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Ben Amaba *Editor*

Advances in Human Factors, Software, and Systems Engineering

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Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

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Ben Amaba
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7th International Conference on Applied Human Factors and Ergonomics

Proceedings of the AHFE 2016 International Conference on Human Factors, Software, and Systems Engineering, July 27–31, 2016, Walt Disney World®, Florida, USA

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Preface

The discipline of Human Factors, Software, and Systems Engineering provides a platform for addressing challenges in human factors, software and systems engineering that both pushes the boundaries of current research and responds to new challenges, fostering new research ideas. In this book researchers, professional software and systems engineers, human factors and human systems integration experts from around the world addressed societal challenges and next-generation systems and applications for meeting them. This book addresses topics from evolutionary and complex systems, human systems integration to smart grid and infrastructure, workforce training requirements, systems engineering education and even defense and aerospace. It is sure to be one of the most informative systems engineering events of the year.

This book focuses on the advances in the human factors, software and systems engineering, which are a critical aspect in the design of any human-centered technological system. The ideas and practical solutions described in the book are the outcome of dedicated research by academics and practitioners aiming to advance theory and practice in this dynamic and all-encompassing discipline. A total of four sections presented in this book. Each section contains research papers that have been reviewed by members of the International Editorial Board. Our sincere thanks and appreciation to the following Board members:

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We hope that this book, which is global and state of the art in human factors in software and systems engineering, will be a valuable source of theoretical and applied knowledge enabling human-centered design of variety of products, services and systems for global markets.

Collierville, USA Ben Amaba
July 2016

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Part I
Systems Engineering Applications

A Tool-Based Hybrid Methodology for Achieving Impactful Cross-Domain Systems Engineering

Dave Campbell, Eric Drewniak, Ryan LaFortune and Garrett Wampole

Abstract The U.S. Air Force's 30-year strategy identifies *Capability Development* as a key area where existing practices are inadequate and need to be transformed in order to keep pace with new threats and the evolving operational environment (American's Air Force: A call to the future, July 2014) [1]. We believe that the traditional model of delegating most systems engineering and design responsibility to capability providers further contributes to delays and design defects, as there is a clear disconnect in the ways that acquirers, users, and both software and systems engineers understand and contribute to a system's design. In this paper, we present a novel approach that uses a combination of technologies that overcome each other's weaknesses, while accentuating each other's strengths, and allows stakeholders with different backgrounds to understand and contribute to a system's design. The result is an improvement in quality, development costs, and schedule performance.

Keywords Systems engineering · Model based engineering · Unified modeling language · Business process management

1 Introduction

The U.S. Air Force's 30-year strategy identifies *Capability Development* as a key area where existing practices are inadequate and need to be transformed in order to keep pace with new threats and the evolving operational environment [1].

D. Campbell · E. Drewniak · R. LaFortune · G. Wampole (✉)
MITRE Corporation, 202 Burlington Road, Bedford, MA 01730-1420, USA
e-mail: gwampole@mitre.org

D. Campbell
e-mail: dcampbell@mitre.org

E. Drewniak
e-mail: edrewniak@mitre.org

R. LaFortune
e-mail: rlafortune@mitre.org

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Traditional Department of Defense (DoD) methods for requirements development, acquisition oversight, and especially systems engineering are insufficient in producing results in the desired timeframe, in a manner that is receptive to frequent decision points and opportunities to change direction. We believe that the traditional model of delegating most systems engineering and design responsibility to capability providers further contributes to delays and design defects, as there is a clear disconnect in the ways that acquirers, users, and both software and systems engineers understand and contribute to a system's design. Our approach uses a combination of technologies that overcome each other's weaknesses, while accentuating each other's strengths, and allows stakeholders with different backgrounds to understand and contribute to the design.

Executable Unified Modeling Language (UML) is used for functionally decomposing the design and identifying interfaces in a manner that software engineers can easily relate to, and transition to implementation. The drawback has been the difficulty for systems engineers using UML constructs to relate to the design and understand the technical details of how data flows through the system and users interact with it. Fortunately, a new generation of tools is allowing us to expand the approach and engage the non-software centric stakeholders by utilizing executable Business Process Management (BPM). Our hybrid approach allows for cross-domain collaboration with each discipline contributing and interacting with the same set of design artifacts, via a tool that is appropriate for their domain. We feel this approach applies to complex system development and sustainment activities attempting to improve quality, control software development costs, and increase schedule performance. In this paper, we provide a case study on employing this novel technique, and discuss the realized benefits.

2 Core Technologies

Central to the framework and methodology is Model Based Engineering (MBE), which generally encompasses key concepts such as early systems engineering and analysis through executable system models. The ability to perform dynamic analysis at any stage in the lifecycle is key, and the higher the model fidelity the greater the value of the model [2]. Two key technologies used to implement these principles are UML and BPM.

2.1 Unified Modeling Language

An industry standard general purpose modeling language, UML provides a way to visualize the design of a system at varying levels of abstraction and detail. UML 2.0 specifies 13 types of diagrams for defining the structure and behavior of a system, including component interactions [3]. There was a time when the use of UML was merely to provide static diagrams. Today its use has much evolved, and in executable form can instrument the design description to provide for dynamic analysis. It is not uncommon for a UML model to automatically generate application-specific code and system documentation. In this case, the model is the design and provides engineering value throughout the life of the system.

Because the different concepts in UML vary in level of abstraction and detail, it was once thought that a UML model could easily be used by acquirers, users, and both software and systems engineers alike. In reality, much of the content in a UML model is inherently implementation-focused. While very valuable for software engineers, they are difficult to understand for systems engineers and other stakeholders who do not think in terms of code implementation [4].

2.2 Business Process Management

BPM is a discipline for workflow management. The discipline involves identifying, designing, executing, documenting, measuring, monitoring, and/or controlling business processes [5]. Very different from an implementation-like definition, business processes are defined using a combination of four self-expressive notions. An *Event* controls under what conditions the process starts and how to map external data to things that the process deals with. A *Process* identifies a step being performed by a "user" or the "system." User processes can have flexible user interfaces defined that present and can modify process data. An *Intermediate Event* allows triggering of processes outside the normal flow (e.g., perform a process repeatedly on a schedule, take a different path if a process does not complete on time, etc.). Finally, a *Gateway* is a control path of process execution based on criteria, and can take into account process data and/or user interaction.

BPM allows non-software centric stakeholders to contribute to the system design, guaranteeing critical details relating to the intent of the system do not get lost in the translation by software developers. However, the business processes alone do not provide sufficient detail to directly transition to implementation.

A relatively recent development in business process management tools is the ability to define processes that can be directly executed. Executable BPM tools typically allow application-specific integrations to be provided that enable Processes to implement some level of their requisite business logic. Our approach utilizes this capability to enable two-way communication between executable UML and BPM models.

The combination of the two technologies under strictly enforced synchrony allow all stakeholders to contribute to the system's design, and the software to be written accordingly, resulting in an improvement in quality, software development costs, and schedule performance.

3 Model and Business Process Organization

To employ our tool-based hybrid methodology for a system, the Requirements, Structure, Interfaces, and Data will be captured in an executable UML model and Business Processes in an executable BPM authoring/management tool. Below is our recommended organization.

The *Requirements* package shall contain a UML representation of the system requirements, derived from the system specification, which are typically maintained in an electronic database. The *Structure* package shall contain the functional decomposition of the system into modules that present coherent portions of functionality. The structure may itself be presented at several layers of abstraction using the UML composition relationship. The *Interfaces* package shall contain two main types of information. A number of UML events that specify the types of information that can traverse interfaces; and a set of Interface classes that specify reception operations for one or more events. *Data* contains UML representations of application-specific data formats that are used in defining system interfaces. A critical aspect of the data objects are that they should provide a method for accessing all of the attendant details and fields of a given format along with methods for marshalling and un-marshalling an actual instance of the data object from its wire representation to a UML object.

The *Business Processes* define system functionality involving the collaboration of several structural components of the system to accomplish some business case. Each business process has corresponding code in the executable UML model that accomplishes the desired behavior within the modeled architecture. The results of this execution can then be used for analysis and comparison of proposed solutions.

3.1 Structure

The Structure is the set of classes that form the backbone of the model. It serves several purposes including linking requirements to the model, displaying relevant system interfaces, declaring ports that are used to expose the interfaces, and outlining business-logic to support execution.

3.2 Interfaces

The Interfaces are the classes that define event receptors for which incoming or outgoing data messages are needed to achieve all or part of a particular system-related task. The Interfaces only describe the actual data that needs to be exchanged, not how the data is exchanged or if the data is needed as an input or as an output. The direction of the data flow is given by the port's contract (see below for further information regarding ports). It is important to choose the correct messages for each interface according to two restrictions. First, all messages in the interface must travel in the same direction. For example, all messages in a given interface must be incoming, or all messages must be outgoing. Second, all interfaces exposed by one port must comply with the same physical message exchange requirements defined by the port's configuration.

In order to create a new system interface, the proper event reception operations also need to be created. All event signatures should be defined using arguments that describe the application-specific messages that are input or output from the interface.

A port is required to provide additional information about an interface and expose it to the rest of the model. One port may expose multiple interfaces. The interfaces that belong to a particular port are known as the port's *contract*. Ports come in two flavors: *provided interfaces* are used for incoming messages, and *required interfaces* are used for outgoing messages. Any one port may expose multiple provided or required interfaces, but the event receptions defined by any one interface cannot be split between the provided and required sides of the port's contract.

3.3 Business Processes

Business logic that implements behavior can be embedded directly into the UML model, but in our approach is primarily implemented via business processes. Each business process represents a flow or use-case through the system. Although they may be authored in a separated tool, they operate in an environment that encompasses the artifacts developed inside the UML model.

4 Architecture Overview

Our case study is an architecture comprised of components that communicate via a Goddard Mission Services Evolution Center (GMSEC) message bus. The GMSEC architecture is an open-source messaging framework for building ground and flight data systems [6]. At the core of our architecture is an executable UML model that defines the interfaces and interactions between system components. Some of the components include satellites and satellite simulators, control services, data services, and data retrieval tools. While the model provides reference implementations of these components at varying levels of fidelity, any modeled component can be turned on or off on the fly to be replaced with an actual implementation hosted elsewhere. Having this flexibility greatly reduces the time required to integrate new software into the architecture and makes the architecture inherently agile. Figure 1 visually depicts the system architecture.

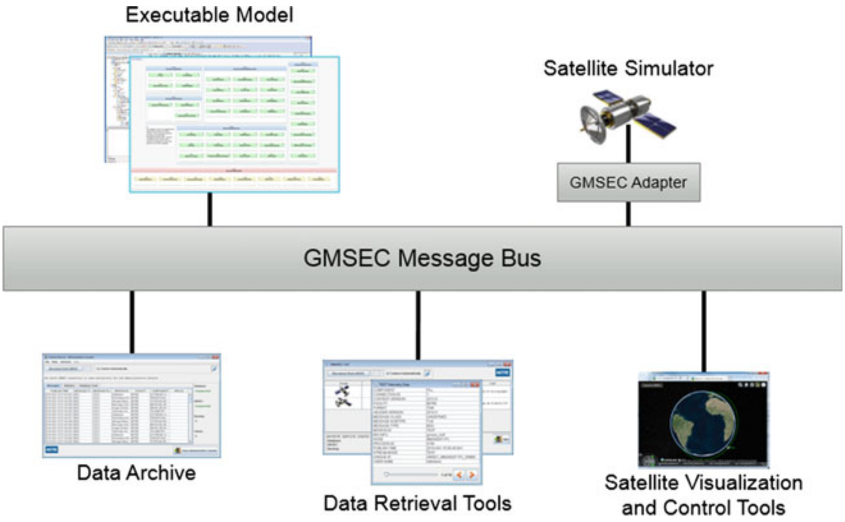

Fig. 1 A visual depiction of the system architecture

4.1 GMSEC Message Bus

The GMSEC message bus is responsible for delivering GMSEC messages between components connected to it.

4.2 Executable Model

The executable model defines interfaces between components, and provides the capability to exercise these interfaces. That is, a modeled component will respond to stimulus in the same manner as the fully implemented software would. Even though the internal processing may be different, any interactions with the component will conform to the interface specifications.

4.3 Satellite Simulator

The satellite simulator is a commercial off-the-shelf (COTS) product that can be configured to generate telemetry and simulated satellite data products. The simulator communicates with a piece of middleware that we developed, and translates output from the native formats into appropriate GMSEC messages and publishes them on the message bus.

4.4 Satellite Visualization and Control

The satellite visualization and control tool is a full-featured homegrown tool used to send instructions to any of the simulated satellites using GMSEC messages (which are then translated by the GMSEC adapter to native simulator messages), and to use the published telemetry data to plot its location relative to the Earth. When in use, this tool overrides some model components.

4.5 Data Archive

The data archive is a service that records all published GMSEC messages in a MongoDB [7] database. It also listens for *Archive Retrieval Request Message* queries and responds with an *Archive Retrieval Response Message* per the GMSEC interface specification [8].

4.6 Data Retrieval

One tool used for data retrieval is the Telemetry Viewer. This tool aides users in forming an *Archive Retrieval Request Message* (e.g., start and stop times, how to deliver results, etc.) which is sent to the archive service, and provides a viewer for displaying the telemetry data, textually and graphically.

5 Business Processes

We now have a solid understanding of the system's structure and interfaces, and a general idea of the workflows this system should implement. Systems engineers are specialists at designing these workflows, and preserving the intended user interactions with the system. Thus, there is value in allowing the systems engineers to encode their subject-matter expertise in an executable manner that can be subjected to dynamic analysis. This could be done natively in UML using State Machine Diagrams. However, as we have discussed, this can be extremely cumbersome for a systems engineer who may not be an expert at software development. Due to the different types of states (i.e., simple states, composite states, and sub-states) and transitions (i.e., local and external), a comprehension of some advanced programming concepts is required to effectively build a state machine. For example, using composite states implies concurrency. The engineer must understand data access and manipulation in a concurrent system, and other concepts relating to synchrony. Further, it is common practice to embed source code level instructions inside the machine when entering states, exiting states, and on state transitions. Thanks to a new generation of tools, this is where we will use executable BPM to allow systems engineers to design the flows, while abstracting them away from UML's implementation-oriented constructs.

5.1 A Simple Workflow

Consider the following workflow within our architecture. A user wishes to submit a payload task to the satellite. Before the task can execute, it must be reviewed and approved by the satellite manager. Figure 2 shows the BPM implementation of the "Approve Task" business process. When the process is performed, the satellite manager is presented with a user interface displaying the task ID and description, and can interact directly with the user interface to approve or reject it. The author of the business process defines the event required to start it, as well as the simple flow shown in the figure. Note the lack of software engineering concepts in the definition of the business process implementation.

While this example is extremely simple, it demonstrates how the systems engineer can describe workflows without worrying about what actions at the source code level need to occur to actually approve or reject a task. Once again, those details are handled elsewhere by software experts.

5.2 A Complex Workflow

Now consider a more complex process, where the publication of a GMSEC message triggers the execution of a business process. In this case, the message will be a

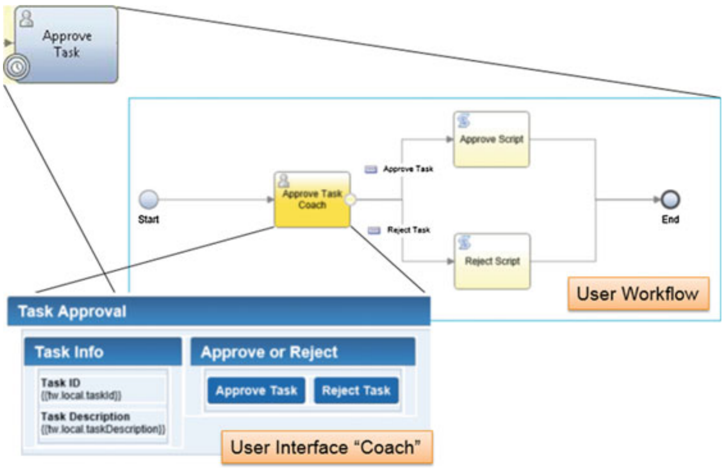

Fig. 2 A business process for approving or rejecting a satellite task

failure indicator, and will launch a business process that reports the error and proposes solutions to the user.

In order to have GMSEC messages start business processes, a middleware application was created called the BPM-GMSEC Adapter. This software listens on the GMSEC message bus for any messages that have been specified as trigger events by any of the business processes. Upon receipt of any of these messages, the adapter will programmatically start the appropriate BPM event and pass along all message data as process arguments, resulting in a new executable instance of the business process. Similarly, the adapter also allows the performance of business processes to create and send new GMSEC messages. Figure 3 shows how to create a business process triggered by a GMSEC message using the BPM-GMSEC Adapter and IBM Process Designer as the business process authoring tool.

Suppose there is a failure with the Satellite Simulator. If non-critical, the failure message can originate at the satellite simulator itself. In the event of a complete crash or loss of connection with the GMSEC message bus, the failure can be detected by missing heartbeat messages or a component experiencing a response timeout on a request, and can then publish the failure message.

The author of the business process simply selects the failure indicator message from a drop-down menu for the trigger event. From his perspective, the implementation details of how the message will be originated or how it will actually be delivered to the process manager is unimportant. He is only concerned with the workflow, that is: when there is an error, what high-level actions should be taken. In any case, the systems engineer is the expert in these user-level flows and can define them with simple high-level steps rather than writing software directly or constructing complex state machines.

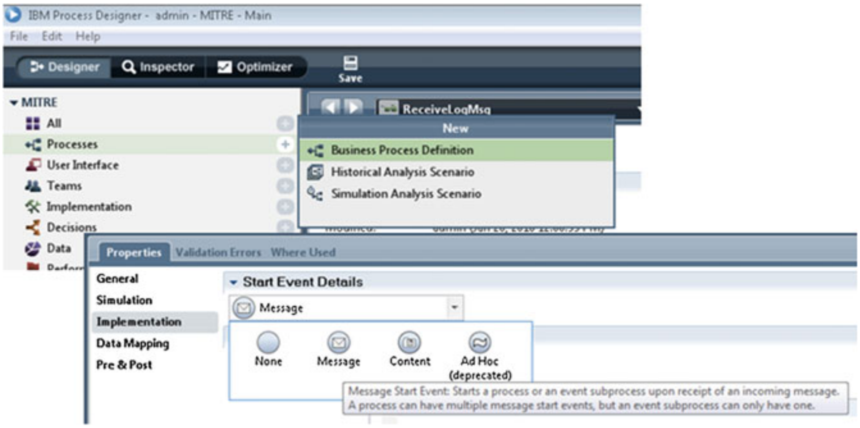

Fig. 3 A screenshot from IBM process designer, showing how to create a process that is triggered by a GMSEC message

6 Conclusions

Using our tool-based hybrid methodology, we are able to achieve impactful cross-domain systems engineering by enabling stakeholders with different backgrounds to understand and contribute to the design. Doing this allows the stakeholders to contribute in their area of expertise, and not in areas where they need to infer the intent of other engineering disciplines.

Engineering in this manner is faster, less expensive, ensures fewer defects, and ensures that the actual implementation more closely resembles the desired workflows. We feel this approach applies to complex system development and sustainment activities, and represents a step towards improving U.S. Air Force capabilities development practices.

References

1. America's Air Force: A call to the future, July (2014)
2. Campbell, D., Wampole, G., Wheeler, T.: Using model based engineering to own the technical baseline. Procedia Manufact. **3**, 1995–2002 (2015)
3. Unified Modeling Language: http://www.uml.org/index.htm
4. Unified Modeling Language: https://en.wikipedia.org/wiki/Unified_Modeling_Language
5. Business Process Management: https://en.wikipedia.org/wiki/Business_process_management
6. Goddard Mission Services Evolution Center (GMSEC): https://gmsec.gsfc.nasa.gov
7. MongoDB: https://www.mongodb.org
8. GMSEC Interface Specification: National Aeronautics and Space Administration, Goddard Space Flight Center, Feb (2013)

Development of Weight-in-Motion Data Analysis Software

Rafiqul A. Tarefder and Md Amanul Hasan

Abstract While volumetric data were sufficient for roadway design in the past, weight data are needed for better design of roadways now-a-days. While weight and volume data are collected by the Weigh-in-Motion (WIM) devices installed along the roadside, there is no reliable software to analyze the abstract data from the WIM devices. To that end, this study has developed a Data Analysis Software (WIMDAS) in C# programming language. This software uses the data collected from WIM stations (class file and weight file) as inputs. Using some complicated mathematical formulas inputs are analyzed and software outputs the following parameters: traffic volume and distribution such as total traffic, monthly distribution, class distribution, hourly distribution; general traffic configuration such as number of axle per truck, axle spacing; and axle load spectra for different axles such as single, tandem, tridem and quad axles. The outputs are used as inputs in the new pavement mechanistic empirical (ME) design software for predicting performances of roadways pavements. This software is capable of bringing-in several benefits including design efficiency, time, system analysis, and accuracy, which are covered in this paper.

Keywords Software development · Traffic · Roadway design · Mathematical formula · System analysis · Accuracy

1 Introduction

Traffic is one of the primary inputs in pavement design as it represents the magnitude and frequency of the loading that is applied to a pavement. However, in past only volumetric data was used to determine pavement life. Later Equivalent

R.A. Tarefder (✉) · Md A. Hasan
Department of Civil Engineering, University of New Mexico, Albuquerque, NM 87113, USA
e-mail: tarefder@unm.edu

Md A. Hasan
e-mail: amanulhasan@unm.edu

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Single-Axle Load (ESAL) method was used to determine the pavement life [1]. This approach is based on converting the pavement damage caused by an axle with a specific weight and configuration into an equivalent damage from a standard 18-kip (80-kN) single-axle load. Then, pavement life is accounted for by the ESALs that have accumulated during its life. However, this empirical method cannot give reliable result due to rapid growth of traffic, change of vehicle characteristics, and absence of weather consideration. Therefore, a new Mechanistic Empirical (ME) pavement design procedure is widely accepted as this method provides the capability to handle different axle configuration and other factors [1]. This method requires volumetric and weight data to calculate the pavement distresses.

The ME design procedure (ME design software) requires detailed traffic inputs to calculate the pavement life. These inputs are mentioned here:

i. Volumetric information:

- Two-way annual average daily truck traffic (AADTT)
- Number of lanes in the design direction
- Percent trucks in design direction
- Percent trucks in design lane
- Monthly Adjustment Factor
- Vehicle Class Distribution
- Hourly Truck Distribution
- Traffic Growth Factors.

ii. Weight information:

- Axle Load Distribution Factors.

iii. General Traffic Inputs

- Vehicle operational speed
- Number of axles per truck
- Axle configuration
- Wheelbase distribution.

These volume and weight traffic data are collected by the Weigh-in-Motion (WIM) devices along roadside. These WIM devices store the volumetric raw data into “class” files (C-card) and axle load data into “weight file” (W-card). These raw data are too large to be handled manually or by simple spreadsheet. For this reason, software called TrafLoad was developed to abstract the raw WIM data. However, WIM data are sometimes questionable due to sensor error or other technical reasons. Past studies show that use of TrafLoad is not reliable because it only performs rudimentary checks for valid site IDs and lanes and direction values, and does not provide a sophisticated QC procedure [2]. Thus, several studies were conducted to introduce more sophisticated QC procedures in order to adjust the error. These procedures were developed based on monitoring axle spacing, peak patterns of tandem axles and percentages of gross vehicle weight. These procedures can indicate whether WIM data is erroneous or not. However, these studies didn't describe how to handle the erroneous data [3, 4]. In addition, there is no efficient and user-friendly software available in the literature, which can effectively handle the WIM data. Therefore, this study has developed a Data Analysis Software (WIMDAS) in C# programming language. This software uses the data collected from WIM stations (class file and the weight file) as input outputs aforementioned data that can be directly used in the pavement ME design software. In addition, before processing this software performs a structured QC procedure to deal with the erroneous data.

2 WIM Data

WIM station classifies each vehicle according to the Federal Highway Administration (FHWA) classification and stores the number of each type of vehicle in each lane for a specific period of time. It also stores the weight of each axle of a vehicle and spacing between the axles. Raw data is stored into two special file formats. Volumetric data is stored in a class file which has an extension of *. CLA (C-card) and axle load data is stored in a weight file with an extension of *. WGT (W-card). In class files, each row contains the total information of volumetric data for 15 min. Where, in weight file, each vehicle information is stored in separated row. Detailed description of rows in class and weigh file are given in Tables 1 and 2 respectively.

Table 1 Description of a row in class file

Field	Position	Size	Description
1	1	1	Record type
2	2	2	FIPS state code
3	4	6	Station ID
4	10	1	Direction of travel code
5	11	1	Lane of travel
6	12	2	Year of data
7	14	2	Month of data
8	16	2	Day of data
9	18	2	Hour of data
10	20	5	Total volume
11	25	5	Class 1 count
12	30	5	Class 2 count
13	35	5	Class 3 count
14	40	5	Class 4 count
15	45	5	Class 5 count

(continued)

Table 1 (continued)

Field	Position	Size	Description
16	50	5	Class 6 count
17	55	5	Class 7 count
18	60	5	Class 8 count
19	65	5	Class 9 count
20	70	5	Class 10 count
21	75	5	Class 11 count
22	80	5	Class 12 count
23	85	5	Class 13 count
24	90	5	Class 14 count
25	95	5	Class 15 count

Table 2 Description of a row in weight file

Field	Position	Size	Description
1	1	1	Record type
2	2	2	FIPS state code
3	4	6	Station ID
4	10	1	Direction of travel code
5	11	1	Lane of travel
6	12	2	Year of data
7	14	2	Month of data
8	16	2	Day of data
9	18	2	Hour of data
10	20	2	Vehicle class
11	22	7	Total weight of vehicle
12	29	2	Number of axles
13	31	3	Axle weight 1
14	34	3	Axles 1–2 spacing
15	37	3	Axle weight 2
16	40	3	Axles 2–3 spacing
17	43	3	Axle Weight 3
18	46	3	Axles 3–4 spacing
19	49	3	Axle weight 4
20	52	3	Axles 4–5 spacing
21	55	3	Axle weight 5
22	58	3	Axles 5–6 spacing
23	61	3	Axle weight 6
24	64	3	Axles 6–7 spacing
25	67	3	Axle weight 7

(continued)

Table 2 (continued)

Field	Position	Size	Description
26	70	3	Axles 7–8 spacing
27	73	3	Axle weight 8
28	76	3	Axles 8–9 spacing
29	79	3	Axle weight 9
30	82	3	Axles 9–10 spacing
31	85	3	Axle weight 10
32	88	3	Axles 10–11 spacing
33	91	3	Axle weight 11
34	94	3	Axles 11–12 spacing
35	97	3	Axle weight 12
36	100	3	Axles 12–13 spacing
37	103	3	Axle weight 13

3 Weigh-in-Motion Data Analysis Software (WIMDAS)

3.1 Description

The raw WIM files are text files, which cannot be used in the ME design software without further processing. In addition, these files are too large to process with simple spreadsheets. Therefore, it is badly needed to develop a data processing software to process the raw data. WIMDAS is a highly efficient software written in C-sharp (C#) language, which can perform QC as well as generate the ME design inputs. The WIMDAS uses data collected from WIM stations as inputs. After analyzing the raw data, the software gives the outputs that can be directly used in ME design software.

The main interface of WIMDAS is shown in Fig. 1. It has three modules, which are mentioned below:

(i) Traffic Distribution (First Module): The first module deals with the traffic classification and distribution. It analyzes the class file and calculates total vehicle, Annual Average Daily Truck Traffic (AADTT), directional distribution, hourly distribution, monthly distribution, average axle per truck and so on.
(ii) Weight Distribution (Second Module): The second module analyzes the weight distribution of the vehicle.
(iii) Axle Load Spectra (Third Module): The third module generates the axle load spectra, axle per truck, axle spacing, and wheelbase distribution.

Fig. 1 Startup screen of WIM Data Analysis Software (WIMDAS)

3.2 Working Methodology

WIM data are stored in text file. Therefore, WIMDAS is developed such a way that it can read the raw text messages and extract the key information using some complicated mathematical formulas. It also can detect the errors in the WIM raw data. Moreover, WIMDAS can eliminate the error data for simplification. In addition, it can also replace the error data by averaging adjacent rows. Thus, it minimize the chance to reduce total volume of traffic/load. Finally, it can able to generate outputs for in text and xml format. These format can be directly imported by the ME design software. The working methodology of WIMDAS is shown in Fig. 2.

3.3 Quality Checks

WIM data are sometimes questionable due to sensor error or other technical reasons. In addition, past studies revealed that predicted pavement life is highly sensible to the quality of WIM data [5, 6]. Thus researchers recommend to perform quality checks in order to get good result. There are 14 quality checks for class data and 15 quality checks for weight data. Table 3 lists the quality checks for class data used in this software.

Table 4 lists the quality checks for weight data used in this software.

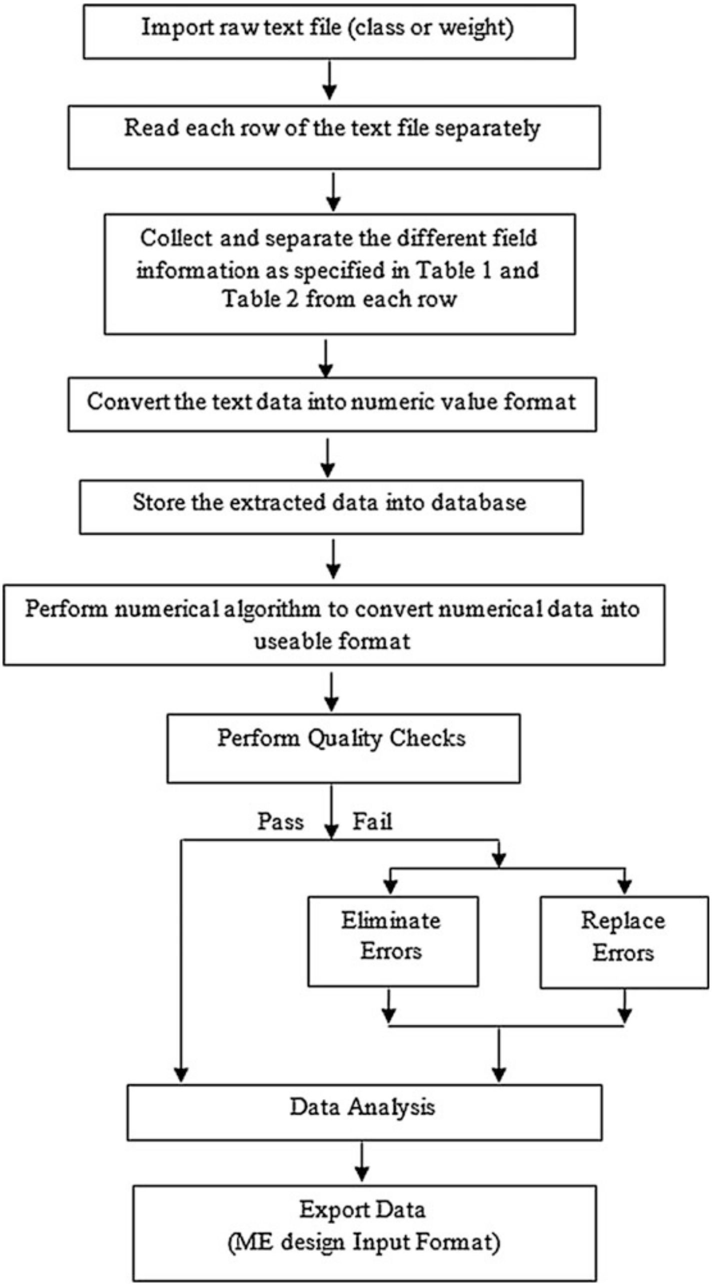

Fig. 2 Startup screen of WIM Data Analysis Software (WIMDAS)

Table 3 Quality checks for class data

Check No.	Descriptions
1	The record belongs to a C-file, e.g. if Record Type ≠ C then "ERROR"
2	The record belongs to New Mexico, e.g. if State Code ≠ 35 then "ERROR"
3	The WIM site ID is unique, otherwise show "ERROR"
4	The direction is correct, e.g. if Direction ≠ 1 or 5 then "ERROR"
5	The lane number is correct, e.g. if Lane Number ≠ 1 to 4 then "ERROR"
6	The year is unique and correct, e.g. if Year ≠ 10 then "ERROR"
7	The month is correct, e.g. if Month ≠ 1 to 12 then "ERROR"
8	The day is correct, e.g. if Day ≠ 1 to 31 then "ERROR"
9	The time is correct, e.g. if Hour ≠ 0 to 23 then "ERROR"
10	The total hourly volume per lane does not exceed the maximum limit, e.g. if Total Hourly Lane Volume > 3000 then "ERROR"
11	The total volume in the outside lanes collected between 1 a.m. and 2 a.m. does not exceed the same volume collected from 1 p.m. to 2 p.m., e.g. if Hour 1 Total Lane Volume > Hour 13 Total Lane Volume then "ERROR"
12	The total outside lanes volume is not constant for four consecutive hours, e.g. if Hour X Total Lane Volume = Hour X + 1 Total Lane Volume = Hour X + 2 Total Lane Volume = Hour X + 3 Total Lane Volume then "ERROR"
13	The percentage of motorcycles is less than 5 %, e.g. if % Motorcycles > 5 then "ERROR"
14	The percentage of unclassified vehicles (classes 14 and 15) is less than 5 %, e.g. if Percentage of Unclassified Vehicles > 5 then "ERROR"

Table 4 Quality checks for weight data

Check No.	Descriptions
1	The year is unique; otherwise show "ERROR"
2	The month is correct, e.g. if Month ≠ 1 to 12 then "ERROR"
3	The day is correct, e.g. if Day ≠ 1 to 31 then "ERROR"
4	The time is correct, e.g. if Hour ≠ 0 to 23 then "ERROR"
5	The WIM site ID is unique, otherwise show "ERROR"
6	The direction is correct, e.g. if Direction ≠ 1 or 5 then "ERROR"
7	The lane number is correct, e.g. if Lane Number ≠ 1 to 4 then "ERROR"
8	The vehicle class is correct, e.g. if Vehicle Class ≠ 4 to 13 then "ERROR"
9	The number of axles is consistent with the number of axle spaces, e.g. if Number of Axles ≠ Number of Axle Spaces + 1 then "ERROR"
10	The number of axles is consistent with the number of axle weights, e.g. if Number of Axles ≠ Number of Axle Weights then "ERROR"
11	The gross vehicle weight is consistent with the sum of axle weights, e.g. if Sum of Axle Weights ≠ GVW then "ERROR"

(continued)

Table 4 (continued)

Check No.	Descriptions
12	The number of axles is consistent with the vehicle class, e.g. if Number of Axles ≠ Range of Axles for that vehicle class then "ERROR"
13	The sum of axle spaces is consistent with the maximum length, e.g. if Sum of Axle Spaces > 115 ft (35 m) then "ERROR"
14	The axle weights are within acceptable range, e.g. if Axle Weight ≠ 440 lbs (200 kg) to 33,000 lbs (15,000 kg) then "ERROR"
15	The axle spaces are within acceptable range, e.g. if Axle Spacing ≠ 2 ft (0.6 m) to 50 ft (15 m) then "ERROR"

4 Conclusion

The new ME design software requires the volume and weight data collected by the Weigh-in-Motion (WIM) devices installed along the roadside for predict the pavement life. However, there is no reliable software to analyze the abstract data from the WIM devices. To that end, this study has developed a Data Analysis Software (WIMDAS) in C# programming language. The developed software can be used to process the WIM data. The output from the software can be directly exported to the AASHTOWare pavement ME design software. The authors of this study highly expect that this software may be useful to analyze WIM data and use it in the pavement design.

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References

1. AASHTO: Guide for design of pavement structures. American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C. (1993)
2. Wilkinson, J.: Chaparral systems corp, TrafLoad user's manual. NCHRP Report 538, Part 3, Washington, D.C. (2005)
3. Ramachandran, A.N., Taylor, K.L., Stone, J.R., and Sajjadi, S.S.: NCDOT quality control methods for weigh in motion data. In: Public works management policy, vol. 16, pp. 3–19. Sage Publications (2011). doi:10.1177/1087724X10383583
4. Mia, D., Turochy, R.E., Timm, D.H.: Quality control of weigh-in-motion data incorporating threshold values and rational procedures. Transp. Res. Part C: Emerg. Technolo. **36**, 116–124 (2013). doi:10.1016/j.trc.2013.08.012

5. Hasan, M.A., Islam, M.R. and Tarefder, R.A.: Site specific versus pavement mechanistic empirical default traffic data on interstate pavement performance. Accepted, 95th annual meeting of the transportation research board, Transportation research board, Washington, D.C. (2016)
6. Tarefder, R., Rodriguez-Ruiz, J.I.: WIM data quality and its influence on predicted pavement performance. Transp. Lett.: Int. J. Transp. Res. **5**(3), 154–163 (2013)

Play and Learn—A Serious Game for a Better Understanding of Severe Accidents in Nuclear Power Plants

Agnès Peeters, Stéphanie Tillement and Céline Grousson

Abstract This paper analyzes the results of a joint pedagogical experiment based on the “Sprintfield” serious game. It described the motivations and the creation of this game as well as the way it meets two issues: teaching the difficulties met by the operators in a nuclear power plants in case of severe accident and teaching the particular human behavior in case of crises. Thanks to this role-playing game, students experience a disturbed situation similar in main aspects to the TMI accident; they undergo the same kind of feelings as the operators team did and understand the importance of human and organizational factors on safety, besides technical ones.

Keywords Serious game · Human factors · Educational innovation · Risk control · Crisis situation · Simulation · Role playing game · System engineering

1 Introduction

The main purpose of this paper is the analysis of a joint “Sprintfield” experiment.

“Sprintfield” is a new pedagogical tool, developed by Ecole des Mines de Nantes and based on a twofold approach: the simulation of a real complex system and role-playing games (RPG). The goal of this tool is to place the players, within a team, in a disturbed situation in order to “show” them the difficulties met by a crisis team and the influence of the human behavior, in abnormal operation, on the possible system evolutions.

A. Peeters (✉)
Institut Supérieur Industriel de Bruxelles, Brussels, Belgium
e-mail: peeters@isib.be

S. Tillement · C. Grousson
Ecole Des Mines de Nantes, Nantes, France
e-mail: stephanie.tillement@mines-nantes.fr

C. Grousson
e-mail: celine.grousson@mines-nantes.fr

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This experiment has been performed as part of the cursus of students from a French engineering school (Ecole des Mines de Nantes) on one side and, on the other side, from the nuclear orientation of a Belgian engineering school (ISIB).

This paper first presents the context of this experiment and its motivations. Secondly, the “Sprintfield” serious game is described; this description involves the objectives of the project and the making of this powerful tool. Then, the collaboration between the two universities is developed and a specific attention is paid to the results. Finally, some conclusions will be drawn.

2 Context

The experiment described in the following is the result of a dual issue. The first issue concerns the need to underline the influence of the human behavior in case of crises. Indeed, in the framework of crisis management, human factors are of huge importance but are also very difficult to explain in a theoretical way. Hence, an experiential learning seems to be a solution. The second issue concerns a big challenge for nuclear science professors: teaching accidents in a correct and systemic way. Of course, we currently have a lot of technical details and scientific datas about the progress of severe accidents as TMI or Chernobyl. Therefore, an “a posteriori” analysis is quite easy, with a chronological description of the events and the plant evolution. Nevertheless, how to explain the operators’ confusion, the ambiguity of messages, timing aspects and so on … Students usually say: “Why didn’t the operators do this or that?”, “Why didn’t they correctly understand what was happening?” …

This experiment is also the result of a collaboration between two European universities.

The first one is a French university: Ecole des Mines de Nantes. It trains “no-specialist” engineers and attaches a great importance to human sciences and social sciences. Courses on safety and on organizational and human factors (OHF) take place during the cursus because, throughout their careers, engineers may have to work in a risky professional environment. Nevertheless, the risk perception of students is generally disturbed by a misrepresentation, amplified by some media messages. Hence, in order to correctly deal with risk management, it is important to modify this perception and to clarify the preconceptions laying in the student minds.

The second one is a Belgian university: Institut Supérieur Industriel de Bruxelles (ISIB), a department of Haute Ecole Paul-Henri Spaak. This institution trains engineers, with one of the following specialization: chemistry, physics and nuclear sciences, mechanics, electricity, computer science and electronics. The proposed training consists of 5 years of lectures, laboratories, projects and internships. A multidisciplinary approach has been chosen, with a large place to practical activities. Lectures mainly concerns technical and scientific aspects. Soft skills are slightly and gradually introduced during the cursus.

This experiment took place in the cursus of Belgian students in Nuclear Engineering, during the fifth and last year of this cursus. These students have technical and scientific knowledge about nuclear power plants, in various fields: neutronic science, thermal-hydraulic science and safety studies. They also learned the main postulated accidents for PWR (Pressurized Water Reactor) as Loss of Coolant Accident (LOCA), steam generator tube rupture accident or steam pipe failure accident and the analyses of some actual accidents (i.e. Chernobyl, Three Mile Island and Fukushima) is part of the safety module.

3 Sprintfield Serious Game

3.1 Motivations and Objectives

The objectives of this serious game development were to expose students to real cases in order to show them the complexity of actions and decisions in risky situations.

Case analysis are a way to introduce reality and real cases in theoretical lectures. Nevertheless, the knowledge acquisition is still limited [1]. Students imagine and dread with hardness difficulties and constraints linked to the studied case. They do not have any experience of risky professional situations. Moreover, they did not develop any feeling of responsibility related to risk management.

Both simulations and role-playing games force students to take an active attitude in their learning [1–3]. Nevertheless, role-playing games confront students to real issue and force them to act; they feel the situation instead of just thinking about them. Students are involved in the game evolution and, consequently, are highly involved in the learning process.

This innovative project wants to make students involved in risk management and bases on two pedagogical assumptions: the acquisition of OHF theories is facilitated by experiment and the fact of living of complex situations helps develop intra- and inter-personal competences.

3.2 Description

"Sprintfield" is an active method where students live a degraded professional situation. The retained context is a real and well-documented accident occurred in a nuclear power plant. Each player has a specific role with specific objectives and specific information. In respect with creation rules of RPG, instructions are very general and differ from a player to another [4] and the game evolves according to random events or to actions and decisions from players [5]. However, players have to work together in order to save the nuclear power plants. Consequently, they have to organize themselves, to define a way of work and to communicate in an efficient way. This role-playing game has the form of a computing interface with a limited number of datas and possible actions.

At the end of the game, a two-phases debriefing is organized. The first one take place immediately after the game, without real time for reflection. The second one take place weeks later, students have time to analyze what they lived and the way they react. During these debriefings, students also have to explain (or try to explain) their behavior and decisions. Which elements do influence the decisions? What is at the origin of these disturbing elements? They have to justify what they did. It allows making them aware to their responsibilities.

4 The Pedagogical Experiment

4.1 Initial Phase

At the beginning, a short presentation of the experiment is performed. The context of the scenario is explained: participants are operators in a nuclear power plant, it is night, the technical team is reduced (only one available technician) and, at the morning, they will have to hand over to the daily team and to expose the plant situation.

As soon as the situation is well understood by every participant, teams are randomly generated and roles are randomly distributed. (In our particular case, attention has been paid in order to have specialists and no-specialists in all the teams.) Teams are distributed in the room and each participant receives a badge with his role, a general document about the nuclear power plant (descriptions, schemas …) and a specific document explaining his role (objectives, legal responsibilities, place in the hierarchy, rights and duties …).

Students have time to read and understand the documents; there is no timing limitation.

4.2 Simulation Phase

As soon as a team is ready, the software is started. First, participants discover a short description of the graphical user interface, the way to interact with the technician, the different indicators and the order panel.

Then, the simulation really start …

After a warning message, participants have a specific timeframe to do something or to decide not to do anything. This timeframe is indicated on the screen by a red countdown. The technician gives information about the status of systems and sometimes proposes actions to perform. The participants can only say to this technician to perform the action or not; it is not possible to ask the technician to do something else or to ask for a data. Sometimes, there are many warnings within short timeframe and, sometimes, nothing happens during several minutes.

The game finishes when a safe situation is recovered or when the accident is reported to the authorities.

4.3 Feedback Phase

At the end of the game, participants need a break to chill out and to release the stress and pressure, accumulated during the simulation phase.

After this break, each team has to prepare a short presentation about the final state of the nuclear power plant and the succession of events and decisions leading to this state. Indeed, the night is over, the daily team arrives and useful information have to be transmitted.

Finally, each team must determine the level of the INES scale associated to this final state.

5 Analysis of the Experiment Course

During the entire game, the teachers adopt a “ghostly attitude”; they do not interact with the students. Nevertheless, they circulate between tables and move from one team to another. The main observations and their interpretations are presented in this section.

Indeed, as soon as the game starts, we can observe different working ways …

During the reading part, some students highlight the text, other ones make notes or annotate the documents and others are just reading without any other activity.

At the end of the reading phase, some teams start immediately the game while other teams discuss about the role of each player.

The geometry of each team is also revealing. The placement of the computer and of the participants around the table vary from a team to another (see Fig. 1). In this

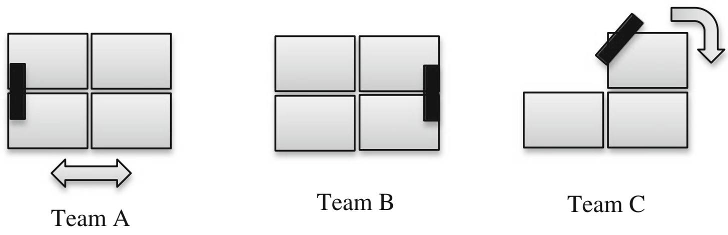

Fig. 1 Spatial organization of each team (*black rectangles* symbolize the computers)

specific experiment, teams A and B were composed of 4 players (2 with a kind of “chief” functions: 1 safety responsible and 1 exploitation responsible, and 2 operators: 1 for the primary circuit and 1 for the secondary circuit) while team C was composed of 3 players (the 2 operators and 1 responsible). After the documents reading, players of team A changed their position in order to have the two operators close to the keyboard). Team B did not change anything and team C kept the computer owner close to the computer but this player slightly moved in order to make the screen more visible for the other team members.

The use of the badge (with the role of the player) will also vary: some teams forget theses badges, in other teams the badges are on the table or attached on the participant clothes, some participants add their name to the badge.

During the simulation phase, the stress due to the elapsing timeframe is high and generally leads the participants to perform the first proposed action as a “reflex action” without actual reasoning, discussion or reflection. Nevertheless, some teams decide not to perform the action and other teams start discussing and forget the timing.

Communication within each team varies. In some teams, there is almost no discussion, one participant is in front of the computer and the others participants focus their attention on their own papers and scarcely look to the screen. In other teams, the discussion is very important and the decisions are the fruits of actual consensus. In this last case, there is no consideration of the roles.

During the simulation phase, some teams make many notes and write approximatively everything. The results is a good information transmission to the daily team but players use several additional seconds or minutes at each step of the simulation. The direct consequence is a reduction of the time allocated to decision-making process. Other teams are immersed in the simulation and completely forget keeping notes about the simulation course. The presentation to the daily team is thus poorer and mainly contains the most discussed decisions.

The role appropriation by each participant presents a large amount of levels. As previously said, some teams erase the specific roles and each player operates in the same way. In other teams, the roles are taken seriously and conflicts may even emerge, according to the character of the gamers.

Another part of this experiment is the participation of “nuclear specialists” and “no-specialists”. The game has been developed in order to be accessible to uninitiated students; no technical knowledge is required to play. Nevertheless, initiated students use their scientific background and have a slightly different vision of the accident course. Each team of the experiment was composed with initiated and uninitiated students. This combination led—in each team—to the transmission of technical datas and improved the discussions in qualitative and quantitative ways. The result was mainly a good collaboration between participants with respect of each other.

6 Following of the Experiment

The gamers were happy at the end of the experiment and realized they learned a lot in a funny way. They have a unique opportunity to live a disturbed situation in a nuclear power plant within a safe environment. They felled the same difficulties as the TMI team and, consequently, improved their comprehension of some "mistakes".

The experiment was fruitful for each students. The following of the associated academic modules uses this experience to develop the study of human factors and their impact on the evolving of a perturbed situation.

At the end of the experiment, students mainly highlighted the following aspects. The first action during the simulation is a "reflex" action and could dramatically change the safety level of the nuclear power plant. Students also experimented the impact of the stress (mainly due to the flashing countdown) on reflections and reactions or on discussions between team members. Neither the hierarchy level nor the legal responsibility of some roles did actually affect the experiment course.

Pictures were taken during the experiment and, during the debriefing phase (several days or weeks later), they have been shown to the students. It was very surprising for them to discover how different their attitudes and reactions to a same situation were. It also initiated a discussion about no-verbal communication.

For the Belgian students, this experiment also served as basis to develop the study of the Three Mile Island accident. The students did not know that the "Sprintfield" scenario bases on this true story. During the analysis of the TMI accident progression, they realized that it was the same situation as what they lived a few weeks before. Their interest was boosted up because this description left a purely academic explanation and theoretical description, it became real. Consequently, the comprehension of this accident was improved, mainly on the human aspect and on the reaction of operators to conflicting information, lack of proper datas …

7 Conclusions and Perspectives

"Sprintfield" is a powerful tool to introduce the main notions about the way human factors in disturbed situations influence the system evolution [6] as well as the origins and mechanisms of these human factors or group dynamic.

"Sprintfield" is willingly a simplification of a real nuclear power plant. Its main objective is not to improve or check the nuclear knowledge of the students but really to emphasize the human and organizational factors. A more realistic (and, consequently, quite more complex) modelling will mask these aspects. Nevertheless, this model has to be sufficiently conform to physics and reality to stay credible for students aware with nuclear technologies. "Sprintfield" meets this dual challenge!

No-specialist students understand the basis of the nuclear power plant operation thanks to simple and clear documents. Specialist students, familiar with these basic notions, may apply their knowledge and speculate on the consequence of the proposed actions.

Based on the same principle, the interface is sober and composed of four separate parts (control panel, interaction with the technician, status of the safety components and warnings). Nevertheless, it could be improved by increasing the interactivity and allowing the team to propose actions or to ask the technician checking some components.

Future developments for this serious game should be to increase the interactivity, to propose more accidental sequences, to add a previous phase with a few actions to perform before entering the disturbed situation (hence, it will increase the role appropriations). Finally, the evaluation grid used by the teachers should be re-analyzed and maybe deeper developed.

A more systematic use of pictures or films during the debriefing phase will increase the efficiency of this pedagogical system.

The collaboration between both universities increases the anchor of the game with reality. Indeed, in actual teams, team members do not have the same profiles, the same experiences or knowledges, the same points of view. They do not know each other very well and it influences the interactions and their quality.

Finally, the objectives of this pedagogical experiment have been achieved. The students' perception of the human factors and difficulties met in disturbed situations has been highly improved and it led to a better and deeper understanding of severe accidents, including their specific challenges.

References

1. Van Stappen, Y.: La méthode des cas. Revue Pédagogique collégiale **3**(2), 16–18 (1989)
2. Legendre, R.: Dictionnaire actuel de l'éducation. Guérin, Montréal (2005)
3. Chamberland, G., Lavoie, L., Marquis, D.: 20 formules pédagogiques. Presses de l'Université du Québec, Québec (1995)
4. Prégent, R.: La preparation d'un cours. Editions de l'Ecole Polytechnique de Montréal, Montréal (1990)
5. Mucchielli, R.: Méthodes actives dans la pédagogie des adultes. ESF éd., Issy-les-Moulineaux (2008)
6. Reason, J.: Understanding adverse events: human factors. Qual. Health Care **4**, 80–89 (1995)

Design and Implementation of a Complex Virtual Reality System for Product Design with Active Participation of End User

Filip Górski, Paweł Buń, Radosław Wichniarek, Przemysław Zawadzki and Adam Hamrol

Abstract The paper presents studies on design and implementation of a complex Virtual Reality system for product design. Main objective of work presented in the paper was to obtain a tool suitable for on-line work with the clients on configuration of visual features of customized city buses. A complex product such as a city bus can have more than 100 visible features (options), which can be changed to obtain infinite configuration possibilities. The paper presents the overview and functions, as well as development process of the created system. Efficiency of the system in the visual configuration process was confirmed by representatives of the company. Capabilities of the system were tested using a sample of users from all the company departments involved in the bus design process. It confirmed high effectiveness of the system in terms of presenting variability of the product features in a clear visual way and improvement of the whole configuration process.

Keywords Human-systems integration · Virtual reality · Design process

F. Górski (✉) · P. Buń · R. Wichniarek · P. Zawadzki · A. Hamrol
Management and Production Engineering, Poznań University of Technology,
Piotrowo Str. 3, 60-965 Poznan, Poland
e-mail: filip.gorski@put.poznan.pl

P. Buń
e-mail: pawel.bun@put.poznan.pl

R. Wichniarek
e-mail: radoslaw.wichniarek@put.poznan.pl

P. Zawadzki
e-mail: przemyslaw.zawadzki@put.poznan.pl

A. Hamrol
e-mail: adam.hamrol@put.poznan.pl

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1 Introduction

Since its creation, the Virtual Reality (VR) techniques have undergone a significant metamorphosis, from entertainment and experimental applications with simple graphics to dedicated engineering tools, decision-making support systems and advanced training systems [1]. Currently, possibility of use of functionally and graphically advanced programming environments in connection with various peripherals brings users unique possibilities of interaction with virtual worlds. Advanced projection systems and tracking devices bring high level of user immersion into virtual environment, which is further expanded by haptic devices giving the user a sense of touch [2]. Vast potential of VR systems and theoretically unlimited range of possibilities of creation of virtual worlds makes VR a perfect tool for development of complex interactive systems, which ensure realism and immersion. Immersion is a deep sensation of presence in an artificial environment [3]. This feeling is very important in case of using Virtual Reality as a working tool, which requires interest and engagement on the user's side. Using immersive, as well as non-immersive Virtual Reality tools allows more effective work, in scope of medical training [4, 5] or engineering training [6], as well as simulation of operation of a complex device [7]. Emerging of so-called low-cost VR systems, such as Oculus Rift or Microsoft Kinect, as well as easy to learn and cheap or even free software, such as Unity 3D or Unreal Engine, makes access to benefits offered by VR much easier than ever before.

Possibilities of VR systems are more and more often used by companies which deal with design and manufacturing of complex products, especially in the automotive branch. Application of visualization and interaction in a Virtual Environment is now widespread worldwide. Production companies from the automotive branch focus their interest of VR systems mostly on stage of design and Virtual Prototyping of new products [8]. Application of VR on this stage of product development helps elimination of faults during design and faster and less costly preparation of a new product fulfilling the client's requirements in the best way possible.

Automotive products are good examples of configurable or variant products, as they are customizable to a certain degree. Design of a variant product is a specific example of the design process, as realized tasks have a routine character and are often repeated while developing a new variant. The variant product (configurable product) is a type of a product, in which there is a possibility to adjust values of certain features to individual expectations of a recipient [9]. These features are known as options and a process of their adjustment is known as the configuration, which results in a specific variant of a product. For very complex products, the configuration process may be considered as a design process, especially when a number of possible combinations is almost infinite. From the viewpoint of a manufacturing company, the variant product is often named a product family, meaning a part of assortment of a given company with a common design and manufacturing process [10]. Offering each client individualized variant of a configurable product is a strategy known as the mass customization (MC) [11].

Nowadays, the end users can configure their variant of a product by themselves, thanks to special software applications—product configurators. The configurators are used in many branches, although they are the most widespread in the automotive branch. They help the sales process and improve communication between producer and the client. Dynamical development of web-based applications in recent years made the companies share variant product configurators in the Internet with their customers [12].

More and more often, the product configurators are built using capabilities of VR systems. The visual product configurators based on VR techniques available for the end users significantly improve the design process and allow to realize the MC strategy [13, 14]. They increase product attractiveness and its promotion by allowing a customer to take part in the design process in a visual way. It is also possible to improve quality of communication and cooperation between the client and the company, to avoid certain mistakes and misunderstandings, which are less possible if the visual representation of the designed product is available at hand. Proper structuring and programming of such systems allows to accelerate the further stages of the design process, as the data from the configuration can be passed on to the company CAD and PLM systems in order to shorten time of preparation of the product documentation. However, such an approach is rare, as most VR configurators focus more on marketing aspects and less on work on a design process. In general, it can be said that product configurators allow to improve the overall product quality [15].

This paper presents capabilities of a unique, advanced VR system created by the authors in cooperation with an industrial company. This system involves the end user into the design process of a complex vehicle—a city bus. Number of techniques are used to make this more attractive, easier and more effective at the same time, both for the client and the company. The further chapters present basic assumptions, structure and possibilities of the system, as well as the test procedure and results.

2 Materials and Methods

2.1 Purpose and Structure of the System

The paper presents a multimodal, complex system for visual, real-time configuration of city buses, prepared by the authors of this paper. The system, named by the authors as Virtual Design Studio is focused on cooperative work with the clients, for effective selection of visual and technical features of city buses. This system consists of several subsystems, using various VR solutions to accelerate and facilitate selection of an optimal variant of a product in agreement with the producing company. The subsystems are based on hardware for stereoscopic image projection and intuitive interaction with objects placed in a virtual environment. Application of realistic visualizations and immersive environment, allowing testing a selected variant in a way similar to testing of a real product (i.e., virtual walk, interaction with the bus elements) allows to avoid problems and mistakes related to differences between the real product and client requirements. Using text configurators and only basic visual aids—a traditional way—is a cause of many mistakes, as results from practical experience of the company. These problems generate costs, due to need of adjusting product features even after production, when inconsistencies are detected. The system is currently implemented in the company and is available for the clients during sales negotiation process, as well as for internal use. The system is also partially integrated with the CAD and PLM solutions in the company.

The main features of the system are as following:

- Free configuration of selected features of a city bus (more than 100 options), using three independent but integrated systems.
- Stage 1 of configuration—visualization on a touch table (pre-configuration system, used mostly in external locations or events such as trade fairs).
- Stages 2 and 3 (linked together)—stage 2 consists in displaying the product on a large screen with full interaction and configuration possibilities (main configurator, used at company's place), while stage 3 relies on using immersive devices such as a Head-Mounted Display to give client a possibility of virtual walk (immersive configurator, used at company's place in synchronization with the main configurator).
- The configuration and all the functions of the system based on graphical user interfaces (tablet-based or launched on a large touch screen), standard peripheral devices such as mouse, keyboard and joystick, as well as gestures and movement recognized by devices such as optical tracking systems and contact gesture recognition devices.
- Interactivity of bus elements (possibility of opening doors, windows and other animations, as well as sounds and other multimedia).
- Free navigation: predefined and free camera views in two modes: Orbit and Walk (for external and internal vehicle exploration, correspondingly).
- Special multimedia functions, such as exploration mode with additional information about selected bus elements.
- Special set of visualization functions—hiding/showing groups of elements, dynamic sectioning etc.
- Full synchronization between configuration stages in real time, which is especially important between the second and the third stage of configuration. The synchronization is based on net protocols, so is possible to build a dispersed solution for distant collaboration.
- Data exchange interface between the VDS system and the CAD and PLM systems used in the company, allowing quick preparation of documentation necessary for designing a variant of a city bus selected by the client.

The system consists of several main modules. They are as following:

1. Visualization module—it is the main module (Fig. 1, left), which displays a selected product (city bus) and holds all the logic responsible for configuration and visualization. It was created using EON Studio software. It can work in the

Fig. 1 VDS system—visualization module (*left*) and main GUI (*right*)

standard mode for stage 2 of configuration or in an immersive mode for stage 3. It relies on dynamic assignments—all the visual and logical data is loaded from the library each time the system starts.

2. Main graphical user interface—it is usually launched together with the main module. It contains all the functions for configuration and visualization and it is also dynamically created on the basis of library assignments (Fig. 1, right).
3. Auxiliary GUI—it is a simplified interface based on web technologies, so it can be launched on any device with a web browser, for example on a tablet or laptop. It contains only basic configuration functions and can be presented to the client to involve him in the bus design process.
4. Administrative application—it works independently of the basic modules and is used to manage contents of the library and process data exchange between the VDS system and PLM and CAD systems. It is a special, dedicated application, which allows modification and adding of 3D and 2D content to the system without need of programming.
5. Minor modules—there is a number of supporting modules, such as the system launcher which allows to select the bus model and recently saved contract, or a report generator which allows to create a PDF document out of the current configuration.
6. Library—the library is not a module by itself, but rather a set of data, consisting of 3D data (meshes), 2D data (textures, photographs, movies etc.) and logical and metadata (virtual BOMs—bills of material for defined products, connections between options, special conditions, animation paths etc.)

Relations between the system elements are presented in a structural diagram, shown in Fig. 2.

2.2 *Configuration Functions of the System*

The city bus is a very complex product, with more than 300 configurable options, with very wide ranges of values. During the knowledge gathering process in the initial phases of building the system, it was decided to eliminate options which are not represented visually or such a representation would not be required. It allowed

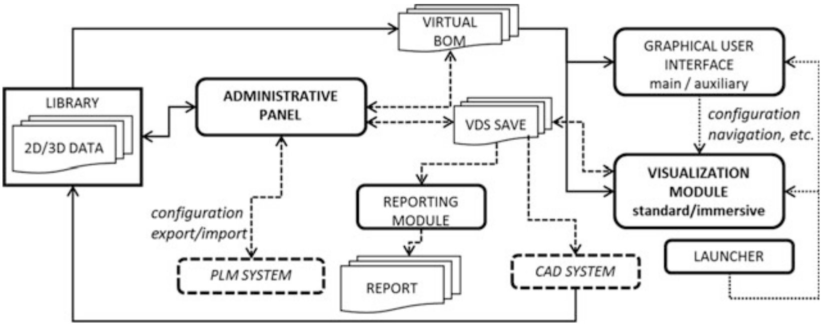

Fig. 2 Structure of the VDS system with indication of data flow directions

to narrow down the option list to approximately 100 options. A certain number of options (40) was left blank for future use or for special client demands. Table 1 presents main groups of options available for dynamic change in the system.

If current option/value range does not cover needs of the client, extra information in form of 3D notes (markers placed in 3D space around the bus) can be defined and stored. Current configuration can be always saved or a previous one can be loaded, to or from a special binary file known as the VDS Save (refer to Fig. 2). On the basis of this file, a report can be generated. The stored configuration can be also imported to or exported from a PLM system in the company, to transfer results of the visual configuration for further use.

2.3 *Visualization Functions of the System*

The VDS system contains a number of visualization functions, which do not influence current product configuration. These functions are as following:

Table 1 Configuration options of the VDS system

Group name	Description	No. of opts
Painting	Coloring in up to 12 zones	4
External features	Engine, wheels and air conditioning	10
Doors and windows	Type and arrangement of doors and windows	12
Seats and handrails	Type, arrangement, material of seats and handrails	14
Interior style	Floor, roof and side panels material	7
Driver's cabin	Equipment of driver's cabin	11
Electric components	Displays, cameras, speakers etc.	14
Equipment	Buttons, mirrors and other components	30
Extra components	First aid kit, fire extinguishers etc.	4
Extra options	Unassigned options, for free use	40

Fig. 3 Some visualization functions—exploration mode (markers in 3D space leading to multimedia content), sectioning of the vehicle

- Free navigation—two navigation modes (Orbit, Walk) with predefined views
- Animations with sounds—motion launched by user, e.g., opening doors
- Exploration mode (Fig. 3)—markers in space leading to extra information
- Tourist mode—predefined camera tours
- Section mode (Fig. 3)—dynamic cutting of the vehicle
- Environment change—load of various predefined scenes (city, garage etc.)
- Multimedia display—movies and pictures of a given bus may be displayed
- Display mode change—stereoscopic display may be turned on and adjusted
- Selective visualization—hiding certain parts of the vehicle.

2.4 *Interaction Channels and Methods*

Main channels of interaction with the VDS system are presented in Fig. 4. It is possible to interact with the system using a number of different interaction devices. The touch (main) GUI should be used mostly for configuration and import/export

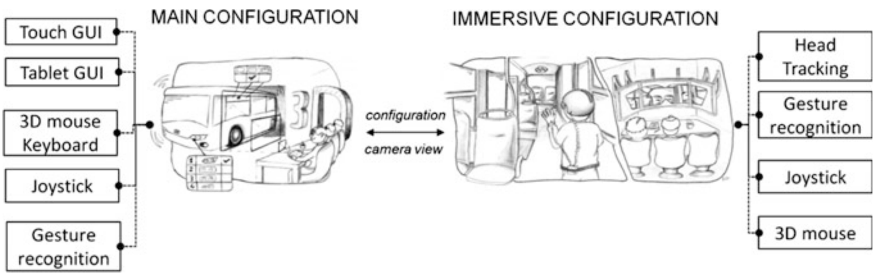

Fig. 4 Interaction channels of the VDS system

functions, while the visualization functions can be operated conveniently using a wireless joystick. Mouse and keyboard are also necessary to a certain extent, as mouse allows launching a context menu inside the visualization module with access to all visualization functions, while keyboard is necessary for text input in some cases.

The system is built in such a way, that it can be operated using almost any interaction device available on the market, provided that a defined communication standard will be maintained—the continuous signals (such as head or hand position in space) are sent to the system via the UDP protocol, while discrete messages (configuration changes, view changes, animations etc.) are sent via the TCP protocol.

The VDS system is adjusted to work with the positional tracking systems, especially in the immersive mode, to allow navigation by naturally walking and looking around. It is also possible to track hands of a user for additional gesture interaction. This interaction is intended to be performed using a Kinect 2.0 device, but almost any hand tracking can be used for the same purpose. Right hand movements allow to change the current camera position by rotate or zoom operations in the Orbit mode or walk and look around operations in the Walk mode. Left hand position switches currently performed navigation operation, while clapping hands resets camera to default position or changes the mode. Fist gesture and index finger gesture using the right hand are also recognized and they can be programmed to switching options, launching animations etc. The gesture recognition has two functions—first of all it should make the interaction more intuitive and natural. The second function is increasing attractiveness of the product, as the functionality is intended to be presented to the client and he is asked to make use of it.

2.5 Test Methodology

The test procedure of the VDS system was an extensive, lengthy and complex process and only selected procedures and results will be presented here. In general, the tests were launched after implementing a prototype version of the VDS system in the company. All the most important divisions of the company were represented, with 15 persons in total taking part in the most important stages of testing. The following assumptions were taken:

- each participant used the system individually or in a company of maximally one other person,
- the participants were fully informed of system's capabilities before tests, including immersive interaction options,
- two technical operators were always present during tests—they were trained before in capabilities and methods of interaction with the system and they assisted the test participants,
- each session lasted from 30 min to 2 h and it consisted in creating a new variant of the product and exploring it.

Fig. 5 Test procedure—participant involved in a virtual walk using HMD device

During the test procedure, the users were offered to use all the system's possibilities regarding different methods of interaction, including use of an HMD device—Oculus Rift DK2 was used (Fig. 5).

The general test results were summarized by survey studies, in which the participants were asked 40 questions, regarding usefulness of particular functions of the system, grouped in three categories: importance of functions (3-point scale), contents of visualization and technical aspects. This helped to formulate guidelines for improving and developing the system. The users were also asked to answer one summarizing question, which was "what are the two most important functions of the system from your viewpoint?". This was aimed at finding out which aspect of the system is the most valued by the company. The following functions were presented to choose from:

(a) dynamic visual representation of selected bus features,
(b) virtual walk around the bus,
(c) exchange of configuration data between the system and the PLM systems in the company,
(d) possibility of actively involving client into the process by giving him access to GUI and gesture interaction.

A separate path of testing focused on effectiveness of interaction with the system using tracking and gesture recognition. Ten inexperienced users (first time users) were asked to perform navigation operations and gestures using the Kinect 2.0 device. They were explained in basics of gesture navigation procedures and they attempted to perform the following sequence:

1. Navigate around the bus in the Orbit mode (perform full 360° rotation around the vertical axis and full 90° rotation around the horizontal axis).
2. Zoom in, but in a way to stay outside the vehicle.
3. Reset the Orbit camera by clapping above head.
4. Enter the Walk mode by clapping below waist.
5. Open the bus doors by selecting appropriate animation action and launching it using hand gestures (fist and index finger).
6. Navigate in the Walk mode to enter the bus, go to the center of the bus.
7. Look around the bus in every direction.
8. Reset the Walk mode by clapping.

The time of performing the above mentioned operations was recorded. The reference time (perfect time of a fully trained operator) was determined as 30 s. The users were also asked about their impression of the gesture-based navigation and answered in range between 1 (ineffective) to 5 (very effective).

3 Test Results

3.1 Gesture Interaction Results

The results of Kinect navigation tests are presented as a column chart in Fig. 6. Every user is summarized by a speed coefficient relative to the reference time (with 100 % being the best time—equal or exceeding the reference 30 s, 50 %—two times slower, i.e., 60 s etc.) and point value of answer to the question about general impression of the gesture interaction.

It is visible that the range of results is wide, with the worst-performing user obtaining a result of 33 % (90 s) and the best close to 95 % (32 s), but a general

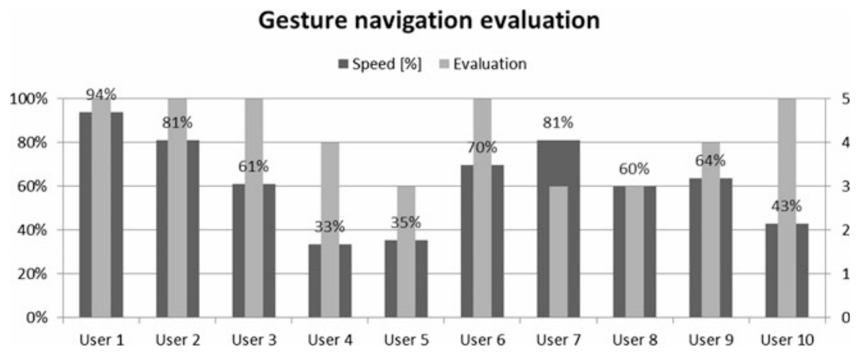

Fig. 6 Results of Kinect tests and evaluation by particular users

assessment of the gesture interaction feature is positive (no score below 3) and not always correlated with a result achieved by a particular user. It means that even if it is difficult and less effective to perform some operations using gestures, it is still considered as being attractive.

3.2 Survey Results

Full survey results are too extensive to put them here, but the general conclusions are as following:

- Most functions are either "very important" or "quite important", only some minor functions were evaluated as unimportant by certain test participants; more functions are needed, as pointed out by some participants.
- Large screen stereoscopic visualization is not required when there is option of using a Head-Mounted Display device for immersive virtual walk.
- The most effective way of interaction with the system is using wireless joystick in connection with a touch screen GUI.
- There are many minor inconsistencies between the model of a product and the real product, despite using exact geometry provided by the company design office—it is very difficult to obtain 100 % realistic representation of a product such complex as a city bus. Anyway, despite inconsistencies, the visualization was still evaluated as effective by all test users.

Distribution of answers for the single, summarizing question is shown in Fig. 7. As visible in the answers, the most users think that the most important functions are visual representation of possible product variants and possibility of export configuration data for further use in the PLM system.

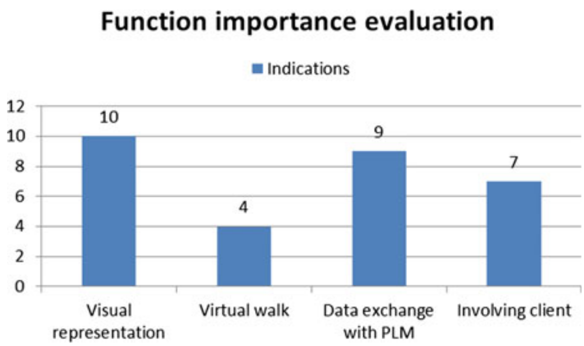

Fig. 7 Distributions of answers for the question of most important system functions

4 Summary

The VDS system created by the authors is a unique solution. It helps both clients, salesmen and designers to work faster and more effectively on design of a new variant of a city bus. The system was implemented in the company recently [16] and is now used in routine work in cooperation with the clients, as well as internally. Before starting the work, such a solution, integrating both full immersive VR and connection with PLM systems was not known to authors as being available anywhere in the world, neither commercially nor as a research result.

The system was assessed very well by the test users. Survey results and direct interviews performed before and after implementation are positive. The following general conclusions may be formulated, regarding the system evaluation and its further development:

- Scenarios of work with the system can consist of totally separate paths—education, marketing and sales variant, with experienced or inexperienced client or with distant collaboration—the company must learn how to utilize them effectively, which is currently defined as a future field of study.
- Application of immersive VR and gesture recognition increases positive feedback about the product and allows to better imagine its final look, provided that the experience is smooth (fluent), which was not always the case during the tests, as the visualization is demanding in terms of required computing power.
- Level of difficulty of operating the system for users not qualified with operation of complex IT systems can be defined as medium high—as results out of the tests, such a user can be trained to use the system on his own during 1–2 working days.
- Immersive features, such as gesture recognition and immersive walk, although not fully effective and easy, help increasing attractiveness of the product in client's perspective, so they should be presented frequently.
- Development of the system from the technical point of view should focus on obtaining better quality graphics and shorter launching time, with more fluent experience.
- The integration of different system modules is based on network data exchange, so theoretically it is possible to build a scattered system, with immersive configuration happening in a different place than the main configuration, maintaining the real-time synchronization. This possibility will be exploited in the future by the company.

Full studies of the system efficiency will be performed after a certain number of vehicles will be configured, purchased and used by the clients, on the basis of work performed in the system. The results of studies conducted so far allow to state, that the system meets the initial requirements, especially as regards improving the client-company communication process, as well as acceleration of the design process.

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References

1. Burdea, G.C., Coiffet, P.: Virtual Reality Technology. Wiley (2003)
2. Basdogan, C., Srinivasan, M.A.: Haptic rendering in virtual environments. In: Stanney, K. (ed.) Handbook of Virtual Environments, pp. 117–134. Lawrence Erlbaum Assoc (2002)
3. Bowman, D.A., McMahan, R.P.: Virtual reality: how much immersion is enough? Computer **40**(7), 36–43 (2007)
4. Hamrol, A., Górski, F., Grajewski, D., Zawadzki, P.: Virtual 3D Atlas of a human body—development of an educational medical software application. Int. Conf. Virtual Augmented Reality Educ. **25**, 302–314 (2013)
5. Zhang, L., Grosdemouge, C., Arikatla, V.S., Ahn, W., Sankaranarayanan, G., De, S., Jones, D., Schwaitzberg, S., Cao, C.G.L.: The added value of virtual reality technology and force feedback for surgical training simulators. Work J. Prev. Assess. Rehabil. **41**(suppl. 1), (2012)
6. Grajewski, D., Górski, F., Zawadzki, P., Hamrol, A.: Application of virtual reality techniques in design of ergonomic manufacturing workplaces. Int. Conf. Virtual Augmented Reality Educ. **25**, 289–301 (2013)
7. Pandilov, Z., Milecki, A., Nowak, A., Górski, F., Grajewski, D., Ciglar, D., Mulc, T., Klaić, M.: Virtual modelling and simulation of a CNC machine feed drive system. Trans. FAMENA **39**(4), 37–54 (2015)
8. Zimmermann, P.: Virtual reality aided design. A survey of the use of VR in automotive industry. In: Talaba, D., Amditis, A. (eds.) Product Engineering, pp. 277–296. Springer, The Netherlands (2008)
9. Jørgensen, K.A.: Product configuration and product family modelling. http://www.kaj.person.aau.dk/digitalAssets/49/49143_productconfigurationandproductfamilymodelling.pdf (2009). Accessed 27 Feb 2016
10. Simpson, T.W.: Product platform design and customization: status and promise. AI EDAM: Artif. Intell. Eng. Des. Anal. Manuf. **18**(1), 3–20 (2004)
11. Salvador, F., de Holan, P.M., Piller, F.: Cracking the code of mass customization. MIT Sloan Manage. Rev. **50**(3), 71–78 (2009)
12. Liechty, J., Ramaswamy, V., Cohen, S.H.: Choice menus for mass customization: an experimental approach for analyzing customer demand with an application to a web-based information service. J. Mark. Res. **38**(2), 183–196 (2001)
13. Grosso, C., Trentin, A., Forza, C.: Towards an understanding of how the capabilities deployed by a Web-based sales configurator can increase the benefits of possessing a mass-customized product. In: 16th International Configuration Workshop, vol. 21, p. 81 (2014)
14. Górski, F., Hamrol, A., Kowalski, M., Paszkiewicz, R., Zawadzki, P.: An automatic system for 3D models and technology process design. Trans. FAMENA **35**(2), 69–78 (2011)
15. Trentin, A., Perin, E., Forza, C.: Product configurator impact on product quality. Int. J. Prod. Econ. **135**(2), 850–859 (2012)
16. Górski, F., Buń, P., Wichniarek, R., Zawadzki, P., Hamrol, A.: Immersive city bus configuration system for marketing and sales education. Procedia Comput. Sci. **75**, 137–146 (2015)

A Hot-Backup System for Backup and Restore of ICS to Recover from Cyber-Attacks

Shinya Yamamoto, Takashi Hamaguchi, Sun Jing, Ichiro Koshijima and Yoshihiro Hashimoto

Abstract Because the techniques of cyber-attacks are developed every day, it is impossible to defend the cyber-attacks completely. Therefore, it is necessary to discuss how to defend proper control against cyber-attacks when the attackers intrude in the ICS. We focus on new ICS structure without stopping the plant operation under the situation, and aim to improve detection, security and restoration abilities of ICS on the continuous process. In this paper, a virtualization technology is used to realize the three purposes. Using the feature of virtualization technology, we propose a hot-backup system for backup and restore of ICS to protect from cyber-attacks.

Keywords Cyber-Attacks · Industrial control system · Security

1 Introduction

Strengthening of cyber security is not a problem only for the IT field. By an appearance of Stuxnet, even the controller of ICS (Industrial Control System) becomes the target of the cyber-attacks [1]. The conventional ICS uses vendor original OS and communication protocol. Additionally it is hardly that the conventional ICS network connected to the IT network. Therefore, cyber-attack to ICS was arduous.

However, the present ICS is connected to IT network to increase production efficiency including the optimization of operation conditions and the acceleration of managerial decisions. In addition, the present ICS is introduced inexpensive or free open source application such as consumer OS, PC terminal and Ethernet-TCP/IP to reduce cost. They have many vulnerabilities. In consequence, these cause the vulnerability of ICS itself.

S. Yamamoto (✉) · T. Hamaguchi · S. Jing · I. Koshijima · Y. Hashimoto
Graduate School of Engineering, Nagoya Institute of Technology, Gokiso-Cho, Showa-Ku, Nagoya 466-8555, Japan
e-mail: cjh17092@nitech.jp

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The cyber-attacks to ICS is not only cause adverse effects for the plant operations, but also cause severe accident such as the explosion of facilities. When IT system restores, the system is generally rebooted. However, ICS of continuous process must be always driven to continue plant operation. Therefore, we must consider that the system is restored without stopping of plant operation. The ICS must maintain the control function even if the sub system is stopped and restored to recover against cyber-attacks.

Because the techniques of cyber-attacks are developed every day, it is impossible to defend the cyber-attacks completely. Therefore, it is necessary to discuss how to defend proper control against cyber-attacks when the attackers intrude in the ICS. Takagi et al. discuss a systematic approach to design robust protection systems against cyber-attacks for ICS [2]. We focus on new ICS structure without stopping the plant operation under the situation, and aim to improve detection, security and restoration abilities of ICS on the continuous process. In this paper, a virtualization technology is used to realize the three purposes. By the virtualization technology, not only independent plural virtual machines can be built on one machine, but also virtual network structure can be changed freely. Using the feature of virtualization technology, we propose a secure ICS with "Dualization of the controller" and "Security Patch update system" and so on.

2 Secure ICS Structure Against Cyber-Attack

Figure 1 shows a structure of ICS. ERP (Enterprise Resources Planning) exists in the enterprise zone, which is used by head office and business functions as the highest layer system. It is necessary to unify the management information such as production schedule, quality control of products, ordering, and stock to plan optimization of the whole company.

Production optimization of the whole factory is performed in MES (Manufacturing Execution System). As shown in Fig. 1, it is located in the middle of enterprise zone and control zone. Generally, MES performs production support and management such as process control, quality control, manufacturing management and point of production (POP) information management. In this research, we call a network above from MES Corporate Network.

Recently, SCADA (Supervisory Control and Data Acquisition) system is adopted for ICS. The function of SCADA system is monitoring of the plant and collection of control data. The SCADA is used to manage the system distributed to the wide area remotely. Generally, the operator supervises the control system through terminals. In the SCADA system, the general-purpose products such as PCs and standardized network protocol are used. Thereby, they have the vulnerability of security for the cyber-attacks by attackers.

ICS has controllers called PLC (Programmable Logic Controller) and DCS (Distributed Control System). The controller reads PV (Process Variable; measurement signals such as flow rate and temperature, the pressure) from Field

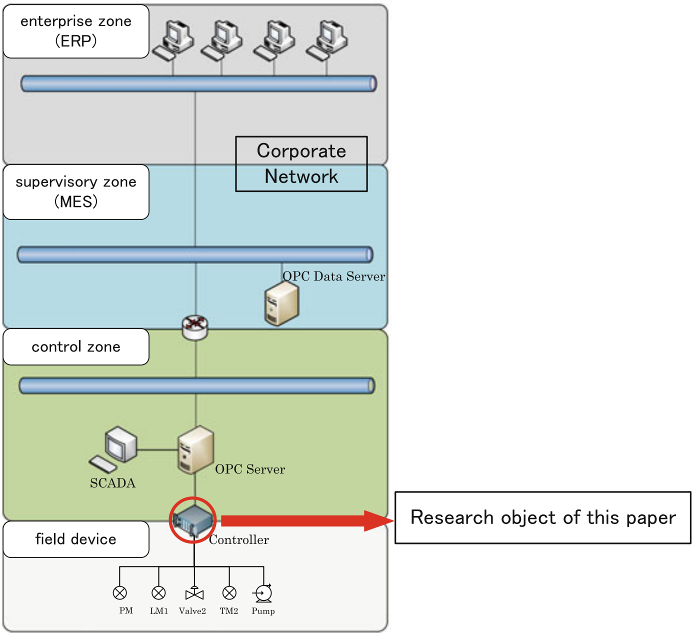

Fig. 1 Structure of ICS

Device. It does control operation based on PV it reads. It out-puts MV (Manipulative Variable) which is quantity of control to the operation apparatuses such as actuators.

The OPC (OLE for Process Control) is an important standard to connect between SCADA and PLC. Even if the apparatuses such as client applications or the controller adopt different communication protocol, they can be connected by a function of OPC. The OPC server accumulates data of PVs, which are sent from controllers. The operator monitor the plant operation through terminals. Figure 2 shows the general structure of ICS's controller. A controller communicates with "Plant" and "Monitoring System" through "Data I/O". The controller generate MV to operate the actuator from a deviation of SV and PV.

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In this paper, we assume that attackers try to make the falsification of SV to controller and to rewrite control program in the controller. We propose a hot-backup system for backup and restore of ICS to recover from cyber-attacks, as shown in Fig. 3. The "Corporate Network" and "Monitoring System" are connected directly. The "Monitoring System" and controller are connected through a SV check system. The SV check system is explained in Sect. 3. The controller has

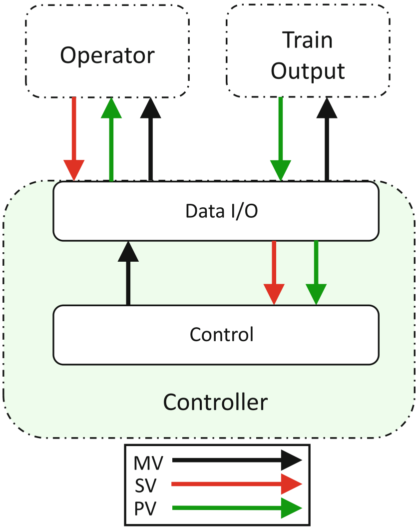

Fig. 2 The general structure of ICS's controller

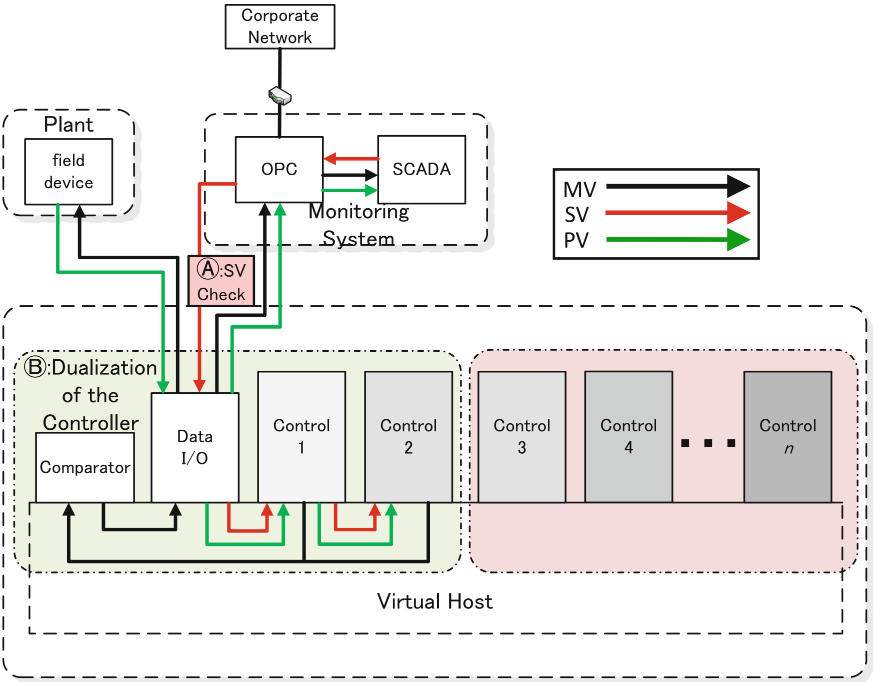

Fig. 3 A hot-backup system for backup and restore of ICS to recover from cyber-attacks

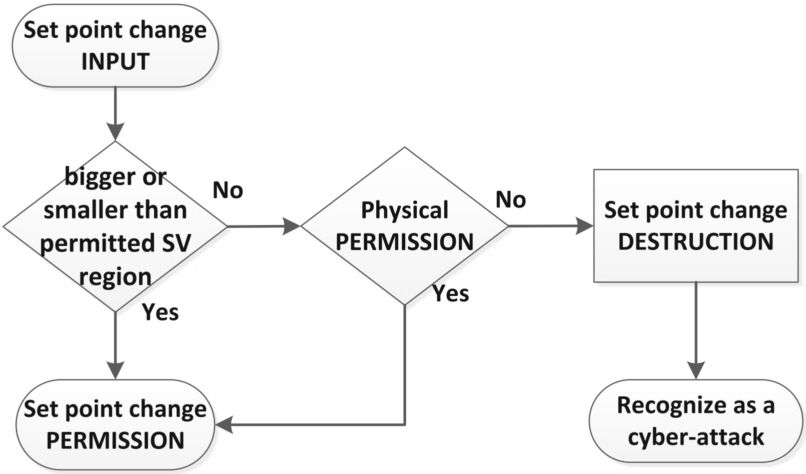

Fig. 4 Flow chart of SV check

"Dualization Controller System" and "Backup and Restore System", too. Each system is explained in Sects. 4 and 5. Moreover, we explain "Security Patch update System" to reduce the vulnerability in ICS is explain in Sect. 6.

3 SV Check System

To damage the plant, attacker may change the SV into the inappropriate SV region. The purpose of SV check system is to protect the plant safety from the inappropriate input of SV change. The flow chart is shown in Fig. 4. When the desired new SV is bigger or smaller than permitted SV region, then the SV change must confirm by the physical permission such as pushing button or turning a physical key by operator. If the SV change cannot permit operator, it may be cyber-attacks. It the SV change permit the operator and the SV change cannot reflect the terminals, it may be cyber-attacks, too. This system can be used as a detection system for cyber-attacks.

4 Dualization Controller System

Some controllers for train have dualization structure for machine trouble as shown in Fig. 5. In the system, comparator compare the MVs from Control 1 and 2. When the Control 1 and 2 are normal, the MVs match and the MV is transmitted to a plant. If the MVs do not match because the Control 1 and/or Control 2 have

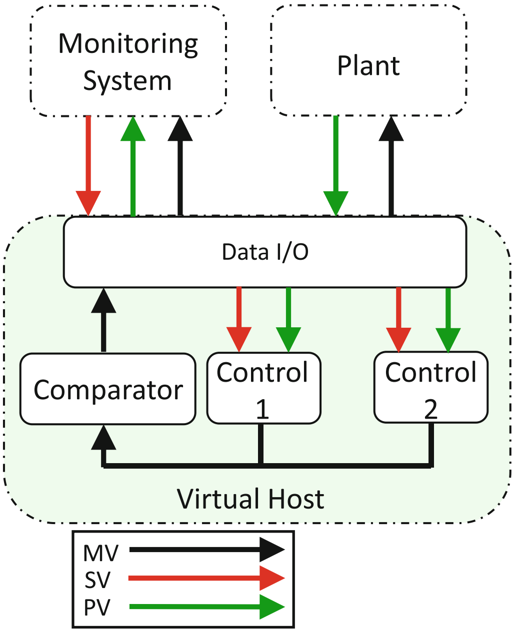

Fig. 5 A dualization of the controller for machine trouble

machine trouble, then the controller must output the suitable MV to stop the train for safety [3].

In this paper, we assume that attackers try to make to rewrite control program in the Controller. In the structure of Fig. 5, attackers may re-write both Control 1 and 2. If attackers rewrite either Control 1 or 2, it is desirable to product by another Control without stopping the plant operation. We propose a dualization of the controller for the cyber-attacks on the continuous plant based on the dualization of the controller for machine trouble as shown in Fig. 6.

The difference between the structures in Figs. 5 and 6, Control 2 does not connect directly to Data I/O, but connect to through Control 1. The structure is adopted to prevent rewriting program of Control 2 by attacker. We consider the Control 2 can get SV and MV through Control 1, even if attackers rewrite the program of Control 1.

At first, a change procedure of the program of Controller is explained. The behavior of this system is determined by combination of the state of Control 1 and 2. In this example, each Control 1 and 2 has following four states.

- P1: program 1 is running.
- P1(P2): program 1 is running, but program 2 is downloading, too.
- P1 $\Rightarrow$ P2: program 1 is stopping, and program 2 is installing to change from program 1.
- P2: program 2 is running.

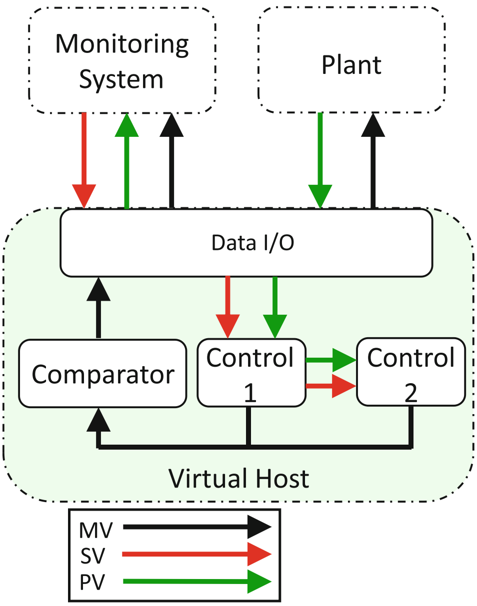

Fig. 6 Dualization of the controller for the cyber-attacks

In this paper, the combination of the state of Control 1 and 2 is explained by brackets such as (state of Control1, state of Control2). The * means the wild card for state. The state transition of rewriting program of Control is shown in Table 1. The Comparator outputs are summarized followings.

- CS1: [*, P1 or P1(P2)]; Comparator outputs P1.
- CS2: [*, P1 ⇒ P2]; Comparator outputs maintain a former MV of Control 2.
- CS3: [*, P2]; Comparator outputs P2.

The <A> and <B> in Table 1 means reasons of Comparator outputs.

<A> To continue operating without stopping the operation of the plant, MV of Control 2 is transmitted to Field Device.

Table 1 State transition of rewriting program of control

State	Activity (control 1)	Control 1	Activity (control 2)	Control 2	Activity (comparator)
1	Steady-state	P1	Steady-state	P1	P1 out
2	Download P2	P1 (P2)	Steady-state	P1	P1 out
3	Input P2	P1 ⇒ P2	Steady-state	P1	<A> P1 out
4	Steady-state	P2	Steady-state	P1	<A> P1 out
5	Steady-state	P2	Receive P2	P1 (P2)	<A> P1 out
6	Steady-state	P2	Input P2	P1 ⇒ P2	<B>
7	Steady-state	P2	Steady-state	P2	P2 out

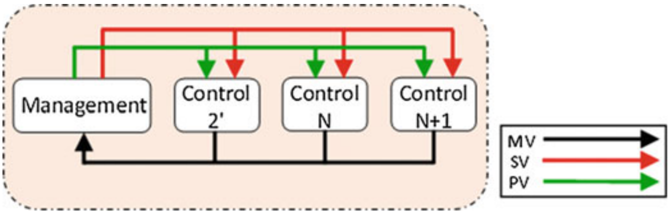

Fig. 7 The structure of security patch update system

<B> To continue operating without stopping the operation of the plant, a last MV of Control 2 based on P1 is maintained and transmitted to Field Device.

Next, let's consider that Control 1 is rewritten from P1 to P2′ by attackers. An appreciate output P1 can be maintained until state 4, [P2′, P1], by Control 2. Therefore, the detection method of state 2, 3, and 4 by cyber-attacks and the protection method to stop the progress from state 4 to state 5 must be considered.

The detection method can be realized by the monitoring the Comparator's judgement. If the comparator outputs the <A> without operator's command, then it means the possibility of cyber-attacks. The protection method without operator's command can be realized by the physical action as same as SV Check.

5 Security Patch Update System

Structure of security patch update system is shown in Fig. 7. Update Security Patch is required that the operation is not adversely affected by Security Patch. Thereby, the Security Patch must be checked whether it is suitable for ICS.

This system uses the structure like a foregoing chapter. Some virtual machines that are the same structure as Control 2 is prepared. Control 2′ is held as the same state. The other control group is hit with various Security Patches. The purpose is a behavior investigation when a Security Patch is applied. These machines are not used real plant operation. Thus, these machines are not outputted for Comparator. However, MV of all Control group is outputted for Management that is the machine of the third party to determine whether each Security Patch is applied to ICS. To create MV, SV and PV is given to the Control group from Management as an identification signal. The difference of behavior Control 2′ and the other Control group can be checked from Management.

The Security Patch evaluated that it does not adversely affect ICS assume Control X. In changing virtual networks, Control X use as Control 2. During this substitution, MV is maintained a former value illustrated by a foregoing chapter. Finally, Control 1 is replaced to Control X. In this method, the ability for security of the ICS controller can be improved with bumpless.

6 Conclusion

In this paper, we proposed a hot-backup system for backup and restore of ICS to recover from cyber-attacks. As prospects for the future, we will implement the proposal system and develop function more. The proposal system is considered for continuous process. It is important to consider others manufacturing processes such as lot production and batch production.

References

1. Macaulay, T., Singer, B.: Cybersecurity for Industrial Control Systems: SCADA, DCS, PLC, HMI, and SIS. CRC Press, Boca Raton, Florida (2011)
2. Takagi, H., Morita, H., Matta, M., Moritani, H., Hamaguchi, T., Jing, S., Koshijima, I., Hashimoto, Y.: Strategic security protection for industrial control system. In: Proceedings of SICE Annual Conference 2015, pp. 1215–1221 (2015)
3. Hirao, Y.: Anzen system to software (in Japanese). Anzen anshin shakai kenkyu, **2**, 61–73, (2012). http://safety.nagaokaut.ac.jp/~safety/wp-content/uploads/2013/12/anzen_02-07.pdf

Life Cycle Cost and Reliability Analysis to Evaluate Gas Destination

Larissa Barreto Paiva, Fernando Luiz Pellegrini Pessoa and José Eduardo Dias, Jr.

Abstract Pre-Salt fields in Brazil have been demanding more complex plants to treat the associated gas due to high gas-oil ratio (GOR) combined with a high CO_2 content. It was proposed a combined methodology of Life Cycle Cost Analysis and Reliability, Availability and Maintainability Analysis to assess gas monetization in oil and gas process plants of offshore oil production platforms. Two scenarios have been compared: Gas Export and Total Gas Reinjection. Methodology indicated the Total Gas Reinjection Scenario with better economic advantages—bigger Net Present Value (NPV)—than Gas Export Scenario, using the evaluation of cost drivers (revenue, capital cost and operational cost) at some economic assumptions. It is important to bring up that the methodology, which has been used in this study, can be applied for further analysis.

Keywords RAM analysis · Life cycle cost analysis · Oil processing · Associated gas destination · Integrated method

1 Introduction

Reliability and Maintainability, as well as Cost and Performance, are vital qualities for Process Plants. The balance between them is very important for the unit to succeed (BS ISO 5760-0:2014). In process plants design for Production Stationary Units background, the level of required investment and changes cost is high. Moreover, times of loss of production cause enormous losses of revenue. For this reason is important to appreciate for a reliable, durable and easy to fix plant, with the lowest number of failures possible [1].

L.B. Paiva (✉) · F.L.P. Pessoa · J.E. Dias, Jr.
Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil
e-mail: laripaiva@gmail.com

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Reliability Availability and Maintainability (RAM) Analysis has gained increasing significance in oil and gas, because their cost with unreliable equipment is high. RAM Analysis is the study able to measure failures and repair times to optimizer the process plant operation [1].

Life Cycle Cost Analysis is a spread technique used for predicting and evaluating a unit financial performance, as well as to focus on company's policy, intend to indicate the best investment [2]. The methodology takes into account important variables like design and operational costs, revenue, decommissioning cost, and also qualitative analysis that meet company's policy, like environment or social issues [3].

In a Life Cycle Cost Analysis, RAM techniques are used to getting the real time of production during the whole life of operation to estimate the plant revenue, and it is also important to determinate the necessary cost for maintenance [3].

Combining both analysis to oil and gas processing plants design is important to optimize the fuels production and maximize the Net Present Value (NPV). Moreover, this combination has presenting good results in several sectors [4].

To treat high gas flowrates, sourced from the high Gas-Oil Ratio (GOR) of Pre-Salt fields, associated with high CO_2 content, it is necessary more complex process plants, with larger equipment and higher energy demand. For this reason, it becomes important an economic evaluation of gas monetization, whereas gas pipelines building are expensive and gas treatment plants for exportation are more complex than for total reinjection to meet the more rigorous specifications required.

The purpose of this study is the application of the integrated methodology Life Cycle Cost Analysis and RAM Analysis to evaluate oil and gas process plants offshore. Two different scenarios of gas destination were compared (total gas reinjection and gas exportation by pipeline) in terms of reliability, maintainability, availability, revenue, capital and operational costs, and Net Present Value (NPV) of the whole life cycle of each plant.

2 Evaluated Scenarios

It was assumed that field exploration period is 25 years for a typical pre-salt production curve, the process plant maximum oil capacity is 180,000 bpd and maximum gas capacity is 7,000,000 Sm^3/d (@ 15.6 °C and 1 bara). Gas Exportation Scenario is represented in Fig. 1 and Gas Total Reinjection Scenario is represented in Fig. 2.

Energy demand from both scenarios was considered to be supplied with fuel gas generated with the own gas production of the platform (Table 1).

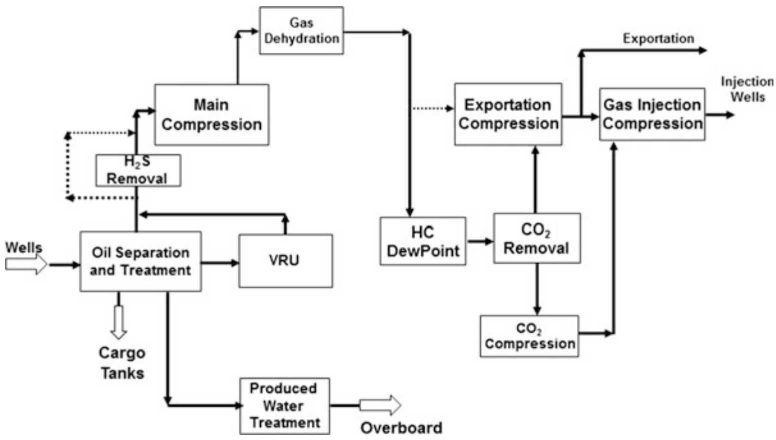

Fig. 1 Block diagram of gas exportation scenario oil and gas process plant

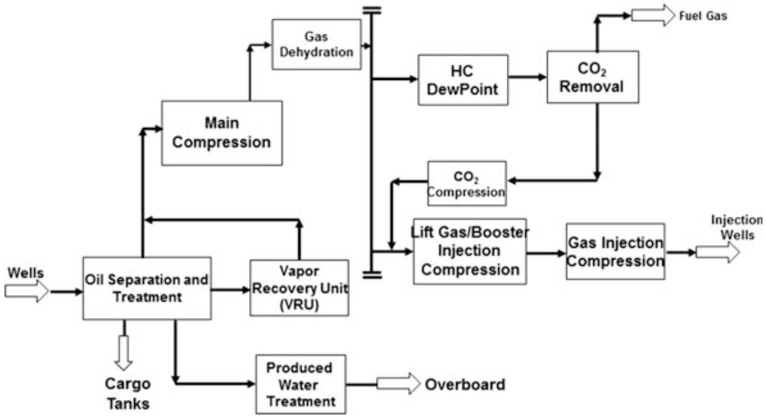

Fig. 2 Block diagram of gas total reinjection scenario oil and gas process plant

Table 1 Comparison between two scenarios

Scenario	Gas export	Gas reinjection
Compressors	Higher capacities	Lower capacities
CO_2 compressors	Four stages	Two stages
H_2S removal	Treats whole gas	Doesn't have
Dew point adjust	For whole gas	Just for fuel gas
CO_2 removal	For whole gas	Just for fuel gas
Gas flowline	For gas exportation	Doesn't have
Flexibility	Possible to operate in Gas Reinjection mode	Doesn't have

3 Methodology of Economic Evaluation

3.1 Life Cycle Cost Analysis (LCCA)

The two proposed scenarios of oil production process plants were compared using LCCA evaluation, which includes all the costs in research and development, construction, operation, maintenance and disposal, and also all revenues in the whole exploration field life cycle.

For scenarios comparison, just the differences between them are relevant, so it was chosen the cost drivers, the costs that would help to decide the best option for the oil production process plant in a field with pre-salt characteristics, considering some technical and economical assumptions.

Several methods can be used to economic evaluation, such us Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI), each one with advantages and disadvantages. The NPV was chosen because it was considered the most suitable for alternatives comparison, and it was calculated just the differences of NPV between the scenarios [5].

Reliability, Availability and Maintainability (RAM) analysis results were used to calculate the real revenue of the plants, incorporating equipment unavailability in cost evaluation (NPV calculation).

For each year of production, the availability in oil and gas production were used to multiplier the expected production volume of each product.

$$\text{Revenue} = \sum_{n=1}^{25}\left[\frac{(\text{Oil Produced Volume})^{n} \times \text{Oil Price}}{(1+\text{Discount Rate})^{n}}\right] + \sum_{n=1}^{25}\left[\frac{(\text{Gas Produced Volume} - \text{Fuel Gas Volume})^{n} \times \text{Gas Price}}{(1+\text{Discount Rate})^{n}}\right] \quad (1)$$

Letter n in Eq. 1 represents a period in years, considering 2014 as base-year for this study. The discount rate used to calculate the ΔNPV was the SELIC rate of 2014, the basic rate of Brazilian economy (10.86 %) [6]. Oil price was considered the average price of Brent in 2014 (US$99.48 per barrel) and gas price was considered the average price of Henry Hub in the same year (US$4.35 per MMBTU or US$0.17 per Sm^3) [7].

For total gas reinjection scenario, the gas revenue is zero, because it is not treated to be sold, just an amount necessary for fuel gas is treated. Therefore, there is only the part of oil revenue in Eq. 1.

The difference in revenue of the two scenarios evaluated was calculated as Eq. 2, the revenue from Gas Export Scenario less the revenue from gas reinjection scenario.

$$\Delta \text{Revenue} = \text{Revenue Gas Export} - \text{Revenue Gas Reinjection} \tag{2}$$

The costs with process plant development, design and construction are the Capital Expenditure (CAPEX). There are many methods to estimate the CAPEX: detailed estimate based on complete engineering design and specifications; study estimate based on knowledge of major items of equipment, with other costs estimated as a percentage of equipment cost; or order-of-magnitude estimate based on similar previous cost data [5].

Considering a preliminary step of process plant design, for this study, CAPEX estimation was done based on major equipment cost, with other costs as a percentage of equipment one. The software Aspen Process Economic Analyzer and available literature were used to estimate equipment cost.

The equipment out of software scope was acquired from available literature and the size of operational capacity was corrected by scaling, using the logarithmic relationship of Eq. 3 [5].

$$\begin{aligned} \text{Equipment Cost} = {} & \text{Equipment Cost Avaiable} \\ & \times \left(\frac{\text{Equipment Capacity}}{\text{Equipment Capacity Available}} \right)^{0.6} \end{aligned} \tag{3}$$

Only differences in process plant between the two scenarios were considering in equipment cost calculation, and consequently the CAPEX estimation represents the differences in capital expenditure from Gas Export Scenario to Gas Reinjection scenario, as Eq. 4. The CAPEX absolutely value of each scenario, individually, wasn't estimated.

$$\Delta \text{CAPEX} = \text{CAPEX Gas Export} - \text{CAPEX Gas Reinjection} \tag{4}$$

The costs with operation and maintenance are the Operational Expenditure (OPEX). It was estimated as a percentage of CAPEX [5]. Just the differences between the scenarios (from Gas Export to Gas Reinjection) were considered.

Maintenance and repairs were estimated as 7 % of CAPEX and operating supplies as 15 % of costs with maintenance and repairs [5]. Therefore, the difference in OPEX between the two scenarios was calculated as Eq. 5.

$$\Delta \text{OPEX} = 0.07 \times \Delta \text{CAPEX} \times (1 + 0.15) \tag{5}$$

The absolutely NPV of each scenario was not calculated, because, for this analysis, just the differences between Gas Export Scenario NPV and Gas Reinjection Scenario NPV were relevant. The value of ΔNPV was calculated as Eqs. 6 and 7.

$$\Delta\text{NPV} = \Delta\text{Revenue} - \Delta\text{CAPEX} - \Delta\text{OPEX} \tag{6}$$

$$\Delta\text{NPV} = \text{NPV Gas Export} - \text{NPV Gas Reinjection} \tag{7}$$

Based on this background, a positive ΔNPV indicates the Export Gas Scenario as the most economically interesting one, and a negative ΔNPV indicates the Reinjection Gas as the most economically attractive scenario.

Even SELIC rate is just available in Brazilian currency, the conversion in dollar was considered the same to apply and withdraw the money. Furthermore, there were variables with high volatility in cost evaluation, like oil and gas price, for example.

3.2 Reliability, Availability and Maintainability Analysis

A commercial software, based on Monte Carlo simulation methods, was used in this study for RAM Analysis. The commercial database OREDA was used to take reliability data's.

Both schedule and unscheduled plants shutdowns, and also preventive and corrective equipment maintenance were included in RAM simulation.

It was used as assumption the necessity of treatment plant be available to specify the oil for sale and the produced water for disposal, if it is not, the production stops.

Another premise was a burning limit of 3 % of gas volume handled per month. It is required from National Agency of Oil, Natural Gas and Biofuels in Brazil (ANP) [8].

One more supposition was a volume of diesel available in platform to substitute fuel gas per 7 days in case of failure in CO_2 removal System, or in CO_2 compressor Unit, or in dew point adjust System. It wasn't considered gas importation from fuel gas flowline, even for Gas Export Scenario.

Therefore, the results of RAM analysis represent the percentage, in volume, of total expected production, that will be produced, considering process plant availability. Thus, they represent the actual volume per the expected one.

4 Results

RAM results are displayed in Table 2. It presents the produced oil volume and process plant availability for oil production considering the whole life cycle.

According to Table 2, it is possible to conclude that the availability of Gas Export Scenario process plant is a little higher than Gas Reinjection one. Thus, the oil revenue considering the whole life cycle is also higher for Gas Export Scenario.

Table 2 RAM results in availability of oil production

Process plant avaiability		
	Gas export	Gas reinjection
Oil produced volume (million barrels)	586.54	585.45
Average efficiency (%)	92.50	92.33

The field's revenue in oil and in gas, considering a process plant with total availability, are displayed in Table 3 (column "Production without unavailability"). Therefore, it is possible to compare with the revenue of both scenarios with RAM results incorporate (considering unavailability) and notices the importance of RAM Analysis in a LCCA for not being too optimist in revenue value.

As expected, because of higher flexibility to Gas Export Scenario, it has a bigger value of oil revenue than the Gas Reinjection one. In addition, it also has gas revenue, due to consider gas treatment for sale.

In Table 4 are presented both Gas Export Scenario and Gas Reinjection Scenario total revenues in present value (applied the discount rate per year), for whole life cycle of the field exploration.

Table 5 presents the difference in CAPEX between the two scenarios evaluated: Gas Export and Gas Reinjection.

Brazilian average cost per kilometer per diameter of a gas flowline is US$80/m pol [9], this value was considered for CAPEX evaluation. Moreover, commercial CO_2 removal membranes skids cost was considered as US$750/m^2 [10]. Other values were obtained from Aspen Process Economic Analyzer.

Table 3 Oil and Gas revenue during the whole exploration field life cycle

Oil revenue (million US$)	
Production without unavaiability	27.00922
Gas Export Scenario	25.08872
Gas Reinjection Scenario	25.04682
Gas revenue (million US$)	
Production without unavaiability	2.82570
Gas export scenario	2.04671
Gas reinjection scenario	

Table 4 Oil and Gas revenue during the whole exploration field life cycle

Revenue (million US$)	
Gas export revenue	27.13543
Gas reinjection revenue	25.04682
Difference	2.08861

Table 5 Differences in CAPEX between two scenarios

CAPEX (million US$)			
	Gas export	Gas reinjection	Difference
Gas flowline	569.44	0.00	569.44
Natural gas treatment	2190.85	373.22	1817.63
Water injection system	3.60	3.30	0.29
Compressors units (except injection compressor)	31.39	15.80	15.59
Total			2402.95

Table 6 Differences in OPEX between two scenarios

OPEX (million US$)	
Difference between scenarios	
Maintenance and repairs	168.21
Operating supplies	25.23
TOTAL	193.44

Table 6 presents the differences between assessed scenarios (from Gas Export to Gas Reinjection) in OPEX.

Both CAPEX and OPEX are higher to Gas Exportation Scenario if compared with the Gas Reinjection one.

Meanwhile the decision criterion was the ΔNPV, calculated using Eqs. 6 and 7. The result was negative (−507.79 million dollars), which means that Gas Reinjection Scenario has a bigger ΔNPV than Gas Export Scenario for these technical and economical considerations.

As much as a cost evaluation, a RAM Analysis would be used alone to help in decision of the best option, or the best scenario. Nevertheless, the results of this study indicate the advantages of using them together.

The importance of RAM Analysis came clear in Table 3, by comparing the revenue of both scenarios evaluated with revenue of an imaginary one without unavailability.

In the other hand, the importance of cost evaluation became apparent comparing the final result, that indicate Gas Reinjection Scenario as a better option, with the RAM Analysis results, that indicate the Gas Export Scenario as the more available one. Therefore, if the analysis was restricting for RAM, it would indicate a partial vision, and doesn´t consider the cost involved to have more flexibility and avaiability.

That’s important to bring up that these results are valid just for the technical and economical assumptions quoted in this paper, but the methodology used could be applied for others scenarios in other conditions.

5 Conclusion

Confronting a Gas Export Scenario with a Gas Reinjection one for the process plant of a field with pre-salt typical characteristics, in terms of cost and availability it was possible to have enough information to decide between them.

The results of RAM analysis indicate the Gas Export Scenario as the most available, which was expected because of its higher flexibility. Meanwhile, using RAM results in a cost evaluation, it was possible to conclude that the cost with more flexibility doesn't worth.

The method used to compare both scenarios in Net Present Value, taking into account the revenue of each scenario, and the differences in CAPEX and OEPX between them, indicates the Gas Reinjection Scenario with a bigger NPV for the technical and economical assumptions.

It is just important to bring up that there were variables with high volatility in cost evaluation. Though, this methodology can be always used to compare the same scenarios, in different technical and economical considerations, or even other scenarios.

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References

1. International Organization for Standardization: ISO 14224—Petroleum and natural gas industries—collection and exchange of reliability and maintenance data for equipment (2006)
2. British Standard Institution: BS ISO 15686-5—building and constructed assets—service-life planning—part 5: life cycle costing (2008)
3. International Organization for Standardization: ISO 15663-2—petroleum and natural gas industries—life-cycle costing part 2: guidance on application of methodology and calculation methods (2001)
4. Kawauchi, Y., Rausand, M.: Life cycle cost (LCC) analysis in oil and chemical process industries (1999)
5. Peters, M.S.: Plant Design and Economic for Chemical Engineers. McGraw-Hill, New York (1991)
6. Central Bank of Brazil. http://www.bcb.gov.br
7. National Agency of Petroleum, Natural Gas and Biofuels ANP: Annual price newsletter—oil, natural gas and fuel prices in national and international market (2015)
8. National Agency of Petroleum, Natural Gas and Biofuels ANP: Technical regulation of burns and losses of natural gas (2000)
9. Ministry of Mines and Energy (MME), Energy Research Company (EPE): Ten-years Plan for Pipeline Transport Mesh Expansion—PEMAT 2013-2022 (2014)
10. Merkel, T.C., et al.: Power Plant Post-Combustion Carbon Dioxide Capture: An Opportunity for Membranes. Membrane Technology and Research, United States (2009)

Part II
Internet of Things and Systems Engineering Lifecycle

Implementation of Human System Integration into the System Engineering Lifecycle and Model Based System Engineering at Airbus Defence and Space

Robert A. Sharples

Abstract This paper provides an overview of the process, practices, developments and synergies that Airbus Defence and Space are implementing Human System Integration (HSI) into the Continuous Engineering/Model Based System Engineering (MBSE) throughout the company. The paper highlights these developments, which include internal research programmes, European Union funded research projects and Airbus internal synergy projects to provide a complete system engineering lifecycle. This research includes an EU funded 3 year project HoliDes—Holistic Human Factors and System Design of Adaptive Cooperative Human Machine Systems [1]. HSI has been incorporated in the project lifecycle via US Military (DoD-Instruction 5000.2) [2] with the introduction of a Human System Integration Plan, which is a key requirement for the validation and verification of any new system or any modification to any existing US military system. Airbus DS has used HSI in several innovative approaches, these include, the dramatic reduction in the manpower and costs of deployment and logistic support for large scale military operations, the integration with our Architectural Framework to provide a system architecture that is compliant with the US and UK Lines of development—Training, Equipment, Personnel (HR), Organisation, Information, Logistics, Concepts and Doctrine and Infrastructure and the introduction of ILS and Training into our MBSE approach. Airbus DS recognises the need to integrate HSI into its system engineering lifecycle as in the past the inclusion of human interaction has generally been missed and as most systems interact with people, HSI provides Airbus DS with complete systems integration process. Our Human System Integration (HSI) work at Airbus DS is evolving from the initial Human View Architectural Framework research [4] and then the nine HSI domains—Manpower, Personnel, Training, Human Factors Engineering, Environment, Occupational Health, Safety, Survivability and Habitability [5].

R.A. Sharples (✉)
Airbus Defence and Space, Hertfordshire, UK
e-mail: robert.sharples@airbus.com

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Keywords Human factors · Human-Systems integration (HSI) · Systems engineering · Model based systems engineering (MBSE) · Architectural frameworks · MoDAF · DoDAF · NAF · DLOD

1 Introduction

This paper is the third in a series of papers defining the Airbus Defence and Space (Airbus DS) Human System Integration (HSI) research and technology roadmap which initially implement Human Views into an Architectural Framework [3] and then HSI and non-functional capabilities [4] and within this paper to publish the initial results of the integration of HSI, Human Views and Architectural Frameworks into our Model Based System Engineering process.

The paper briefly introduces

- HSI and its mapping to the NATO Human Views [5],
- An overview of the Human View implementation within our System of System Framework,
- An overview of the HSI implementation with the HoliDes EU research project,
- An introduction to the Airbus DS Model Based System Engineering (MBSE),
- HSI Operational deployment and costs savings.

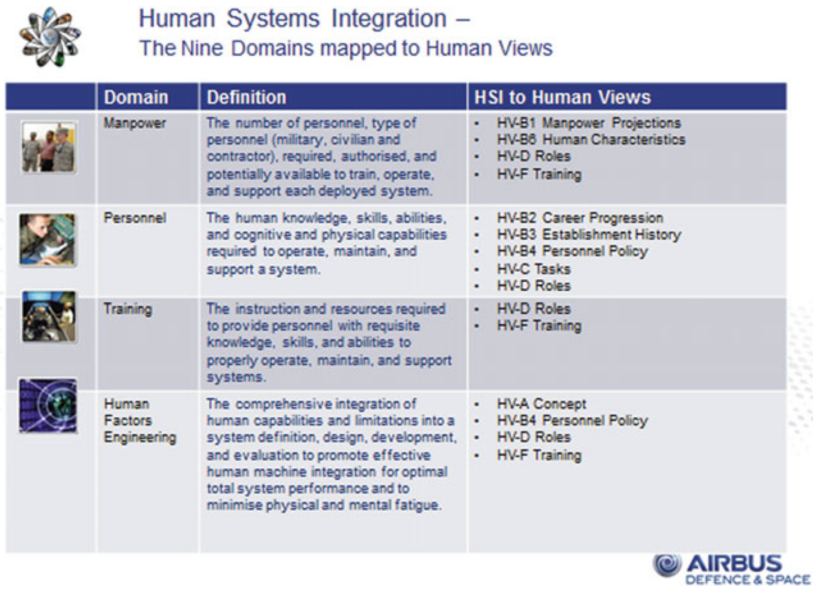
2 Human System Integration (HSI) and Its Mapping to the NATO Human Views

Airbus DS has implemented Human System Integration (HSI) as defined by the US DoD instruction 5000.2 [2]. This document details the DoD set of HSI domains, together with extended set refined at Airbus DS.

Figures 1 and 2 define the HSI domain mappings to the NATO Human Views [5], this mapping has been implemented within the HoliDes research project (Sect. 4) and via two internally funded pilot projects at Airbus DS. An overview of the Airbus DS introduction Human View are detailed in Sect. 3 and the implementation of said Human Views are detailed in Sect. 4.

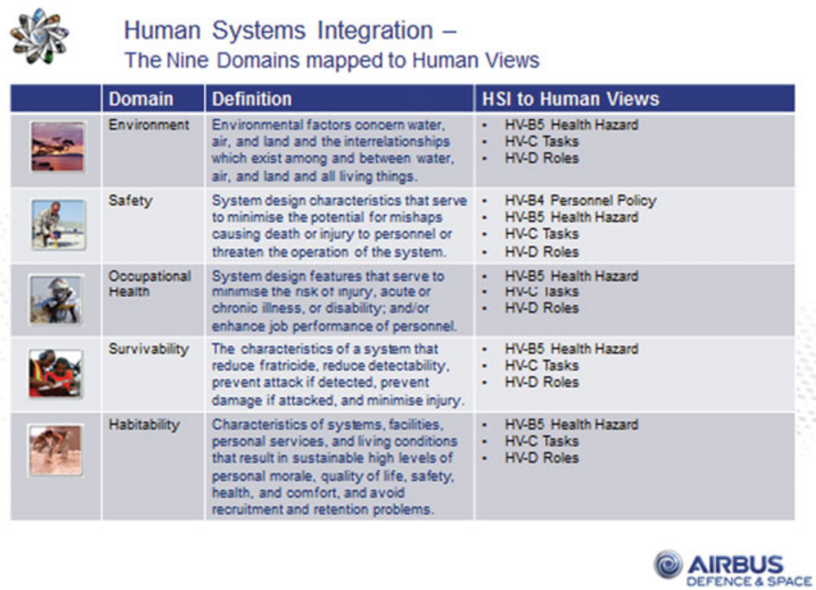
The commonality between the HSI domains and the NATO Human Views can clearly be seen in Figs. 1 and 2, therefore the mapping and integration task was not a difficult one. The difficulty lies with the implementation within a software toolset and the various Architecture Frameworks, as the tool vendors to date, have not implemented any form of Human Views into any software tool sets.

The HoliDes project detailed in Sect. 4, provides an integration of several of the NATO Human View within Sparx Enterprise Architect, via specific templates



	Domain	Definition	HSI to Human Views
	Manpower	The number of personnel, type of personnel (military, civilian and contractor), required, authorised, and potentially available to train, operate, and support each deployed system.	• HV-B1 Manpower Projections • HV-B6 Human Characteristics • HV-D Roles • HV-F Training
	Personnel	The human knowledge, skills, abilities, and cognitive and physical capabilities required to operate, maintain, and support a system.	• HV-B2 Career Progression • HV-B3 Establishment History • HV-B4 Personnel Policy • HV-C Tasks • HV-D Roles
	Training	The instruction and resources required to provide personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support systems.	• HV-D Roles • HV-F Training
	Human Factors Engineering	The comprehensive integration of human capabilities and limitations into a system definition, design, development, and evaluation to promote effective human machine integration for optimal total system performance and to minimise physical and mental fatigue.	• HV-A Concept • HV-B4 Personnel Policy • HV-D Roles • HV-F Training

Fig. 1 Human system integration mapping 1



	Domain	Definition	HSI to Human Views
	Environment	Environmental factors concern water, air, and land and the interrelationships which exist among and between water, air, and land and all living things.	• HV-B5 Health Hazard • HV-C Tasks • HV-D Roles
	Safety	System design characteristics that serve to minimise the potential for mishaps causing death or injury to personnel or threaten the operation of the system.	• HV-B4 Personnel Policy • HV-B5 Health Hazard • HV-C Tasks • HV-D Roles
	Occupational Health	System design features that serve to minimise the risk of injury, acute or chronic illness, or disability; and/or enhance job performance of personnel.	• HV-B5 Health Hazard • HV-C Tasks • HV-D Roles
	Survivability	The characteristics of a system that reduce fratricide, reduce detectability, prevent attack if detected, prevent damage if attacked, and minimise injury.	• HV-B5 Health Hazard • HV-C Tasks • HV-D Roles
	Habitability	Characteristics of systems, facilities, personal services, and living conditions that result in sustainable high levels of personal morale, quality of life, safety, health, and comfort, and avoid recruitment and retention problems.	• HV-B5 Health Hazard • HV-C Tasks • HV-D Roles

Fig. 2 Human system integration mapping 2

created within the tool. Airbus DS has also integrated Human Views within IBMs System Architect.

The HSI domains Manpower, Personnel, Training, Environment, Safety and Occupational Health have a direct mapping to the NATO Human Views. Human Factors has been a domain included in the Airbus DS system engineering process, the HSI implementation enhances and extends its use within the overall process. The Survivability and Habitability domains fall into the non-functional capabilities that are being added to our Model Based System Engineering process, this provides Airbus DS with a complete integration of the HSI domains and integrates into the UK and US Defence Lines of Development—Training, Equipment, Personnel, Information, Concepts and Doctrine, Organisation, Infrastructure and Logistics.

3 Human View Integration into the Airbus DS System of System Framework

The NATO Human Views [5] have been integrated into the Airbus DS System Of Systems Architecture which includes, Capability, Operational, System, Service, Data Standards and Project Views detailed in MoDAF, DoDAF and NAF. Figure 5 details the individual Human Views and how they have been implemented, within the HoliDes project (Sect. 4).

Airbus DS are also in the process of adding further architecture views for Requirements, System Use and Test Cases and Security, SOA and Experimentation and Simulation. Figure 3 defines the overall System of System Framework developed at Airbus DS, this framework provides Airbus DS with the ability to integrate all required project documents and plans required by our internal process or

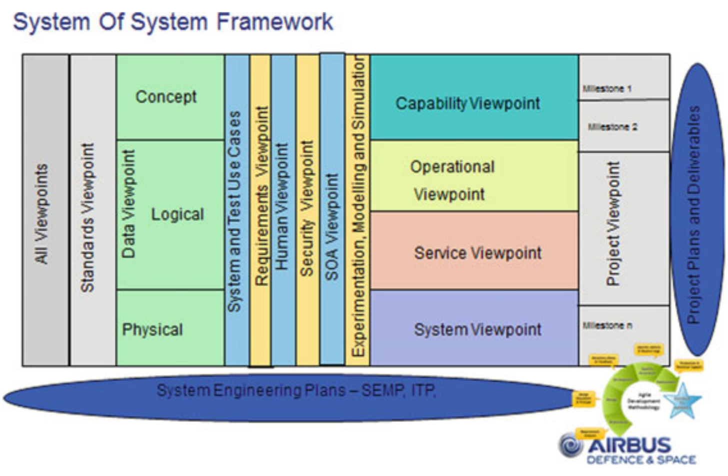


Fig. 3 System of system framework

mandate by the customer, e.g. System Engineering Management Plan, Architecture Plan, Integration and Verification Plans, Project Plans etc. and allows the use of any development process as defined within Airbus DS or required by the customer.

4 Holistic Human Factors and System Design of Adaptive Cooperative Human Machine System (HoliDes)

HoliDes [1] is a 24M euro EU funded research project, with 31 participants from seven European countries (UK, GE, FR, IT, NL, CZ and ES) with four domains, Aerospace, Automotive, Control Room and Medical. Airbus DS is responsible for the Control Room domain which is further broken down into a C2 Border Security System and an Energy Control and Management System.

Human System Integration and Human Views have been integrated into the operational and system modelling performed by Airbus DS within the Control Room domain. Figure 5 defines the overall architectural process, the orange nodes define the implemented Human Views for the control room domain, these views are implemented via model driven generation (MDG) within the architecture tool Sparx Enterprise Architect or Microsoft Office Word documents.

The Human Views were generated alongside the standard DoDAF/MoDAF set of Operational and System Views, using IBMs System Architect. This tool was used to generate the Operational Concepts and System Architecture Models to define the HoliDes Control Room Adaptive Cooperative Human Machine System (AdCoS), which was the basis for the Airbus DS Control Room demonstrator. The Human Views were then integrated into this architecture together the System Use Cases and system requirements.

Figure 4 defines the Airbus Control Room AdCoS, which in turn defines the physical Control Room demonstrator. The AdCoS includes a control room server, control room consoles and operators, who have two independent sensors tracking eye and physically movement and are wearing a wrist tracking device. All the sensor data is collated and sent to the control room supervisor, who then can make decisions on the workload and emotional and physical state of each operator (Fig. 5).

The following have been implemented within Sparx System Architect.

Within the HoliDes Airbus DS work package the following Human Views have been implemented:

- HV-A—Concepts template within Enterprise Architect
- HV-B—Personnel (HV-B1 to HV-B6) template within Microsoft Word
- HV-C—Human Tasks template within Enterprise Architect
- HV-D—Human Roles template within Enterprise Architect
- HV-E—Human Networks template within Microsoft Word
- HV-F—Training Needs template within Microsoft Word
- HV-G—Human Metrics to be implemented in 2016.

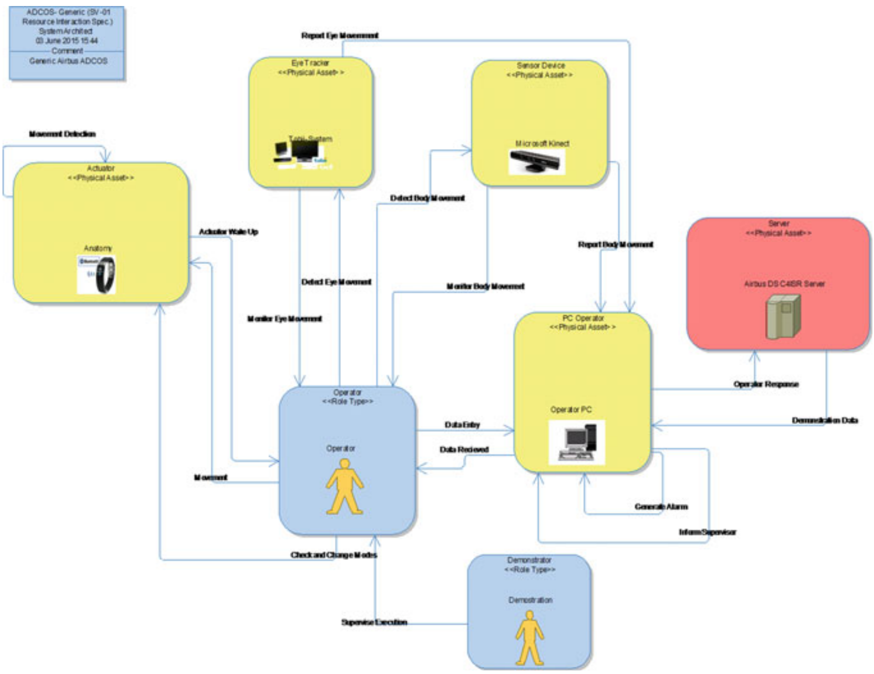


Fig. 4 Airbus DS demonstrator—implemented HoliDes control room AdCoS

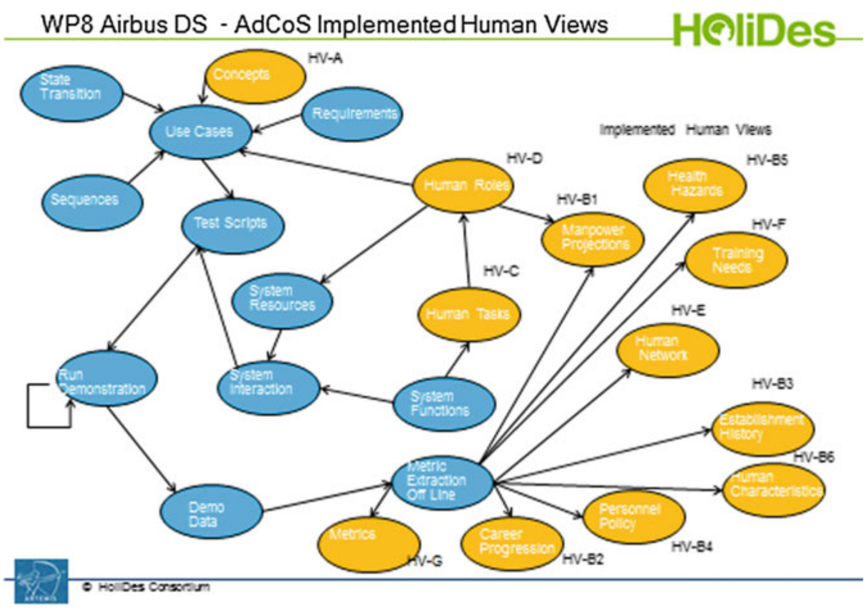


Fig. 5 Implemented human views within the HoliDes architecture

With the project in its third year we have over 35 Architecture artefacts and 20 word documents implemented as follows:

- Six Use Cases (6)
- Human Concept (HV-A) (1) and DoDAF Operational Concept (OV-1) (1)
- DoDAF Operational activity models (2)
- DoDAF Sequence Diagrams, one for each Use Case (6)
- DoDAF State Transition Diagrams, one for each Use Case (6)
- DoDAF Logical Data Model (1)
- DoDAF System Interaction Diagrams (4) and HV-E Human Networks (2)
- DoDAF System Interaction Diagrams for the Airbus DS Holies Demonstrator (2)
- DoDAF System Hierarchy Diagrams (5) and HV-D Roles (5)
- DoDAF System Function Diagrams (8) and HV-C Human Tasks (8)
- Personnel HV-B1 to HV-B6 (6).

5 Model Based System Engineering

Airbus DS has been integrating HSI within its MBSE process using exploitation data from the HoliDes project and internally funded pilot projects. Figure 6 defines the high level view of the MBSE process, which has a well defined Operational and

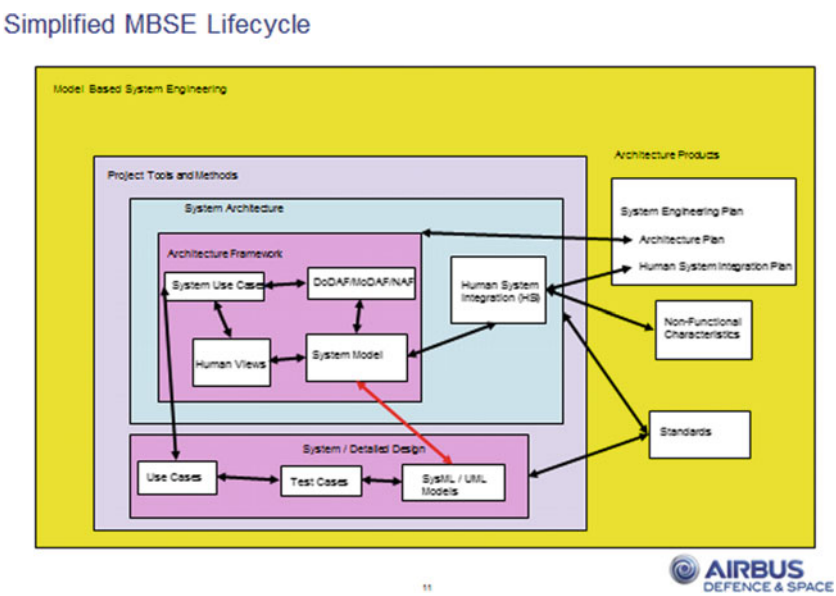


Fig. 6 Simplified model based system engineering interaction

System Architecture, generated from System Use Cases, Human Views, Architectural Frameworks and HSI, together with the well defined interfaces to the various engineering plans project plans and standards. We have a mapping from our System Use and System Test Cases to the detailed design Test and Use Cases, however a problem exists with our inability to re-use large parts of the System Architecture with our Detailed Design model defined in SysML. We are currently working on a mapping from the Architecture Frameworks and the SysML products; in the short term this will alleviate the problem with the use of IBMs System Architect and Sparx Enterprise Architect. The problem is exacerbated as Airbus DS uses at least five software tools for system and enterprise architecture, therefore the aim is to produce an overall tool agnostic mapping and process.

6 Operational Deployment and Cost Savings

The following section defines two examples of the cost savings that Airbus DS has made applying Human System Integration and Model Based System Engineering.

The overall savings and metrics for the Airbus DS Model Based System Engineering process improvements are company confidential; however, one of our four Key Performance Indictors (KPI) was based on data published via an INCOSE conference. It stated that integration of an MBSE process within the system engineering lifecycle would provide savings in the overall system engineering budget, over a four year period of 3, 6, 9 and 12 % respectively. These savings are indicative of the savings we are seeing in the first year of our pilot projects.

Applying Human System Integration and Human Views with our Operational Architectural Model provided large scale reductions in the deployed man power footprints for several large scale military deployments. For obvious reasons the Airbus DS scenarios cannot be detailed in this paper, however the high level reduction in numbers are defined below:

- Deployed Operating Base 1—a reduction of 120 military personnel
- Deployed Operating Base 2—a reduction in 75 military personnel
- Forward Operating Base 1—a reduction in 35 military personnel.

The savings are large in terms of deployed man power hours, the logistics cost of moving the personnel and with the logistic cost of re-supply, food, water etc. However the reduction in deployed personnel resulted in an increased need for communications with the main operating bases back in the UK, but the cost of the extra satellite communication equipment, personnel and traffic was small in comparison to the deployed footprint saving.

References

1. HoliDes Holistic Human Factors and System Design of Adaptive Cooperative Human Machine Systems. This research has been performed with support from EU ARTEMIS JU project HoliDes (http://www.holides.eu) SP-8, GA No.:332933. Any contents herein refelect only the author's views. The ARTEMIS JU is not liable for any use that made be made of this information contained herein
2. Human System Integration (HSI) – Interim DoDI Instructions 5000.2 November 25th 2013
3. Introduction of Human Views into Operational Development within an Architectural Framework. IEEE SysCon 2014 and IBM Innovate 2014, Robert A Sharples, Expert System Architect, Airbus Space and Defence
4. Implementation of HSI and Non-functional Characteristics into the System engineering Lifecycle a practical approach at Airbus Defence and Space. AHFE 2015,, Robert A Sharples, Expert System Architect, Airbus Space and Defence
5. NATO Technical Report TRM-HFM-155 Human View Integration for Network Centric Warfare February 2010

Mobile Application Usability: Heuristic Evaluation and Evaluation of Heuristics

Ger Joyce, Mariana Lilley, Trevor Barker and Amanda Jefferies

Abstract Many traditional usability evaluation methods do not consider mobile-specific issues. This can result in mobile applications that abound in usability issues. We empirically evaluate three sets of usability heuristics for use with mobile applications, including a set defined by the authors. While the set of heuristics defined by the authors surface more usability issues in a mobile application than other sets of heuristics, improvements to the set can be made.

Keywords Human factors · Usability · Mobile apps · Heuristic evaluation

1 Introduction

Human-Computer Interaction (HCI) researchers and practitioners use traditional usability evaluation methods to evaluate the usability of mobile applications. Yet, these traditional methods do not always consider applications built for small screens and rapidly changing environments [1, 2]. As mobile application use has grown exponentially in recent years [3], HCI researchers and practitioners need to address this issue [4]. As argued by the authors in previous work [5, 6], popular usability evaluation methods, such as a Heuristic Evaluation [7], may be modified for use with mobile applications. In this paper, the authors empirically investigate that

G. Joyce (✉) · M. Lilley · T. Barker · A. Jefferies
School of Computer Science, University of Hertfordshire,
College Lane, Hatfield, Hertfordshire AL10 9AB, UK
e-mail: gerjoyce@outlook.com

M. Lilley
e-mail: m.lilley@herts.ac.uk

T. Barker
e-mail: t.1.barker@herts.ac.uk

A. Jefferies
e-mail: a.l.jefferies@herts.ac.uk

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claim. This work will be of importance to HCI practitioners, educators, and researchers—indeed any teams that focus on developing and evaluating the usability of mobile applications.

2 Related Work

Expert-based usability inspection methods, whereby a group of HCI experts evaluates a user interface against a set of principles are currently well established. In particular, Heuristic Evaluation is widely known for being fast and inexpensive [8], as well as for its ability to find more usability problems when compared to other methods [9]. Despite an argument that Heuristic Evaluation may not be as effective as it claims [10], the method is used quite extensively.

As mobile devices become more popular, HCI researchers and practitioners can use Nielsen's popular set of heuristics to evaluate the usability of mobile applications. However, several researchers have argued for the modification of Nielsen's heuristics in order for a more effective usability evaluation of mobile applications [11, 12]. Consequently, since 2003 researchers have defined several sets of guidelines to evaluate the usability of mobile User Interfaces [13–16]. Unfortunately, this research has not addressed vital issues within the mobile phenomena, such as rapidly changing environments, the potential of mobile devices to reduce user's workloads, and the importance of First Time User Mobile Experience. Instead, these works have focused on other areas, such as the ergonomics of a mobile device, and how to find a mobile device if lost.

3 Approach

Our approach within this study was twofold:

1. A Heuristic Evaluation of a mobile application using three sets of heuristics;
2. An Evaluation of Heuristics following the Heuristic Evaluation using a survey.

One of the sets of heuristics was a modified version of a set previously defined by the authors [5]. This set of heuristics account for areas vital to the mobile phenomena, including rapidly changing environments, the potential of mobile devices to reduce user's workloads, and the importance of First Time User Mobile Experience. Other than the set of heuristics from the authors, we selected two other sets of heuristics for the study; namely Nielsen [17] and Bertini et al. [15]. The reason behind this selection was that Nielsen's is one of the most popular sets of heuristics today, and Bertini et al. defined their set for mobile devices.

The authors recruited six HCI Experts using purposive sampling (4 Female, 2 Male). Participants had between 1 and 20 years within HCI experience

(Mean = 7.5, SD = 6.9), and between 0 and 6 years experience within Mobile HCI (Mean = 2.91, SD = 2.2). The study was conducted between February 26th, 2015 and March 16th, 2015. While a small number of participants, the number recruited by the authors was greater than Nielsen's recommendation of three to five evaluators [18]. To reduce the possibility of bias within the study, we assigned a letter to each set of heuristics, and counterbalanced the order of heuristics. Consequently, participants did not know which set of heuristics the authors had defined. Additionally, many aspects of the study were controlled, including the mobile device, mobile application, and the environmental conditions within which the study was conducted.

3.1 Tasks

In a within-subjects study, six participants (n = 6) completed three tasks each on a travel app from a well-established provider. Participants attempted each task on an LG G2 running Android 4.4.2 under good lighting and low ambient noise conditions, as would be expected in a Usability Testing lab. The tasks were:

1. Find a hotel near your current location using GPS for one adult that is available within the next two weeks.
2. Find a return flight for one adult in economy class from London Heathrow to Paris.
3. Read a review of a restaurant in the UK, marking the review as helpful.

3.2 Mobile Application Heuristics

The mobile applications usability heuristics modified from previous work from the authors [5] are below. We designed these with SMART (short for Smartphone Heuristics) to differentiate the heuristics from other sets.

SMART1 Provide immediate notification of application status. Ensure the mobile application user is informed of the application status immediately and as long as is necessary. Where appropriate do this non-intrusively, such as displaying notifications within the status bar.

SMART2 Use a theme and consistent terms, as well as conventions and standards familiar to the user. Use a theme for the mobile application to ensure different screens are consistent. Also create a style guide from which words, phrases and concepts familiar to the user will be applied consistently throughout the interface, using a natural and logical order. Use platform conventions and standards that users have come to expect in a mobile application such as the same effects when gestures are used.

SMART3 Prevent problems where possible; Assist users should a problem occur. Ensure the mobile application is error-proofed as much as is possible. Should a problem occur, let the user know what the problem is in a way they will understand, and offer advice in how they might fix the issue or otherwise proceed. This includes problems with the mobile network connection, whereby the application might work offline until the network connection has been re-established.

SMART4 Display an overlay pointing out the main features when appropriate or requested. An overlay pointing out the main features and how to interact with the application allows first-time users to get up-and-running quickly, after which they can explore the mobile application at their leisure. This overlay or a form of help system should also be displayed when requested.

SMART5 Each interface should focus on one task. Being focusing on one task ensures that mobile interfaces are less cluttered and simple to the point of only having the absolute necessary elements onscreen to complete that task. This also allows the interface to be glanceable to users that are interrupted frequently.

SMART6 Design a visually pleasing interface. Mobile interfaces that are attractive are far more memorable and are therefore used more often. Users are also more forgiving of attractive interfaces.

SMART7 Intuitive interfaces make for easier user journeys. Mobile interfaces should be easy-to-learn whereby next steps are obvious. This allows users to more easily complete their tasks.

SMART8 Design a clear navigable path to task completion. Users should be able to see right away how they can interact with the application and navigate their way to task completion.

SMART9 Allow configuration options and shortcuts. Depending on the target user, the mobile application might allow configuration options and shortcuts to the most important information and frequent tasks, including the ability to configure according to contextual needs.

SMART10 Cater for diverse mobile environments. Diverse environments consist of different types of context of use such as poor lighting conditions and high ambient noise are common ailments mobile users have to face every day. While the operating system should allow the user to change the interface brightness and sound settings, developers can assist users even more for example by allowing them to display larger buttons and allowing multimodal input and output options.

SMART11 Facilitate easier input. Mobile devices are difficult to use from a content input perspective. Ensure users can input content more easily and accurately by, for instance displaying keyboard buttons that are as large as possible, as well as allowing multimodal input and by keeping form fields to a minimum.

SMART12 Use the camera, microphone and sensors when appropriate to lessen the user's workload. Consider the use of the camera, microphone and sensors to lessen the users' workload. For instance, by using GPS so the user knows where they are and how to get there they need to go, or by using OCR and the camera to digitally capture the information the user needs to input, or by allowing use of the microphone to input content.

3.3 Severity Ratings

The usability issue severity ratings used for this study were adapted from Sauro [19]:

- *Minor*: Causes some hesitation or irritation
- *Moderate*: Causes occasional task failure for some users or causes delays and moderate irritation
- *Critical*: Leads to task failure or causes extreme irritation.

4 Results

The evaluators found 145 usability issues (Mean = 48, SD = 9) (Fig. 1). Each evaluation took approximately three hours, with the subsequent analysis taking two days.

While Bertini et al. had defined their set of heuristics for mobile devices, if not specifically for mobile applications, this set surprisingly did not find as many usability issues as Nielsen's or the SMART mobile heuristics we had defined. Nielsen's heuristics, being quite generic and designed for general user interfaces,

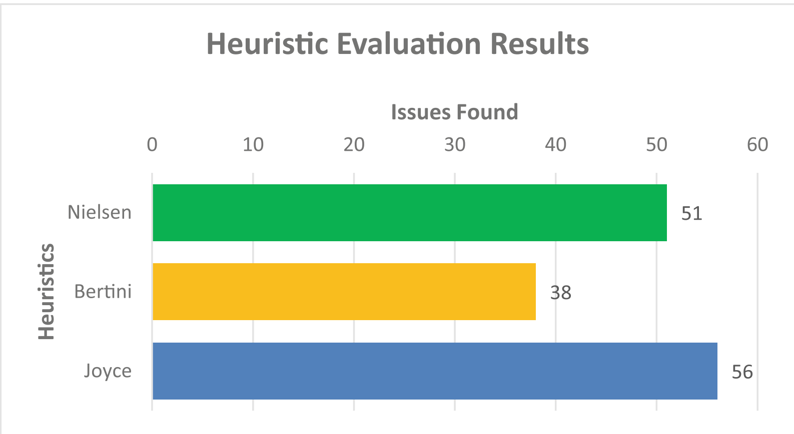

Fig. 1 Heuristic evaluation results

scored quite well. However, our SMART heuristics found the most usability issues, including critical issues.

Following the Heuristic Evaluation, each participant answered several survey questions and offered free text comments to evaluate the same sets of heuristics. This approach gave further insight into the potential for participants to use the SMART heuristics in a professional context, or if changes were required. The questions asked, and the subsequent results, follow.

- Survey Question 1. I would be confident in using this heuristic set to evaluate usability within mobile applications in a professional context.

Creating a set of heuristics applicable to any domain is part of the challenge. Ensuring that the HCI community use a set of heuristics is also part of this challenge. Therefore, we asked participants to what extent they would agree or disagree that they would be confident in using each set of heuristics to evaluate the usability of mobile applications within a professional context. Both Nielsen's and SMART heuristics scored well, with the heuristics from Bertini et al. not scoring as well (Fig. 2).

If a set of heuristics is difficult-to-use, learn, or understand, the HCI community may use other evaluation methods, potentially those that find fewer usability issues. To that end, the next set of survey questions focused on ease-of-use, learning and understanding:

- Survey Question 2: I felt the set of heuristics were easy-to-use.
- Survey Question 3: I felt the set of heuristics were easy-to-learn.
- Survey Question 4: I felt the set of heuristics were easy-to-understand.

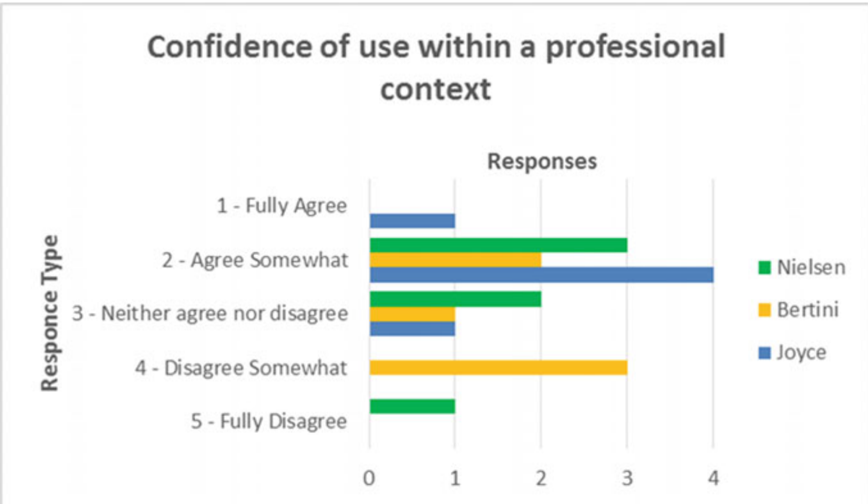

Fig. 2 Participants' confidence in using each heuristic set to evaluate the usability of mobile applications within a professional context

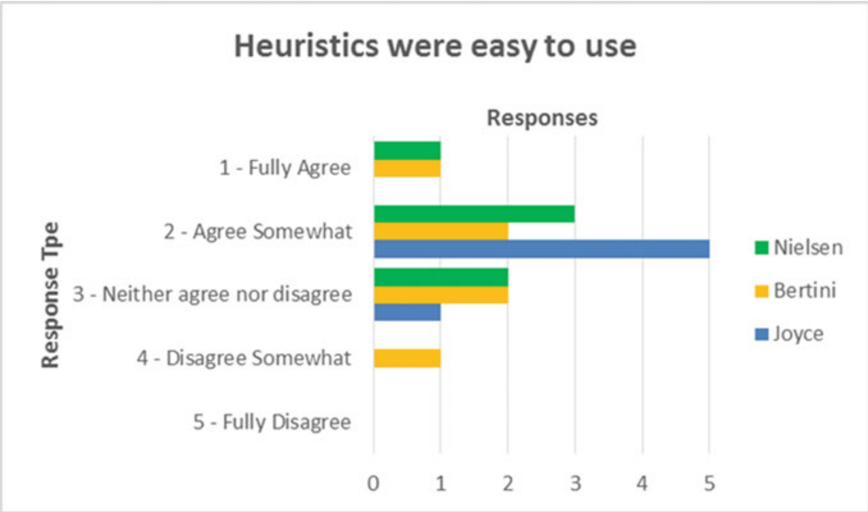

Fig. 3 Participants' perception towards ease-of-use of each set of heuristics

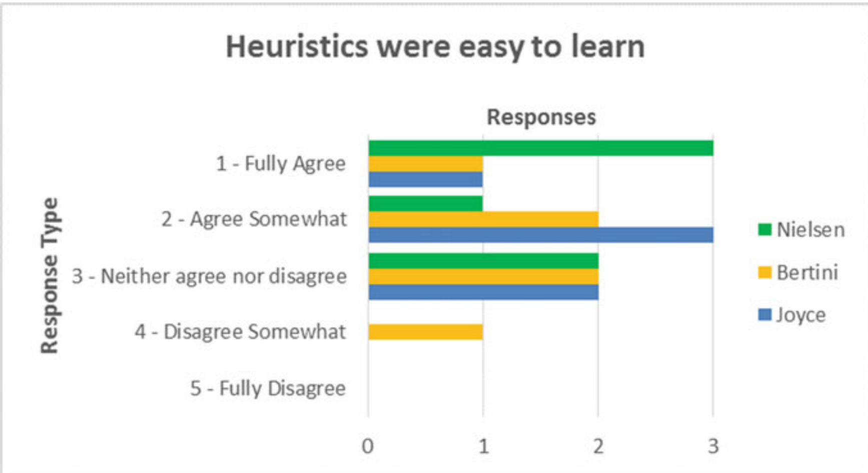

Fig. 4 Participants' perception towards ease-of-learning of each set of heuristics

Regarding ease-of-use, our heuristics scored well overall. Yet, none of the participants fully agreed that our heuristics were the easiest to use (Fig. 3). In terms of ease-of-learning, participants considered Nielsen's heuristics to be easier to learn than other set of heuristics. This is possibly due to familiarity as many HCI practitioners use Nielsen's heuristics regularly. Following Nielsen's heuristics, our heuristics scored higher than Bertini's (Fig. 4). Regarding ease-of-understanding, both Nielsen's and the SMART heuristics from the authors scored identically, with the heuristics from Bertini et al. trailing behind (Fig. 5).

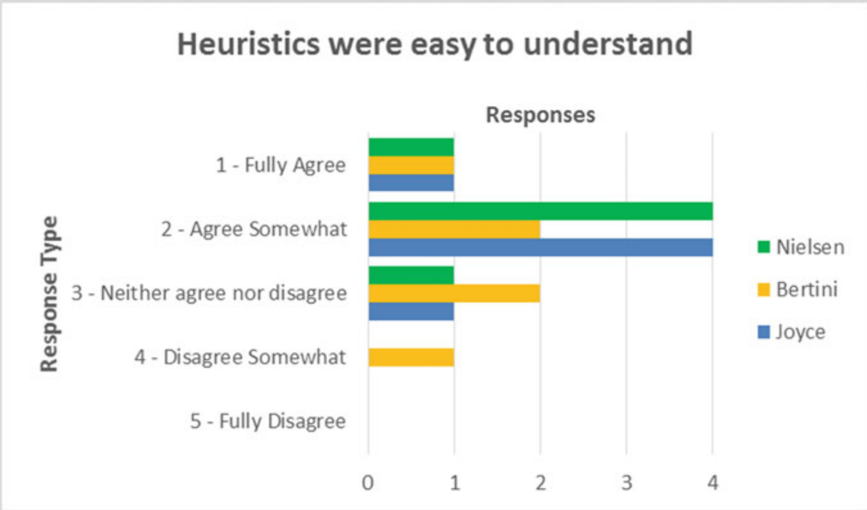

Fig. 5 Participants' perception towards ease-of-understanding of each set of heuristics

5 Analysis

The number of usability issues found during the Heuristic Evaluation differed for all three sets of heuristics. Overall, Nielsen's heuristics scored quite well, most likely because this set of heuristics is generic and applicable to most types of user interface. Conversely, the heuristics from Bertini et al. did not score as well. There could be a number of reasons for this; for instance, this set of heuristics focused on a number of areas that are not relevant to most mobile applications, such as the findability of the mobile device.

Between both the Heuristic Evaluation and Evaluation of Heuristics phases of this study, the authors set of SMART heuristics scored higher than the sets of heuristics from Nielsen and Bertini et al. in almost all areas. Not only did the SMART heuristics find the most usability issues, participants also perceived the SMART heuristics as being the most applicable for mobile application usability evaluations. Comments from participants reflected this perception:

- "*P2: Set C (Joyce et al.) covers essential evaluations for mobile applications.*"
- "*P4: Heuristic A (Nielsen) is too broad to apply to the mobile experience. This is a strong foundation for the categories that need to be evaluated, however the guidelines need to be tweaked to cater to specific needs of mobile users.*"

Interestingly, while participants found that the heuristics from Bertini et al. were applicable to mobile, participants commented that the wording on the heuristics and descriptions was "*a bit clunky (P4)*".

However, while the SMART heuristics from the authors scored highly in most areas, they fell behind Nielsen's in two areas, namely ease-of-use and ease-of-learning. Reviewing participants' comments will help to understand how we can improve the SMART heuristics further:

- *P1:* "*…decrease the number of principles and offer a similar completeness.*"
- *P1:* "*The description for each heuristic is a bit long. If there was a way to describe each heuristic in one sentence, the set would be much easier to go through and understand.*"
- *P2:* "*Two too many heuristics. If possible, a set of 10 works much better.*"
- *P2:* "*Explanations are a bit too long. It requires extra work (cognitive load) for the users to understand Set C (Joyce et al.).*"

6 Conclusion

HCI practitioners and researchers continue to use traditional usability evaluation methods to evaluate the usability of mobile applications. Yet, these methods were designed to evaluate desktop applications, and do not consider issues specific to mobile applications. In this work, the authors empirically investigate a claim from previous publications that one such method—Heuristic Evaluation—can be modified and consequently prove to be more effective in surfacing usability issues specific to mobile applications. Our study demonstrates that this is indeed the case. Additionally, participants felt most confident in using mobile application heuristics defined by the authors to evaluate usability of mobile applications in a professional context. However, the mobile application heuristics defined by the authors need further work; participants felt that the heuristics could be easier-to-use and to-learn, if they were reduced in number, yet were just as comprehensive, and had shorter descriptions.

This research is an important consideration for HCI practitioners and researchers responsible for the usability evaluations of mobile applications. Indeed, any teams responsible for the development of mobile applications can benefit from this work.

Acknowledgments The authors wish to thank the six HCI practitioners that participated in the Heuristic Evaluation and Evaluation of Heuristics.

References

1. Bernhaupt, R., Mihalic, K., Obrist, M.: Usability evaluation methods for mobile applications. In: Lumsden, J. (ed.) *Handbook of Research on User Interface Design and Evaluation for Mobile Technology*. IGI Global (2008)
2. Baharuddin, R., Singh, D., Razali, R.: Usability dimensions for mobile applications-a review. Res. J. Appl. Sci. Eng. Technol. **5**(6), 2225–2231 (2013)

3. Nielsen, J.: Smartphones: so many apps, so much time. Available Online: http://www.nielsen.com/us/en/insights/news/2014/smartphones-so-many-apps–so-much-time.html. (2014)
4. Coursaris, C.K., Kim, D.J.: A meta-analytical review of empirical mobile usability studies. J. Usability Stud. **6**(3), 117–171 (2011)
5. Joyce, G., Lilley, M.: Towards the development of usability heuristics for native smartphone mobile applications. In: *Design, User Experience, and Usability. Theories, Methods, and Tools for Designing the User Experience*, pp. 465–474 (2014)
6. Joyce, G., Lilley, M., Barker, T., Jefferies, A.: Smartphone application usability evaluation: the applicability of traditional heuristics. In: Marcus, A., (ed.) *Design, User Experience, and Usability: Users and Interactions*, (9187), pp. 541–550 (2015)
7. Nielsen, J., Molich, R.: Heuristic evaluation of user interfaces. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 249–256 (1990)
8. Maguire, M.: Methods to support human-centred design. Int. J. Hum Comput. Stud. **55**(4), 587–634 (2001)
9. Jeffries, R., Desurvire, H.: Usability testing vs. heuristic evaluation: was there a contest? ACM SIGCHI Bull. **24**(4), 39–41 (1992)
10. Law, E.L.-C., Hvannberg, E.T.: Analysis of strategies for improving and estimating the effectiveness of heuristic evaluation. In: Proceedings of the Third Nordic Conference on Human-Computer Interaction—NordiCHI '04, pp. 241–250 (2004)
11. Ketola, P., Roykkee, M.: Three facets of usability in mobile handsets. In: Proceedings of CHI 2001 Workshop: Mobile Communications: Understanding Users, Adoption & Design (2001)
12. Po, S., Howard, S., Vetere, F., Skov, M.B.: Heuristic evaluation and mobile usability: bridging the realism gap. Mobile human-computer interaction—MobileHCI 2004. In: *Lecture Notes in Computer Science*, vol. 3160/2004, pp. 591–592 (2004)
13. Weiss, S.: Handheld usability. Wiley (2002)
14. Ji, Y.G., Park, J.H., Lee, C., Yun, M.H.: A usability checklist for the usability evaluation of mobile phone user interface. Int J. Hum Comput Interact. **20**(3), 207–231 (2006)
15. Bertini, E., Gabrielli, S., Kimani, S.: Appropriating and assessing heuristics for mobile computing. In AVI '06: Proceedings of the Working Conference on Advanced Visual Interfaces, pp. 119–126 (2006)
16. Inostroza, R., Rusu, C., Roncagliolo, S., Jiménez, C., Rusu, V.: Usability heuristics for touchscreen-based mobile devices. In: Proceedings of the 2012 Ninth International Conference on Information Technology—New Generations (2012)
17. Nielsen, J.: Ten usability heuristics. Available at: http://www.useit.com/papers/heuristic/heuristic_list.html. (1994)
18. Nielsen, J.: Finding usability problems through heuristic evaluation. In: Proceedings of the SIGCHI Conference on Human, pp. 373–380 (1992)
19. Sauro, J.: Rating the severity of usability problems. Available Online: http://www.measuringu.com/blog/rating-severity.php. (2013)

Fast Subtractor Algorithm and Implementation

Gunamani Jena

Abstract A new fast subtractor based on borrow look-ahead is proposed in this paper. The general condition for minimum time delay in the subtractor has been used to obtain the required result. It passes through 4-gate delay irrespective of number size.

Keywords Borrow Look-Ahead · Fast subtractor

1 Introduction

As the lengths of a typical borrow propagating parallel subtractor increases, the time required to complete a subtraction increases by the delay time per stage for each bit subtracted. The borrow look-ahead subtractor reduces the borrow delay by reducing the number of gates through which a borrow signal must pass. The truth table for the full subtractor is given in Table 1 but this time emphasizes the conditions under which borrow generation occurs.

Entries 3, 4, 5 and 6 show instances where output borrows b_i which is independent of $b_{i-1.}$ In entries 3 and 4 the output borrow is always unity and in entries 5 and 6 it is always 0 (zero). These are known as borrow generate combinations. Entries 1, 2, 7 and 8 show input combinations where the output borrow depends upon the input borrow [1, 2]. In other words, b_i is 1 only when b_{i-1} is 1. These are borrow propagate combinations. Suppose Gi donates the unity borrow generate condition of the ith stage of a parallel subtractor and P_i the borrow propagate condition of the same stage.

Without loss of generality consider the subtraction of two 4-bit binary numbers [3–5].

$$A = A_4\, A_3\, A_2\, A_1$$

G. Jena (✉)
Biju Patnaik University of Technology, Rourkela, Orissa, India
e-mail: drgjena@ieee.org

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Table 1 Truth table of full subtractor

Entries	Ai	Bi	b_{i-1}	b_i	Condition
1	0	0	0	0	Borrow propagate
2	0	0	1	1	
3	0	1	0	1	Borrow generate
4	0	1	1	1	
5	1	0	0	0	No borrow generate
6	1	0	1	0	
7	1	1	0	0	Borrow propagate
8	1	1	1	1	

and

$$B = B_4\ B_3\ B_2\ B_1$$

From Table 1 the borrow generate and borrow propagate (switching) functions in term of A_i and B_i where i = (1, 2, 3 and 4) are found to be

$$Gi = \overline{\mathrm{A_i} \oplus \mathrm{B_i}}$$

$$P_i = \overline{\mathrm{A_i}}\,.\,B_i$$

Please Note: $\oplus$ Exclusive Or

$\overline{\mathrm{A_i} \oplus \mathrm{B_i}}$ Inverse of Exclusive-Or of A_i, B_i.

The unity output borrow of the ith stage can be expressed in terms of G_i, P_i and b_{i-1} which is the unity output borrow of i − 1th stage

$$b_i = P_i + G_i.b_{i-1}.$$

When $G_i = 0$, $P_i = b_i$, $G_i = 1$, $b_{i-1} = b_i$ ($P_i = 0$)

For example, for i = 1, 2, 3 and 4, the b_i s are

$$b_1 = P_1 + G_1.b_0,$$
$$b_2 = P_2 + G_2.b_1 = P_2 + P_1.G_2 + G_1.G_2.b_0,$$
$$b_3 = P_3 + G_3.b_2 = P_3 + G_3P_2 + G_3.G_2P_1 + G_1.G_2.G_3.b_0,$$
$$b_4 = P_4 + G_4.b_3 = P_4 + G_4.P_3 + G_3.G_4.P_2 + G_2G_3.G_4.P_1 + G_1.G_2.G_3.G_4.b_0.$$

The difference of A and B is equal to

$$b_4\ D_4\ D_3\ D_2\ D_1,\ \text{where } D_i = A_i \oplus B_i \oplus b_{i-1}$$

D_i is the difference of ith column for i = 1, 2, 3 and 4, b_4 is the final borrow and it is always zero (0), because there is no fifth column as A and B are 4-bit numbers.

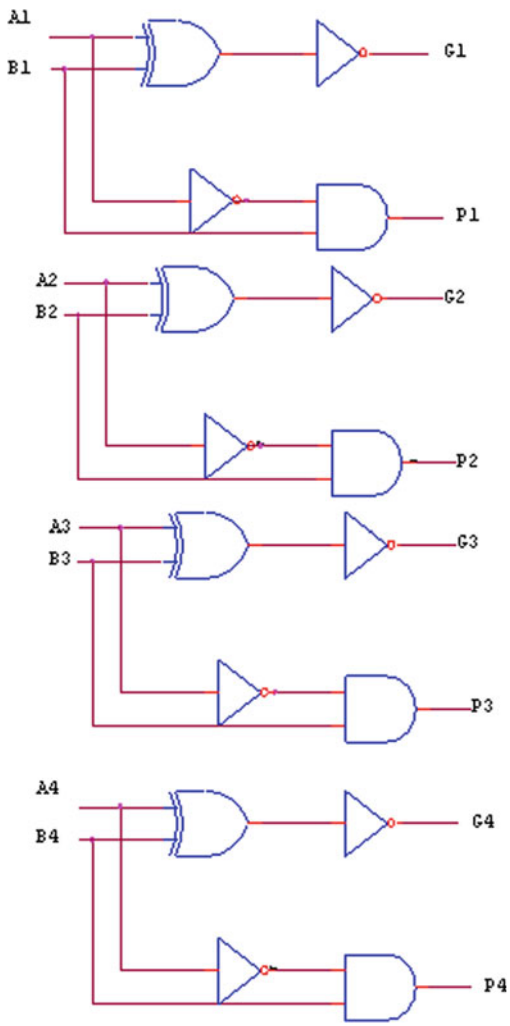
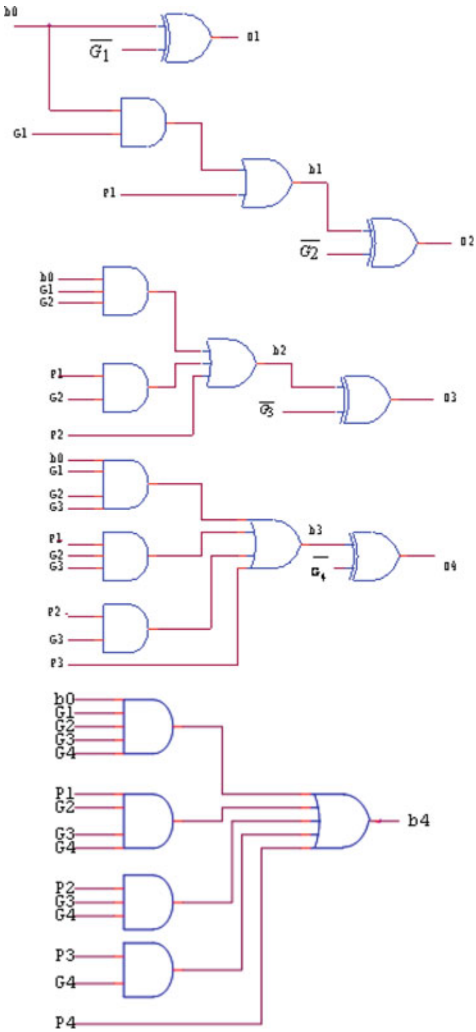


Fig. 1 A 4-bit borrow look-ahead subtractor

Assume that A is greater than B. A realization of a 4-bit borrow look-ahead subtractor is shown in Figs. 1 and 2.

It is seen that the subtraction of two n-bit binary numbers for any finite n can be easily accomplished by a borrow look-ahead subtractor in 4-gate propagation time assuming inverter gate neglected with respect to propagation delay. The price to pay achieving this time saving is the need for a considerable amount of excessive hardware. An example of subtracting the two binary numbers, $1\,0\,0\,1_2$ and $0\,0\,1\,1_2$ by this subtractor is also given as below.

Fig. 2 A 4-bit borrow look-ahead subtractor



We can check (Table 2)

$$\begin{array}{rcccc} A = & 1 & 0 & 0 & 1 \\ B = & 0 & 0 & 1 & 1 \\ \hline & 0 & 1 & 1 & 0 \end{array}$$

It should be noted that if no restrictions are imposed on the maximum allowable number of inputs (fan-in) to a gate, borrow look-ahead subtractor can be realized by a two level AND-OR or OR-AND circuits, which means that the subtraction of 2 n-bit numbers can be accomplished in the 3-gate propagation time. If all the bits of

Table 2 A 4-bit borrow look-ahead subtractor

		$b_0 = 0$
$A_1 = 1$	$G_1 = 1$	$b_1 = 0(b_0)$
$B_1 = 1$	$P_1 = 0$	
$A_2 = 0$	$G_2 = 0$	$b_2 = 1(P_2)$
$B_2 = 1$	$P_2 = 1$	
$A_3 = 0$	$G_3 = 1$	$b_3 = 1(b_2)$
$B_3 = 0$	$P_3 = 0$	
$A_4 = 1$	$G_4 = 0$	$b_4 = 0(P_4)$
$B_4 = 0$	$P_4 = 0$	

the two numbers are available simultaneously at the time when the subtractions performed. This is because the b_i's can be expressed directly in terms of the inputs A_i's, B_i's and b_0, which employ that the subtraction can be expressed directly in terms of the inputs A_i's, B_i's and b_0.

Since the subtractions are switching functions, they can be expressed in the sum-of product or product-of-sum form. By applying a function minimization technique for multiple output circuits we can obtain a minimal two level AND-OR, OR-AND realization of the borrow look-ahead subtractor. This algorithm is applicable for subtraction where A is greater than B. for implementing this algorithm on high speed processor first two bits are tested in order to know A > B or B > A. If B > A, B is subtracted from A with –ve sign attached to the result

2 Implementations

See Figs. 1 and 2.

3 Conclusion

As no restrictions are imposed on the maximum allowable inputs (fan-in) to a gate, the borrow look-ahead subtractor can be realized by a two level (AND-OR), (OR-AND) circuits irrespective of number size. In the implementation, high speed is achieved sacrificing hardware cost. Now-a-days due to the VLSI technology this implementation can be easily achieved.

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References

1. Lee, S.C.: Digital circuits and logic design, 5th ed. Prentice-Hall of India (1987)
2. Winogards, S.: On the time required to perform addition. J. ACM **12**(2), 793–802 (1967)
3. Floress, I.: The logic of computer arithmetic. Prentice-Hall, Englewood, Cliffs, NJ (1963)
4. Winogards, S.: On the time required to perform addition. J. ACM **12**(2), 277–285 (1965)
5. Lee, S.C.: Digital electronics. Prentice-Hall of India (1976)

Human Interaction and User Interface Design for IoT Environments Based on Communicability

Marcia Ikezaki Ferrari and Plinio Thomaz Aquino, Jr.

Abstract This article offers a Human Computer Interaction (HCI) perspective of the projects IoT. The purpose is to introduce how it happens interaction between applications in a IoT environment and the user, through Theory of Action, adjusting the interaction model of the Semiotic Engineering and applying communicability concepts in a projects IoT. The Semiotic Engineering considers interaction as an artifact to communicate a message from the system designer and the user through the interface, called metacommunication. The Semiotics Engineering has two evaluation methods, SIM (Semiotics Inspection Method) and CEM (Communicability Evaluation Method), which are used, respectively, in the inspection and evaluation of the communicability of a system. Finally, this work presents a overall procedure for the semiotic inspection method to projects IoT.

Keywords Human interaction · Internet of things · Communicability design · Semiotic inspection method

1 Introduction

The combination among advancement in the wireless communications, nanotechnology, cost reduction of devices and the internet expansion collaborate on a ubiquitous scenario, in which computers are intrinsic in the environment in a

M.I. Ferrari (✉) · P.T. Aquino, Jr.
IPT—Instituto de Pesquisas Tecnológicas, Av. Prof. Almeida Prado, 532, Butantã, São Paulo, Brazil
e-mail: marcia@luzdigital.com.br

P.T. Aquino, Jr.
e-mail: plinio.aquino@fei.edu.br

P.T. Aquino, Jr.
Computer Science Departament, Centro Universitário da FEI—Fundação Educacional Inaciana Pe. Saboia de Medeiros, Av. Humberto de a. C. Branco, 3972, S. Bernardo do Campo, São Paulo, Brazil

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silently and invisible way [1]. These small computers aware of their surroundings, favorable for communication and available anytime and everywhere characterize the IoT environment [2]. According to Gubbi [3], in 2020, an estimated 40 billion devices will be interconnected and sending data over the Internet, mostly concentrated in fields and environments that aim to support the daily tasks and improve the people's quality of life. Despite these improvements, there are two major problems concerning the safety and privacy of information.

In this scenario, proposing theoretical models that assist in the definition and interaction of man and IoT environment is one of the HCI (Human Computer Interaction) challenges for the next decade. The main purpose of the approach of the HCI in IoT projects is to assist in developing systems, respecting the skills and knowledge of individuals, as well as the dynamics of their behavior, because the success of these systems depends on the information properly collected according to the system developed by the designer, helping to minimize the problems above mentioned [4, 5]. The solutions based on profile mapping, context, interface interaction patterns can reduce a problems associated with the deployment IoT projects [6, 7].

One of the approaches of the HCI area, which includes a model of interaction between man and computer, is the Cognitive Engineering, designed by Norman [8]. This approach aims to establish principles and theories to understand human performance in using computer applications, in order to guide the designer in developing systems that are pleasing and easier [8]. According to Weiser [1], computer system easy-of-use is one of the factors that contributes to the transparency of technology.

The Theory of Action is the model of Cognitive Engineering that explains a traditional interaction that happens between user and computer, through graphical users interfaces [8, 9]. Within this theory, an analysis was performed to understand what happens in the interaction between user and computer system in a projects IoT. These systems allows new ways of interactions that are different from the traditional ones such as keyboard, mouse and monitor, considering other ways interaction as gestures, looking, movement, among others [4]. Another approach to HCI area, Semiotics Engineering encompasses this vision of Cognitive Engineering, bringing the designer into this scenario, thereby setting the interaction between him and the user through the computer system. The computer application is an artifact which represents the system designer to communicate a message from him to the user, which is called metacommunication [10].

The Semiotic Engineering is based on the study of signs, and the communicability is the main property of the system being evaluated for the use quality of a computer system. Based on this theory, a software must be developed taking into consideration the user understanding about the application behavior, the intended audience, for what purpose and principles that define the possibilities of interaction with the system [10, 11].

The identification of the communication rupture, which characterizes a failure in the quality of metacommunication, is performed by a analysis of the signs that are present during the interaction between man and the software, and should be segmented into three classes: static, dynamic and metalinguistic [10, 11]. Signs recognition are important because it reduces the time of the message understanding and helps the user to take a faster and effective decision. If the user do not recognize the sign or have difficulty doing so, semiosis is unsuccessful causing dissatisfaction and discomfort, and lack of communication can be complete [12].

This article proposes the application of the communicability concepts, based on the interaction model of the Norman's Theory of Action [8] and the Semiotic Engineering inspection methods to support design in a IoT environment. The hypothesis of this article is that the high communicability of IoT projects can reduce the problems and errors that can occur in the interaction between man and the IoT system, reducing the cost, time and the need for reconstruction of the computer system, contributing positively to software quality use.

2 The Theory of Action and Semiotic Engineering

The Theory of Action, present in Cognitive Engineering, was proposed by Norman [8] to describe the implementation stages and activities evaluation that occur in the interaction between user and computer. The Theory of Action is represented by two gulfs called, Gulf of Execution and Gulf of Evaluation, describing the cycle of interaction between user and computer. The phenomena involved in this interaction are studied in Cognitive Engineering.

Encompassing the view of Cognitive Engineering, Semiotic Engineering brings the system designer figure, placing it at the forefront of interaction that happens between him and the user, mediated by the computer system. According to Souza [8], the HCI is characterized as a specific case of metacommunication, i.e. the exchange of messages through the established language in the interaction between the user and designer to perform the tasks. The use of the term metacommunication refers to indirect message because the designer is not present at the time of interaction, and unidirectional, because the user in the context of interaction can not continue communicating with the designer.

One of the main advantages of semiotic view over HCI, cited by Souza [10] and Prates and Barbosa [11] is to centralize the attention of researchers in the signs. This theory makes it possible to understand the process of development, use and examination of computer systems. The Semiotic Engineering evaluates how is the communication between the designer, which sends the message and the user, who received, allowing an assessment that will help the designer to make improvement decisions for the system. The essence of the message is displayed as follows: "*Here is my understanding of who you are, what I've learned you want or need to do, in which preferred ways, and why. This is the system that I have therefore designed for you, and this is the way you can or should use it in order to fulfill a range or purposes that fall within this vision* [10]". This template use it in order to fulfill as a scheme, guide the evaluator in a inspection and evaluation of the software.

The goal of communicability is to allow the user, through its interaction with the system, to be able to understand the hypothesis, intentions and decisions used by the designer during the development process. The higher the user understanding of the logic of the embedded designer in the application, the greater your chance to use the application in a creative, efficient and productive way. It's understanding the development process, use and analysis are possible based this theory [10, 11].

The main advantages of semiotic view over HCI, cited by Souza [8] and de Reis and Prates [13], is to centralize the attention of researchers in the signs. HCI artifacts are communicated through signs, the user should be able to interpret, learn and adapt to various contexts of needs and opportunity. Semiotics Engineering based on semiotics which study of signs and signification process. According to Peirce [14], the sign is representation of something that must have meant for someone and may be composed of words, images, sounds, smells, tastes, among others.

The Semiotic Engineering has two qualitative and interpretative methods, SIM (Semiotics Inspection Method) and CEM (Communicability Evaluation Method), to evaluation a quality of transmission and reception of metacommunication in HCI, to identify communication disruptions that could arise in interaction between the user and designer through a system interface [10, 13, 15].

The SIM application is performed by professional expert to evaluation and analyze the issue of metacommunication designer through each sign present in the interface and classified into static, dynamic and metalinguistic, generating a report on the problems encountered. These signs express a distinct meaning in the system and have an expression power serving for different communicative purposes. The text for help or for the system presentation must describe and explain all the items shown in static screens and dynamic interaction. The static signs and dynamic signs are closely linked, so that static screens must communicate and anticipate the actions in the dynamic interaction [9, 10, 15, 16].

The SIM is an inspection method that does not require participate of users in the evaluation, and the expert, from the user's perspective, check the interface out to analyze the quality of the metacommunication issues designer. The steps for the implementation of SIM are composed of five main stages, and the first three are in-spection of signs: metalinguistic, static and dynamic. At the end of each inspection, one metamessage is generated and completed with the previous one, and the fourth stage is the comparison of these three metamessages. Finally, in the fifth and final stage, takes place the evaluation of the system's communicability [15–17].

The CEM is a method that evaluates the user metacommunication reception quality. In this method, an observation of the users takes place in a controlled environment, recording these interactions for further detailed analysis of the problems encountered [9, 10, 15].

The purpose of CEM is to expand the knowledge of designers and evaluators concerning the interpretation of the user regarding the computer system, obtained through user's images while handling the interface, in which its communicability is analyzed by checking what can occur during this interaction. The evaluation of the quality of this communication is performed by an expert in CEM, through associations of one or more predefined expressions called tags, which identifies breaks and works "as if the words were placed in the user's mouth," or, as the definition of Prates and de Souza [18], is a rebuilt verbal protocol.

Tags are used to categorize the user's reaction during the interaction, which means that the evaluator interprets the user's reaction by explaining it through statements that he could supposedly say at that moment, as if he were expressing himself aloud. The evaluator identifies patterns of behavior that are associated with expressions of communicability present on the tags [10, 16]. There are thirteen tags: "Looks fine to me", "I give up", "I can do otherwise", "Thanks, but no, thanks", "Where is it?", "What happened?", "What now?", "Who did that?", "Where am I?", "Oops!", "I can't do it this way", "What's this?", "Help!", "Why doesn't it?".

3 Internet of Things (IoT)

The IoT emerges as an important precursor of ubiquitous computing and its essence is a set of "things" interconnected through the Internet, in order to provide various information about the environment in which they are placed at any time, besides of allowing remote management of multiple devices next to them. The "thing" in the context IoT can be broad and styling any object with processing capacity and connected to the network [3].

The IoT is the combination and interlacing of ubiquitous computing, Internet protocols, sensors and communication devices, and the objects, forming a system where-by the real world and digital symbiotically interact. The "smart" objects will not only collect data on and around themselves, but they will be interconnected among them and to the Internet, receiving and sending data and information [19, 20].

For Atzori et al. [21] and Singh et al. [22] the IoT paradigm is the result of the convergence of the following three views: "Things" Oriented Vision, Internet Oriented Vision and Semantics Oriented Vision. Based on this vision, Koreshoff et al. [23] mapped the studies found in IHC which were classified in each of the views addressed by Atzori et al. [21], as shown in Fig. 1. According to the authors, previous research have focused on "Things Oriented Vision", explained by proximity and constant interaction of man with the object. User satisfaction in the interaction with the objects or the environment is an important point for the IoT systems to meet the ease of use coming to the transparency of technology, as pointed by Weiser [1].

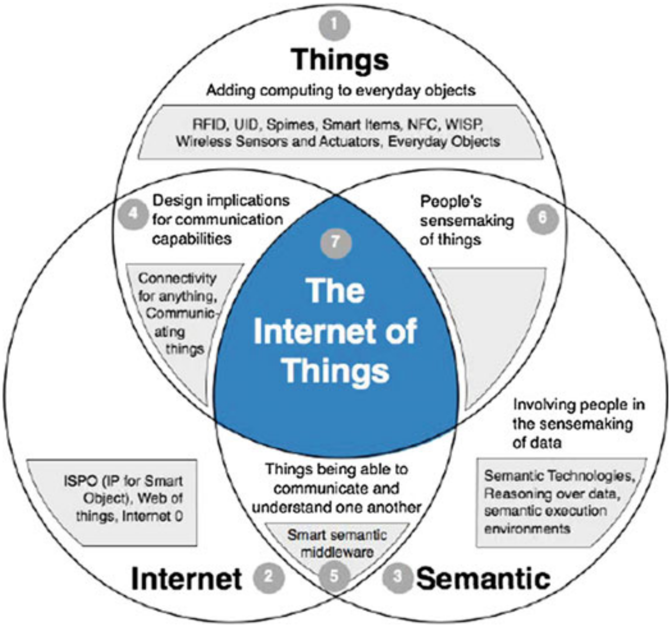


Fig. 1 Koreshoff et al. [23] vision. Modified version of Atzori et al. [21] 'Internet of Things' paradigm

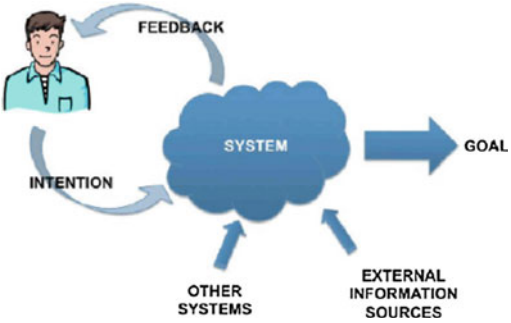
4 Communicability Designer in a IoT Environment

The "ITU Internet Reports" [27] shows that the paradigm of IoT must dispose of the system "at anytime, anywhere and for anything." Understanding the current con-text of users, devices and the environment is an essential factor for the IoT systems to reach the objectives, considering the communication that takes place between the user and the computer, the user and the devices, and the devices themselves.

According Atzori et al. [21], the IoT systems participate in a collaborative communication, will be context-sensitive and may have proactive and autonomous behaviors, because the connection and interaction between devices and the social, environmental and user context enable ubiquitous systems or IoT anticipate the actions of man, with minimal or no human intervention. Proactivity autonomy allows the system to take action and to decide, when necessary, the best way to use the system within a contexto.

According to Pereira et al. [24], Context Sensitive Computing has been studied over the past three decades encompassing from desktop applications to IoT systems, but the popularization of Context Sensitive Computing happened after the presentation of the computing concept ubiquitous by Weiser [1].

Fig. 2 The image shows the interaction diagram based on the man's intention



A classic, referenced and widely accepted definition is from Dey [25], in which the context is all information that can be used to characterize the situation of an entity, which can be a person, a place or an object considered relevant to the interaction between the user and the application, including both the user and the application themselves. The more relevant aspects of the context should answer the following questions: "Where is the person?", "With whom the person is?" and "Which resources are available?".

Vega-Barbas et al. [26] propose an IoT architecture approach, based on the concepts of context aware computing and defending the idea that the designers of IoT should not ignore individuals in the development process of IoT systems. From this approach, they have an interaction model based on the user's intentions, as shown in Fig. 2.

Considering the main characteristics that influence the interaction between man and the IoT environment, the Theory of Action, of the Cognitive Engineering [8], has been adapted to consider the interaction between the IoT environment and the user, enabling the interaction visualization and understanding how it occurs. The IoT environment, context-sensitive, may become aware of the user's purpose without their direct intervention, represented in Fig. 3 by the dotted line. The environment can respond autonomously and proactively anticipating the user's action and stimulating their reaction. The user receive the environmental stimulus, makes a decision and react to the stimulus, closing the cycle of this new gulf. In Fig. 3, these new gulfs are called "Proactive Behavior" and "Human Stimulate Reactive", which are represented by the dashed line.

According to Souza et al. [28], the Semiotic Engineering can encompass and complement the Theory of Action by involving the designer figure featuring the metacommunication process. The Cognitive Engineering emphasizes the system designed for the device and how the user interprets the system in this process. In its turn, Semiotic Engineering considers the interaction as a conversation that takes place between the user and the designer, through a channel and a communication language represented by the interaction between the user and the application, so that the user can reach his goal [10, 28].

Paula's research [29] proposes the development of a tool to support the designer's reflection during the design HCI. This tool consists of extending the

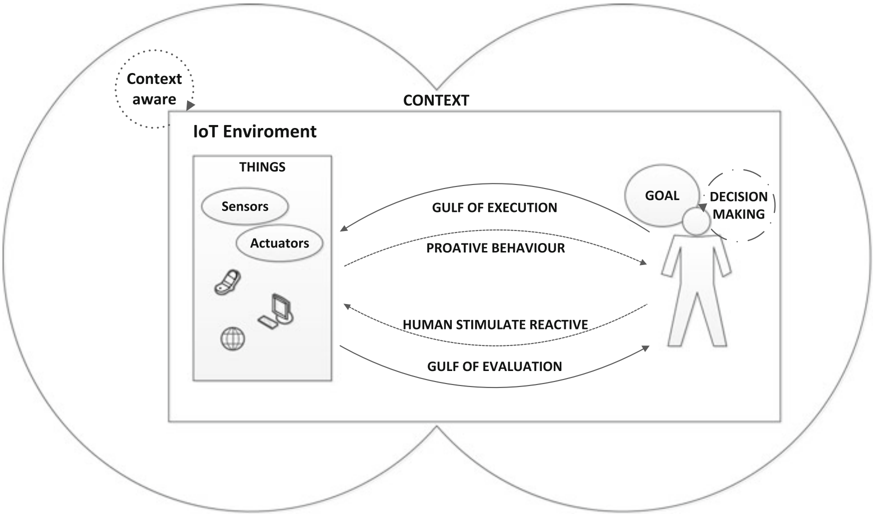


Fig. 3 The Theory of Action, defined by Norman [8], presents originally on continuous line the traditional interaction. *Dashed line* represents an adaptation of the traditional model of interaction in a IoT environment

representation of the scenarios, task model adaptation and a model of interaction that supports the purpose of this research, for the adaptation of the interaction of Semiotic Engineering model, emphasizing the user-system interaction, present in means of communication, shown in Fig. 3.

This model of the interaction unit was divided into two, one being the Gulf which represents the traditional interaction, and the other gulf that was adapted from the model, establishing two models of flow "conversation".

Despite the interactions models of the talks have the same goal, subject and the same language that compose the dialogues, your lines may differ between models. Similar to a conversation between people, the difference can happen for various reasons, such as: who initiates the conversation, increase, decrease or even changing a particular language among others. As talk is composed of signs, they may be different in the two interactions. The construction and representation of the dialogue between the designer and the user is a suggested tool as a support in the construction of an interaction design project of an interface, under the Centered Design in Communication view. The structuring of the dialogues can also provide a guidance to fill the information in the meta-message model [10].

Despite the presence of the two models in the adaptation of the Theory of Action of Semiotic Engineering, the metamessage is unique in both cases, because the information necessary to fulfill the message does not change between them.

In the evaluation of metacommunication, the inspection of the signs is independent of your domain or technology used in the application, as Bento [30] research, which performs the inspection of signs, dividing them into classes that

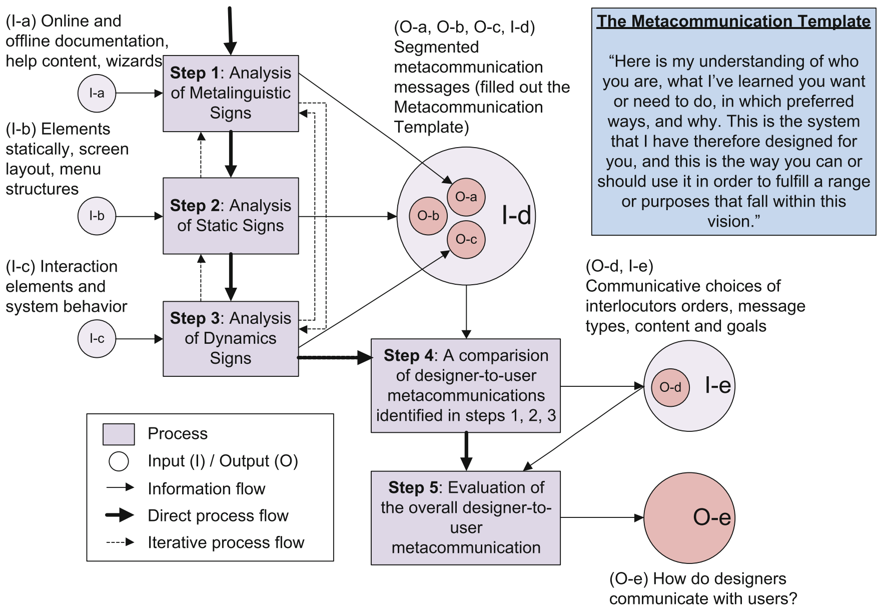


Fig. 4 The SIM is carried out in five distinct steps: Analysis of Metalinguistic Signs, Analysis of Static Signs, Analysis of Dynamic Signs, a contrastive comparison of designer-to-user metacommunications identified in steps 1, 2, 3, and a conclusive appreciation of the quality of the overall designer-to-user metacommunication [17]

guide the identification, description, prevention, and recovery of the communication breakages. This inspection of signs is divided into five steps, as shown in Fig. 4, applied for traditional interaction.

For de Reis and Prates [13], the absence of metalinguistic sign does not preclude the application of MIS, even though it may generate a reconstruction of restricted and poor metamessage. However, according to Bento [30], the absence of metalinguistic sign can indicate knowledge of the system, or an easy to use interface that does not require a tutorial or explanation, as can happen in projects IoT. Many of the objects from one environment IoT are present and can be used on the user's day.

The research of Alves et al. [31] shows that communication failures occurred by the non-recognition of the sign by the user. According to surveys, the failure in the interpretation of designer in relation to the users of the interface, was one of the causes of the cited problem because, according to Aquino [6], designers end up defining a generic profile based on pre-established concepts of the user, and in some situations considering personal characteristics. This problem can also be extended to projects in an IoT environment.

5 Conclusion

The close relationship between HCI and IoT projects has as main purpose to build intelligent and connected objects that respect human skills and knowledge, as well as the dynamic user behavior. The success of these projects depends on information properly collected and in compliance with the system architecture design plan, reducing the above mentioned issues. In an IoT environment, the human and computer interaction happens through objects containing embedded technology to sense or interact with their internal state and external environment, mostly with the internet.

The object, existing in an IoT environment, has a computer processing capability and is connected to the internet, thus allowing it to be intelligent and independent from human stimulus to understand and analyze both context and environment. Information can be obtained from other smart objects, or data capture around based on its analysis and knowledge. According to this scenario, this paper analyzes the Action Theory in Cognitive Engineering with the purpose of assessing the interaction model between the "intelligent" device in an IoT environment and the user for a comprehensive understanding of this type of interaction.

Based on an adapted interaction model from Cognitive Engineering, the purpose of this work was to apply the concepts of the communicability to different interaction means between systems and users in an IoT environment. The adapted model includes two gulfs that were considered as two "conversational" flow models. The conversation has a theme representing the subject on which the user and the system discuss for the purpose to reach a common objective. The conversation structure is composed of dialogs expanded into conversational sub-threads, which consist of speeches between the user and the system. The speeches should use the same language used in a sign system.

The construction and representation of a dialog between the designer and the user is a suggested tool to support the construction of an interaction project in an interface under the supervision of the Communication Centered Design at the same time that it guides the preparation of a metacommunication message. The signs identified are classified and verified as a guide to identify the possible communication gaps at the moment of the project and if the system defines alternate means to prevent and recover failures.

Semiotic Engineering presents two methods to assess the quality of the product use: the SIM (Semiotic Inspection Method), which investigate the static, dynamic and metalinguistic signs in the interface to send the message according to the designer's view; and the CEM (Communicability Evaluation Method) extension, which is used to evaluate collaborative systems in regards to the analysis of the message received by the user. This work focused on the SIM method. The next steps provide for the execution of experiments using the SIM and studies related to CEM method.

The adaptation of the interaction model from Semiotic Engineering, the SIM is used as resources to apply communicability concepts in projects for IoT environments, and have as purpose to establish an increase of the communicability level in the human-computer interactions, thus improving the quality of the system use.

References

1. Weiser, M.: The computer for the 21st century. IEEE Pervasive Comput. **1**, 19–25 (1991)
2. International Telecommunication Union. ITU Internet Reports 2005: The internet of things. Geneva (2005)
3. Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M.: Internet of things (IoT): a vision, architectural elements, and future directions. Future Gener. Comput. Syst. **29**, 1645–1660 (2012)
4. Furtado, E.S., Militão, G., Andrade, R., Miranda, L.C., Oliveira, K.: Ubiquidade, Múltiplos Dispositivos e Tangibilidade. In: Baranauskas, Souza and Pereira (org.). I GranDIHC-BR — Grandes Desafios de Pesquisa em Interação Humano-Computador no Brasil. Relatório Técnico. Comissão Especial de Interação Humano-Computador (CEIHC) da Sociedade Brasileira de Computação (SBC), pp. 23–26 (2014)
5. Koreshoff, T.L., Leong, T.W., Robertson, T.: Approaching a human-centred internet of things. In: 25th Australian Computer-Human Interaction Conference on Augmentation, Application, Innovation, Collaboration, 2013, Adelaide. Proceedings…, pp. 363–366. ACM, New York (2013)
6. Junior, A., Picap, P.T.: padrões e personas para expressão da diversidade de usuários no projeto de interação [online]. São Paulo: Escola Politécnica, Universidade de São Paulo. Tese de Doutorado em Sistemas Digitais. [acesso 2016-03-10]. Disponível em: http://www.teses.usp.br/teses/disponiveis/3/3141/tde-15092008-144412/. (2008)
7. Masiero, A.A., Aquino Jr, P.T.: Creating personas to reuse on diversified projects. In: Human-Computer Interaction: Design and Evaluation: 17th International Conference, HCI International 2015, Proceedings, Part I. vol. 9169 of the series Lecture Notes in Computer Science, Los Angeles, CA, USA, pp. 238–247, 2–7 Aug 2015
8. Norman, D.A.: Cognitive engineering. In: Norman, D., Draper S.W. (ed.) *User Centered System Design*, pp. 31–61. Lawrence Erlbaum, Hillsdale (1986)
9. Barbosa, S.D.J., da Silva, B.S.: Interação Humano-Computador, p. 408. Elsevier, Rio de Janeiro (2010)
10. de Souza, C.S.: The Semiotic Engineering of Human-Computer Interaction, p. 307. The MIT Press, Massachusetts (2005)
11. Prates, R.O., Barbosa, S.D.J.: Introdução à Teoria e Prática da Interação Humano Computador fundamentada na Engenharia Semiótica. In: Kowaltowski and Breitman (org.). XXVII Congresso da Sociedade Brasileira de Computação. Jornadas de Atualização em Informática (JAI), pp. 263–326 (2007)
12. Bhutkar, G., Poovaiah, R., Katre, D., Karmarkar, S.: Semiotic analysis combined with usability and ergonomic testing for evaluation of icons in medical user interface. In: 3rd International Conference on Human Computer Interaction, 2011, Bangalore. Proceedings…, pp. 57–67. ACM, New York (2011)
13. de Reis, S., Prates, R.O.: Applicability of the semiotic inspection method: a systematic literature review. In: 5th Latin American Conference on Human-Computer Interaction (IHC+CLIHC'11), 2011, Porto de Galinhas. Proceedings…, pp. 177–186. Brazilian Computer Society, Porto Alegre (2011)
14. Peirce, C.S.: Semiótica, 337 p. Ed. Perspectiva, São Paulo (2012)

15. de Souza, C.S., Leitão, C.F.: Semiotic engineering methods for scientific research in HCI. Synth. Lect. Human-Centered Inform. **2**(1), 1–122 (2009)
16. de Souza, C.S., Leitão C.F., Prates, R.O., da Silva, E.J.: The semiotic inspection methods. In: VII Brazilian Symposium on Human Factors in Computing Systems, 2006, Natal. Proceedings…, pp. 148–157, ACM, New York (2006)
17. Bim, S.A.: Obstáculos ao ensino dos métodos de avaliação da Engenharia Semiótica. 2009. 181f. Tese (Doutorado) – Pontifícia Universidade Católica R. J., Rio de Janeiro (2009)
18. Prates, R.O., de Souza, C.S.: Extensão do Teste de Comunicabilidade para Aplicações Multi-usuário. Cadernos do IME **13**, 46–56 (2002)
19. Borgia, E.: The Internet of Things vision: key features, applications and open issues. Comput. Commun. **54**, 1–31 (2014)
20. Miorandi, D., Sicari, S., Pellegrini, F.D.E., Chlamtac, I.: Internet of things: vision, applications and research challenges. Ad Hoc Netw. **10**, 1497–1516 (2012)
21. Atzori, L., Iera, A., Morabito, G.: The internet of things: a survey. Comput. Netw. **54**, 2787–2805 (2010)
22. Singh, D., Tripathi, G., Jara, A.J.: A survey of internet-of-things: future vision, architecture, challenges and services. In: IEEE World Forum on Internet of Things, 2014, Seoul. Proceedings…, pp. 287–292 [s.i.]: IEEE (2014)
23. Koreshoff, T.L, Leong, T.W., Robertson, T.: Approaching a human-centred internet of things. In: 25th Australian Computer-Human Interaction Conference on Augmentation, Application, Innovation, Collaboration, 2013, Adelaide. Proceedings…, pp. 363–366. ACM, New York (2013)
24. Perera, C., Zaslavsky, A., Christen, P., Georgakopoulos, D.: Context aware computing for the internet of things. IEEE Commun. Surv. Tut (2013)
25. Dey, A.K.: Understanding and using context. Pers. Ubiquit. Comput. **5**(1), 4–7 (2001)
26. Vega-Barbas, M., Casado-Mansilla, D., Valero, M.A., López-De-Ipiña, D., Bravo, J., Flórez, F.: Smart spaces and smart objects interoperability architecture (S3OiA). In: Proceedings of IMIS 2012, pp. 725–730 (2012)
27. International Telecommunication Union. ITU Internet Reports 2005: The internet of things. Geneva (2005)
28. Souza, C.S., Leite, J.C., Prates, R.O., Barbosa, S.D.J.: Projeto de Interfaces de Usuário: perspectivas cognitivas e semióticas. In: Fuks (org.). XIX Congresso da Sociedade Brasileira de Computação, 1999, Rio de Janeiro. Anais…, pp. 420–470. Jornadas de Atualização em Informática (JAI), Rio de Janeiro (1999)
29. de Paula, M.G.: Projeto de Interação Humano-Computador Baseado em Modelos Fundamentados na Engenharia Semiótica: Construção de um Modelo de Interação. 2003, 87f. Dissertação (Mestrado) – Programa de Pós-graduação em Informática do Departamento de Informática da PUC-Rio, PUC-Rio, Rio de Janeiro (2003)
30. Bento, L.F.H.: Desenvolvimento de Interfaces em Diferentes Tecnologias para Teleoperação de Robôs Móveis. 2010. 181f. Dissertação (Mestrado) – Instituto de Ciências Exatas da Universidade Federal de Minas Gerais, Minas Gerais (2010)
31. da Alves, A.S., Ferreira, S.B.L., de Veiga, V.S.O., Monteiro, I.T., da Silveira, D.S., Raposo, A.B.: Novas estratégias comunicativas como fator de qualidade na interação de surdos em um sistema organizacional. In: 12th BRAZILIAN Symposium On Human Factors In Computing Systems, 2013, Manaus. Proceedings…, pp. 122–131. Brazilian Computer Society, Porto Alegre (2013)