useful for understanding the concepts of PPC.*". Another participant suggested the offering of additional games targeted at different learning objectives and postulated higher learning achievements: "*Game was great… need more such games with different concepts. It encourages involvement and understanding real life scenarios*.". Another participant articulated his or her content by stating that the game "[…] *is one of the best way[s] to learn practical industrial problems. This is [a] very nice Game.*"

Criticism was only articulated in regard to the length of the experiment and the administered questionnaires, or to suggest improvements to the game's user interface.

5 Discussion

The presented study provides valuable insights into the acceptance of business simulation games and serious games in general.

First, the overall acceptance of serious games for conveying knowledge of production planning and control and quality management was high, as highlighted by predominantly positive qualitative feedback.

Second, the findings regarding the determinants for attainted performance are counter-intuitive: People with a higher inclination towards serious games and people with higher need for achievement reached—on average—lower scores in the game. We assume that our newly integrated Decision Support System that suggests rather good values causes this effect: Players with the desire to outperform others (e.g., due to their high need for achievement or their high inclination towards games) try to outsmart the game and eventually make mistakes. These are currently difficult to compensate and may then lead to poorer performance compared to those players that solely rely on the suggested values. Surprisingly, we learned that the overall intention to use the game is *not* governed by the attaint performance, but seem to relate to the number of changes to the game environment. Therefore, a follow up study should investigate how performance evolves, depending on the number of rounds played and the number of lessons learned from toying around with the game's controls.

Third, from the perspective of the personality traits and states the study revealed that the trinity of self-efficacy in interacting with technology, need for achievement, and attitude towards serious games are basic constituents of the acceptance of business simulation games, with the latter being the strongest. As these three dimensions are closely interwoven and due to the small sample size, their isolated influence on the usage intention cannot be calculated yet and we suggest a replication with a larger sample. But even now, we observe the strong influence of the attitude towards serious games on the intention to use a serious game (similar to [20]). This seems obvious at first, but unfolds its considerable consequences at the second glance: Serious games will work splendidly, but only for people who enjoy games. People that do not enjoy games might be excluded if teachers exclusively build on game-mediated knowledge dissemination. Hence, we strongly argue for multi-method didactical approaches. Meaning that learning material should be provided in various forms to fit the diverse wants and needs of an increasingly diverse audience.

Fourth, the combination of the UTAUT2 and the SG-TAM model to investigate the acceptance of the QI-Game and business simulation games in general seems to be very promising. Despite the small sample, seven of the eleven dimensions positively relate to the intention to use the game. More importantly, the two strongest predictors *Performance Expectancy* and *Transfer of Skill* originate from the two different models and their influence on BI sustains, even if controlled for the other variable [$r_{PE,BI \backslash TOS} = 0.420$, $p = 0.010 < 0.05$; $r_{TOS,BI \backslash PE} = 0.276$, $p = 0.099 < 0.1$]. This indicates that both models complement each other and may—in combination—contribute more explained variance in BI and later USE than each individual model. Likewise, the newly introduced concept of the *time-value tradeoff* for modeling the invested time for pervading a subject matter also relates to BI and seems to be adequately distinct from the other dimensions of our model. Hence, introducing a time-value tradeoff seems reasonable and a valuable contribution to the methodology of technology acceptance research. Obviously, a follow up with a significantly larger sample should address these two hypotheses.

Fifth, although the strongest predictors could only be picked manually (i.e., without controlling for cross-correlations), we found that *Performance Expectancy* and *Transfer of Skill* were the two dominant predictors that govern the intention to use the game. This directly relates to guidelines for designing future business simulation games for conveying production planning and control, quality management, Systems Thinking and alike: First, these games must be designed and introduced in the way that the individual learners perceive them as directly valuable for their short term benefit, e.g. by positively relating the interaction with the game and the insights gained therefrom to an increased performance in an upcoming exam. Second, by strengthening the belief that the lessons learned in the game will have a long-term benefit in the later work experience and providing adequate examples.

Based on the empirical findings and the analysis of the dimensions from the acceptance models from above, Table 2 presents practical guidelines for designing serious games and to increase their efficacy and likelihood of use.

Table 2 Guidelines for business simulation games derived from the study

Priority	Guideline
1	Provide clearly visible short-term benefits of using the game. E.g., by making clear that the conveyed skills will be beneficial for an upcoming exam. (Based on PE)
2	The player must perceive the presented environment as a simulacrum of the reality. E.g., by portraying realistic production processes. (Based on TOS)
3	Consider learner diversity, especially in regard to different levels of inclination towards games. E.g., by augmenting the game environment with traditional forms of knowledge dissemination. (Based on ASG)
4	Create enjoyable learning environments. E.g., by including potential players in the development to ensure target specific aesthetics and playfulness. (Based on HE)
5	Avoid unnecessary complexity of the user interface and the simulation model, and provide a focused learning experience. E.g., by reducing the perceived effort for mastering the game through guided tutorials, help functions etc. (Based on EE)
6	Provide adequate and immediate feedback on the learning performance. E.g., by linking the learning objectives with the company's profit or by adding motivational incentives (badges, leaderboards, …). (Based on REW)

In summary, the results of the study highlight an increasing importance of Systems Thinking and unfolds principles to design serious games to convey this methodology.

6 Limitations and Outlook

The findings presented above need to be validated with alternative game concepts and different learning objectives to evaluate if the same pictures emerge and the same design guidelines can be concluded. Furthermore, they are based on a small, rather young, and homogeneous sample. Future studies should address the upcoming shift in the demographic structure of many western societies and should investigate the interrelationship of age, the ability to cope with complex socio-technical production systems, and the intention to use business simulation games as a training vehicle.

The study had an unusual high dropout rate. We found hints that this rate is related to a lack of interest in gaming and a lack of perceived learning discipline. A follow up study in a controlled environment with fewer dropouts should investigate the causes for the lack of interest that eventually yields in quitting the study and the game.

The current study did not address if the Systems Thinking abilities were actually positively influenced by the game. We learned from previous studies that the players indeed increased their performance across multiple rounds of the game and that the game positively influenced the attitude towards quality management [24]. Still, the external benefits of this approach in regard to Systems Thinking abilities have not yet been shown. Apart from that we are curious how Systems Thinking abilities might be operationalized in order to formally evaluate the effectiveness.

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The Dimensions of Seaports Management in a Static Systemic Approach: A Case Study for Poland

Janusz Rymaniak

Abstract The paper presents a proposal for studying seaports as an open system. The Author emphasises the specific nature of seaports, their role and intra-organisational functions, as well as their positioning in terms of location. This forms the basis of the research concept, especially the dimensions, criteria and their indicator operationalisation. The research study applies taxonomic methods to verify the assumptions based on the example of Polish seaports in the years 2004, 2009 and 2014 (static approach). The study conclusions constitute a contribution to the discussion on the current importance of organisational efficiency management and organisation's identity, as well as the areas of development of seaports as economic nodes of social and spatial importance.

Keywords Seaports management · Resource based view · Systems engineering · Static systemic approach

1 Introduction

Creating a common European economic area accompanied by the globalisation processes, leading to the free flow of goods, services, capital and labour, result in new development requirements in each of the European Union Member States. Particularly important is the issue of an effective physical flow of goods and services, which requires that an appropriate infrastructure be developed and maintained.

Major infrastructural nodes include seaports. They play various functions, such as production, transport, logistics (forwarding and warehousing), and distribution [1]. First and foremost, seaports are gateways of the European Union, i.e. a set of entrances and exits serving the physical flow of people, goods and services. This requires a structural approach accounting for the development and providing the current technical capacity for the port functioning within the triad: foreland—basins

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and internal territory of the port, the proximal hinterland (within the port area) and the distal hinterland (cooperative and/or commercial). Development of the above mentioned areas is conditioned not only by the existence of port functions. The development level has an impact on the significance of the port in the local area, region or the maritime industry.

The administrative bodies of the uniting Europe also establish institutional conditions by implementing the TEN-T (Trans-European Transport Networks) programme, which is an EU programme regarding the road, railway, waterway and airway networks. The above mentioned infrastructure elements facilitate and accelerate the economic and social integration processes, and their implementation will enhance the development of the regions' potential, which is the major link of the EU.

At the present stage of the transformation, the discussed processes are the basis for taking decisions influencing the Member States' economic growth, as placing infrastructure elements (such as ports) on the TEN-T map preconditions the particular regions' development. This also regards the countries which joined the European Union after 2000. They are in the implementation phase, making use of the EU financing. This group also includes Poland. Research studies and expert appraisals are carried out to be used by local and state authorities, to enable them to make effective, development-oriented decisions on infrastructure. The objective of the pilot study regarding seaports was obtaining answers to the following questions:

- What developmental types of seaports are there in Poland?
- What is the position and role of seaports in view of directions of Poland's seaside regions development?

To reach these objectives, some theoretical assumptions and research methodologies were adopted, and thus obtained research results were analysed.

2 Seaport as a Research Object

The specialist literature provides various definitions of a seaport (maritime port). For the purposes of the research problems contemplated in this study, it is necessary to focus on the physical aspect of a port. In this sense, a port is a form of developing by humans a place at the border of two kinds of natural resources, i.e. at the junction of land and water [2]. The main purpose of developing such a place is gaining an extra possibility to move people and freight (products, goods, services etc.). Thus, the settlement function is extended to include enhancement of forms of contact with the surrounding areas [3]. In terms of choosing the junction, a port is a place where cargo and passengers are moved/ move directly between vessels and the shore and other means of transport. Thus, a port ensures exchange of services [4].

The contemporary developmental trends seen in seaports consist in an evolution of directions outlined for Europe by UNCTAD. They are modernized, taking into account the current globalization trends, the need to make evolutionary changes, the need for cargo unitization and containerization, and the need to implement pro-ecological solutions [5]. These are the preferred traits being the signs of the contemporary seaports “modernity”, creating an environmentally friendly system focused on three directions of development: internal structural development of a port, stimulating the local area development via extending the relations between the port and the surrounding area (the port city and the region), the port and the cluster. The clusters integrate various businesses and institutions around production and services in ports, and increase the businesses effectiveness level, which also results in growth of the port area and region.

Examining the role and significance of a port and its developmental capacity requires a systemic approach, as well as accounting for the resources [6]. In this sense, the port is a set of specific and specialised kinds of resources, without which the functioning of a port would be hindered or impossible. Systemically, a seaport consists of three parts of equal importance, which are prerequisites of its existence: the foreland, the proper port, and the hinterland (Fig. 1).

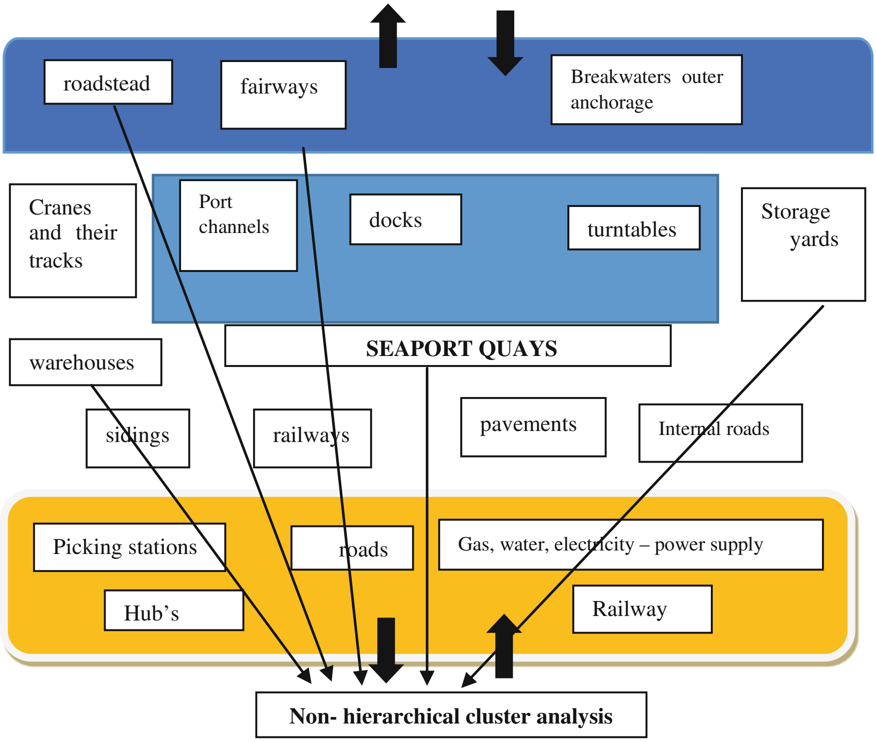

Fig. 1 Framework for the port research study in a static systemic approach

The foreland comprises various kinds of facilities that facilitate and/or enable physical access to the port. In the normative nomenclature they are referred to as facilities, equipment and systems being part of the infrastructure for providing access to ports [7]. These include: fairways, leading light beacons, fixed and floating navigation signs, external breakwaters, lighthouses and electric beacons, electric power supply facilities, and also other systems (e.g. monitoring systems, FANSWEEP integrated mine-sweeping and hydrographic system; POLARTRACK laser set, "Vessel Traffic Service"—integrated system for vessel traffic supervision and control, etc.). All of these, referred to as the access infrastructure, are located in the basins in front of the port, and also onshore (e.g. lighthouses). They enable safe vessel traffic due to the port positioning and indicating the traffic routes for the vessels.

The proper port consists of two parts: the aquatic area and the land area. The aquatic part of the port includes its internal waters such as outport, port canals, basins, docks and turning basins. The facilities installed in the land part include wharves and other mooring facilities (pile dolphins, piers, jetties, shore reinforcements), freight lifts and cranes with rail tracks, storage yards, warehouses, silos, hardened surfaces, roads, electric power supply networks, water supply and sewage systems, gas pipelines etc. In the normative nomenclature, the equipment of a proper port is referred to as port infrastructure.

The third part is the hinterland, i.e. the access area to the port from the land side [8]. Hinterland may be proximate or distal. The proximate hinterland comprises the road, railway, waterway or pipeline networks. Some of the elements playing the role of transport nodes such as airports or railway stations fulfilling the classification functions for airports (e.g. Zajączkowo Tczewskie for Gdańsk) are located within 100 km from the seaport. The distal hinterland, in turn, comprises classification terminals referred to as dry ports. A dry port needs a direct transport link, or the so-called shuttle service, to the high-capacity seaport and it is capable of fulfilling all the functions of a seaport except for loading and unloading goods to/from vessels [9]. The access infrastructure and port infrastructure are subject to legal regulations [10]. Their scope is stipulated in appropriate legal acts, and their provisions are mandatory in the extent provided for therein. In the context of research approaches, infrastructure is also divided into two kinds, referred to as infrastructure and suprastructure [11]. The term "suprastructure" is understood as movable tangible assets characterized by: possibility to change the place and function, or a shorter period of (d)investment. These include e.g. mobile cranes, vessels of variable functions (e.g. floating warehouses), temporary use of car parks for storage of containers, etc. Thus, the division introduced by researchers accounts for the effects of technical progress which more and more often enables application of flexible and seasonal organizational solutions aimed at performance, efficiency, and cost effectiveness.

3 Research Methodology

Seaports constitute diversified sets in terms of types, functions and volumes as well as many other possible dimensions of research. Therefore, carrying out a research study in this area requires adopting some methodological assumptions making up the methodological bases.

It is vital that the common factual basis be specified to allow measurement of various functions and tasks performed in varied scopes by various ports [12]. In this study, such basis is the research construct called converted cargo units. These include five basic categories and cargo groups adopted in the commercial nomenclature, record-keeping and reporting: Liquid bulk (no cargo unit); Dry bulk (no cargo unit); Large containers; Ro-ro units (self- and non-self- propelled) and Other general cargo (including small containers). In addition to this, two other kinds of actions have been included, i.e. marine fishery which is subject to separate regulations and record-keeping, and national as well as international passenger transport. Maritime fishery operations are recorded as the volumes of unloaded catch in ports. The passenger transport, in turn, which is recorded in statistics as a number of carried passengers, has been converted to the average of 55 kg per one passenger. Thus, a unified transshipment base was obtained in the form of tonnage expressed in thousands of tonnes. Also, all the research dimensions were accounted for, presenting the elements found in various types of ports.

Table 1 contains the set of research measures applied in this study. The ratios presented in the Table describe the characteristics, size and specific nature of the seaport; its positioning within the location; accessibility of the foreland and hinterland; wharves and transshipments. Measures representatives were applied, which resulted from two reasons: the nature of the study and availability of data. The selective choice of the ratio kinds resulted from the fact it was a pilot study. This is a sufficient procedure to specify particular developmental types of ports. The time period to which the study refers to, taking into account the years 2004 and 2009, requires adjustment of the measures to the data resources being at hand, which were recorded in various institutions and published later.

This is a static type study regarding the years 2004, 2009 and 2014. Thus, the time period covered by the study reflects the situation of seaports in the year of Poland's accession to the European Union, and the results of two 5-year periods of the ports functioning (the years 2009 and 2014). The 5-year intervals result from the fact that any investments and modernizations of the infrastructure are time- and capital consuming. Therefore, it was decided the time span corresponded to the nature of the problem.

For the purpose of the study, appropriate databases were gathered. These included the available statistical data published in statistical yearbooks, legal acts regarding the port infrastructure contained in legal databases, records kept by appropriate state institutions—the Maritime Offices in Szczecin, Słupsk and Gdynia, and the data found in the records and reports kept by harbour master's offices and port authorities offices. The fishery data were obtained from the IT

Table 1 Ratios adopted for statistics-based research study of ports

Symbol	Ratio name	Ratio explained
P01	Port size	expressed in ha
P02	Share of the port area in the city (region) area	port area in ha/city/region area × 100
P03	Ratio (%) of the ship size limits set by the port, and the size limits for a ship to pass through the sound	Dimensions: length × width × depth
P04	Draught ratio: draught in the port in relation to draught in the sound	–
P05	Ports functionality	In the function relation from 1 to 9
N01	Operable wharves ratio	Total operable wharves/total wharves
N02	Transshipment wharves ratio	Total transshipment wharves/total wharves
N03	Operated transshipment wharves ratio	Operable transshipment wharves/total operable wharves
N04	Transshipment wharves operability ratio	Operable transshipment wharves/total transshipment wharves
N05	Mean length of wharves	Total length of wharves/q-ty of wharves
N06	Operated transshipment wharves length	Length of operated transshipment wharves/q-ty of wharves
N07	Significance of port area	percentage of port area in the port region
N08	Cargo traffic structure	Unloading volume per loading unit
N09	Percentage of hinterland availability	Length (Km) of electrified double track railways, connecting within 100 km from the port
W01	Converted cargo unit	(K tonnes)
W02	Volume of transshipment per inhabitant	in tonnes
W03	Cargo traffic per 1 km^2 of the city	in tonnes
W04	Cargo traffic per 1 wharf	in tonnes
W05	Transshipment efficiency of operated wharves	Transshipment operations per 1 running meter of operated transshipment wharf, in tonnes

systems operated by the Fishery Monitoring Centre in Gdynia, which in the years 2013–2015 was a division of the Fishery Department of the Ministry of Agriculture and Rural Development. The obtained as well as processed data now form the database named PORTY_POLAND.

The study applies the non-hierarchical cluster analysis method. Non-hierarchical cluster analysis aims to find a grouping of objects which maximises or minimises some evaluating criterion. Some of these algorithms will iteratively assign objects to different groups while searching for some optimal value of the criterion. This method maximises the separation of those clusters while minimising intra-cluster distances relative to the cluster's mean or centroid. The algorithm typically defaults to Euclidean distances, however, alternate criteria, such as different distance or dissimilarity measures, can be accepted by many implementations. If not, alternate distances or dissimilarities may be transformed to be compatible with Euclidean representation [13]. In the presented research study, the ratios were standardized, and an analysis was made for the set of 28 objects (group excluding the four biggest Polish seaports), and 32 objects (the group including all seaports in question). Based on the analysis of the results, it was decided that the four major seaports should be excluded and treated as a separate set, and that the others should be placed in 4 other clusters, thus creating five clusters for each of the years in question.

4 Discussion

With its 770 km long coastline (440 km of maritime border), Poland has a number of maritime ports and harbours of different sizes. Their formal status is regulated by the Act on maritime ports and harbours, which also established three entities to manage the biggest seaports of particular significance for the national economy: Gdańsk, Gdynia and Szczecin & Świnoujście sea port complex. These are the biggest seaports in Poland. Apart from them, 29 ports have the formal status of a maritime port, granted by the relevant Minister pursuant to the legal regulations. This means there is a total of 33 physical locations with a seaport status, however, the study for the years 2004–2009 includes data regarding 32 maritime ports. This is due to the fact that in the study period the port of Sierosław did not fulfil any port functions, and its functioning is dependent, among other things, on the local authorities decision regarding the foreland (namely, dredging the fairways allowing access to the port from the sea).

The results of determining the developmental types are presented in Table 2. The table shows the specific nature of the Polish seaports development. In the studied period, the four biggest Polish seaports showed the definitely highest values of all the studied ratios. They make up the sixth cluster, which is one of the main determinants of industrial growth of the Pomeranian Bay and the Vistula Lagoon. They are universal, but at the same time specialized ports. They feature dynamic growth through developing container transshipment (Gdańsk, Gdynia, Szczecin), international transport of passengers (Gdynia, Świnoujście, Gdańsk), or, ultimately, liquefied gas (Świnoujście). Compared to the other ports that are not of primary significance for the national economy, their growth rate reflects the saying "the bigger, the better". The most typical entity of the sixth cluster is Gdańsk, with the smallest distance (the cluster centre).

A self-contained function is fulfilled also by other ports: Elbląg, Police and Darłowo. They exemplify the effects of three different causes of positioning. Police is a separate developmental type: it is a specialized port for serving the AZOTY chemical plant. The port is used for transshipment of bulk materials such as

Table 2 Port clusters for the years 2004, 2009 and 2014

PORT	YEAR			STABL
	2004	2009	2014	POSIT.
Darłowo	1	1	1	X
Dziwnów	1	1	2	–
Dźwirzyno	5	3	2	–
Elbląg	4	4	4	X
Frombork	1	1	2	–
Gdańsk	6	6	6	X
Gdynia	6	6	6	X
Hel	1	1	2	–
Jastarnia	1	1	2	–
Kamień Pomorski	5	1	2	–
Karsibór	5	3	3	–
Kąty Rybackie	5	3	2	–
Kołobrzeg	1	5	1	–
Krynica Morska	5	1	2	–
Lubin	5	3	2	–
Łeba	5	3	2	–
Mrzeżyno	2	1	2	–
Nowa Pasłęka	5	3	2	–
Nowe Warpno	2	1	2	–
Police	3	2	5	X
Przytór	5	3	3	–
Puck	5	1	2	–
Rowy	1	1	2	–
Stepnica	2	3	2	–
Szczecin	6	6	6	X
Świnoujście	6	6	6	X
Tolkmicko	5	1	2	–
Trzebież	1	1	2	–
Ustka	1	1	2	–
Wapnica	5	3	2	–
Władysławowo	1	1	2	–
Wolin	5	3	3	–

phosphates, apatites, ilmenites, potassium chloride, fertilizers, ammonia, sulphuric acid. Its activity concentrates on the production components needed by the chemical plant, and the final products, i.e. chemical fertilizers. The cargo traffic in 2014 amounted to 1.750 K tonnes. For many years, this has definitely been the Polish fourth biggest seaport in terms of cargo traffic, and according to the ratios it is defined as a self-contained proactive developmental type, with significant dynamics of utilizing its production capacities. As a result of the "shortest distance" calculation methodology, each year it is defined by a different number (see Table 2), but still each time it is a self-contained type.

The port of Elbląg is configured similarly. Also in this case it represents a self-contained developmental type. Its specific nature is that it has the kinds of resources that are typical for a well-developed multi-functional port, along with the stationary infrastructure of the wharves and hinterland (railway sidings). Simultaneously, the port location in the Vistula Lagoon means a considerable dependence on the political relations between Poland and Russia, both in terms of opening the Strait of Baltiysk for traffic and of fairway dredging in the Russian part of the Lagoon. Nevertheless, due to the size and significance of the port and the results, and despite its sinusoidal transshipment trend, the port continually represents a self-contained developmental type.

The remaining ports make up three developmental types with variable configurations of clusters over the particular years. Only the port of Darłowo, defined as stable in terms of the configuration, has been continuously defined as the first developmental type. This type was assigned to nine other ports in 2004, fourteen ports in 2009 and the port of Kołobrzeg in 2014. Categorizing the ports and the changeability of the categorization over the individual years covered by the study prove the significant impact of the three parameters regarding the infrastructure, transshipment and access to the hinterland. The presented evolution of the type assigning proves that there is diversity in directions of development, and that the ports of Kołobrzeg and Darlowo have gradually been emerging as developing deep-sea ports. The discussed type is a rare example of a duopoly [14], in which the development of Darłowo led to the situation in which the nature of development is now decided by both ports, which in 2014 had the same distance value (1550).

The remaining two developmental types are conglomerations of small ports with the dominating fishery function [15]. The third type is represented by the ports located in the Pomeranian Bay and the Vistual Lagoon, including the small, decreasingly active ports near Świnoujście (Przytór and Karsibor) as well as Wolin. This type may be described as degressive, and its only option of development is yachting in the case of Wolin. However, the third type in 2009 and the second type in 2014, which made large clusters in terms of numerical strength and included ports with various locations, may be referred to as the transitional type. These ports were looking for their developmental identity, and their fishery functions were more and more extensively supplemented by tourism (boat trips for tourists, powerboating, yachting). Some of the ports have been developing extensive marinas to serve the emerging sailing routes in West Pomerania and the Vistula Lagoon.

The presented results of the research study show the directions of development followed by the Polish ports.

5 Conclusions

The 32 Polish seaports are considerably diversified in terms of size and functions. The major role is played by the four major seaports which pursuant to the legal acts constitute the ports of primary importance for the national economy—Gdańsk, Gdynia, Szczecin & Świnoujście. They are part of the European system as members of ESPO (European Sea Ports Organisation). The organization was established in 1993 to represent the port owners, ports associations and port authorities of the European Union Member States and Norway. The significance of the organization derives from the fact that 90 % of the European cargo traffic goes through more than 1200 seaports operating in 23 Member States, and over 400 M passengers are served each year by ports offering ferry and cruise liner services. Therefore, seaports create an internal market of the integrating political entity, and the four biggest Polish ports are among the 432 European ports being ESPO members.

The study results indicate the directions of development of the ports. It is definitely possible to distinguish a group of large trading ports that are the most important for the freight and passenger traffic (Gdańsk, Gdynia, Świnoujście, Szczecin). The second developmental group is made up by the types that develop the same function (Police, Darlowo, Kołobrzeg) or have a significant potential in terms of infrastructure and location (Elbląg). The remaining ports base their development on fishery and tourism functions, with more and more uniform patterns of equipment and development capacities [16]. As these are only small ports managed by the local self-governments, their significance is being gradually limited and there are attempts to reconfigure the area use in favour of alternative land uses (residential housing, tourism) or forms of activity (e.g. onshore wind farms, marinas etc.)

This specific convergence of development leads to gradual disappearance of historically developed maritime and fishing traditions in some places, such as deep-sea fishery function in Władysławowo and Hel or rowing boat fishing in the Szczecin Lagoon and the Pomeranian Bay. The research study results also prove that the assumed and implemented options of the port development strategies are focused on the trading functions in 25 % of the ports, whereas the smallest ports gradually search for solutions in tourism options [17]. An extreme polarization has taken place, with a clearly defined direction of the ports developmental options.

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