Safety and Security Engineering VI

WIT PRESS

Editors
C.A. Brebbia,
F. Garzia &
D. Poljak

Safety and Security Engineering VI

WITPRESS

WIT Press publishes leading books in Science and Technology.
Visit our website for new and current list of titles.
www.witpress.com

WITeLibrary

Home of the Transactions of the Wessex Institute.
Papers presented at SAFE VI are archived in the WIT eLibrary in volume 151 of
WIT Transactions on The Built Environment (ISSN 1743-3509).
The WIT eLibrary provides the international scientific community with immediate and
permanent access to individual papers presented at WIT conferences.
Visit the WIT eLibrary at www.witpress.com.

Sixth International Conference on Safety and Security Engineering

SAFE VI

Conference Chairmen

C.A. Brebbia
Wessex Institute of Technology, UK

F. Garzia
University of Rome 'La Sapienza', Italy

D. Poljak
University of Split, Croatia

International Scientific Advisory Committee

Sponsored by

WIT Transactions on the Built Environment
International Journal of Safety and Security Engineering

Organised by

University of Rome 'La Sapienza', Italy
Wessex Institute of Technology, UK

WIT Transactions

Safety and Security Engineering VI

Editors

C.A. Brebbia
Wessex Institute of Technology, UK
F. Garzia
University of Rome 'La Sapienza', Italy
D. Poljak
University of Split, Croatia

WIT*PRESS* **Southampton, Boston**

Editors:

C.A. Brebbia
Wessex Institute of Technology, UK

F. Garzia
University of Rome 'La Sapienza', Italy

D. Poljak
University of Split, Croatia

Published by

WIT Press
Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK
Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853
E-Mail: witpress@witpress.com
http://www.witpress.com

For USA, Canada and Mexico

Computational Mechanics International
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
E-Mail: infousa@witpress.com
http://www.witpress.com

British Library Cataloguing-in-Publication Data
A Catalogue record for this book is available
from the British Library

ISBN: 978-1-84564-928-9
eISBN: 978-1-84564-929-6
ISSN: 1746-4498 (print)
ISSN: 1743-3509 (on-line)

The texts of the papers in this volume were set individually by the authors or under their supervision. Only minor corrections to the text may have been carried out by the publisher.

No responsibility is assumed by the Publisher, the Editors and Authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. The Publisher does not necessarily endorse the ideas held, or views expressed by the Editors or Authors of the material contained in its publications.

Printed in Great Britain by Lightning Source, UK.

Preface

This Volume contains some of the papers presented at the sixth International Conference on Safety and Security Engineering held in Opatija, Croatia. The Meeting follows the success of the other conferences in the series, which started in Rome (2005); followed by Malta (2007); Rome (2009); Antwerp (2013); and Rome (2015).

The Conference provides a forum for the presentation and discussion of the most recent developments in the theoretical and practical aspects of the important fields of Safety and Security Engineering, which due to its special nature, is an area of research and application which brings together many engineering disciplines from the traditional to the most technologically advanced.

This diversity is reflected in the contents of this Volume which cover a wide range of topics, from technical solutions, to systems and human resources; identifying procedures to prevent and mitigate natural or man-made events that can cause damage to people or property.

This Volume is no 151 of the WIT Transactions on the Built Environment, and is being widely distributed throughout the world in paper and digital format. The contributions are also permanently archived in the eLibrary of the Institute (http://libary.witpress.com) where they are permanently and easily available to the international community.

The Conference is sponsored by the International Journal of Safety and Security Engineering, whose aims are the same as those of the Meeting, ie to attract the latest research and applications in the field.

The Editors are grateful to all authors for their contributions, and to the members of the International Scientific Advisory Committee and other colleagues who helped to review the papers and hence ensure the quality of this book.

The Editors
Opatija, Croatia
2015

This page intentionally left blank

Contents

Section 2: Critical infrastructure protection

Section 3: Emergency response

Section 4: Security surveillance systems

Section 8: Systems safety

Section 1
Risk analysis, assessment and management

This page intentionally left blank

Methods of health risk assessment for human exposure to high frequency electromagnetic fields

D. Poljak[1], M. Cvetković[1] & H. Dodig[2]
[1]*University of Split, Croatia*
[2]*Marine Electronics Center, Croatia*

Abstract

The paper reviews some topics in human exposure to high frequency (HF) electromagnetic fields based on certain integral equation formulations and related numerical solution procedures. Illustrative computational examples are related to the human eye and the human brain exposed to HF radiation. The obtained numerical results for specific absorption rate (SAR) are compared against exposure limits proposed by ICNIRP (International Commission on Non Ionizing Radiation Protection).
Keywords: human exposure, high frequency radiation, specific absorption rate, integral equation formulation, numerical solution procedures.

1 Introduction

The tremendous growth of wireless communication systems in modern society has increased the public concern regarding possible adverse health effects due to exposure to high frequency (HF) radiation. The HF exposure assessment is based on the calculation of SAR distribution.

A comprehensive review on this hot issue could be found in many papers, e.g. [1–3]. As measurement of induced fields in the body is not possible human exposure assessment is carried out by using appropriate computational models [2–5]. Theoretical models are being used to simulate various exposure scenarios, and thereby establish safety guidelines and exposure limits for humans [6, 7]. Computational models can be classified as either realistic models of the body (or particular organs) mostly based on Magnetic Resonance Imaging (MRI) [2, 3, 8–

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150011

10], or simplified models, computationally much less demanding but failing to provide accurate results in most of the exposure scenarios.

This paper reviews the use of integral equation approaches in bioelectromagnetics developed by the authors.

Related illustrative computational examples presented in the paper are related to the human eye and the human brain exposed to HF radiation [11, 12]. The eye exposure is based on the hybrid boundary element/finite element method (BEM/FEM) of solution of the Helmholtz equation. The brain exposure is analyzed by solving the set of coupled surface integral equations (SIEs) via the Method of Moments (MoM). The obtained maximal values of SAR are compared to the exposure limits proposed by ICNIRP.

2 HF dosimetry basics

The principal task of HF dosimetry is related to the assessment of thermal effects, i.e. to determine the level and distribution of the electromagnetic energy absorbed by the body. The main dosimetric quantity for quantifying the influence of HF fields is the specific absorption rate (SAR) and related temperature increase.

Due to the mathematical complexity of the problem most of the early stage researchers investigated simple models such as plane slab, cylinders, homogeneous and layered spheres and prolate spheroids [13] while recent anatomically based computational models comprising of cubical cells are dominantly related to the application of the Finite Difference Time Domain (FDTD) methods. The Finite Element Method (FEM) and Boundary Element Method (BEM) are generally used to a somewhat lesser extent [13–15].

The specific absorption rate (*SAR*) represents a fundamental quantity in HF dosimetry. *SAR* is defined in terms of the rate of energy *W* absorbed by, or dissipated in the unit body mass *m*:

$$SAR = \frac{dP}{dm} = \frac{d}{dm}\frac{dW}{dt} = C\frac{dT}{dt} \tag{1}$$

where *P* stands for dissipated power, *C* is the specific heat capacity of tissue, *T* is the temperature and *t* denotes time.

Also, *SAR* is proportional to the square of the internal electric field:

$$SAR = \frac{dP}{dm} = \frac{dP}{\rho dV} = \frac{\sigma}{2\rho}\left|E\right|^2 = \frac{\sigma}{\rho}\left|E_{rms}\right|^2 \tag{2}$$

where E and E_{rms} is the peak and root-mean-square value of the electric field, respectively, ρ is the tissue density and σ is the tissue conductivity.

SAR distribution generally depends on the incident field parameters, the characteristics of the exposed body, ground and reflector effects, respectively. *SAR* of the biological body reaches maximal values when the electric field is oriented parallel to the long body axis.

3 The eye exposure to HF radiation

The human eye exposed to plane wave represents an electromagnetic scattering from lossy dielectric object. The eye model is based on the Stratton-Chu formulation and Helmholtz equation. The hybrid BEM/FEM approach with edge elements is applied to the assessment of related internal fields.

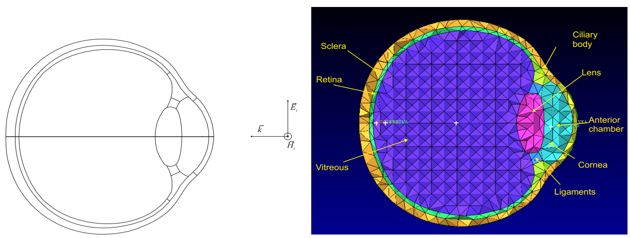
3.1 Formulation

A plane wave incident on the corneal part of the eye represents an unbounded scattering problem (as shown in Fig. 1).

According to Stratton-Chu formulation, the time-harmonic electric field occurring at the exterior of the scattering problem is expressed by the following boundary integral equation [11]:

$$\alpha\vec{E} = \vec{E}_i + \oint_{\partial V'} \vec{n}' \times \left(\nabla' \times \vec{E}\right) G dS' + \oint_{\partial V'} \left[\left(\vec{n}' \times \vec{E}\right) \times \nabla' G + \left(\vec{n}' \cdot \vec{E}\right) G\right] dS' \quad (3)$$

where $\vec{E}_i$ is the incident field, $\vec{n}'$ is an outer normal to surface $\partial V'$ bounding the volume V and α is the solid angle subtended at an observation point.



(a) (b)

Figure 1: (a) Model of the eye exposed to plane wave; (b) meshing detail, an eye is modeled with 36027 tetrahedral elements.

Furthermore, G represents the fundamental solution of the Helmholtz equation:

$$\nabla^2 G + k^2 G = -\delta(\vec{r} - \vec{r}') \quad (4)$$

The interior of the eye containing inhomogeneous regions is represented by equation [11]:

$$\nabla \times \left(\frac{1}{k_B} \nabla \times \vec{E} \right) - k_A \vec{E} = 0 \quad (5)$$

where subscripts A and B denote the exterior and interior region, respectively.

3.2 Boundary element solution

The boundary integral equation (3) is handled via the boundary element method (BEM) [3], while the partial differential equation (5) is solved by means of finite element method (FEM).

Namely, applying the weighted residual approach to equation (5) and introducing the vector test functions $\vec{W}_i$ the following integral representation is obtained [3, 11]:

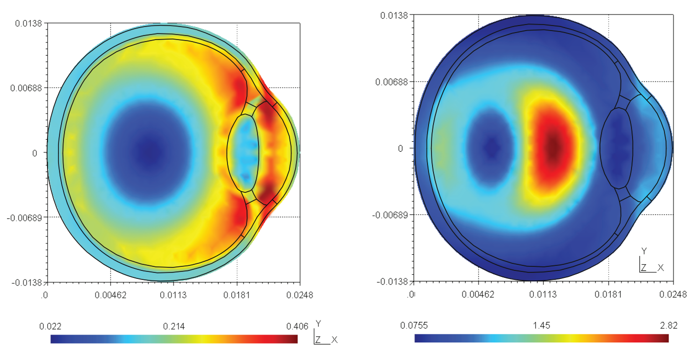
$$\int_{V'} \left[\nabla \times \left(\frac{1}{k_B} \nabla \times \vec{E} \right) - k_A \vec{E} \right] \cdot \vec{W}_i dV' = 0 \tag{6}$$

Once the electric field $\vec{E}$ is determined, *SAR* can be computed from (2).

3.3 Numerical results

Fig. 2 shows the numerical results for the SAR distribution within the eye obtained via the hybrid BEM/FEM procedure due to the incident plane wave with power density of 10 W/m^2.

The calculated SAR results presented in this work are in a satisfactory agreement with the results reported in [16].



(a) (b)

Figure 2: Computed SAR in the eye induced by plane wave of power density 10 W/m^2 at frequency (a) 1 GHz; (b) 2 GHz.

The results for SAR at different frequencies, averaged over the whole eye, are given in Table 1.

From the presented numerical results it can be seen that the hot spots formation occurs below the frequencies of 6 GHz, while at higher frequencies the electromagnetic energy is focused at the eye surface. Also, the whole eye averaged SAR values stay below the ICNIRP exposure limits [6].

Table 1: The whole eye averaged *SAR* at *f*= 1 GHz, 2 GHz, 4 GHz and 6 GHz.

Frequency [GHz]	SAR [W/kg]
1	0.3352
2	0.6189
4	1.2617
6	1.0689

4 The brain exposure to HF radiation

The model of the human brain exposed to HF electromagnetic fields is based on the surface integral equation (SIE) approach. The formulation can be derived from the equivalence theorem and by using the appropriate interface conditions for the electric and/or magnetic field, as depicted in Fig. 3.

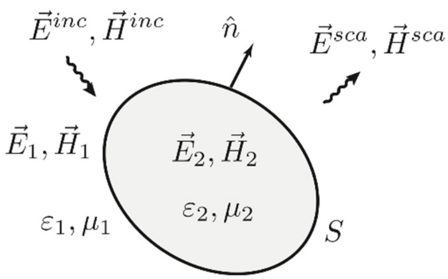


Figure 3: The brain represented by a lossy homogeneous dielectric.

The lossy homogeneous object representing the brain is excited by the incident electromagnetic field ($\vec{E}^{inc}$; $\vec{H}^{inc}$).

4.1 Formulation

Using the equivalence theorem, two equivalent problems can be formulated, in terms of the equivalent electric and magnetic current densities $\vec{J}$ and $\vec{M}$ existing at the surface *S*, one for the region 1 (exterior to dielectric) and other for the region 2 (inside the dielectric) [17–20].

The boundary conditions at the surface *S* are satisfied by introducing equivalent surface currents $\vec{J}_2 = -\vec{J}_1$ and $\vec{M}_2 = -\vec{M}_1$ at the surface. Following the same procedure for the interior equivalent problem, yields another homogeneous domain of ("2; _2). Again, the equivalent surface currents $\vec{J}_1$ and $\vec{M}_1$ are introduced.

Performing certain mathematical manipulations, the following set of integral equations is obtained [10]:

$$\begin{aligned} &j\omega\mu_n \iint_S \vec{J}(\vec{r}\,')G_n(\vec{r},\vec{r}\,')\,\mathrm{d}S' - \\ &-\frac{j}{\omega\varepsilon_n}\iint_S \nabla'_S\cdot\vec{J}(\vec{r}\,')\nabla G_n(\vec{r},\vec{r}\,')\,\mathrm{d}S' + \\ &+\iint_S \vec{M}(\vec{r}\,')\times\nabla' G_n(\vec{r},\vec{r}\,')\,\mathrm{d}S' = \begin{cases}\vec{E}^{inc}, & n=1\\ 0, & n=2\end{cases} \end{aligned} \tag{7}$$

where the Greeen's function for the homogeneous medium is given by:

$$G_n(\vec{r},\vec{r}\,') = \frac{e^{-jk_nR}}{4\pi R}; \quad R = |\vec{r}-\vec{r}\,'| \tag{8}$$

and R is the distance from the source to observation point, respectively while k_n denotes the wave number of a medium n, ($n = 1; 2$).

4.2 Solution by the method of moments (MoM)

The numerical solution of the coupled SIEs is carried out via the method of moments (MoM). A view to the triangular brain model mesh is shown in Fig 4.

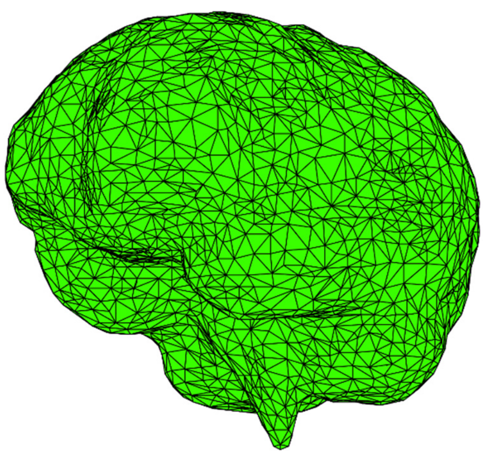


Figure 4: Triangular mesh of the homogeneous brain model.

First, the equivalent electric and magnetic currents $\vec{J}$ and $\vec{M}$ in (7) are expressed in terms of a linear combination of basis functions $\vec{f}_n$ and $\vec{g}_n$, respectively.

$$\vec{J}(\vec{r}) = \sum_{n=1}^{N} J_n \vec{f}_n(\vec{r}) \tag{9}$$

$$\vec{M}(\vec{r}) = \sum_{n=1}^{N} M_n \vec{g}_n(\vec{r}) \tag{10}$$

where J_n and M_n are unknown coefficients, while N is the total number of triangular elements.

Applying the weighted residual approach, i.e. multiplying (7) by the set of a test functions $\vec{f}_m$ and integrating over the surface S, after performing some mathematical manipulations, it follows:

$$\begin{aligned}
&j\omega\mu_i \sum_{n=1}^{N} J_n \iint_S \vec{f}_m(\vec{r}) \cdot \iint_{S'} \vec{f}_n(\vec{r}\,')G_i \, dS' \, dS + \\
&+\frac{j}{\omega\varepsilon_i} \sum_{n=1}^{N} J_n \iint_S \nabla_S \cdot \vec{f}_m(\vec{r}) \iint_{S'} \nabla'_S \cdot \vec{f}_n(\vec{r}\,')G_i \, dS' \, dS + \\
&\pm \sum_{n=1}^{N} M_n \iint_S \vec{f}_m(\vec{r}) \cdot [\hat{n} \times \vec{g}_n(\vec{r}\,')] \, dS + \\
&+ \sum_{n=1}^{N} M_n \iint_S \vec{f}_m(\vec{r}) \cdot \iint_{S'} \vec{g}_n(\vec{r}\,') \times \nabla' G_i \, dS' \, dS = \\
&= \begin{cases} \iint_S \vec{f}_m(\vec{r}) \cdot \vec{E}^{inc} \, dS & , i = 1 \\ 0 & , i = 2 \end{cases}
\end{aligned} \tag{11}$$

where subscript i denotes the index of the medium. The details of the procedure could be found elsewhere, e.g. in [10].

4.3 Numerical results

Computational examples are related to the brain exposure to plane wave at f=900 MHz and 1800 MHz, respectively. Surface of the brain is disretized using 696 triangular elements and 1044 edge-elements while the corresponding brain parameters are listed in Table 2.

The power density of the incident plane wave is P = 5mW/cm^2 and is oriented perpendicular to the right side of the brain (positive x coordinate).

Fig. 5 shows the *SAR* distribution in the brain at *f*=900 MHz for the case of horizontal polarization.

Table 2: Permittivity and conductivity of the brain.

Human brain parameters			
900 MHz		1800 MHz	
ε_r	σ [S/m]	ε_r	σ [S/m]
45,8054	0,7665	43,5449	1,15308

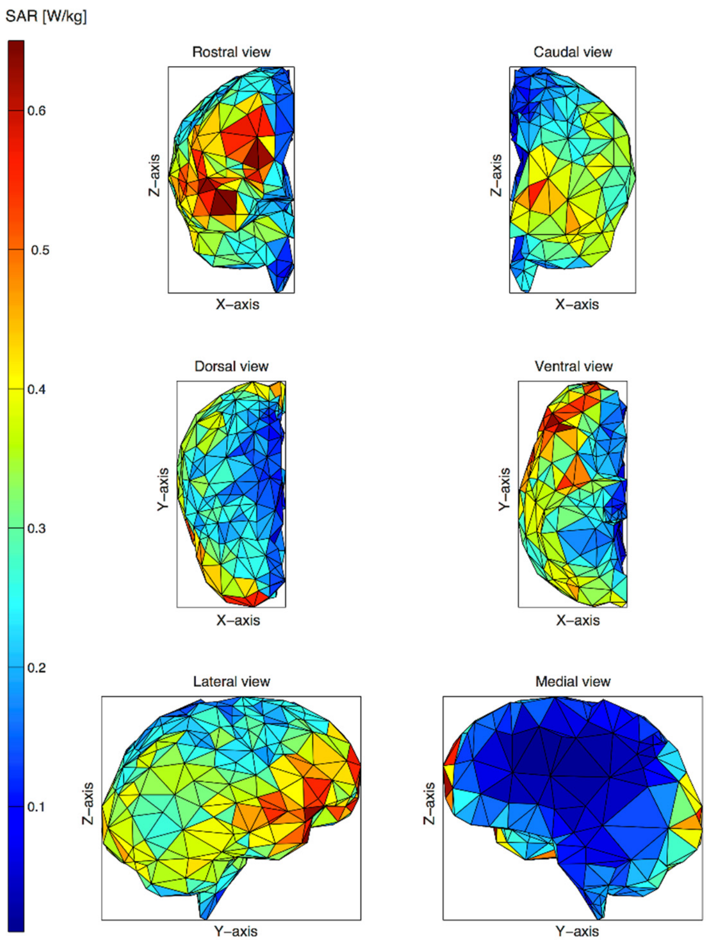


Figure 5: *SAR* distribution at *f*=900 MHz.

The obtained peak and average *SAR* values for both polarization types and for at *f*=900 MHz and *f*=1800 MHz are given in Table 3.

Table 3: Peak and average *SAR* values for different exposure scenarios.

	H		V	
	900 MHz	1800 MHz	900 MHz	1800 MHz
SAR_{max} [W/kg]	0,856486	4,390451	0,866016	2,678407
SAR_{avg} [W/kg]	0,174457	0,411736	0,158206	0,348032

The calculated peak SAR values in the brain do not exceed the ICNIRP limits [6] for localized SAR (10 W/kg in the head and the trunk for the occupational exposure).

However, the exposure limit for the general public exposure limit (2W/kg localized in the head and trunk) has been exceeded in the case of 1800 MHz (both 1800V and 1800H).

5 Conclusion

The paper reviews the application of integral equation formulation in HF dosimetry featuring the human eye and brain, respectively, exposure to high frequency electromagnetic fields. The problems are solved by solving the governing equations using the hybrid BEM/FEM solution method for Helmholtz equation and MoM solution for surface integral equation. The governing equations are solved by means of certain BEM procedures. Illustrative computational examples are related to the assessment of SAR in the eye and brain due to the plane wave exposure.

Future work will be devoted to the extension of the present homogeneous brain computational model which would include different neighboring tissues.

References

[1] J.W. Hand: Modeling the interaction of electromagnetic fields (10 MHz–10 GHz) with the human body: methods and applications, *Physics in Medicine and Biology*, vol. 53, no. 16, pp. 243–286, August 2008.

[2] D. Poljak, Electromagnetic fields: Environmental exposure. In: Nriagu JO (ed.) *Encyclopedia of Environmental Health*, volume 2, pp. 259–268 Burlington: Elsevier, 2011.

[3] D. Poljak, D. Cavka, H. Dodig, C. Peratta, A. Peratta, On the Use of Boundary Element Analysis in Bioelectromagnetics, *Eng. Anal. Bound. Elem. (Special issue on Bioelectromagnetics)* Vol. 49 (2014) pp. 2–14.

[4] N.F. Nielsen, J. Michelsen, J.A. Michalsen, and T. Schneider, "Numerical calculation of electrostatic field surrounding a human head in visual display environments", *Journal of electrostatic,* **36**, pp. 209–223, 1996.

www.witpress.com, ISSN 1743-3509 (on-line)

[5] Krish. D. Singh, Nicola S. Longan and Bernard Gilmartin: "Three Dimensional Modeling of the Human Eye Based on Magnetic Resonance Imaging", Investigative Opthamology and Visual Science, 47, pp. 2272–2279, 2006.
[6] International Commission on Non-Ionizing Radiation Protection, "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHZ)," Health Physics, vol. 74 No. 4, pp. 494–522, April 1998.
[7] International Commission on Non-Ionizing Radiation Protection, "Guidelines for limiting exposure to time-varying electric and magnetic fields (1 HZ–100 kHZ)," Health Physics, vol. 99 No. 6, pp. 818–836, December 2010.
[8] T. Nagaoka, K. Saito, M. Takahashi, K. Ito, S. Watanabe: Estimating specific absorption rates in pregnant women by using models at 12-, 20- and 26-weeks' gestation for plane wave exposures, International Symposium on Electromagnetic Compatibility – EMC Europe, Hamburg, Germany, pp. 1–4, September 2008.
[9] T. Togashi, T. Nagaoka, K. Saito, M. Takahashi, K. Ito, S. Watanabe, T. Ueda, M. Saito, H. Ito, H. Osada: *Development of Japanese 7-month pregnant woman model and evaluation of SAR generated by mobile radio terminals*, 1st European Conference on Antennas and Propagation – EuCAP 2006, Nice, Italy, pp. 1–4, August 2006.
[10] M. Cvetković, D. Poljak, An Efficient Integral Equation Based Dosimetry Model of the Human Brain, *Proc. of the 2014 International Symposium on Electromagnetic Compatibility (EMC Europe 2014),* Gothenburg, Sweden, September 1–4, 2014, pp. 375–380.
[11] H. Dodig, D. Poljak, A. Peratta, Hybrid BEM/FEM Edge Element Computation of the Thermal Rise in The 3D Model of The Human Eye Induced By High Frequency EM Waves, *2012 International Conference on Software, Telecommunications and Computer Networks*, Split, 2012.
[12] I. Laakso and A. Hirata, "Reducing the staircasing error in computational dosimetry of low-frequency electromagnetic fields," Phys. Med. Biol., 2012.
[13] D. Poljak, Human Exposure to Electromagnetic Fields, WIT Press, Southampton-Boston, 2003.
[14] D. Poljak, "Advanced Modeling in Computational Electromagnetic Compatibility", New Jersey: John Wiley & Sons, Inc., 2007.
[15] International Commission on Non-Ionizing Radiation Protection (ICNIRP) and International labour organization: "Visual display units: Radiation protection guidelines", International labour office, Geneva 1994.
[16] A. Hirata: *Temperature increase in human eyes due to near-field and far-field exposures at 900 MHz, 1.5 GHz, and 1.9 GHz*, IEEE Transactions on Electromagnetic Compatibility, vol. 47, no. 1, pp. 68–76, February 2005.
[17] W. C. Chew, M. S. Tong, and B. Hu, Integral Equation Methods for Electromagnetic and Elastic Waves. Morgan & Claypol Publishers, 2009.

www.witpress.com, ISSN 1743-3509 (on-line)

[18] R. Harrington, "Boundary integral formulations for homogeneous material bodies," Journal of electromagnetic waves and applications, vol. 3, no. 1, pp. 1–15, 1989.
[19] A. J. Poggio and E. K. Miller, "Integral equation solutions of three–dimensional scattering problems," in Computer Techniques for Electromagnetics, Second Edition, R. Mittra, Ed. Hemisphere Publishing Corporation, 1987, ch. 4, pp. 159–264.
[20] K. Umashankar, A. Taflove, and S. Rao, "Electromagnetic scattering by arbitrary shaped three-dimensional homogeneous lossy dielectric objects," IEEE Transactions on Antennas and Propagation, vol. 34, no. 6, pp. 758–766, 1986.

This page intentionally left blank

Sectional integration of spatial impacts of environmental risks

J. Betáková[1], M. Lorko[1] & J. Dvorský[2]
[1]Dubnica Institute of Technology, Slovakia
[2]University of Žilina, Slovakia

Abstract

An effort to increase competitiveness of an area creates the platform for applying environmental management. It is a market oriented development process covering various sectional interests with the aim of making an integrated concept for further development. The aim of this study is to evaluate potential risks of effectiveness of spatial impact of selected tools of environmental management on regional development and the creation of references to make this activity more effective. The research method comes from the principle of multilevel complex analysis of particular factors influencing the development of residential settlement. As the practice is not a practice of isolated or comparative management, but of the infiltration through various subsystems levels, based on their efficiency, we concluded that their functionality is insufficient.
Keywords: environmental management, environmental risk, settlement system.

1 Introduction

Recently, the answers to current questions regarding safety, which are considered an inseparable part of life and space quality in which particular activities occur in objective time, have obtained the value of notice. A definition of environmental safety is presented in the terminology of safety management (2004). The terminological dictionary of terms in the area of crisis management and state defense planning administered by the Ministry of the Interior of the Czech Republic defines it in extended version as "the state when human society and ecological system interact with each other in a permanently sustainable way, all natural sources are fully available to individuals and there are mechanisms for the management of crisis and conflicts directly or indirectly connected with the

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150021

environment. In this state threats associated with the environment and caused by nature or by society developed processes (eventually by their combination) either intentionally, unintentionally or caused by an accident are minimized. These threats can cause or make already existing social tension or armed conflict even worse. The vast majority of them do not respect the state borders and can often act globally" (2004). If we talk about sustainable development, we think of ecological security in environmental and social context, then, as Jelšovská and Mikulová [1] warn, contemporary deterioration of the environment is a greater threat for the planet's inhabitants than a well-equipped army.

2 Environmental management as a tool of the sustainable spatial development policy

The notion of environmental management is a general term; it can be set more politically, but also more administratively, organizationally or managerially. According to its orientation, there is preference for individual tools that are characterized by strong mutual cohesion. Basically, we can divide them into legislative, economic, organizational, regulative, planning and communicative, oriented to the information gathering. While these are more or less formal instruments, methods create the way of their usage. The main aim of environmental management is the protection and improvement of the environment by restraining negative environmental impacts, implementing the measures for the protection of the environment, influencing particular documentation (e.g. master plans) and legislation, and raising environmental awareness. Orientation to long-term goals, continuity and the permanence of these processes, the bonds between planning and implementation, and control of these processes are of great importance. The execution of all mentioned processes in the environment of partnership, participation, subsidiarity and coordination of the interests of all actors of this process is necessary.

3 Master planning as a coordinating and spatially integrating tool of environmental management

Master planning solves systematically and comprehensively spatial organization and the functional use of a territory, determines its principles, suggests objective and time coordination of the activities influencing the environment, ecological stability, cultural-historical values of the territory, spatial development and landscaping in accordance with the principles of sustainable development. The majority of the component laws in the field of environmental legislation matches the protection of the environment component in accordance with a master plan, or the permitting of specific activity or object in the process of land use planning or building permit. In this context, the master planning act makes the platform for the integration of the processes of the creation and protection of the environment and spatial-developmental processes. Individual activities, of manufacturing and non-manufacturing character, are presented and intersected in various ways in the area where it is possible to follow their cumulative and synergic influences and impacts. We are not able to affect their impact by simple data summarization gained in the process of environmental impact assessment of specific projects because it's possible to map cumulative and synergic influences and impacts in the best way in their spatial projection reflected by a master plan. We can say that master plans make the presumptions for permanent coincidence of all activities within the territory, the maximization of the use of its potential for development with a unique respect to the environment protection, acquiring ecological balance and securing sustainable development for the economical use of natural sources and for preserving natural, civilizational and cultural values.

Currently, in practice, there is a real fear of preferring commercial and political interests to an effective sustainable territorial development policy. In this context, the implementation of environmental management tools and methods gets the value of being noticed. We can say that it is a market-oriented development process covering various sectional interests and strategies with the aim of creating an integrated concept of the profiting development of a particular territory. It's unreal to expect the improvement of a spatial development situation and the activities connected with it without any systematic and synergic solution of particular problems. From a spatial development point of view, the inner quality of the institutions of public administration has an important influence on sustainable development. We need to be aware of the fact that municipalities and cities face the difficult conditions associated with the decay of a financial cohesion to regular financial flow. The position of the creator of the stimulations, the conditions for acquiring new investment source that is necessary for further development becomes dominant from the position of the regulations and the limits for private sector.

In reaching this goal, diagnostics of potential risks and a succession of the complex solution plan within the context of sustainable development of objective territorial unit is very important.

4 Theoretical scopes of risk assessment

As Šimák [2] states, risk management is an instrument for the identification of risk that can decrease the level of complex security; it's even the instrument for a risk analysis, its assessment, classification, setting the priorities and consequently even the instrument for its decrease. Thus, it becomes an inseparable part of the process of increasing the security and its consequences. It enables us to assess the weaknesses and strengths of management activities and creative processes, to improve technological and working processes and to improve the function of mentioned systems. Risk assessment is the process of determination of its intensity through the consideration of the possible extent of damage and losses that can cause a risk phenomenon as a risk consequence. Each manager should be aware not only of the risk and the reason for its origin, but even the characteristics of a negative event associated with its growth to a crisis. That is the result of its specific assessment (for more see [2]). The risk, from its structure point of view, can be defined even as a combination of the probability of the origin of a specific event and its consequences. Janošiková and Hudecová [3] state that each type of risk has its characteristic sources and factors that are classified to outer risk sources (external factors), e.g. economic, sociological, physical, technological, political, legal and inner risk sources (internal factors – e.g. informative systems, management style, colleagues, organizational structure, employees' competences etc.). According to the Guidance of the Ministry of Finance of the Slovak Republic to risk management and analysis, we consider environmental risk as the risk being associated with a possible negative influence on the environment. Based on the methodology of the assessment of selected risks at a domestic level, the analysis of specific models HRVA (Hazard Risk Vulnerability Assessment) precedes the creation of the assessment model of natural risks in a specific area. The methodology of the assessment of natural risks was proposed by a synthesis of information of used HRVA models for the assessment of the risks and the environment vulnerability at domestic level applicable within the conditions of the Slovak Republic. Proposed progress of risk assessment consists of 9 partial steps – analysis of an area, risk identification, analysis of historical data on risks, the determination of the probability of the risk occurrence in the area, analysis of the area's vulnerability, the determination of a degree of area damage, setting the relevant risk score, assessment of a risk matrix and a risk comparison and the determination of the priorities of their decrease (for more also see [4] and [5]).

5 Theoretical-methodological scopes

In this study we analyzed the implementation of spatial impacts of economic instruments of the environment management on the development territory of a municipality. The assessment range is determined upon qualitative and quantitative assessment of the influence of emerging potential risks and barriers of the implementation of selected instruments for the execution of the conceptual aims of the development of objective spatial structure related to a criteria of sustainable development, based on the compatibility of conceptual sectorial aims with the priorities of territorial development of specific territory with conceptual and strategic developmental materials of an objective spatial unit. The assessment is bound to selected economic instruments of environmental management having the assumption of significant impacts on the environment in this field: housing, manufacture, civic amenities and social infrastructure, sport and recreation, traffic, technical infrastructure, sewage, landscaping, natural elements and components (also see [6] and [7]). The assessment of instruments consists of the main formal-methodological steps:

1. The review of individual instruments of their assessment by a 5 grade scale concerning the acquired criteria of sustainable development (significant influence, positive influence, slightly positive influence, negative influence, indetermination of the influence)
2. The formulation of the compatibility between particular conceptual aims with the assessment of a 4 grade scale (compatibility, partial compatibility, incompatibility, indetermination)

3. The assessment of conceptual aims in terms of their negative or positive impacts concerning
   - wider relations (international agreements, sectional conceptions, plans and programmers, trans boundary impacts, master plans, activities and conceptions already assessed according to the act on environment impact assessment);
   - population impacts (health implications, comfort factor, socioeconomic impacts);
   - impacts on the natural environment (air, climate, water, soil, mineral environment, flora and fauna, protected elements of nature conservation, ecosystems);
   - impacts on the urbanized environment (cultural heritage, housing, social infrastructure, recreation, spas, traffic, technical infrastructure, manufacture, waste management);
   - specific impacts.

The overall assessment of significant expected impacts on the environment, the definition of cumulative impacts and the scheme of measures for the mitigation of impacts.

6 Work methodology

The study focuses on the spatial implementation of economic instruments of environmental management and the assessment of potential risks. We analyzed a master plan of direct and indirect economic environmental instruments in the context of their local projection and sustainable development of the objective territory. Fees, payments, revenues, taxes, recoveries, fines, penalties, grants, donations, subventions, loans, tolls, backup systems, insurances and bonds were analyzed here. We generated economic instruments of environmental management by sectorial implementation into the groups for economic instruments applied in these fields:

1. Water management (WatM);
2. Waste management (WasM);
3. Air protection (AP);
4. Forest management (FM);
5. Agriculture land (AL);
6. Environmental aspects of the environment protection in the tax system of the Slovak Republic (EP).

Specific instruments and their spatial impacts are examined in the relation to legislative-legal regulations in the Slovak Republic, aiming to integrate them into the preparation process of the municipality master plans and the system of strategic planning. Progressiveness of the approach consists of the analysis and selection of suitable planning and information mechanisms with the purpose of expanding the methodological basis for mutual interaction of particular types of planning at a local level and of spatial impacts of selected activities participating in the management of the development potential of the settlement structure and following implemental and methodological recommendations.

The study issues from the presumption that the integrating factor for effective spatial development compatible with the goals of sustainable development is spatial quality and its relative time-spatial continuity of the planning at a national, regional and local level. The principle of sustainability makes the presumption and a basic statement for the assessment of developmental potential of the territory in the context of generating the origin of potential risks with the goal of preceding the negative impact on settlement development preventively.

There are methods of logic research, comparative method and analytic-systematic method in the search for specific instruments of environment management, the method of induction and deduction in conclusions practically applied in this work (also see [8] and [9]). Complex analysis based on the theory of systematic analysis and the synthesis of theoretical and empirical progress in the research can be considered as a basic method of the research. Determining factors of contemporary development of urban structures with the use of the methods of complex spatial assessment, comparison, economic analyses and statistical methods are researched by systematic approach. The process itself can be divided into 3 developmental stages:

- Analysis of theoretical information and practical experiences compatible with the implementation of particular instruments of the environment management and its spatial impacts on the development of the settlement unit;
- Analysis, quantification and the use of qualitative methods in the assessment of synergic and cumulative impacts in the context of sustainable development of the settlement and the system of planning mechanisms;
- Summary and formulation of the conclusions for practical application of progressive approaches towards the assessment of developmental spatial potential of the settlement unit.

7 Methodology of variance analysis of selected risks

The objective case study (selected file – 180 respondents) dealt with the perception of dominant environmental risks and their impacts. It's possible to determine the identity or the diversity of average values of selected risk between particular fields with the help of a quantitative method of the analysis of selected risks' variance in selected fields. Specific scales have been rated from 1 to 10. Variance analysis of selected risks plays a significant role in assessing the survey and discussion in a particular field. Variance analysis of selected risks consists of the following stages:

- Define *selected characteristics* (average, variance) from the objective case study in selected fields and risks.
- Make a decision on the suitability of the use of *parametric* or *non-parametric* test variance analysis of the risks regarding the conditions set on their realization.

- Determine if average values of selected risks between the fields are identical by *testing* the variance the assumptions of selected risks using the parametric F-test and non-parametric Kruskal–Wallis test.

8 Variance analysis of selected risks

The process of the selected file was carried out with the support of statistical software STATGRAPHICS CENTURION XV [10]. Elementary selective characteristics, such as average value and the variance, are calculated in tables stated below.

Table 1: Average values of selected risk according to fields (source: own data processing).

Risks	Fields					
	1. WatM	***2. WasM***	***3. AP***	***4. FM***	***5. AL***	***6. EP***
Financial risk	1.32	3.84	2.06	2.79	3.74	4.15
Operational risk	2.28	1.71	3.04	3.98	6.97	1.14
Personal risk	5.87	6.14	6.67	6.81	2.57	1.96
Legislative risk	5.18	5.9	5.78	5.71	6.05	4.51
Security risk	6.40	6.84	6.98	7.07	6.04	5.93
Weak law enforcement	6.48	7.18	1.89	2.68	4.81	3.35
Territory competitiveness	4.15	2.73	6.41	4.15	5.15	6.47

Table 2: Variance values of selected risk according to fields (source: own data processing).

Risks	Fields					
	1. WatM	***2. WasM***	***3. AP***	***4. FM***	***5. AL***	***6. EP***
Financial risk	0.15	0.24	0.12	0.85	1.13	1.02
Operational risk	0.78	0.85	0.64	0.23	1.81	1.64
Personal risk	1.84	1.21	1.06	2.21	3.14	0.81
Legislative risk	0.85	0.64	0.71	0.91	0.81	1.03
Security risk	1.36	1.42	1.51	1.79	1.84	1.74
Weak law enforcement	1.05	2.68	0.94	2.14	1.19	1.64
Territory competitiveness	1.25	1.36	2.41	0.75	1.74	2.00

Analysis of variance is carried out using a parametric F-test, respectively, and the non-parametric Kruskal–Wallis test. A parametric test can be performed subject to the following two conditions:

- Homoscedasticity – risks variance identity between particular fields. Results are summarized in Tab. 3.
- Values normality – probable model of normal diversion of risk assessment in particular fields. Results are summarized in Tab. 4.

A non-parametric Kruskal–Wallis test can be performed subject to the presence of variance homoscedasticity. However, risk values in particular fields are not distributed normally.

Table 3: Bartlett‘s test for homoscedasticity verification (source: own data processing).

Risks	**Bartlett's test [P-value]**
Financial risk	0.154
Operational risk	0.078
Personal risk	0.104
Legislative risk	0.687
Security risk	0.254
Weak law enforcement	0.085
Territory competitiveness	0.028

Table 4: Pearson's x^2-test for risk value normality verification (source: own data processing).

Risks	**Pearson's x^2-test [P-value]**
Financial risk	0.075
Operational risk	0.047
Personal risk	0.002
Legislative risk	0.359
Security risk	0.124
Weak law enforcement	0.311
Territory competitiveness	0.037

Bartlett's test results in 95 per cent probability of accepting the assumptions of identical variance of financial risk, legislative risk and security risk among fields. Heteroscedasticity – variance heterogeneousness consists of 95 per cent probability of operational risk, personal risk, weak law enforcement and territory competitiveness in particular fields. Pearson's x^2-test results in 5 per cent importance of financial risk, legislative risk and security risk having regular distribution in selected fields. Operational risk, personal risk, territory competitiveness risk and weak law enforcement risk don't consist of regular distribution in particular fields of case study.

It's possible to make a good parametric F-test in financial, legislative and security risk. A non-parametric test can be made in operational and personal risk and in a weak law enforcement in particular fields. The competitiveness risk doesn't fill the conditions for making parametric as well as non-parametric test. That's the reason why the analysis of variance cannot be made or the results are not trustworthy when executing the test.

Table 5: Parametric F-test of risks variance analysis (source: own data processing).

Risks	**F- test [P-value]**
Financial risk	0.00145
Legislative risk	0.08034
Security risk	0.15215

Table 6: Non-parametric Kruskal–Wallis test of risks variance analysis (source: own data processing).

Risks	**Kruskal–Wallis test [P-value]**
Operational risk	0.00001
Personal risk	0.03556
Weak law enforcement	0.04739

Primary interpretation of the results of the risks analysis from Tables 5 and 6:

- There's a probability of 95 per cent that we accept the assumptions that the variance of average values of financial risk are different in specific fields of the study;

- There's a probability of 95 per cent that we can assume that variance differences of average values of legislative and security risk in particular fields of the study is statistically not important and thus we accept the assumptions of average values identity;
- There's a probability of 95 per cent that among the variance of average values of personal risks, there are the greatest differences among the fields;
- There's a probability of 5 per cent that the variance of operational risk, as well as a weak law enforcement risk, within particular fields are statistically significant.

9 Survey assessment and discussion

The submitted study is based on the presumption that safety is multifactorial and multilevel phenomena with its content, structure and functions overreaching not only the limits of one scientific branch, but even all the scientific disciplines. Križovský [11] issues from the view of the existential threats and their risks of settlement unit development. Attention is paid to environment safety and its aspects. He generates specific environmental limits of spatial development as basic determinants of the development of cities and municipalities.

The view of the relations between procedural theories and the assessment processes in their content and time determination shows various positions of the assessment within master planning processes and their development. We examine the immediate saturation of human needs at the time of the assessment, but we assess the characteristics and the influence on a spatial system and its elements even in relation to future functional use. Generally, the presumption that the limits and restrictions do not operate in the area isolated, but synergistically, was confirmed. The determination of limiting and restricted factors for specific activity comes from the consideration of a functional relation between the characteristics of master planning elements of abiotic, biotic and socioeconomic complex and the objective activity of social practice. We consider the value characteristics, or possible interactions of the characteristics that are latent during the assessment. However, they can be activated by the execution of specific activity in the assessed territory in the future. We observed even the relation of the execution of particular activities of the settling to the qualities in a more detailed way by the examination of a spatial quality of the settlement systems. It's, more or less, an objective process, even though the determination of the value scale is of the subjective perception character. If the values of the parameters reach certain values, the system changes from a stable to a liability state. If this critical point (bifurcation point) is interfered with, the system structure is changed and achieves a new stable system. In this context, a synergy is the key phenomena in the evolution movement of complex systems (settlement systems).

We can conclude that there is an insufficient efficiency of economical instruments of environment management and their spatial implementation within the research. From the point of view of economic and environmental efficiency, we can consider the current approach as ineffective, because fulfilling the stimulation and the allocation function is the part of the environment goals. In this context, we agree with the statement of Floreková and Čuchranová [6] that the capacity limit of an environment set by polluters must be implicitly set by the amount of the payments that polluters pay. In order to affect the polluters of an environment in terms of economic theory, their optimal level should be derived from the amount of utmost expenses necessary to decrease the pollution unit.

10 Conclusion

Economic instruments of environment management are indirectly related to the absence of complex professional management. The insufficient integrity of these activities is closely related to the cohesion of risk management, territory marketing and a completely undervalued and abandoned prevention function of possible socioeconomic impact on further development. These activities don't possess an adequate instrument, neither of methodic nor legislative scope within the master planning, as their interconnection with the execution stage is the basis.

It's necessary to prepare suitable solutions to decrease unfavorable consequences resulting from any risk situations. An additive integrity of particular factors is not crucial in this process; what is crucial is their mutual cooperation in the final synergistic quality within the space-time with the emphasis on the moments of revolutionary changes in the settlement systems and their related complex perception of the safety of the objective territory as a compact unit.

We can conclude that our progress in master planning misses the strategic objectivism of economic and social goals and qualified foundation not only for applying the principles of sustainability and their classification into the process of documentation creation of the master planning. From the point of view of master planning, there is insufficient understanding of a complex activity of it, predominantly its function of coordination and all the aims closely related to the development of an urbanized and natural country in the Slovak Republic. The novelty of the submitted approach consists in modern view of the integrity as a persisting process of quantitative and qualitative progressive developmental changes in the context of sustainable spatial development.

Acknowledgements

The authors would like to thank to the Ministry of Education of the Slovak Republic for the support. Research was funded by KEGA Project no. 005DTI-4/2014.

References

[1] Jelšovská, K., Mikulová, E. Environmental security, In.: *University of Žilina, Faculty of special engineering*, vol. 1, pp. 86-88, 2010.

[2] Šimák, L. Crisis management in public administration, *Faculty of special engineering*, University of Žilina, p. 245, 2004.
[3] Janošíková, G., Hudecová, D. Risk assessment methodology selected at national level, *Ministry of interior of the Slovak Republic*, [online] http://www.minv.sk/?Dokumenty_na_stiahnutie_CO, p. 30, 2013.
[4] Holla, K. and kol. Complex model of risk assessment of industrial processes MOPORI. n: *Communications*: scientific letters of the University of Žilina, vol. 15, no. 2, s. 63–68, 2013.
[5] Kelíšek, A., Klučka, J., Ondrušek, M., Strelcová, S. Economic security – A principal component of multilevel security concept in global economy, In: *Communications*: *scientific letters of the University of Žilina,* Vol. 13, No. 2, s. 44–48, 2011.
[6] Florekova, L', Cuchranova K. Applying of the economic tools in the system of environmental managing, In.: *Acta Montanistica Slovaca*, Faculty of Mining, Geology, Process Control and Geotechnology (FBERG), Kosice, Vol. 6, pp. 225–230, 2001.
[7] Finka, M., Interdisciplinary Aspects of Spatial Quality Development in Settlement Systems, *Bratislava: Road*, p. 165, 2001.
[8] Finka, M., Kluvankova-Oravska, T. The concept of polycentricity in current theory and practice of management area, In: *Forecasting papers,* Forecasting Institute SAV Bratislava vol. 2, no. 1, pp. 23–37, 2010.
[9] Haviernikova, K. Selected aspects of clusters initiatives in the field of industry in the Slovak republic In: *Metal 2012: 21st international conference on metallurgy and materials*, Tanger, 2012.
[10] Statgraphics, *Software Statgraphics Centurion XVII,* 2014 [online] Available at: http://info.statgraphics.com/download-trial?&__hssc=&__hstc=251493209.2c537766ae0c7a3eada5bf7a11a4c695.1418632351830.1418632351830.1418632351830.1&hsCtaTracking=d8e0219d-8368-487d-a39b-8f69849e1868%7Cca0011b4-305c-43fe-b137-ea927ae0ac37
[11] Križovský, S. Identifying risk the security of citizens, In.*: Kosice security revue*, vol. 3, no. 2, pp. 94–104, 2013.

Occupational hazard prevention and control in a quarry environment: exposure to airborne dust

G. Alfaro Degan, D. Lippiello & M. Pinzari
Department of Engineering, ROMA TRE University, Italy

Abstract

Dust emissions may be considered among the most critical hazards to be found in quarries due to the design and nature of this working environment. Not only does dust impair the quality of the air from an environmental perspective, but it also impinges on the health and safety of workers. Those responsible for the quarry must demonstrate their compliance with industry standards and legal regulations, and are thereby required to implement several dust mitigation techniques in order to comply with air quality standards and pollutant emission limits. The aim of this paper is firstly to evaluate how quarry workers are affected by the mitigation techniques designed to reduce the impact of dust emissions on the environment. Secondly, an attempt is made to determine which of the proposed strategies is the most effective both in reducing emissions and in reducing the workers' exposure, and thus defining a suitable strategy on which to focus. The analysis is carried out in four consecutive phases. In the first, the PM_{10} concentration is sampled and the daily exposure of workers to the respirable fraction of airborne dust is measured. In the second, mitigation techniques, are applied to the main sources of dust according to the technical guidelines stipulated in international standards and norms. In the third phase, the pollutant concentration (PM_{10}) is resampled at various points throughout the quarry plant and a further sampling campaign is carried out with personal samplers to assess workers' exposure and their daily dose. A comparison of these two sets of values allows both the effectiveness of the applied dust mitigation techniques and the influence of PM_{10} concentration on the respirable fraction of airborne dust to be quantified. In the final phase, personal samplers are used in order to test the Functional Analysis Space Technique risk assessment procedure in forecasting the daily dose.
Keywords: PM_{10}, respirable dust, workers' exposure, quarries, FAST.

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150031

1 Introduction

The emission of airborne particulates (PM_{10}) constitutes an important aspect of the problems regarding health and safety management and also of environment issues related to quarry activities. They may cause adverse effects in the area surrounding the extractive site especially concerning the quality of the air, but also in regard to the workers who operate the plant machinery.

In order to safeguard the health of quarry workers there is legislation in force nationally (Legislative Decree 81/08) and internationally (BS OHSAS 18001:2007), both of which take a similar approach [1]. The quarry responsible is required to act according to common criteria, and must, wherever possible, eliminate exposure risks from pathogen agents, including airborne pollutants. Should elimination of such risks prove impossible, they must be reduced to a minimum, giving priority to those measures which are aimed at reducing the risk at its source. Nevertheless, the airborne particulate pollutant emitted into the atmosphere must be limited in accordance with Legislative Decree 152/06, through the adoption of a series of specific technical measures at each single source. The quarry responsible must also guarantee that same the level of safety has been maintained, by periodically measuring both the amount of occupational exposure and the emissions into the environment.

This paper presents a case study in the extractive industry sector in the Lazio region of Italy in order to evaluate the effect the containment measures and the measures to reduce emissions carried out at source have on the exposure of the quarry workers. The paper also aims to investigate any possible correlation between the different types of measures and the exposure levels; and finally to make a tentative prediction of the occupational exposure to the respirable particulate matter from data of its concentration in the environment.

With regard to the literature, the aspects relating to the containment of emissions have generated a certain interest in the scientific community ever since the first attempts were made to analyse the problem of airborne pollution at extractive sites [2], in the form of propagation mechanisms and mathematical modelling of the diffusion phenomena [3]. Numerous authors have focused on monitoring emission levels with respect to the main sources in quarries, concentrating especially on unpaved roads used by site machinery and vehicles [5–7], drilling and cutting rock, and work on the quarry face [8, 9], as well as meteorological aspects, and techniques of measurement of particulate emissions [10, 11]. Much literature may be found in relation to the extractive industry about the evaluation of worker exposure to airborne particulates, especially regarding respirable crystalline silica [12, 13] , but also studies concerning inert dust in quarries [14, 15] as well as those aimed at evaluating the adverse effects of exposure to airborne particulates on workers' health [16]. In this framework, much in-depth research has been conducted with regard to mitigation and control of the concentration of airborne particulates especially in relation to the environment [17, 18], whereas there would appear to be lack of research regarding the effectiveness of containment measures on the daily dose absorbed by workers.

2 Materials and methods

The research was carried out in a quarry which is located near Rome, Italy. The quarry produces basalt granules and the hazard analysed was inert airborne dust derived from basalt rock.

The analysis procedure was subdivided into four distinctive phases.

Firstly, a series of measurements was carried out to determine both the daily dose of the respirable fraction of airborne dust to which the machinery operators were exposed and the relative content of environmental PM_{10} present in the atmosphere in specific locations on site. This initial phase allowed the starting conditions to be evaluated. Only after this phase had been completed were the containment measures implemented, as described in detail below. After modifying the plant, both the daily dose of the respirable fraction of airborne dust and the relative content of environmental PM_{10} were measured again. The monitoring stage of the study was then completed by conducting a comparative analysis. The Functional Analysis Space Technique (FAST) methodology, [19], was used to test for correlations between the values obtained before and after the preventative measures had been carried out, and also used to attempt to predict the occupational daily dose of respirable airborne dust from PM_{10} concentration data.

The entire monitoring programme lasted two years from spring (March–April) 2012 to spring 2014. The instrumentation utilised measured both the environmental PM_{10} concentration and the daily dose of the respirable fraction of airborne dust gravimetrically. The PM_{10} concentration was measured using a TCR Tecora Bravo Plus M sampler with a specialized sampling head which conforms to the UNI EN 12341 specifications. The particulate was collected on cellulose nitrate filters of 47 mm in diameter. Gravimetric measurements were then carried out on the filters both before and after sampling. This analysis was conducted at the Mechanical Engineering Department of Roma 3 University by means of an analytical balance (Exacta series ABT 120-5 DM) with a sensitivity of five decimal places. Before carrying out the weighing operations the filters were prepared in a drier so as to reduce any error due to the hygroscopy of the instrumentation or filters themselves. Each value was determined on the basis of three independent but consecutive weightings. With regard to the reliability of the measurements, the effects of experimental uncertainty were considered to be linked to two factors: firstly in connection with determining the deposited mass and secondly regarding the uncertainty due to the volume of air captured in the sample. The first aspect was quantified through blank filter analysis, whereas the second was quantified following the calibration of the air inlet sampling pumps by means of a bubble primary flow calibrator accredited by the United Kingdom Accreditation Service (UKAS) and calibrated both for high and low flow rates and the associated random error (within ±1% error). The combination of the two effects cited above allows the total uncertainty associated with the measurement to be estimated within two standard deviations. Personal exposure was measured concurrently with the environmental PM_{10} concentration by means of a personal sampler (aspirator SKC model 224 PCEX8) featuring a cyclone preselector with a flow stabiliser and filter cassettes, and which conforms to UNI EN 481 (1994) and UNI EN 482 (1998) specifications. The measurement of the respirable dose absorbed by the subject worker was carried out using the same weighing method as used for the environmental PM_{10} measurements.

2.1 Location of study

The measurement campaign was carried out in a basalt granule quarry in the Lazio region of Italy. Basalt is extracted from the rock face using single row blasting. The quarried material is then loaded and transported by dumper truck to the processing yard where it is crushed and selected. In the plant itself the material is then transported by means of conveyor belts connecting the various plant stations described below. The instruments which indicate the environmental airborne dust (PM_{10}) content were located in four working areas (or functional areas) that are: I – Quarry face area; II – Loading, unloading and manoeuvring area; III – Tertiary crushing area; IV – Primary crushing area.

There were 9 workers responsible for the plant operation who were subdivided into four groups corresponding to the different natures of their tasks.

A: Workers responsible for the quarry face and blasting operations (3 people);
B: Workers responsible for the transportation or loading of material (2 people);
C: Workers responsible for the tertiary crusher (2 people);
D: Workers responsible for the primary crusher (2 people).

2.2 Preventative measures

In order to carry out the preventative measures, firstly the sources of dust emission were identified, then appropriate measures were then taken according to the nature of each specific type of emission as shown below. The sources were classified into three general categories [20]:

1) Sources due to the production and processing of quarried material;
2) Sources due to transporting, loading and unloading quarried material;
3) Sources due to stockpiling quarried material.

2.2.1 Material production and processing

Production and processing refers to any activities involving cutting, drilling or crushing the material in question which generate airborne particulate. In such cases every attempt is made to enclose the source and, as this method cannot be carried out hermetically, to minimise the emission of dust into the air by employing a fog dust suppression system. The primary crusher and the cone crushers are therefore covered by means of welding sheet-metal screens onto the body of the machinery (see Figure 1(a)).

The material entering the various plants should also be kept sufficiently damp by installing a wetting system (Figure 1(b)).

Enclosing the processing plants also allows the particulate emissions to be channelled into special chimneys fitted with nozzles which spray the dust. This abatement system has the capacity to discharge $1.66\ 10^{-4}\ m^3/s$ of water at a

(a) (b)

Figure 1: Some details of preventative measures.

working pressure of 5 10^5 Pa. The chimney height was greater than the height of the plant structure in all cases, with the exception of the chimney of the secondary cone crusher, which was lowered due to issues regarding the stability of the plant structure but which was more than ten metres above floor level in any event.

2.2.2 Transporting, loading and unloading

Transporting, loading and unloading regards any activity involving the transport or movement of the material in question. The procedure in these cases is wherever possible to enclose the material (e.g., by means of covering the material by tarpaulins while it is being hauled by vehicles). However, should this prove impractical, impossible or only achievable in part, the material should be partially covered and have a wetting system installed at the emission points. For instance the second option should be employed where material is transported via conveyer belts. In this case the belt should be enclosed by a covering and the transfer point should have a spray system installed.

With regard to loading and unloading operations, the attention is focused on limiting the speed of the material during these activities by means of installing deflectors as well as reducing drop heights to a minimum. The measures to mitigate the effect of vehicles raising dust clouds whilst in motion are to limit vehicle speed to 30 km/h and to install a capillary wet dust suppression system throughout the quarry road network. As a consequence of the recorded frequency of transit (five vehicles per hour) it was deemed necessary to employ a wet dust suppression method which covered the entire yard surface with 5 10^{-4} m^3/m^2 of water.

2.2.3 Stockpiling

The location of the mounds of quarried material should be determined by the nature of the material to be stockpiled. Particular attention must be paid to the position of stockpiles of the smallest size of aggregate in order to take advantage of any structures, embankments or natural topological features which could provide barriers or shelter from the wind so as to try to prevent air currents from lifting particulate into the atmosphere. All of the stockpiles were equipped with a spray system in order to keep the stockpiled material sufficiently damp.

3 Results

3.1 First measurement campaign (*ante operam*)

The first phase of the measurements was carried out to evaluate the concentration of airborne dust present before the preventative measures were implemented. To this end, the four functional areas were chosen as described in 2.1. Each of the four locations was monitored for a period of four hours on three separate, unrelated occasions over a period of twelve days. The aim was to ensure representative measurements and therefore they were carried out during a period in which the plant machinery was fully functioning at its maximum capacity (i.e. under the heaviest normal workload) and in time windows which ensured values which were representative of normal emissions and of any variations in those emissions. The results obtained are the mean airborne pollutant (PM_{10}) concentrations (expressed in $\mu g/m^3$) during the observation period and are summarised in table 1 below.

Table 1: *Ante operam* data of PM_{10} concentration expressed in $\mu g/m^3$.

Location	Campaign I	Campaign II	Campaign III	Mean	Std. Deviation
I	14250	12960	15730	14313	1131
II	10920	9870	11350	10713	621.7
III	17230	18290	13270	16263	2160
IV	9720	8990	10150	9620	478

With regard to the workers' exposure, three measurements were carried out for each type of task. Due to the fact that the workers who were responsible for the quarry face and blasting operations (members of group A) were not exposed continuously over time, these tasks were not monitored. The length of the monitoring time was that of a standard working day (07:30–16:30 excluding breaks). The values recorded are given in table 2 and are expressed in $\mu g/m^3$.

Table 2: *Ante operam* data of respirable daily dose for individual subjects.

Subject from	Campaign I	Campaign II	Campaign III	Mean	Std. Deviation
Group B	1020	1360	1230	1203	171.5
Group C	1380	1530	1400	1436	81.4
Group D	930	1260	1180	1123	172.1

3.2 Second measurement campaign (*post operam*)

The second measurement campaign was a repetition of the measurements in 3.1 recorded in the same way, in the same locations, under similar conditions. However, these measurements were conducted to evaluate the concentration of airborne dust present after the preventative measures had been implemented on the machinery and at the dust sources (i.e., carried out *post operam*). The results for the concentration of airborne pollutant and personal exposure are given below in table 3 and table 4 respectively and expressed in μg/m^3.

Table 3: *Post operam* data of PM_{10} concentration expressed in μg/m^3.

Location	Campaign I	Campaign II	Campaign III	Mean	Std. Deviation
I	5720	4230	4870	4940	610
II	4790	4030	3850	4223	407
III	4390	5890	6310	5530	824
IV	3670	3530	5010	4070	667

Table 4: *Post operam* data of respirable daily dose for single subjects [μg/m^3].

Subject from group	Campaign I	Campaign II	Campaign III	Mean	Std. Deviation
Group B	840	1020	910	923	90.7
Group C	1070	1190	1060	1106	72.3
Group D	820	1010	1090	973	138.6

3.3 Comparison of the data

The percentage of reduction in terms of daily dose absorbed for each worker as well as the percentage of reduction of the PM_{10} concentration for each functional area may be calculated from the results of the monitoring carried out before and after the modifications were made to the plant. The data are given below.

The measurements of PM_{10} concentration were taken from within the functional areas of the plant in which the constant presence of a worker is required to operate the machinery (with the exception of Area A, i.e., the quarry

Table 5: Reduction for each type of task expressed as a percentage of the *ante operam* daily dose.

	Subject from A	Subject from B	Subject from C	Subject from D
Daily dose reduction [%]	-	23.2%	22.9%	13.3%

Table 6: Reduction expressed as a percentage of the *ante operam* environmental PM_{10} for each functional area.

	Area A	Area B	Area C	Area D
PM_{10} concentration reduction [%]	65.4%	60.5%	66.0%	57.9%

face and blasting area). This fact gives rise to a further point for analysis. Since the daily absorbed dose is known for each of these workers, a correlation analysis is carried out between the values of the environmental PM_{10} and the dose absorbed by the worker in the same functional area. In table 7 below the composition of the air sample is given as a mean percentage for each functional area both before and after the preventative measures had been carried out on the plant.

Table 7: Comparison of the percentage of air samples.

Functional area	PM_{10} [%]	Respirable fraction [%]
Area B ante operam	89.90	10.10
Area B post operam	82.06	17.94
Area C ante operam	91.88	8.12
Area C post operam	83.32	16.68
Area D ante operam	89.54	10.46
Area D post operam	80.70	10.30

Thus to summarise the outcome of the monitoring, a factor may be defined for each of the functional areas which characterises the composition of that specific air sample, as shown below:

$$K_n = \frac{D_n}{C_n} \tag{1}$$

where:
K_n represents a factor which expresses the air sample composition of one specific functional area;
D_n expresses the value of the *post operam* dose of the i^{th} functional area [μg/m^3];
C_n is the value of the PM_{10} concentration of the same functional area [μg/m^3].

These parameters assume the values given below for each functional area:

Table 8: Factors for the air sample for each individual functional area.

	K_b	K_c	K_d
Ante operam	0.11	0.08	0.11
Post operam	0.21	0.20	0.23

4 Risk evaluation

A proposal for the evaluation of the occupational daily dose absorbed by the workers from the PM_{10} concentration data is given below. Such an evaluation may be used as a forecast in that it allows the respirable dose to be estimated in advance, applying a time-space framework to the task to be introduced. The reliability of the procedure was tested, although limited to this particular case study, by measuring the resultant occupational dose.

4.1 Functional Analysis Space Technique (FAST)

The proposed instrument of analysis to predict the risk associated with a new task is the method of functional space analysis. The idea is based on characterising the two typical risk evaluation components separately: the danger and the target or worker. The danger is characterised by defining its intensity spatially, that is to say by defining the concentration of the airborne particulate inside the plant or, as in the case in question, inside functional areas. The worker and his or her presence is characterised by means of time-space discretization of the tasks carried out within the plant and is defined by the period of time spent within a determined functional area. Whenever the agent and the worker are both present (i.e., when the worker is exposed to the airborne hazard) the risk evaluation procedure may be followed as described below. The mean PM_{10} concentration values are indicated in the penultimate column of table 3 for each functional area. It is assumed that the composition of the air sample is constant (throughout the particular functional area and over time) in terms of both its PM_{10} concentration component and its respirable fraction of the particulate matter, according to the values from eqn (1), which are summarised in table 7. Lastly, given that the period of time a worker spends doing a ‘new’ task in a particular functional area is known, and considering the various contributory factors with respect to a standard working day (see table 9), the calculation of the dose which will be absorbed by worker X is carried out as follows:

Table 9: Period of time spent in each of the functional areas by worker X.

Functional area	Time period [minutes]
B	180
C	180
D	120

$$D_x = \sum_{i=1}^{n} \frac{K_i C_i \Delta t}{T_0} \qquad (2)$$

where:
D_x expresses the value of the dose relative to the worker performing task X and expressed in [μg/m^3];
K_i expresses the calibration factor for the ith functional space [n];
C_i expresses the value of the mean PM_{10} concentration relative to the ith functional space [μg/m^3];

Δt expresses the period of time spent in the i^{th} functional space [min];
T_0 expresses the length of a standard working day equal to 480 minutes [min];

On its application the proposed method returns a dose of 1007.34 μg/m^3.

5 Discussion and conclusions

It may be confirmed that the containment measures carried out to reduce particulate emissions produced the expected results with regard to the plant analysed and the data gathered in this case study. The mean reduction in the concentration of PM_{10} was recorded as being between 58% and 66% depending on the functional area. This reduction also determined a reduction in the occupational dose of the respirable particulate matter absorbed by workers carrying out tasks in the plant. It is interesting to note that even though the worker is in exactly the same functional area monitored for PM_{10}, there appears to be a considerable reduction in the absorbed dose. For a given functional area the reduction recorded was between 13% and 23%. These data may be explained in the light of the fact that the aim of implementing the containment measures was in fact the reduction of PM_{10} emission into the atmosphere and thus predictably the most immediate effect was a reduction in the concentration of this pollutant. Furthermore, it should also be noted that the conventional definition of 'respirable', as defined by EN UNI 481/94, is a cumulative lognormal distribution with a median value of equal to 4.25 μm. Even considering typical references from the literature regarding quarries [21] about the granulometric composition of airborne dust the data appears to be consistent with the state of the art. The containment measures adopted therefore appear to be more effective on the larger sized of the PM_{10} which, mass density being equal, also constitute the heaviest part and resulting in a considerable reduction in concentration. With regard to the respirable fraction and the smaller sized particles of the PM_{10}, the reduction appears to be more complex, which is probably also due to the lesser effect of the gravimetric deposition.

From this finding regarding the change in the airborne particulate composition following the modifications implemented on the plant, an application of the functional space method is used to predict the dose absorbed by a worker. This example stems firstly from being able to access PM_{10} concentration data for the plant from the checks the quarry company are required to perform regularly to monitor the environment, but also from an attempt to reduce the number of personal samples which would otherwise need to be carried out on all of the workers. Besides, the opportunity of knowing the concentration to which a worker will be exposed in advance, albeit approximately, allows the employers to evaluate whether workers should be provided with protective equipment such as breathing masks or filters. Under the simplifications made that the PM_{10} concentration is constant in a given functional space and that its relationship with the respirable fraction is also constant at least within a given functional space, a prediction of the occupational dose for a given task was made. The result was then verified experimentally utilising a dosimeter, which recorded a value that was 9% greater than predicted.

References

[1] Alfaro Degan G., Lippiello D., Pinzari M. (2009). Occupational health and safety management systems: comparison between BS OHSAS 18001: 2007 and Italian Decree 81/2008. WIT Transactions on Biomedicine and Health, Vol. 14, WIT Press, 2009, ISSN: 1743-3525, pp. 401-409, doi: 10.2495/EHR090391.

[2] Patrucco, M., Clerici, C. Problemi di inquinamento particolato nell'attività di cava: aspetti generali del controllo e della riduzione. Bollettino dell'Associazione mineraria subalpina, 9, pp. 123-131, 1986.

[3] Vella, J.A., Camilleri, R., 2005. Fine dust emissions from softstone quarrying in Malta. Xjenza. 10. pp. 47-54.

[4] McCain, J. D., Pyle, B. E., McCrillis, R. C., 1985. Comparative Study of Open Source Particulate Emission Measurement Techniques, in Proceedings of the 78th Air Pollution Control Association Annual Meeting, Detroit, MI.

[5] Abu-Allaban, M., Hamasha, S., Gertler, A. Road dust resuspension in the vicinity of limestone quarries in Jordan. Journal of the Air & Waste Management Association, 56 (10), pp. 1440-1444, 2006.

[6] Piras, L., Dentoni, V., Massacci, G., Lowndes, I.S. Dust dispersion from haul roads in complex terrain: the case of a mineral reclamation site located in Sardinia. International Journal of mining reclamation and the environment, 28(5), pp. 323-341, 2014.

[7] Alfaro Degan, Lippiello D, Pinzari M. Total Suspended Particulate from mobile sources in an Italian opencast quarry: a proposal to improve US EPA ISC3 model. Advances in Safety, Reliability and Risk Management. Proceedings of Proceedings of the European Safety and Reliability Conference (ESREL). Ed: C. Berenguer, A. Grall, C. & Guedes Soares, Taylor & Francis Group: London, pp. 2984-2990, 2012.

[8] Cole, C. F., Fabrick, A.J. Surface Mine Pit Retention. Journal of the Air Pollution Control Association, 34, pp. 674-675, 1984.

[9] Organiscak, J.A., Page, S.J. Field assessment of control techniques and long-term dust variability for surface coal mine rock drills and bulldozers. International Journal of Surface Mining, Reclamation and Environment, 13, pp. 165-172, 1999.

[10] Alfaro Degan G., Di Bona G., Lippiello D., Pinzari M. PM_{10} dispersion model in quarrying activities: a comparison of an ISC3 approach with a mono/multivariate geostatistical estimation. WIT Transactions on Ecology and the Environment, WIT Press, 2006, ISSN: 1743-3541, vol. 86, pp. 111-120, doi: 10.2495/AIR060121.

[11] Alfaro Degan G., Lippiello D., Pinzari M. Monitoring airborne dust in an Italian basalt quarry: comparison between sampling methods. In: WIT Transactions on Ecology and the Environment. WIT Press, 2013, ISSN: 1743-3541, vol. 174, pp. 75-84, doi: 10.2495/AIR130071.

[12] Lira, M., Rabbani, K.E., Barkokebas, J.B. *et al.* Risk evaluation and exposure control of mineral dust containing free crystalline silica: a study

case at a quarry in the Recife Metropolitan Area. Work-A Journal of Prevention, Assessment & Rehabilitation, 41 (1), pp. 3109-3116, 2012.

[13] Golbabaei, F., Barghi, M.A., Sakhaei, M. Evaluation of workers' exposure to total, respirable and silica dust and the related health symptoms in Senjedak stone quarry, Iran. Industrial Health, 42 (1), pp. 29-33, 2004.

[14] Bujak-Pietrek, S., Mikolajczyk, U., Szadkowska-Stanczyk, I. Dust Concentration Analysis in Non Coal Mining. Exposure evaluation based on measurements performed by occupational hygiene Laboratories in the years 2001-2005 in Poland. Medycyna Pracy, 62 (2), pp. 113-125, 2011.

[15] Bratveit, M., Moen, B.E., Mashalla, Y.J.S., Maalim, H. Dust exposure during small-scale mining in Tanzania: A pilot study. Annals of Occupational Hygiene, 47 (3), pp. 235-240, 2011.

[16] Kumar, C.H.K., Mallikarjuna, R.N., Singh, S.B.M. *et al*. Deterioration of pulmonary function in stone quarry workers Biomedical Research-India, 25(2), pp. 261-266, 2014.

[17] Alfaro Degan G., Lippiello D., Pinzari M. Valutazione sull'efficacia delle metodologie di contenimento dell'emissione di inquinanti aerodispersi in attività estrattive a cielo aperto: un caso di studio nel comparto laziale. GEAM. Geoingegneria ambientale e mineraria, 139 (2), pp. 5-12, 2013.

[18] Bluvshtein, N., Mahrer, Y., Sandler, A. Evaluating the impact of a limestone quarry on suspended and accumulated dust. Atmospheric Environment, 45 (9), pp. 1732-1739, 2011.

[19] Alfaro Degan G., Lippiello D., Pinzari M. A geostatistical approach to the functional analysis space technique: a case of study. Advances in Safety and Reliability – Proceedings of 16th European Safety and Reliability Conference (ESREL). Ed: Kolowrocki K, Taylor & Francis, Vol. 1, pp. 45-52, 2005.

[20] Patrucco, M.. Sicurezza ed ambiente di lavoro. Particolati aerodispersi, Politeko, Torino, 2003.

[21] Madungwe, E., Mukonzvi, T.,. Assessment of Distribution and Composition of Quarry Mine Dust: Case of Pomona Stone Quarries, Harare. Atmospheric and Climate Sciences 2, pp. 52-59, 2011.

Designing a risk management framework for forecasting national security issues

S. Meyer-Nieberg, S. Pickl & M. Zsifkovits
Institut für Theoretische Informatik, Mathematik und Operations Research, Fakultät für Informatik, Universität der Bundeswehr München, Germany

Abstract

Detecting and identifying future risks is a major issue for public decision makers, especially in the field of national security. Decision makers need to identify threats in order to be able to react to them adequately and so reduce risks. Therefore, we established a general risk management support guideline for public decision makers with a focus on national security. The framework aims at identifying future risks, analyzing and evaluating them, so that concrete actions can be set that tackle the potential threat. The risk management framework is thereby based on the core process of the ISO31000 risk management norm. Therefore we are combining several techniques and tools from the field of Operations Research (OR) to guide the decision maker through the risk management core process (risk identification, risk analysis, risk evaluation). Especially in the field of risk identification, the collection of high quality data is a key issue as this data is the foundation for the further creation of possible future scenarios. Therefore, the risk identification faces up to six individual steps of analysis, including qualitative and quantitative OR methods. Several tools were developed that enable a country-based screening for developing threats as well as an internet-based topic monitoring. Out of the concluding catalogue of hazards possible future scenarios are designed, analyzed, and ranked according to their probability of occurrence and importance. Finally, these scenarios are evaluated using a variety of quantitative OR methods, simulation models (mainly ABM and SD), or Fuzzy Logic Analysis.
Keywords: risk management, risk management process, operations research, OR, ISO31000.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150041

1 Introduction

The modern world is interconnected on a broad scale making it difficult to predict future developments (Habegger [8]). Especially in the security and military domain, decision makers are facing significant change. (Buch [2]). However, an early detection and analysis of developing threats in the area of national security plays a major role. Strategic foresight is often cited as a tool to inform public policy and decision makers of potential future developments decreasing the chance of harmful surprises. While it stems from the economic sector it has been recently applied more and more in the area of national security (Habegger [8]).

In this paper, we introduce a risk management framework based on the ISO31000 norm for the area of public policy that is designed to take potential future risks into account.

2 Risk management process: the ISO31000 norm

Risk management is the means by which the policy maker keeps risks for humans and their livelihoods as low as possible, or at least within acceptable bounds. This leads to the question of where the level of acceptance can be set. These aspects make the risk management process even more complex and lead to the need of comparisons and planning from a holistic perspective (Federal Office for Civil Protection, 2014: 4).

Therefore, a structured guideline through the process of risk management might be helpful to cope with future risks, especially in the public sector with its huge spectrum of uncertainties. There is a standardized risk management process structure available, called ISO3100 norm. This generalized process guideline is a promising framework for such a structured process. According to the definition of the ISO31000 risk management process, it is structured as shown in Figure 1 (ISO31000, 2009).

At its core, the process guides through the identification of risks, their analysis, and finally their evaluation. These three steps are the basis for the resulting risk treatment. However, before starting with the risk identification, the decision maker needs to establish the context of the field of interest. The risk management core process is furthermore accompanied by "Communication and Consultation" and "Monitoring and Review" as interactive tasks that need to be handled by the decision maker continuously.

As we identified the risk management core process as being ideal for the support of several approaches from the field of Operations Research (OR), we created a framework that supports the decision maker and guides through the management core process based on several OR approaches and tools. However, one has to note that the presented and recommended tools need to be selected, analyzed and evaluated for every case separately. Thus, the process needs adaption for each application that might be evaluated. However, the basic structure stays unchanged.

www.witpress.com, ISSN 1743-3509 (on-line)

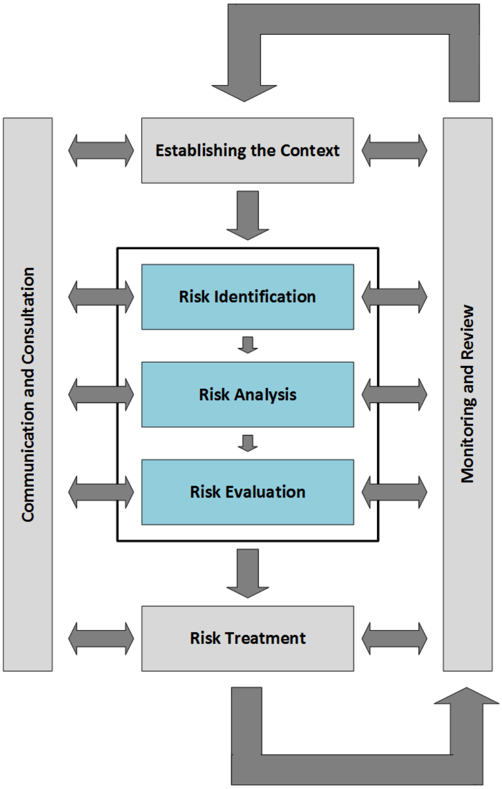


Figure 1: ISO risk management process (ISO31000, 2009).

In general, the process is based on the earlier established context of interest and leads to concrete recommendations for responding to the risk. For the general context we estimated issues from national security and military interventions.

3 The risk management framework

As explained above, we concentrate on establishing a framework to support decision makers in the risk management process in its core tasks: risk identification (RI), risk analysis (RA), and risk evaluation (RE) (as shown in Figure 2).

In the core process, each task is a single unit and needs to be completed before the next step can be handled, as the information from each task is the basis for the following. The documentation of tasks and their findings as well as the transfer of knowledge across several steps thereby play a major role in the overall process. In the military domain these tasks are generally known as "risk assessment".

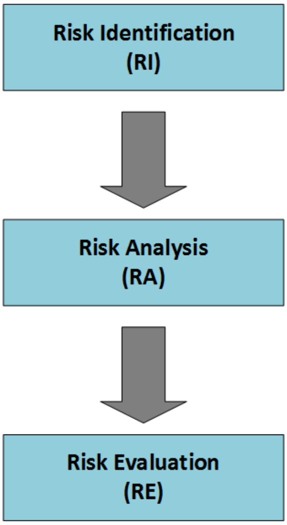


Figure 2: Core tasks in the risk management process.

In the upcoming section the three steps of the risk management core process are explained in more detail and several tools are presented for future use and combination in one overall risk management framework.

3.1 Risk identification: catalogue of hazards

After establishing the general context one has to define the problem area itself and analyze it in detail. The objective of this step is to collect and structure as much hazard data as possible in order to create therewith a catalogue of hazards. The catalogue of hazards thereby describes, which threats are existing in the predefined future time horizon. Especially for the field of national security the consideration of several existing qualitative and quantitative methods is a promising approach for finding areas of interest. Originally, foresight focused on only one particular area, e.g. science and technology, health, or environment (Habegger [8]) neglecting potential interconnections between different sectors. However, restricting the analysis to a single sector may present a risk in itself if the area of national security and public policy is concerned. The risk management process must therefore take several areas into account and must select the particular focus points very carefully. Therefore, qualitative and quantitative methods for future analysis have been identified and analyzed in a project conducted at the Universität der Bundeswehr München and supported by the Planungsamt of the German Federal Armed Forces. The aim is to gain general insight into existing and potential future risks. These first insights and data are of great importance, as the further analysis is based on those findings (such as the definition of keywords, prioritization of regions, etc.). Interviews with experts might give first ideas of potential threats. Additionally, internet searches, scientific or technical publications, social media may alert the analyst to potential developments. While single signals may not appear as important, the coincidence of several signals from different sectors may represent a key issue for the organization. Here, however human judgment is required. Therefore, the information gained has to be analyzed by experts with respect to underlying emerging issues. After the area of interest has been narrowed, an issued-centered scanning is recommended (Amanatidou *et al.* [1]). In this paper, we propose to use a combination of several approaches, such as qualitative and quantitative OR methods, an early warning tool and a tool for internet based topic monitoring, both developed at the Universität der Bundeswehr Munich, as well as Google trends analysis. However, the ideal combination of tools depends on the prior defined context. Finally, the used tools should give information for the catalogue of hazards, whereby the use of expert interviews or focus groups is recommended for the final step in this phase.

Concerning national security, it is worthwhile to observe a country's social and economic developments. Several organizations provide indicators describing a country's properties over time. The time-series can be used a) to analyze the past and current situation and b) to predict the future development. The early warning tool developed provides thus an indicator-based approach, where indicators can be chosen with respect to the area of interest and emerging issues. Examples might be the infant mortality rate which is one of the key factors in Goldstone's model on political instability. In some cases, new, specially designed, indicators will have to be used. For many purposes, however, the set of country-based indicators that is provided by the World Bank may already offer sufficient information: The set of indicators spans several areas ranging from data concerning agricultural and rural development over health, education, and poverty to urban development. The early warning tool allows a structured integration into a risk management process. The country-based tool enables the visualization of the past development of indicators and a prediction into the future by making use of quantitative methods for future analysis (Masala and Pickl [11]). Furthermore, explanatory models, as for example the model in (Goldstone *et al.* [7]) which addresses the political instability of states are provided. The modular tool enables the analyst to detect geographical areas where e.g. political instabilities are more likely to come up in the nearer future than in others. An example is shown in Figure 3.

The internet is one of the vastest sources of data and information today, containing blogs, discussion forums, news sites as well as dedicated databases. Data can take many forms ranging from multimedia to text files and can be presented in several formats. The use of the internet or more correctly the use of Web Mining techniques in Future Research has gained more and more momentum in recent years (Palomino *et al.* [13]). Therefore, a topic monitoring tool was developed. The tool is able to cope with multilingual information and comprises three components: a keyword-based internet search, an analysis component, and a user interface for visualization. The analyst defines high-level keywords that are automatically translated into several languages and the web is screened on articles about this issue (Stutzki [14]). The actual search is

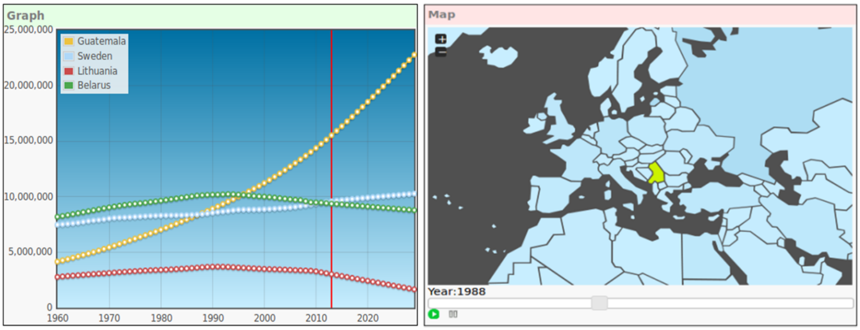
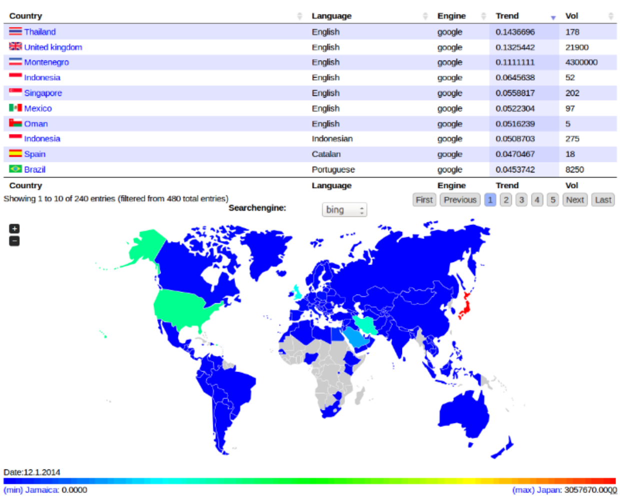


Figure 3: Output in early warning tool.

performed by commercial search engines. An example for national security purposes might be screening the web for pages and articles on “civil unrest”, “civil war”, “riots”, “demonstrations”, or others. The results are then summarized, analyzed, and visualized for the user. Since the interest does not only lie in the relative or absolute prevalence of a topic but additionally in the ongoing activity, the tool developed also takes this factor into account. The application also allows for analyzing the quantity of published articles on a topic as well as the country of origin of the articles (Stutzki [14]; Hauschild *et al.* [9, p. 15]) (as shown in Figure 4).



Country	Language	Engine	Trend	Vol
Thailand	English	google	0.1436696	178
United kingdom	English	google	0.1325442	21900
Montenegro	English	google	0.1111111	4300000
Indonesia	English	google	0.0645638	52
Singapore	English	google	0.0558817	202
Mexico	English	google	0.0522304	97
Oman	English	google	0.0516239	5
Indonesia	Indonesian	google	0.0508703	275
Spain	Catalan	google	0.0470467	18
Brazil	Portuguese	google	0.0453742	8250
Country	Language	Engine	Trend	Vol

Figure 4: Output in topic monitoring tool.

This method might be very useful combined with Google Trends, a real-time index of the volume of queries that people enter into Google. Our tool does not provide this capability, since Google at the moment does not offer an API which would allow the integration. Especially with full access one can find query-trends in special geographical areas. Thus, the keywords from the trend detection will also be tested for being search engine queries at Google by a larger number of people. Using this tool is already successfully used for detecting economic trends (Choi and Varian [3]) and the outbreaks and spreads of diseases (Carneiro and Mylonakis [4]). Just like in the topic monitoring tool, detected keywords can be clustered based on their frequency on a geographical map.

Additionally, the use of further quantitative methods is recommended. The question of which methods may be applicable depends on the specific context of the risk management. The reason is, that a maximal possible number of data should be used in order to identify possible future threats. Weaknesses and limitations of single approaches should be compensated by using a selected set of different approaches.

The findings of these steps are finally analyzed using the qualitative method of expert interviews or focus groups, where a group of experts on the established content is confronted with the data gathered in the earlier steps as well as with the resulting geographical maps. On this basis the experts are discussing the results, summarize and evaluate the existing sample of threats and include them in the catalogue of hazards. The whole documentation and the catalogue of hazards are now passed into the next step of the process, the risk analysis.

3.2 Risk analysis: define and analyze scenarios

In the next step the decision maker creates possible future scenarios based on the existing data coming from the prior risk identification stage. Ideally, the expert from before support the scenario designing process. Thereby, the scenarios are firstly just collected on a broad range. Afterwards, the scenarios are ranked according to whatever criteria is needed. Furthermore, a ranking according to relevance and the uncertainty of occurrence is done, as the sum of all scenarios needs to be reduced. We developed the prototype of a software tool that detects the most relevant scenarios needing further analysis based on the experts' ratings. The advantage thereby is that the information is transferred without interruption to the next steps of analysis. Even if experts or decision makers change over steps, the information and data stays stored in the tool.

The scenarios being detected as relevant should be analyzed in more detail in a further step. Interconnections to several external influences as well as interconnections between scenarios might give additional insights into the scenario's network. Therefore, based on the approach of Vester [15] each scenario is illustrated in a network based on existing influences (positive [+] and negative [-]). This also allows for getting additional insights into relevant reinforcing factors in the scenarios.

Hereby, the "Communication and Consultation" as well as the "Monitoring and Review" in the general risk management framework are of great importance, as newly identified impact factors should be further analyzed in following steps of analysis in the risk identification phase. Thus, in the next cycle of analysis e.g. additional keywords are to be analyzed in the tools used for trend detection. Furthermore, the network might be useful in the final step, the risk evaluation. Especially, if simulation is chosen to be the ideal tool for the risk evaluation.

3.3 Risk evaluation: a multi-model approach

As the hazards were already detected and analyzed in detail, as well as relevant scenarios designed, the final step of the risk management tool deals with the evaluation of the scenarios. Therefore, the underlying findings and data from earlier steps need to be considered in order to decide, which approach fits best for an analysis. A unique approach for all scenarios is not estimated to deliver meaningful results, as the data basis for each scenario might differ significantly. Therefore, each scenario should be evaluated with a methodology that is able to handle the given case. For our research interest of national security and military threats we detected four different approaches that lead to meaningful results in the evaluation phase, statistical testing, system dynamics modeling, agent based modeling, and fuzzy-logic analysis.

If there is sufficient statistical data available, especially the statistical methods might be considered for evaluation and analysis. If the problem allows an analysis from the macro view and the prior conducted network analysis already shows meaningful insights, System Dynamics modeling might be chosen as shown. An application of a System Dynamics model can be found in (Hauschild *et al.* [9]) where it was used to analyze scenarios concerning the effects of the demographic change on the personnel structure and recruitment of the German Federal Armed Forces. If there is data on a micro level available and agents' actions can be estimated, Agent-Based modeling might be the most promising tool for evaluating the future scenarios and getting an idea of future likely changes. This model type is used to depict the behavior of autonomous agents, describing the potential actions and interactions between them and the environment. They are typically employed to analyze the collective, emergent behavior of the system under interest (Macal and North [12]). Agent-based models have been used in the social and political sciences for several years addressing topics as diverse as epidemics or ethnic conflicts (Epstein [5, p. xii]). (Hauschild *et al.* [9]) describes e.g. the development of an Agent-Based Model for analyzing social conflicts and unrest in Guinea. However, if the techniques presented so far cannot be used, a Fuzzy-Logic analysis might be conducted. Therefore, a list of several future scenario outcomes is developed and their relevance is weighted. In the field of application at hand, we might consider human, ecological, economic, supply security, and immaterial factors. Therefore, possible outcomes need to be defined, such as killed and injured population or the damage of living environment.

4 Conclusion

The use of OR-tools in (public) risk management and crisis management is widely accepted. However, especially the complexity of risk management for potential future threats demands a clearly structured process that guides the decision maker through various steps to a decision. Thus, risk management is a continuous process that does not deliver concrete values, but in general supports decision makers through showing possible scenarios and outcomes based on the underlying decisions made. Therefore we applied several tools and approaches to the ISO31000 normed risk management process and structured the decision making process based on three main steps, the identification of risks in a predefined context, the analysis of those risks based on possible scenarios, and finally the evaluation of the detected scenarios of interest and importance to the decision maker.

As the decision is – at best – just as good as the data available, especially the risk identifications stage plays a major role and combines several approaches. Therewith, we want to compensate limitations of single approaches and get a broad sphere of influencing factors. The qualitative approach allows for correcting implausible or unlikely trends in the data and adds another, very important view on the topic. However, the review and communication all through the risk management process is a key factor for success. Especially for combining the different methods and implementing a framework that considers learning effects from the different approaches used, further research is needed.

Acknowledgement

The support by the Planungsamt der Bundeswehr is gratefully acknowledged.

References

[1] Amanatidou E, Butter M, Carabias V, Könnölä T, Leis M, Saritas O, Schaper-Rinkel P, van Rij V (2012) On concepts and methods in horizon scanning: Lessons from initiating policy dialogues on emerging issues. Science and Public Policy 39(2): pp. 208–221.
[2] Buch, H. (2014) Interview with Heinrich Buch, Dipl. Pol., Oberst a.D., Senior Advisor at COMTESSA.
[3] Choi, H., Varian, H. (2011): Predicting the Present with Google Trends, Special Issue: Selected Papers from the 40th Australian Conference of Economists, Vol. 88, pp. 1–9.
[4] Carneiro, H.A., Mylonakis, E. (2009) Google Trends: A Web-Based Tool for Real-Time Surveillance of Disease Outbreaks, Surfing the Web, Vol. 49, pp. 1557–1564.
[5] Epstein, J. (2008): Generative Social Science. Studies in Agent-Based Computational Modelling. Princeton University Press.
[6] Federal Office for Civil Protection (2014) Integrated Risk Management, Bern, Switzerland.
[7] Goldstone, J.A. *et al*. (2005): A Global Forecasting Model of Political Instability, in Annual Meeting of the American Political Science.
[8] Habegger, B. (2010): Strategic foresight in public policy: Reviewing the experiences of the UK, Singapore, and the Netherlands, Futures 42, pp. 49–58.
[9] Hauschild, D., Leopold, A., Lohmann, S., Masala, C., Meyer-Nieberg, S., Pickl, S., Plenk, S., Tepel, T., Zsifkovits, M. (2014): Quantitative Methods of Future Studies, Final Report, Universität der Bundeswehr München.

[10] ISO31000 (2009) Risk Management – Guidelines for principles and implementation of risk management.
[11] Masala, C., Pickl, S. (2013): Foresight Analysis: Quantitative Methoden der Zukunftsanalyse, Wehrwissenschaftliche Forschung – Jahresbericht 2013, pp. 58–59.
[12] Macal, C. M. and North, M. J. (2010). "Tutorial on agent-based modelling and simulation." Journal of Simulation 4(3): pp. 151–162.
[13] Palomino, M.A, T. Taylor, T. and Owen, R. (2012): Towards the Development of an Automated, Web-based, Horizon Scanning System, Proceedings of the Federated Conference on Computer Science and Information Systems, pp. 1009–1016.
[14] Stutzki, J. (2014): Multilingual Trend Detection in the Web, Proceedings of the 4th Student Conference on Operational Research SCOR 2014, OASICS, Vol. 37, pp. 16–24.
[15] Vester, F. (2000): Die Kunst vernetzt zu denken: Ideen und Werkzeuge für einen neuen Umgang mit Komplexität; DVA Stuttgart.

Risk assessment of a petroleum product pipeline in Nigeria: the realities of managing problems of theft/sabotage

A. Ambituuni[1], P. Hopkins[2], J. M. Amezaga[1], D. Werner[1] & J. M. Wood[3]
[1]School of Civil Engineering and Geoscience, Newcastle University, UK
[2]Penspen Ltd, UK
[3]Pipeline engineering consultant, UK

Abstract

Pipelines carrying oil and gas are very safe forms of energy transportation, but they do sometimes fail.

In the Developed World these failures are usually associated with impact damage (e.g. from earth moving equipment), corrosion, or manufacturing faults in the pipeline materials. In the Developing World theft and sabotage is a major, and increasing cause of failure. Countries such as China, Mexico, and Nigeria have major problems with theft of pipeline products, sabotage, and vandalism.

This paper reviews pipeline failures in Nigeria, focusing on pipelines carrying hydrocarbon liquids. The review clearly shows that theft/sabotage is the major cause of failure to pipelines, and the recorded failure rates (0.35 per km-year) are well above failure rates reported on other pipeline systems around the world.

Fatalities from pipeline failures range from 0.04 to 0.38 per km-yr, depending on the region in Nigeria. Additionally, on average, the operator of the pipeline system considered in this paper loses about $US100million/year due to these failures. This value does not consider the costs associated with payment of compensation, fines, environmental clean-ups, litigation, etc. The paper concludes with recommendations to improve pipeline safety systems to reduce these fatalities and costs.

Keywords: pipeline risk assessment, petroleum products, theft, sabotage, Nigeria.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150051

1 Introduction

The transportation and distribution of liquid petroleum products in Nigeria is mainly by pipeline and road truck tankers [1]. Pipelines are generally considered the safest form of transporting energy, including petroleum products [2]. Hazards from pipeline operations are due to the possibilities of loss of containment (LOC) [3], with risks of fatality from fire and/or explosions, in addition to environmental damage. Pipeline risk should therefore be assessed in order to develop appropriate mitigation measures.

1.1 Pipelines in Nigeria

Fig. 1 shows the pipeline systems used for transporting petroleum products (mainly Premium Motor Spirit (PMS), Automated Gas Oil (AGO) and House Hold Kerosene (HHK)) in Nigeria. The pipeline system is strategically classified into five operational regions. The Nigerian National Petroleum Corporation (NNPC) own and operate the 5001 km asset through its subsidiary, the Pipeline Petroleum Marketing Company (PPMC). The PPMC pipeline network is made up of multiproduct systems for products supply: the buried pipelines link the refineries with distribution depots. There are 4 refineries in the country: one each in Kaduna and Warri; and two in Port-Harcourt, with a nameplate capacity of 438,750 billion b/d. The Kaduna refinery is also linked to the Escravos terminal, through Warri, by a crude oil pipeline. The pipelines are divided into nine systems [4].

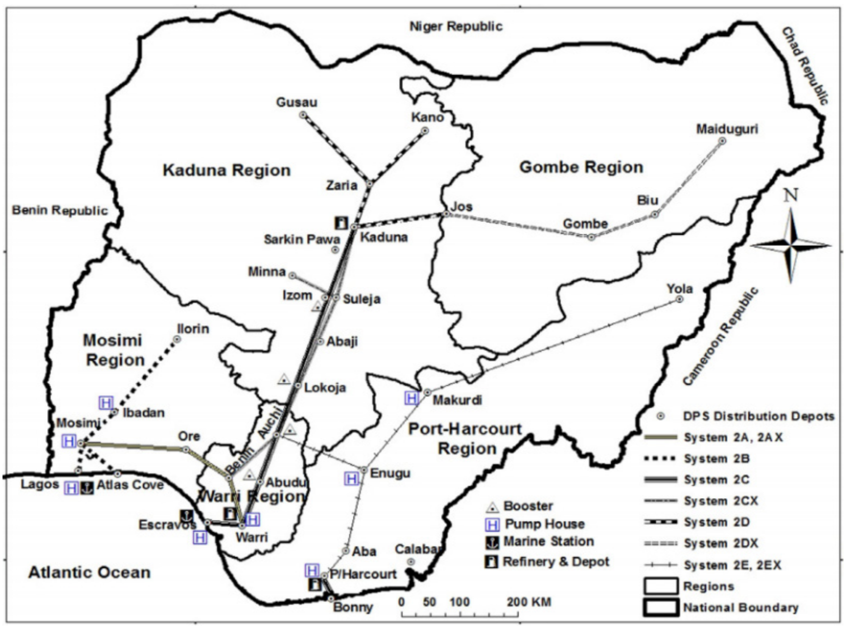


Figure 1: Map of Nigeria showing pipeline network and facilities [4].

1.2 Risk assessment of pipelines

A full risk assessment of a selected pipeline (such as the system in Fig. 1) is a complex task that may require specialist software (e.g. PHAST, EFFECT, SAFETI) [3] and risk expertise to interpret results correctly. There are a variety of different systems in use for identifying hazards, analysing failure likelihood or probabilities, evaluating failure consequences, and estimating risk values**.** These systems use qualitative or quantitative assessments to develop a suitable methodology. Palmer-Jones *et al.* [5] placed the systems into three generic methodologies:

- point-scoring;
- ranking; and,
- quantified [6, 7].

This paper considers these three methodologies, and tailors a method utilising analytical techniques that best suit risk assessment of the petroleum product pipelines in Nigeria. The results produced the risk management strategies we recommend in this study.

1.3 Theft from pipelines

Pipelines carry many valuable fluids such as crude oil and gasoline: these products have high market values. In recent years, these products have been stolen from pipelines; for example, oil theft costs the Chinese oil industry more than $124.6m (2006 prices), and led to 2,877 arrests [8]. Also, in Mexico, crime groups stole fuel (crude oil, gasoline, diesel, LPG, etc.) estimated at $250 million (=3 million barrels) in the first 4 months of 2011. The criminals will make an estimated $750 million on stolen fuel this year. The heavily-armed gangs hijack trucks, and also siphon fuel directly from pipelines. The gangs have even built tunnels and pipelines to facilitate the thefts [9]. Associated Press [10] says:

"In 2009, the U.S. Justice Department said U.S. refineries bought millions of dollars worth of oil stolen from Mexican government pipelines and smuggled across the border in illegal operations led by Mexican drug cartels expanding their reach."

The Developed World is also experiencing an increase in theft from pipelines [11]. Figures on liquid pipelines in Western Europe show an increase in theft from pipelines. Various factors contribute to theft/vandalism, e.g.: poverty; lack of basic services; corruption amongst government officials; etc. [12]. Oil theft in Nigeria (the Niger Delta) costs Shell up to $4.5bn a year in lost revenue. Theft from oil pipelines is sophisticated, with a supply and demand chain. The loss of oil from this theft is estimated at 100,000 barrels/day. This theft comes at huge cost. Examples of the human 'cost' of theft, in Nigeria include [8]:

- Dec 2006: >260 killed in Lagos;
- May 2006: >150 killed in Lagos;
- Dec 2004: >20 killed in Lagos;
- Sept 2004: >60 killed in Lagos;
- June 2003: >105 killed in Abia;
- Jul 2000: >300 killed in Warri;
- Mar 2000: >50 killed in Abia;
- Oct 1998: >1,000 killed in Jesse.

www.witpress.com, ISSN 1743-3509 (on-line)

2 Methodology of pipeline risk assessment

The methodology used for analysis of pipeline risk in this study draws relevant techniques from various frameworks. This combines both quantitative and qualitative approaches to obtain results that overcome limitations in the data required for risk assessment of long pipelines, especially in developing countries.

2.1 Establishing pipeline characteristics

This involved the collection of pipeline data to establish the general context of the pipeline. We obtained data related to the construction, operation, and maintenance of the pipeline from PPMC. Using this data, it was possible to establishing the characteristics of the pipeline and its operating parameters: including pipeline diameter, wall thickness, steel grade, length, fluid type, line capacity, design flow rate (min/max), design pressure, cathodic corrosion protection, depth of cover, etc. The details were used for various calculations.

2.2 Risk analysis using historic data

Historic incident data was obtained from the pipeline operator (NNPC, PPMC). The historic data used comprised data for 13 years (from 2000-2012) containing information on accidents and failures in the entire 5001km pipeline system across the 5 operations and distribution zones. This also includes details of fatalities, quantity and financial value of product loss, failure causal factors, etc.

2.2.1 Failure frequencies

Failure frequency is the likelihood that a hazard (pipeline failure) occurs. It is expressed in 1000 kilometre-years. Failure in a pipeline can occur due to a range of potential threats. These threats can be time dependent (e.g. internal/external corrosion and material fatigue), or time independent (e.g. ground movement, third party interference and incorrect operations). Failure of a high pressure pipeline can occur as a leak or rupture. Leaks are defined as fluid loss through a stable defect, while ruptures are fluid loss through an unstable defect which extends during failure, such that the release area is normally equivalent to two open ends [13].

Failure frequency can be computed from historic data. For this study, we adopt and modify the model presented in De Stefani *et al.* [14] (see eqn (1)). Failure frequency is therefore taken as the sum of reported failures f due to:

- f_{TPD} failure due to third party damage;
- f_{MF} failure from mechanical faults;
- f_{CO} failure from corrosion;
- f_{NH} failure from natural hazard;, and,
- f_{IN} failure from ‘interdiction’ (sabotage and pilferage).

$$f = f_{TPD} + f_{MF} + f_{CO} + f_{NH} + f_{IN} \tag{1}$$

www.witpress.com, ISSN 1743-3509 (on-line)

2.2.2 Consequence analysis

Consequence analysis involves assessing the effects of accidents in order to determine the severity of pipeline failure. Using historic data, the consequence of releases are assessed at this stage. They include: ignition frequencies; fatality; volume loses; financial loses; and, environmental damage.

2.2.3 Risk estimation

Risk estimation is expressed in terms of Societal (SR) and Individual Risk (IR). SR is a measure of risk to a group of people while IR is defined as a measure of the frequency at which an individual, at a specific distance from the pipeline, may be expected to sustain a specified level of harm from realisation of a specific hazard. IR measures have different values for a given incident or set of incidents. For this study, we assume an individual at a point *x,y* from the pipeline, and adopted the calculated failure frequencies from eqn (1), and associated ignition frequencies to estimate a value of IR from point *x,y* with eqn (2). The inspected pipeline ROW in section 2.3 was used as a contextual framework for the calculations.

$$IR_{(x,y)} = \sum_{j=1}^{n} (f.dx.p_i.p_{cy})_j \quad (2)$$

f = rupture frequency (per km-yr), p_i = ignition probability, p_{cy} = casualty probability, dx =step length (m) [6]

2.3 Condition of right of way: site survey

To improve the contextual understanding of the pipeline, a site inspection was conducted on a section of the pipeline (system 2B – along the Mosimi to Atlas-cove section) to obtained site specific data on the condition of right of way. The section of the pipeline inspected was selected due to its importance: 2B accounts for 70% of the product importation. In total, about 13km of that section was inspected over a period of four days (from 17th to 20th June, 2014). Details of the inspected coordinates are given in Table 1. The inspected area cuts across towns, villages and countryside.

Table 1: Coordinates of section of pipeline ROW inspected.

Start point coordinate:	6°35'00.4″N	3°16'15.2″E
End point coordinate:	6°27'55.14″N	3°15'14.91″E
Distance:	13.26 km	
Initial bearing:	008°01′00″	
Final bearing:	008°01′07″	
Midpoint:	06°31′28″N	003°15′45″E

3 Result and discussion

3.1 Failure frequencies

Table 2 shows the regions, the length pipelines, number of reported failures from year 2000 to 2012 and the computed failure frequency per Km year.

Table 2: Failure frequencies within each NNPC distribution region.

Regions	**L (km)**	**Failure incidents**	**Failure frequencies per km year**
Port-Harcourt (PH)	1526.6	9246	0.47
Warri (WR)	1561.2	4659	0.23
Mosimi (MS)	512.6	3419	0.51
Kaduna (KD)	1132.8	2443	0.17
Gombe (GB)	267.8	2642	0.76

The 13 year mean value of failure per km-year across the entire NNPC-PPMC pipeline network is 0.351 per km-year. This value is very high compared to failure frequencies from other international data source such as:

- the conservation of clean air and water in Europe (CONCAWE) with a computed failure rate of 0.54E-3 and 0.24E-3 per km-yr from 1971 to 2011 and 2007 to 2011 respectively;
- UKOPA with failure frequency of 0.23E-3 per km-yr from 1962 to 2012; and US with failure rate of 0.135E-3 per km year from 1994 to 2012.

There is therefore a need explore and understand the relationship between high failure rate in Nigeria and causal factors.

Eqn (1) gives the formula for computing failure classification based on causal factors. Failure data from 2000 to 2012 is represented in Table 3. Based on this data, natural hazards (f_{NH}) is zero. The failure causal classification is limited to two types;

1. Failure due to interdiction f_{IN} – defined as the deliberate or intentional act of destruction on a system such as transport pipeline. This failure classification is believed to be a combination of failure from third party damage (f_{TPD}) and f_{IN}.
2. Failure due to rupture, which is also believed to be a combination of manufacturing faults and corrosion (f_{MF} and f_{CO}).

As expected, f_{IN} is the largest contributory factor. This failure causal factor has a mean contributory value of 96.49% of the pipeline failures while failure from rupture (i.e., f_{MF} and f_{CO}) accounts for 3.51% (see Table 3). Even if the data from interdiction is excluded from the analysis, failure frequency of the pipeline (from 2000 to 2012) remains higher (0.00757) than what is reported internationally. Care needs to be taken in interpreting this result as it does not give in-depth details of causal factors. For instance, the term 'rupture' was given as a failure cause without regards to its technical definition.

f_{IN} has assumed various dimensions within the Nigerian oil and gas industry. Consequently, various terms such as 'oil theft', 'bunkering', 'fuel scooping', 'pipeline sabotage', and 'oil terrorism' have been used to describe the act of illegal tampering to the pipelines. The trend of product pipeline interdiction has evolved in the recent years with possible links to socio-political events. For instance, the likely reason for the increase between 2004 to 2005 (see Fig. 2) – the largest in absolute terms – is possibly linked to reported failures to fulfil promises made by politicians to the population before the 2003 general elections, especially in the Niger Delta. The increase is mostly influenced by the upsurge in interdiction within the Port-Harcourt region, which forms part of the Niger-Delta [4].

Table 3: Yearly % failure contributory factors.

Year	Absolute F(Interdiction)	F(in)% Contribution	Absolute F(Rupture)	F(Rup) % contribution
2000	984	87.78	137	12.22
2001	461	94.66	26	5.34
2002	516	95.20	26	4.80
2003	779	94.20	48	5.80
2004	895	92.17	76	7.83
2005	2237	99.07	21	0.93
2006	3674	99.76	9	0.24
2007	3224	99.38	20	0.62
2008	2285	98.58	33	1.42
2009	1453	98.18	27	1.82
2010	836	97.21	24	2.79
2011	2768	99.32	19	0.68
2012	2230	98.85	26	1.15

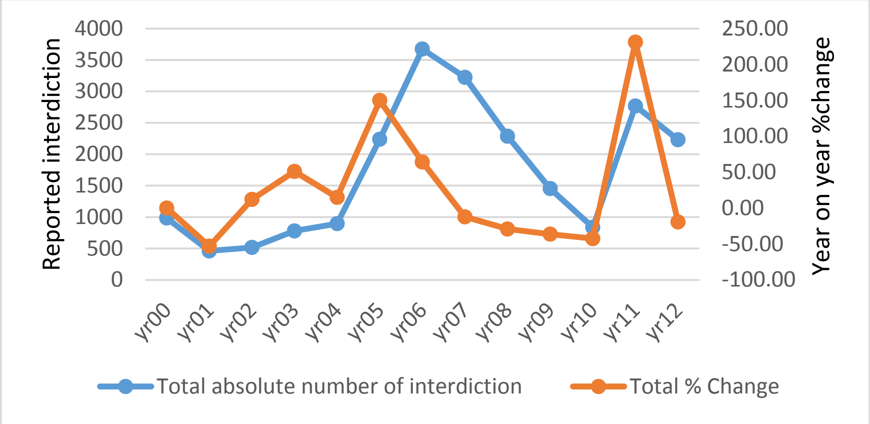


Figure 2: Total national absolute number of interdiction and % change.

The drop in national interdiction figure within 2006 to 2010 may be attributed to the amnesty granted to ex-militants by the Nigerian Government. The programme appears to have substantially reduced interdiction until 2010. From 2010 to 2011, interdiction increased over 200%, making it the highest national percentage increase on record. This was the period of general elections. It is therefore noted that interdiction and failure frequencies on pipelines in Nigeria may be influenced by socio-political events. With this knowledge, security can be enhanced along the pipeline as periods of general elections approach.

3.2 Failure frequency and age of pipeline

The pipeline systems were constructed in two periods: 1978/80 and 1995. From Table 4 it can be seen that there is a significant difference between failures from interdiction across the two construction periods. The newer lines have a higher hit rate. This reveals that interdictors attack lines irrespective of the age of the pipeline. Failure due to rupture increased with pipeline age; unfortunately, the available data did not permit further analysis to ascertain the precise relationships (i.e., whether the failure is related to time dependent threats (e.g. internal/external corrosion and material fatigue) or time independent (e.g., ground movement and incorrect operations).

Table 4: Pipeline age and mean failure frequency. Note that f_{IN} is failure due to interdiction and f_{Rup} is failure due to rupture.

Variable	N (yrs)	Mean	StDev	Minimum	Maximum
F_{IN} (1995)	13	0.493	0.428	0.057	1.180
F_{IN} (1978/80)	13	0.765	1.065	0.000	3.208
f_{Rup} (1995)	13	0.02011	0.01230	0.00390	0.03902
f_{Rup} (1978/80)	13	0.00203	0.00365	0.00000	0.01132

3.3 Consequence analysis

The consequences of pipeline failure are examined in this section.

3.3.1 Ignition causes and frequencies (p_i)

Failure records from 2007 had causes of ignition. Prior to 2007, only the numbers of ignitions recorded per year were reported. Of the 106 ignitions recorded from 2007 to 2012, about 75% were as a result of (Fig. 3):

- deliberate arson after scooping fuel;
- unintentional fire as a result of scooping; or,
- bomb attack.

Most of the sources of fire from mechanical faults are not clearly reported; however, one incident was attributed to sudden rupture. Third party damage is not a major causal factor, but sparks from electric overhead cables, bush burning for hunting purposes, and construction activities were mostly the source of fire from third part damage. From Table 5 it can be seen that Port-Harcourt region (PH), Warri (WR), Mosimi (MS) and Kaduna regions all have ignition per failure incidents within the same range (i.e., about 1 in 50), while Gombe (GB) region recorded the lowest ignition frequency of approximately 1 in 100 reported failures. There are questions as to the reason why ignition rate is high in PH, WR and MS regions. Perhaps this could be associated to the type of technology used in illegal hot tapping, or the flash point of the product involved. However, emergency response capability can be enhanced to reduce such incidents with this information. Leak detection and incident response technologies should focus on the high risk regions.

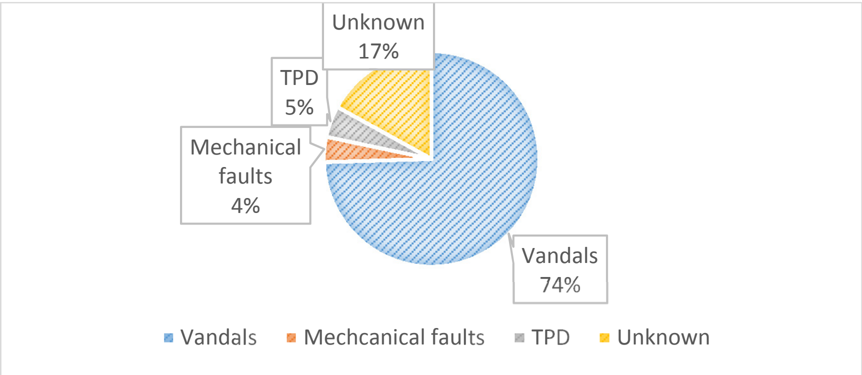


Figure 3: Ignition causal factors.

Table 5: Ignition frequencies within NNPC-PPMC distribution regions.

Regions	Pipeline failure (2000 to 2012)	Fire incidents (2000 to 2012)	Ignition frequency
PH	9246	206	2.23E-02
WR	4659	122	2.62E-02
MS	3419	76	2.22E-02
KD	2443	50	2.05E-02
GB	2642	27	1.02E-02

3.3.2 Fatality

The fatality of a pipeline failure within each distribution region (as represented in Table 6) can be determined. No fatality has been recorded from pipeline failures in GB and KD regions. On average, the pipeline systems in PH, WR and MS regions recorded fatality of 0.044, 0.071 and 0.38 per km-yr. These fatality rates could be a direct function of the high ignition frequencies within these regions. However, surprisingly, KD region recorded no fatality even though the ignition frequency in that region is similar to ignition frequencies in PH, WR and MS. This suggests that other influencing factors (as discovered during the pipeline right of way inspection) may include the proximity of buildings to the pipeline, incident response time, ease of access to incident sites, etc.

3.3.3 Product losses and financial values

The scale of problem of product losses can be seen in financial terms in Fig. 4. From this figure, the spike in 2005–2006 and 2011–2012 may be related to the political issues discussed in section 2.1. On average, the operator loses about 100 million USD per year. This value does not even considers cost associated with payment of compensation, fines, environmental clean ups, litigation, etc.

Table 6: Fatalities from 1998 to 2012. Updating from Anifowose *et al*. [4].

Regions	Fatality report (1998 to 2012)
PH	1004
WR	1665
MS	2889
KD	0
GB	0

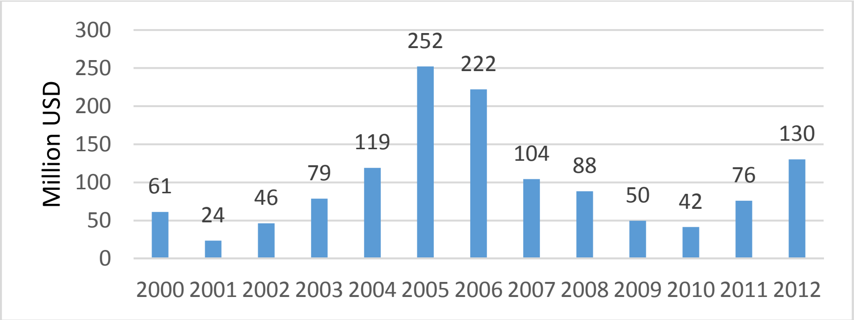


Figure 4: Dollar value of product loss.

3.4 Individual risk based on historic data

Fig. 5 illustrates the calculated IR associated with the section of the pipeline inspected. The figure also illustrates the IR limits established by BSI PD8010-3 [13]. At about 40m from the pipeline, the IR value is not within the BSI PD tolerable limits. Above 40m the IR value is tolerable if the risk is ALARP. The

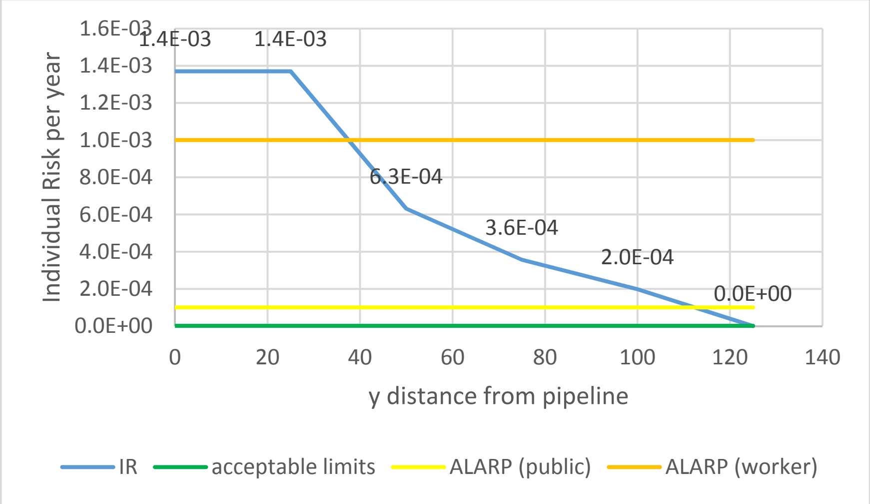


Figure 5: Pipeline IR values.

www.witpress.com, ISSN 1743-3509 (on-line)

ROW inspection conducted reveals that in many cases buildings and other public infrastructures are located less that a meter from the pipeline. This may be the reason for the high fatality rates.

4 Conclusion

The risk associated with the Nigerian petroleum product pipelines was assessed using historic data and site data. The failure frequency of the pipelines was found to be extremely high (0.351 per km-yr) when compared to failure frequencies of international pipelines (e.g., the UK and USA). This is mainly due to pipeline interdiction. Consequently, the ignition frequencies, fatality, and product losses from the Nigerian pipelines are found to be high. This ultimately made the values of Individual Risk for these pipelines to fall outside tolerable limits.

Although we recognise that the poor safety performance of the pipelines are influenced by wider socio-political issues in Nigeria, the information provided via this assessment, and some concepts of engineering and pipeline risk and integrity management, can help in managing and optimising the performance of the pipeline. Hence, in Section 5 we make recommendations to improve the pipeline's safety and environmental management system.

5 Risk management recommendations

1. The pattern of interdiction on these pipelines reveals how the pipeline industry is affected by socio-political issues. Therefore, these issues should be an integral part of the pipeline risk management. To better understand the dynamics of these issues, a detailed *Environmental and Social Impact Assessment* (ESIA) should be conducted across the entire network. Aggrieved communities should be identified, a royalty payment system should be designed as compensation to land owners, and community incident reporting/response system should be enhanced using the 'one-call' system.
2. *Inline inspections and air surveillance* systems should be designed and implemented. Inspection can be carried out internally by X-ray or Gamma ray crawlers or intelligent pigs. These enable the detection of internal and external corrosion, drill holes, and cracks within the wall of the pipeline. The intervals of inspection and frequencies of surveillance can be extrapolated from the assessed pattern of failure frequencies in this study. Surveillance should be vigorous, especially in political election years.
3. Optical intrusion *electronic detection systems* can be used to monitor activities of interdictors. The system includes a fibre optic, usually installed 12 to 24 inch above the pipeline. Should the cable become damaged, the monitoring device issues an alarm to the pipeline logic controller and/or the supervisory control and data system. Response can then be initiated.
4. *Public education* needs to be enhanced. Individuals (especially within intolerable risk zone) should be educated about the hazardous nature of petroleum products, pipeline dangers, and appropriate emergency responses.

www.witpress.com, ISSN 1743-3509 (on-line)

5. The pipelines' *rights of way need to be properly maintained*. Encroachment of buildings should be stopped, with strict regulations and appropriated land compensations.

Acknowledgement

This paper is part of a three year PhD research at Newcastle University funded by the Petroleum Technology Development Fund (PTDF), Nigeria.

References

[1] A. Ambituuni, J. Amezaga, E. Emeseh, Analysis of safety and environmental regulations for downstream petroleum industry operations in Nigeria: Problems and prospects. Environmental Development 9 (2014) 43-60.
[2] P. Hopkins, Why failure happen and how to prevent future failures, International Congress on Logistics, Transportation and Distribution of Hydrocarbon., J. Pipeline Eng., Guadalajara, Mexico, 2012, pp. 77-91.
[3] M. Dziubiński, M. Frątczak, A.S. Markowski, Aspects of risk analysis associated with major failures of fuel pipelines. J. Loss Prev. Process Ind. 19 (2006) 399-408.
[4] B. Anifowose, D.M. Lawler, D. van der Horst, L. Chapman, Attacks on oil transport pipelines in Nigeria: A quantitative exploration and possible explanation of observed patterns. Applied Geography 32 (2012) 636-651.
[5] R. Palmer-Jones, S. Turner, P. Hopkins, A new approach to risk-based pipeline-integrity management. The J. Pipeline Eng. 8 (2009) 229-239.
[6] Y.D. Jo, J.A. Bum, A method of quantitative risk assessment for transmission pipeline carrying natural gas. Journal of hazardous materials 123 (2005) 1-12.
[7] W.K. Muhlbauer, Pipeline Risk Management Manual: Ideas, Techniques, and Resources, Elsevier, 2004.
[8] BBC, BBC News 2006.
[9] A. Harrup, D. Luhnow, Mexican Crime Gangs Expand Fuel Thefts, The Wall Street Journal, The Wall Street Journal, 2011.
[10] E. E. Castillo, Associated Press on MSNBC 2010.
[11] Anon., 2013 Performance of European cross-country oil pipelines. Statistical summary of reported spillages in 2011 and since 1971, CONCAWE.
[12] H. C. Imig, "Mitigating Risks". World Pipelines 10 (2010) 109.
[13] PD8010-3, BSI Standards Pipeline systems –Part 3: Steel pipelines on land – Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major accident hazard pipelines containing flammables, BSI Standards Publication 2013.
[14] V. De Stefani, W. Zoe, A. Micheal, A Model to Evaluate Pipeline Failure Frequencies Based on Design and Operating Conditions, 2009 Spring Meeting & 5th Global Congress on Process Safety, Center for Chemical Process Safety (CCPS) 24th International Conference, 2009.

Whole body vibrations: experimental assessment of anthropometric differences on the effects of WBV exposure in quarry workers

G. Alfaro Degan, D. Lippiello & M. Pinzari
Department of Engineering, ROMA TRE University, Italy

Abstract

The human biomechanical response to whole body vibrations (WBV) is affected by the inertial characteristics of the body itself, among which the anthropometric parameters of the subject, such as body mass and shape, are the most relevant.

Although human exposure to mechanical vibration is universally recognized as a significant risk factor for workers, Directive 2002/44/EC indicates the minimum health and safety requirements regarding the exposure to risks arising from physical agents, stating that risk assessment may be essentially based on appropriate information available from the manufacturer without the obligation of carrying out any measurements. For this reason, information such as the machine type and model, operating conditions, driving style, soil type, and workplace characteristics are declared together with the manufacturer's vibration measurements carried out in accordance with specific ISO EN Standards. Clearly, these data do not refer to the specific operating conditions and they do not consider the inertial and geometric parameters of the driver himself (as if these factors could not affect the exposure results). This study aims to evaluate the relationship between the WBV exposure values of loader vehicle drivers and their main anthropometric characteristics, i.e., height and weight. In this case study, the responses of drivers to vibrations from the same vehicle are analysed by means of several sampling campaigns. A correlation study is then presented along with some considerations which are proposed in order to quantify the observed differences and to predict exposure values from anthropometric data.
Keywords: whole body vibration, anthropometric differences, loader vehicle workers.

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150061

1 Introduction and motivation

Extractive activities and quarries in general constitute an atypical sector as they give rise to numerous critical issues in relation to occupational exposure of workers in this field. Extractive plant operation inevitably produces physical agents such as noise and vibrations, as well as the emission of numerous airborne pollutants, all of which may have a considerable detrimental effect on the health of the machinery operators.

This study is conducted in the field of health and safety in the workplace concerning the evaluation of the risk of exposure to physical agents with particular regard towards whole body vibrations (WBV). The paper aims to evaluate any correlation which may exist between machinery vibrations and the body characteristics of the machinery operators who are exposed to them.

It is well known that, ever since the first studies carried out on machinery, [1], human exposure to mechanical vibrations may be a substantial risk factor for the machinery operators and may have a detrimental effect on their health, [2]. The EU legislated on question with the enactment of Directive 2002/44/CE, introducing related technical standards [3–5]. It has become obligatory for the company in charge of the activity to evaluate such risks, to determine the daily dose to which the machinery operators are exposed, and to implement the prescribed minimum health and safety measures by various means [6] in order to reduce their effects.

Among the first consequences of this legislation is the focus of attention on the levels of exposure linked to the use of means of transport in general and in particular heavy machinery vehicles with regard to the planning stages and determining containment measures [7], as well as the phase in which the exposure itself is evaluated [8].

Due to its particular characteristics, the extractive sector has often been chosen as the ideal scenario in which to analyse the problem [9], both in terms of purely monitoring [10, 11], as well as of studying the correlated effects on operators health [12–14] and synergistic effects [15]. More specifically, the typical quarry machinery and vehicles [16], are a source of particularly significant vibrations, especially when the vehicles are used to carry out the heavy loading and unloading activities for which they were designed [17].

The scientific community has predominantly concentrated on the differences in terms of exposure linked to the type of machinery [18] or to the degree of its wear and tear [19] as well as other variables such as the type of terrain involved, the driving speed, or the ergonomics of the operator's seat [20].

From the beginning, in the interests of monitoring, it was deemed necessary be able to reliably predict the degree of exposure to the physical agent in question through further study focused on defining prediction methods and models [21–24].

Since the surrounding experimental conditions (such as the type of source machinery, the working environment, the time period of exposure, and the driving style) were apparently identical in these cases, it seemed natural to investigate possible causes of such differences. Therefore, this paper aims to analyse the variability of WBV in relation to the physical characteristics of the subjects (considering subjects' height and weight as parameters) in order to determine the nature of any such variability in this respect and then to carry out a quantitative analysis should such a correlation exist.

2 Materials and methods

2.1 Methods of risk evaluation of occupational exposure to WBV

According to European Directive 2002/44/EC [11], the assessment of WBV (Whole Body Vibration) exposure for a seated person requires the calculation of the daily exposure parameter A(8), expressed as the equivalent continuous root mean squared (RMS) acceleration over an eight-hour period:

$$A(8) = a_w \sqrt{\frac{T_{esp}}{8}} m / s^2 \quad (1)$$

In equation (1), a_w is the equivalent continuous frequency-weighted RMS acceleration over a T_{esp} period (where T_{esp} is the duration of the occupational exposure).

The calculation of the equivalent acceleration a_w involves determining the three frequency-weighted components a_{wx}, a_{wy} and a_{wz} along the three orthogonal axes of a standard reference system established by the International Standard ISO 2631-1 (97). The horizontal axes of vibration, x and y, define the seat plane, where the x axis is the fore-and-aft vibration; the y axis is the lateral vibration; and the z axis is the vertical vibration. Specific weighting factors are indicated by ISO 2631 to account for different sensitivities of the human body depending on the vibration frequency. For a seated person the frequency-weighted acceleration components along x and y must be multiplied by a factor of 1.4, accounting for the higher sensitivity of the human body along these directions when considering the frequency range of maximum sensitivity (between 0.5 and 2 Hz for the x and y axes, and between 4 and 8 Hz for the z axis). According to Equation (2), only the highest of the three acceleration values registered along the three axes is included in the calculation of the exposure parameter A(8):

$$a_w = \max (K_x * a_{wx}, K_y * a_{wy}, K_z * a_{wz}) \quad (2)$$

where:

$$K_x = K_y = 1.4; K_z = 1 \quad (3)$$

The parameter A(8) is compared with a daily exposure action value (EAV=0.5 m/s^2) and a daily exposure limit value (ELV=1.15 m/s^2).

The value of A(8) can be a function of any of the three axial vibration components, depending on the type of vehicle, the task performed, and the specific field conditions. The maximum acceleration component for a given vehicle, is often the result of a combination of various different work phases (e.g., driving along the flat, or going uphill, or loading etc.), each characterized by a different dominant axis. In such cases Equation (3) is used to calculate the exposure parameter

$$A(8)=\sqrt{\frac{1}{8}\sum_{i=1}^{n}a_{wi}^{2}\cdot T_{i}} \qquad (4)$$

where a_{wi} and T_i represent the highest component of the equivalent RMS (root mean square) acceleration and the exposure duration for the i-th work phase respectively.

When A(8) is higher than the action value EAV, a risk containment programme must be determined to reduce the level of exposure, which may not exceed the limit value ELV.

As risk evaluation through the calculation of A(8) is outside the scope of this paper, we shall limit ourselves to studying the value of a_w, determined using the methods defined above (ISO 2631-1 (97)).

2.2 Test environment and instrumentation

The measurements were taken in relation to two distinct types of vehicle (see Figure 1):

- An articulated backhoe loader (FAI 575, Year 1991), weight 6.7 tonnes;
- A skid-steer loader model FAI 348, registered in 1997, weight 2.3 tonnes.

The acquisition of the data and its subsequent elaboration was carried out using a 4 channel Soundbook system. Having four channels allowed four different accelerometers to be measured simultaneously: the first was attached to the pillar of the vehicle in order to measure the phenomenon of the source vibration; the remaining three channels (the triaxial accelerometer) measured the vibrations transmitted to the driver's body through the x, y, and z axes (the transducer was positioned between the driving seat and the driver's buttocks).

The technical specifications and the positioning of the accelerometers are shown in table 1.

Due to the considerable weight of the machinery, the weight of the driver was considered irrelevant in the measurement of the vibrations of the machinery itself, thus it is assumed that there are no input errors owing to any variation in the physical configuration of the machinery-sample-instrument system of measurement.

2.3 Experimental campaign

During the experiment the subjects (the vehicle drivers) were asked to drive along a pre-established track at a constant speed for a total time of 120 minutes.

Each driver repeated the course 5 times for each of the two available vehicles, thus allowing an arithmetic mean to be calculated from 5 samples for each of the three axis measurements.

Table 1: Instruments utilized.

Model	*Sensitivity*	*Position*
Triaxial accelerometer SEN027-PCB 356B40	X axis: 10.52 mV/(m/s^2) Y axis: 10.55 mV/(m/s^2) Z axis: 10.88 mV/(m/s^2)	Driving seat of the vehicle corresponding to the position of the driver's sacroiliac joints (his/her buttocks).
Uniaxial accelerometer PCB 393A03	Single axis: 102.2 mV/(m/s^2)	Axis sensitive in the same direction as the Z axis of the triaxial accelerometer (vertical axis).

(a) (b)

Figure 1: The machinery used: (a) a FAI 575 backhoe loader, (b) a FAI 348 skid-steer loader.

2.3.1 Sample tested

The population which underwent the test was comprised of two different groups of subjects, who were subdivided as follows.

- Group 1: 30 drivers (10 women and 20 men) of equal height of 174 cm (tolerance ± 1.5 cm) and of variable weight.
- Group 2: 25 drivers (4 women and 21 men) of equal weight of 76 kg (tolerance ± 2 kg) and of variable height.

At the end of the tests, each individual was attributed an arithmetic mean of the weighted acceleration values, relative to each of the three axes x, y and z, as indicated by (5):

$$\overline{a}_{wx} = \frac{1}{5}\sum_{i=1}^{5} a_{wx_i} ; \overline{a}_{wy} = \frac{1}{5}\sum_{i=1}^{5} a_{wy_i} ; \overline{a}_{wz} = \frac{1}{5}\sum_{i=1}^{5} a_{wz_i} \qquad (5)$$

In accordance with Directive 2002/44/CE, the value assigned to a_w is the highest of the three acceleration values of K_x *a_{wx}, K_y*a_{wy}, K_z *a_{wz} (see (2)) expressed in m/s^2:

$$a_w = \max(K_x * \overline{a}_{wx} ; K_y * \overline{a}_{wy} ; K_z * \overline{a}_{wz}) \qquad (6)$$

3 Results

3.1 Characteristics of the source signal and relative repeatability

As mentioned above (§ 2.2), in order to check the repeatability of the source vibration signal, the vibrations of the two test vehicles themselves (FAI 348, FAI 575) were measured using an accelerometer (uniaxial accelerometer PCB 393A03) which was attached to a/the pillar/column of the bodywork/chassis. It was deemed of the utmost importance that the source signal be kept as constant as possible so that any differences in results obtained from the measurements between subject's WBV (whole body vibrations) might be considered to be due solely to differences in the body characteristics between subjects.

From analysing the acceleration values of the vibrations, within the frequency range of 0.04-500Hz, recorded on the pillars/columns of the two test vehicles, means and standard deviations were obtained (as shown in table 2).

Table 2: Source signal characteristics.

Vehicle	Arithmetic mean (m/s^2)	Standard deviation (m/s^2)
FAI 348	0.23	0.008
FAI 575	0.28	0.007

The low standard deviation indicates that the input was a substantially uniform vibration signal and thus exhibiting a good level of repeatability at the source.

3.2 Presentation of the results

The graphs showing the values of a_w for the FAI 575 and the FAI 348 respectively, are given below, and are subdivided into the types of population tested (*Group 1*, fixed height, and *Group 2*, fixed weight).

3.2.1 Backhoe loader Model FAI 575

Figure 2 shows the results of the measurements recorded from Group 1 (fixed height of 174 cm ± 1.5 cm) expressed in terms of a_{Wmax} (m/s^2).

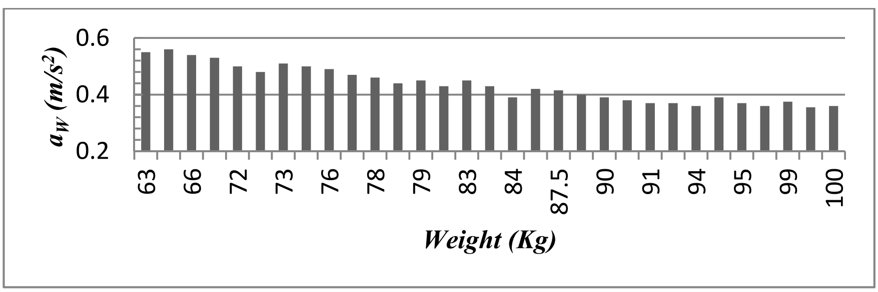


Figure 2: Results of the measurements recorded from Group 1 expressed in terms of a_{Wmax} (m/s^2).

Figure 3 shows the results of the measurements recorded from Group 2 (fixed weight of 76 Kg ± 2 kg).

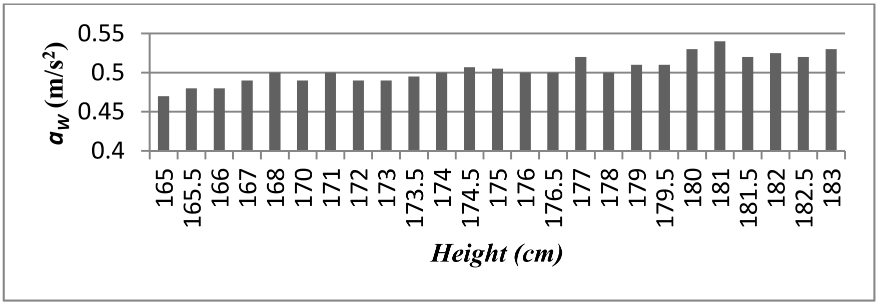


Figure 3: Results of the measurements recorded from Group 2.

3.2.2 Skid-steer loader: model FAI 348

Figure 4 shows the results of the measurements recorded from Group 1 (fixed height of 174 cm), indicating in particular the trend of a_w as a function of the different weights of the drivers who took part in the test.

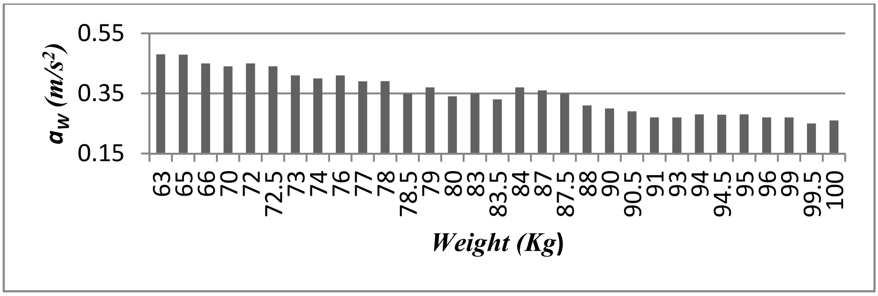


Figure 4: Results of the measurements recorded from Group 1.

4 Discussion

Using cubic polynomial functions, the trend lines are then calculated in order to highlight any trend connected with the values obtained from the measurements. The graphs in figures 5 and 6 show the cubic polynomial functions that best fit the measured data (the trend lines) for the model FAI 575 backhoe loader for Group 1 (fixed height of 174 cm, variable weight), and for the model FAI 348 skid-steer loader again for Group 1.

Both the graphs clearly show the respective trend lines falling, highlighting the phenomenon of the WBV decreasing as body weight increases.

In contrast, the graphs shown below in figures 7 and 8 indicate analogous trend lines (cubic polynomials) this time for Group 2 (fixed weight of 74 kg, variable height), for model Fai 575 (figure 7) and for model FAI 348 (figure 8)

www.witpress.com, ISSN 1743-3509 (on-line)

respectively. Lastly, figure 9 shows a comparison between the data from the two groups with variable weight and fixed height. The global trends of the two sets of measurements (cubic polynomials) appear to be similar.

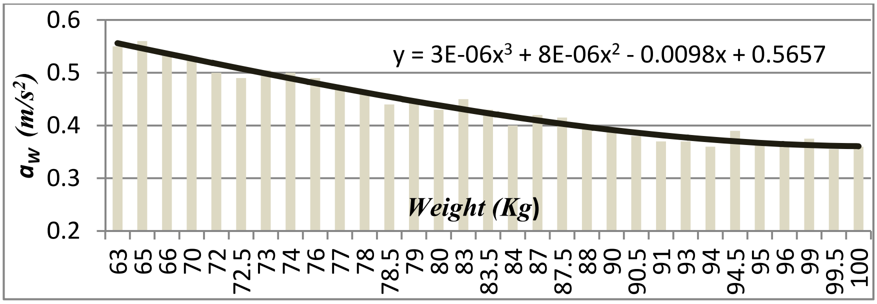


Figure 5: Trend line of the model FAI 575 backhoe loader.

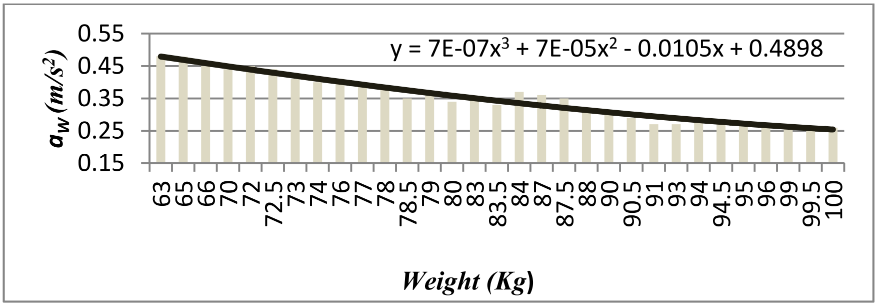


Figure 6: Trend line of the model FAI 348 skid-steer loader.

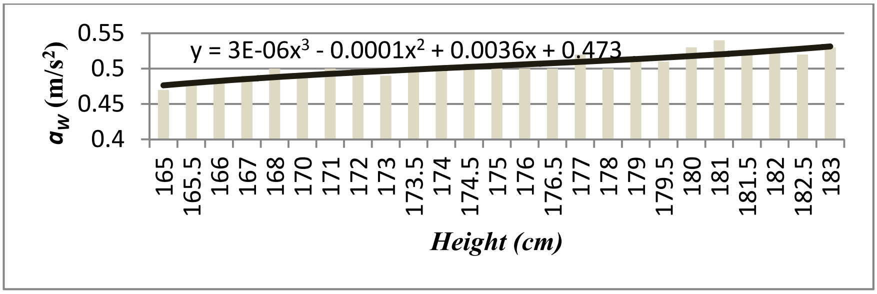


Figure 7: Trend line of the model FAI 575 backhoe loader.

www.witpress.com, ISSN 1743-3509 (on-line)

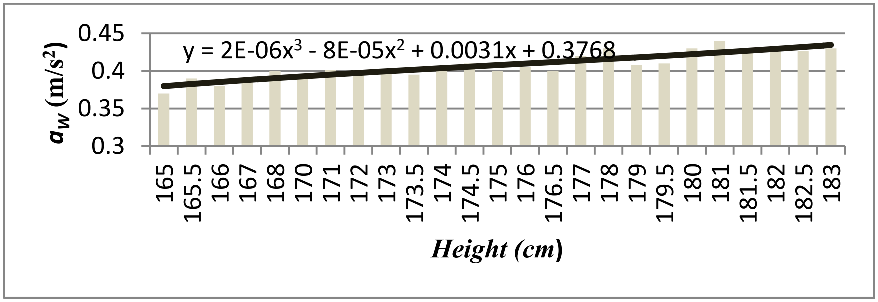


Figure 8: Trend line of the model FAI 348 skid-steer loader.

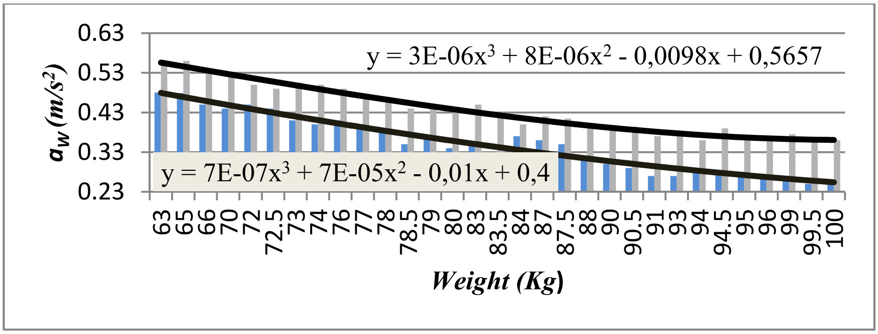


Figure 9: The trend lines from the WBV data measured with cubic polynomials.

5 Conclusion

The evaluation of whole body vibrations (WBV) is a particularly difficult problem, in that the phenomenon is generally affected by a vast number of variables. Results of measurements appear to be affected by subjective parameters such as the technique of the driver and the obsolescence of the vehicle as well as by environmental parameters such as the type of path taken by the vehicle and the speed it is driven.

One of the parameters which most evidently influences the extent of WBV appears to be connected with the subject's physical characteristics. Both the available literature and the experiments performed clearly confirm that for a given input vibration, the transmitted vibration depends strongly on the physical constitution of the subject exposed to the vibrations.

In order to investigate any dependence of parameters of body height and weight on the outcome of the WBV measured, it was first necessary to adopt an experimental methodology which provided an input vibration signal which was both as constant and as easily repeatable as possible. In order to do so, a standard course was established which all of the drivers in the experiment had to cover at a fixed speed in an identical time period. This arrangement was proven to be successful by the repeatability of the measured signal, indicated by its low standard deviation.

Secondly, thanks to the kind cooperation of students in the Engineering Department of Roma Tre University, two homogeneous groups of drivers were selected: one consisting of a population of identical height (Group 1) and the other of identical weight (Group 2).

The results of the WBV measurements carried out on the two groups of drivers (*Group 1*: 30 drivers, fixed height and variable weight; *Group 2*: 25 drivers, fixed weight and variable height) indicated a clear correlation between the value of a_w and body characteristics.

In particular, for a given driver height, as driver weight increases, the value of a_w decreases; and for a given weight, as height increases, the value of a_w also increases.

In order to obtain data which are as reliable as possible, the experiments were repeated on two different vehicles (a model FAI 575 backhoe loader and a model FAI 348 skid-steer loader): in both experimental campaigns the output data gave a_w values whose global trends appear to be very similar for both of the test vehicles.

The experiments brought the following results to the fore:

- The WBV are influenced by the body characteristics of the driver;
- When height is constant, subjects who are lighter in weight appear to be more exposed to WBV;
- When weight is constant, subjects who are taller appear to be more exposed to WBV.

Furthermore, plotting the resulting trend lines from the WBV data measured with cubic polynomials brought to light the fact that they are very similar (see fig. 9).

From this observation, one might assume that there is a mathematical function which, for a given value of WBV transmitted to a subject of a given weight, one would be able to predict the value of vibration for another driver of the same weight but of any given height.

Or alternatively following the same logical process, on the basis of the data obtained one could equally well predict the value of WBV of a driver of the same height as a subject which had been measured, but of a different weight.

Acknowledgement

The authors would like to give their thanks to the students from the academic year 2013–2014 of the Department of Engineering of Roma Tre University for their kind cooperation.

References

[1] Village, J, Morrison, J.B., Leong, D.K.N. Whole Body vibration in underground load haul dump vehicles. Ergonomics, 32 (10), pp. 1167-1183, 1989.

[2] Lings, S, Leboeuf-Yde, C. Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992-1999. International Archives of occupational and environmental health. 73 (5), pp. 290-287, 2000.

[3] Mechanical Vibration and Shock-Evaluation of Human Exposure to Whole-Body Vibration-Part 1: General Requirements. ISO Standard 2631-1, 1997.

[4] A1, Mechanical Vibration - Measurement and Calculation of Occupational Exposure to Whole-body Vibration with Reference to Health - Practical Guidance - EN 14253:2003.

[5] Earth-Moving Machinery - Laboratory Evaluation of Operator Seat Vibration. ISO Standard 7096, 2000.

[6] Alfaro Degan G, Lippiello D, Pinzari M. (2009). Occupational health and safety management systems: comparison between BS OHSAS 18001: 2007 and Italian Decree 81/2008. WIT Transactions on Biomedicine and Health, Vol. 14, WIT Press, 2009, ISSN: 1743-3525, pp. 401-409, doi: 10.2495/EHR090391.

[7] Donati, P. Survey of technical preventative measures to reduce whole-body vibration effects when designing mobile machinery. Journal of sound and vibration, 253 (1), pp. 169-183, 2003.

[8] Paddan, G.S., Griffin, M. J. Evaluation of whole-body vibration in vehicles. Journal of Sound and Vibration, 253 (1), pp. 195-213, 2002.

[9] Scarlett, A.J., Stayner, R., M. Whole-body Vibration on Construction, Mining and Quarrying Machines - Evaluation of Emission and Estimated Exposure Levels. HSE Books, Sudbury (Suffolk), 2005.

[10] Aye, S. A., Heyns, P. S. The evaluation of whole-body vibration in a South African opencast mine. Journal of the South African Institute of Mining and Metallurgy, 111 (11), pp. 751-757, 2011.

[11] Bernardo, C., Matos, M. L., Santos Baptista, J. Whole Body Vibration in open pit mining-a short review. In Occupational safety and Hygiene II, Proceedings of 10th Annual Congress of the Portuguese-Society-of-Occupational-Safety-and-Hygiene on Occupational Safety and Hygiene (SPOSHO). Ed: Arezes, P.M. *et al*. CRC Press-Taylor & Francis Group, Vol. 2 pp. 459-464, 2014.

[12] Howard, B., Sesek, R., Bloswick, D. Typical whole body vibration exposure magnitudes encountered in the open pit mining industry. Work, 34 (3), pp. 297-303, 2009.

[13] Mandal, B. B., Srivastava, A. K. Musculoskeletal disorders in dumper operators exposed to whole body vibration at Indian mines. International Journal of Mining Reclamation and Environment, 24 (3), pp. 233-242, 2010.

www.witpress.com, ISSN 1743-3509 (on-line)

[14] Eger, T., Salmoni, A., Cann, A. *et al.* Whole-body vibration exposure experienced by mining equipment operators. Occupational Ergonomics, 6 (3-4), pp. 121-127, 2006.
[15] Alfaro Degan G, Lippiello D, Lorenzetti S, Multari F, Pinzari M. Combined evaluation of the noise and vibration at a travertino quarry. Recent Developments in Acoustics, Noise and Vibration. Proc. of 16th International Congress on Sound and Vibration (ICSV16). Eds. M. Pawelczyk & D. Bismorvol, IIAV: Krakow, vol. 3, pp. 1940-1947, 2009.
[16] Kumar, S. Vibration in operating heavy haul trucks in overburden mining. Applied Ergonomics, 35 (6), pp. 509-520, 2004.
[17] Frimpong, S., Galecki, G., Chang, Z. Dump truck operator vibration control in high-impact shovel loading operations. International Journal of Mining Reclamation and Environment, 25 (3), pp. 213-225, 2011.
[18] Massacci, G., Dentoni, V. Occupational exposure to whole-body vibration: unfavourable effects due to the use of old earth-moving machinery in mine reclamation. International Journal of Mining Reclamation and Environment, 27 (2), pp. 127-142, 2013.
[19] Mayton, A., Jobes, C., Miller, R. Comparison of whole body vibration exposures on older and newer haulage trucks at an aggregate stone quarry operations. In. ASME V, Proceeding of the International Design Engineering Technical Conference and Computer and Information in Engineering, Ed. ASME Group, Amer. Soc. Mechanical Engineers, pp. 685-691, 2008.
[20] Eger, T., Contratto, M., Dickey, J. Influence of Driving Speed, Terrain, Seat Performance and Ride Control on Predicted Health Risk Based on ISO 2631-1 and EU Directive 2002/44/EC. Journal of low frequency noise and vibration active control, 30 (4), pp. 291-312, 2012.
[21] Eger, T., Stevenson, J., Boileau, P. Predictions of health risks associated with the operation of load-haul-dump mining vehicles: Part 1-Analysis of whole-body vibration exposure using ISO 2631-1 and ISO-2631-5 standards. International Journal of Industrial Ergonomics, 38 (9-10), pp. 726-738, 2008.
[22] Eger, T., Stevenson, J., Boileau, P. Predictions of health risks associated with the operation of load-haul-dump mining vehicles: Part 2-Evaluation of operator driving postures and associated postural loading. International Journal of Industrial Ergonomics, 38 (9-10), pp. 801-8185, 2008.
[23] Alfaro Degan G, Lippiello D, Lorenzetti S, Pinzari M. (2013). Vibration assessing models: comparison between methods. WIT Transactions on Biomedicine and Health, Vol. 16, WIT Press, 2013, ISSN: 1743-3525, pp. 59-69, doi: 10.2495/EHR130061.
[24] Alfaro Degan G., Lippiello D., Pinzari M. A geostatistical approach to the functional analysis space technique: a case of study. Advances in Safety and Reliability - Proceedings of 16th European Safety and Reliability Conference (ESREL). Ed: Kolowrocki K, Taylor & Francis, Vol. 1, pp. 45-52, 2005.

Fire protection of emergency electrical devices: effect on the level of risk – a case study of a rail tunnel

M. Lombardi & G. Rossi
Dipartimento di Ingegneria Chimica Materiali Ambiente, Safety Engineering "Sapienza", Roma

Abstract

The paper proposes the main results obtained from the Quantitative Risk Analysis developed on an existing tunnel, according to the Ministerial Decree "Safety of Railway Tunnels" (October 28th 2005).

The fire produces the most severe scenario among the possible emergencies in confined area, thus the regulations in Europe and in Italy (Technical Specifications for Interoperability, Decision December 20th 2007, Ministerial Decree October 28th 2005) obligate to direct adoption of measures and devices for prevention and protection to reduce the probability of occurrence of this specific critical scenario and the containment of the fire effects.

To mitigate the damage, the difficulty of providing an effective external rescue in a short time involves supplementary safety measures aimed at improving the process of self-rescue.

Keywords: fire safety engineering, emergency lighting, rail tunnel, safety electrical system, quantitative risk analysis.

1 Introduction

In rail and road tunnels the occurrence of fire is the most dangerous scenario in terms of resulting emergencies [1].

Therefore, the best practice and current regulations require measures and devices for prevention and protection, designed to reduce the probability of occurrence of fire (critical scenario) in tunnel and to control the effects in case of its occurrence [2].

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150071

In order to mitigate the damage, the difficulty of providing an effective external rescue in a short time involves supplementary safety measures aimed at facilitating the process of self-rescue activated as consequence of the fire scenario.

Accordingly, the safety electrical system, which supplies the emergency lighting and, where provided, also the internally illuminated exit signs, must be protected by faults, as far as possible, ensuring high reliability in case of impact/fire.

The case study shows the results of quantitative risk analysis developed for the specific risk assessment of a rail tunnel located in Italy and subject to the Decree "Safety of railway tunnels" (October 28th 2005). Current analysis and the resulting project were aimed at verifying the primary importance of the reliability of the safety electrical installations. Defining the infrastructural conditions of the tunnel, the performance of safety devices that influence the risk level of the system, was found to be the main safety parameter.

Derived observations are essentially suitable to all cases of collective transport systems in underground and they suggest a useful indication also for the case of road tunnels (that differ from rail tunnels by physical characteristics of fire and number of people exposed).

The Quantitative Risk Analysis highlights the influence of the performance of safety devices, in particular of emergency lighting, on the risk profile characteristic of the tunnel system.

The availability of technical solutions, that ensure the certified reliability of the performance in case of fire, allows us to design high safety standards at extremely affordable costs, where the alternatives are analytically evaluated. Thus, in some cases (such as this case study) a "not adaptable" system becomes compliant with the safety expectations of the community, as required by specific technical standards.

1.1 Safety of rail tunnel: regulatory framework

The current regulations, relevant to the case of railway tunnels, are constituted by European Technical Specifications of Interoperability (TSI) and national regulations.

In particular, for the purpose of regulatory requirement, the specific rules are:

- Commission Decision, December 20th 2007 "Technical specification of interoperability relating to safety in railway tunnels in the trans-European conventional and high-speed rail system"
- Ministerial Decree "Safety of rail tunnels", October 28th 2005 (Italian law)

Both sources require a specific approach for the safety compliance of existing infrastructure and for the new tunnels, through a system of prescriptive and performance requirements.

The Decision refers to the "not systemic" approach of performance: the single railway subsystems guarantee minimum performance levels. For some of them, the safety subsystems defined, the TSI relate to EN 50126 (RAMS approach in the railway system) with the specific Safety Integrity Level (SIL), that define acceptable rates of unreliability. However, the definition of safety subsystems is unclear, especially with regard to infrastructure devices (and therefore the Electromotive Force and Emergency Lighting in tunnel).

The Decree proposes both minimum safety requirements and quantitative risk analysis. This approach provides an integrated project. The safety level is measured by quantitative indicators: Individual Risk (IR), which proposes normalization of expected value of fatalities by the number of exposed and Societal Risk, which evaluates Back-Cumulated risk Distribution (BCD).

The design of tunnel meets the safety requirements imposed by the standard where the risk indicators take a value compliant with predefined thresholds of acceptability according to ALARP criterion (As Low As Reasonably Practicable). This approach allows the safety systemic design (also economically, with costs-benefits evaluation).

2 Subsystems electrical safety: minimum performance requirements

According to design of the safety systems the request of performance refers to criteria of good practice since a specific request of performance in terms of availability and reliability is not expected. For both the electrical (safety) devices and the emergency lighting systems the Decision requires that: "*Electrical installations relevant for safety (Fire detection, emergency lighting, emergency communication and any other system identified by the Infrastructure Manager or contracting entity as vital to the safety of passengers in the tunnel) shall be protected against damage arising from mechanical impact, heat or fire.*

The distribution system shall be designed to enable the system to tolerate unavoidable damage by (for example) energizing alternative links. The electrical supply shall be capable of full operation in the event of the loss of any one major element. Emergency lights and communication systems shall be provided with 90 minutes backup".

The Italian Decree defines the minimum performance required to the emergency lighting system: "*The electrical components for supply of emergency systems (lighting and power) must be protected from damage caused by failures and accidents.*

The installations of electric power supply must also provide suitable configurations or redundancy such as to ensure, in the event of single failure, the loss of short sections of the system, but not higher than 500 meters".

The safety devices should ensure the high fault protection (i.e. high reliability of components and appropriate redundancy of system) in usual operation, and the high reliability performance (durability in terms of exposure to fire, and protection against short-circuit due to failures) under fire conditions.

3 Case study

The evaluation of quantitative risk analysis is applied to railway tunnel (case study), whose geometric configuration, infrastructures and typical fire make it particularly difficult to verify the compliance with expected levels of safety. Thus, the comparative evaluation of alternative designs and traffic management is required.

The tunnel (see Figure 1) has a length of 2050 meters and complex infrastructural configuration: the end W consists of a subway station, to follow a first section (mono-directional tunnel) is about 250 meters in length (cross-section of about 26 m^2), then follow a room of about 100 meters and a section of about 1700 meters (mono-directional tunnel) on which an underground station is inserted. Actually the tunnel does not have an emergency lighting system.

The materials and solutions have not allowed a safety compliance configuration. Thus, innovative solutions in terms of safety management are necessary.

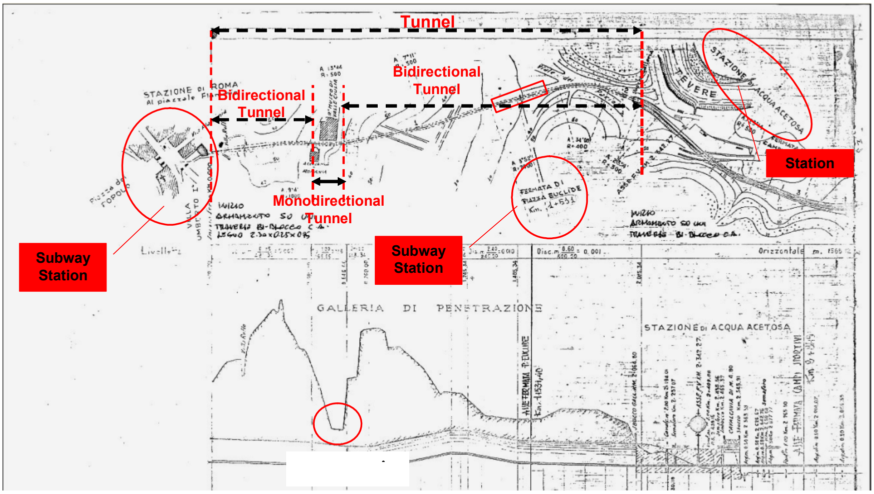


Figure 1: Layout of railway system.

The checking procedure, according to the Italian decree, highlights the need to adopt Extensive Risk Analysis (see Figure 2).

3.1 Systems safety design A

A platform that meets the minimum measures (0.5 m) of the Decree and an emergency lighting system were provided.

The compliance minimum design adopts a system of Electromotive Force and Emergency Lighting protected by a general fire, with cables compliant with the IEC 60331

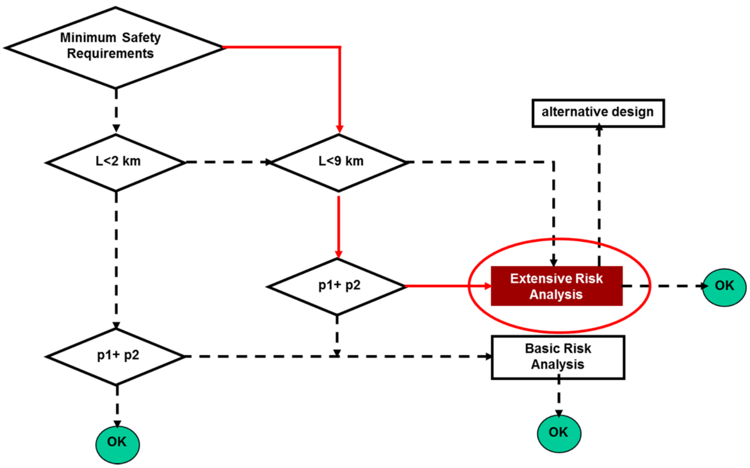


Figure 2: Checking procedure for safety evaluation of railway system.

3.2 Systems safety design B

According to the improved design, following the same geometric conditions of the infrastructure, the systems of Electromotive Force and Emergency Lighting show an enhanced fire performance as required by DIN 4102 and are able to keep thermal stresses higher than those foreseen by IEC 60331, especially for the wiring. All other conditions of the design A are unchanged.

4 Quantitative risk analysis: relevance of safety systems

The two described designs have been verified by developing a coupled process of simulation (fire and exodus). To determine the real conditions [5] of thermal and chemical harmfulness of exposed subjects and safety devices, a strategy of simulation in two steps was adopted [7]:

- Modelling of the rolling stock set up with the real materials that are characterized by chemical properties and simulation of the likely fire curve of the train (minimum ignition).
- The likely fire curve, derived from the small scale simulation, was compared with the experimental fire curve of Ingason [6] (see Figure 2)

This approach allows us to characterize the fire behaviour of the rolling stock in use in the tunnel, following two steps (fire and exodus) of simulation that return likely the actual conditions of hazard.

In large-scale simulation (simulation of fire to the train in tunnel and simulation of exodus) the relevant characteristics to the development of the

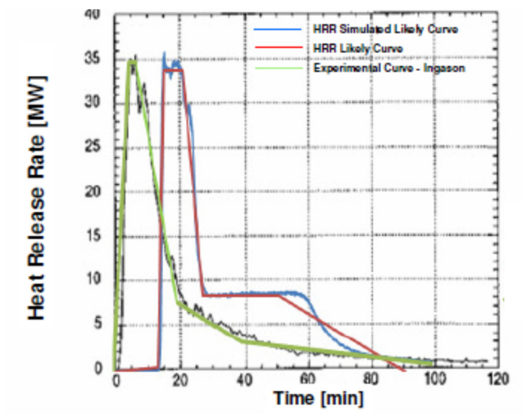


Figure 3: Comparative analysis of fire curves.

hazard [8, 9] were highlighted. To the same geometrical conditions of the tunnel, is:

- subsystem 1: availability, in the transient pre-flash over, of the electromotive force (emergency lighting system).
- subsystem 2: availability, in the transient pre-flash over, of emergency lighting (conditioned on the availability of the subsystem 1).
- subsystem 3: reliability, efficiency and effectiveness of emergency lighting in the transient post- flash over.

Considering the portion of electric backbone, that supplies the emergency lighting, and its (small) distance from the train (length of section about 5 meters), the system and the devices are subject to thermal stresses (T = 300°C) after 16 minutes from ignition.

Since the wiring is not protected from the fire there is a fast loss of system availability (250 meters of section) that results in the electric short circuit of device more thermally stressed.

5 Results

Figure 4 shows the trend of visibility (black line) less than 3 meters and the motion laws of exposed subjects in the case of Design A: the majority of exposed subjects are unable of self-rescue.

The solution of Design B, following the same conditions, leads to much better results (see Figure 5), since the expected duration of the devices performance is equal to about 46 minutes from the start of the emergency (30 minutes, according to the certification E30, from the start of thermal critical stress).

The traditional design (Design A) shows a deficit of safety, which is improved only by the expensive (and relatively not efficient) construction of a smoke extraction system, located in the room (fires localized in the first section of tunnel).

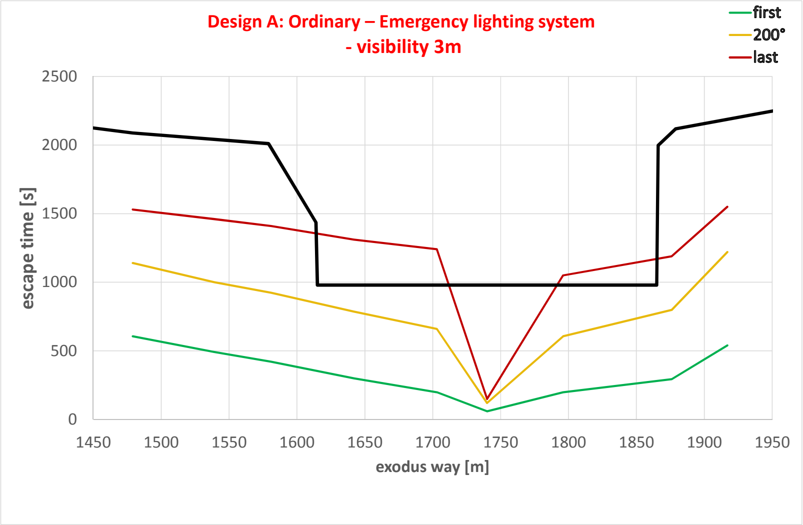


Figure 4: Motion law – visibility less than 3 m (Design A).

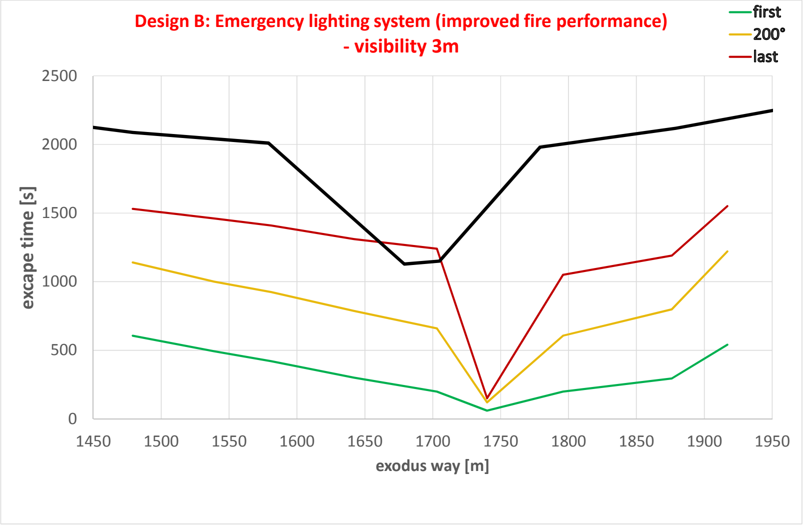


Figure 5: Motion law – visibility less than 3 m (Design B).

It is also required a radical decrease of the level of service and the replacement of the rolling stock. Thus the tunnel, according to results from the analysis, should be radically redesigned.

The number of fatalities associated with the solutions A and B is very different (as shown in Figure 6).

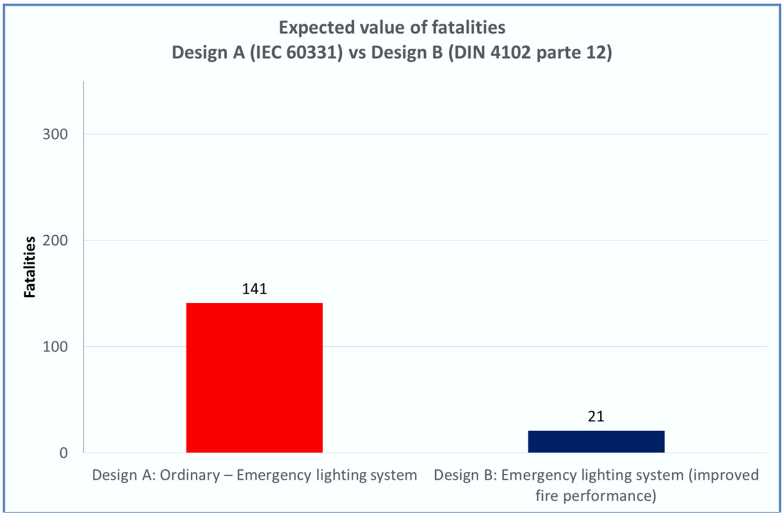


Figure 6: Expected value of fatalities (Design A vs. Design B).

Given other variables relevant to the process of self-rescue and to the emergency management, the study has developed all scenarios of the Event Tree Analysis, by obtaining the probability and the corresponding damage [3, 4].

The evaluation also allowed us to achieve the values of the risk indicators relating to both designs [10] (see Figures 7 and 8).

Based on these results a cost-benefit analysis (CBA) was also made, so check the equivalent cost-effectiveness of the system of wiring (see Table 1). The analysis requires the choice of a conventional economic value to life (evaluated at €1,500,000) as risk indicators refer to the number of fatalities.

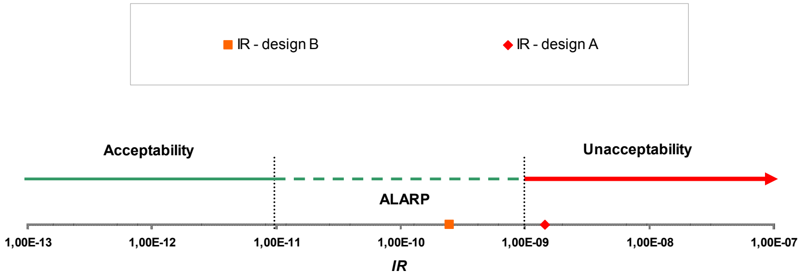


Figure 7: Individual risk indicator (Design A vs. Design B).

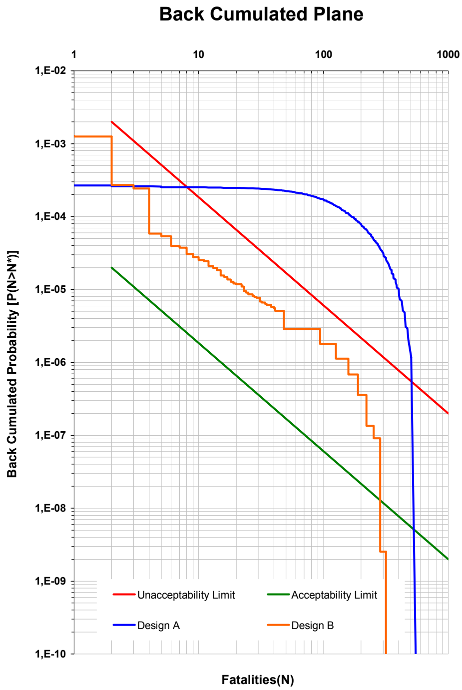


Figure 8: Societal risk – back cumulated distribution indicator (Design A vs. Design B).

The CBA applied to the devices, considering the amortization period of 25 years, returns a judgment of absolute convenience (see Table 1).

Table 1: Cost-benefit analysis (amortization period: 25 years).

Benefit - Cost Evaluation		
Estimated incremental cost	[€]	1.17E 05
Risk decrease (ΔR)	[F]	3.13E-03
Value of a life year	[€]	1.5E 06
Annual decrease	[€]	4.7E 03
Amortization	[Y]	25
Benefit	[€]	1.17E 05
BCE		ok

6 Conclusions

Quantitative Risk Analysis shows that the system performance of Electromotive Force and Emergency Lighting, under fixed conditions of emergency scenario, is the primary determiner of risk level relating to the fire events. The evidence of this result is clear if you take methods of analysis “expert and scientifically sustainable”, by improving the traditional methodologies typical of the safety compliance analysis (ex NFPA 130 and Ministerial Decree 10/28/05).

The performance of safety devices (in particular, of emergency lighting) on the characteristic risk profile of the tunnel system are highlighted.

The availability of technical solutions ensures the certified reliability of the performance in case of fire.

High safety standards are obtained at extremely affordable costs.

The compliance with the safety expectations of the community, as required by specific technical, is verified.

In Italy, for both road and rail tunnels, safety targets that suggest safety requirements related to safety levels are fixed.

Operators must prove the achievements of the above safety targets by quantitative risk evaluation.

References

[1] Camillo, A., Guillaume, E., Rogaume, T., Allard, A., F. Didieux, F. (2013). Risk analysis of fire and evacuation events in the European railway transport network. Fire Safety Journal 60, pp. 25–36.

[2] Diamantidis, D., Zuccarelli, F., Westha, A. (2000). Safety of long railway tunnels. Reliability Engineering and System Safety. 67c, pp. 135–145.

[3] Guarascio M., Lombardi M., Rossi G. (2007). Risk Analysis and acceptability criteria. Safety and Security Engineering. II. SAFE Malta, 2007.

[4] Guarascio M., Lombardi M., Rossi G. (2007). Road tunnels safety rules in Italy: the tunnel country. Safety and Security Engineering, II. SAFE Malta, 2007.

[5] Hu, X., Wang, Z., Jia, F., Galea, E.R. (2012). Numerical investigation of fires in small rail car compartments. Journal of Fire Protection Engineering. 22(4), pp. 245–270.

[6] Ingason, A., (2006). Design fires in tunnels. Safe & Reliable Tunnels. Innovative European Achievements, Second International Symposium, Lausanne.

[7] Lombardi, M., Rossi, G., Sciarretta, N., Oranges, N. (2013). Fire design: direct comparison between fire curves. The case study of a nursery. American Journal of Engineering and Applied Sciences. Volume 6, Issue 3, pp. 297–308.

[8] McGrattan, K., Hamins, A. (2006). Numerical Simulation of the Howard Street Tunnel Fire. Fire Technology, 42, pp. 273–281, 2006.

[9] Schebel, K., Meacham, B. J., Dembsey, N. A., Johann, M., Tubbs. J., Alston, J. (2012). Fire growth simulation in passenger rail vehicles using a simplified flame spread model for integration with CFD analysis. Journal of Fire Protection Engineering 2012 22 (3), pp. 197–225.
[10] Vrijling, J. K., van Hengel, W., Houben, R. J. (1998). Acceptable risk as a basis for design. Reliability Engineering and System Safety. 59, pp. 141–150.

www.witpress.com, ISSN 1743-3509 (on-line)

This page intentionally left blank

Chemical risks to workers' health in contaminated sites

S. Berardi & E. Bemporad
Department of Production Plants and Human Settlements, Italian Workers' Compensation Authority (INAIL), Italy

Abstract

The presence of hazardous chemical agents and carcinogens/mutagens in unsaturated soil and/or groundwater, or their use in clean-up activities, doesn't necessarily entail a risk to human health. It depends on the toxicological characteristics, the concentration of the substance, the transport mechanisms and the exposure media. In Italy, the management of chemical risk to workers' health in contaminated sites is currently not standardized. For this reason, in 2013 a team of experts in the management of contamination sites and of occupational risks, coordinated by INAIL, began to work out a document dealing with the operative instructions to protect the health of workers present for any reason in a contaminated site. This document addresses the main aspects related to the protection of workers exposed to contaminants considering both the toxic and the carcinogenic effects of chemicals. In this paper a particular issue, addressed in the document, is discussed: the proposed methodology to check the presence of chemical and carcinogen/mutagen agents at workplace for the inhalation exposure pathway.
Keywords: chemical risk, workers' health, soil contamination.

1 Introduction

A contaminated site can be defined as an area, or portion of a territory, in which anthropogenic phenomena have led to such changes in chemical, physical and/or biological properties of the soil, subsoil and groundwater to cause a hazard for the human health and/or for the environment. The presence of contaminated sites is a common problem in all industrialized countries and derives from the presence of human activities, such as factories, mines, landfills. In Italy,

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150081

potentially contaminated sites are about 32,000 and more than 4,837 are really contaminated by organic pollutants and/or heavy metals [1].

The presence of hazardous chemical agents and carcinogens/mutagens (collectively referred to as "chemical agents" later in the paper) in unsaturated soil and/or groundwater, or their use in clean-up activities, doesn't necessarily imply a risk to human health and safety. It depends on the toxicological characteristics, the concentration of the substance, the transport mechanisms and the exposure media. In Italy, the management of chemical risk to workers' health in contaminated sites is currently not standardized.

For this reason, the Research and Technical-Scientific Sector of the Italian Workers' Compensation Authority (INAIL) is going to publish an operational guidance titled "The chemical risk to workers in contaminated sites". In the document hazards are chemical agents and/or carcinogens/mutagens present in the unsaturated and/or groundwater (these chemicals may, or may not, be correlated with work activities on the site); all the workers present for any reason on a contaminated or potentially contaminated site are likely to be exposed; the exposure modes are vapour and soil dust inhalation, dermal contact and ingestion; finally, the damages taken into account are the occupational diseases from health risks and the injuries from safety risks.

This paper reports the principal contents of the guidance and in particular the proposed methodology to check the presence of chemicals and carcinogen/mutagens at workplace for the inhalation exposure pathway and the criteria to determinate the CR_{air} (the reference concentration for each pollutant in outdoor and indoor air below which workers can be considered as "not actually exposed"), and the strategy for environmental monitoring to make a comparison with the CR_{air}.

2 Description of the procedure

In the guidance, the term "chemical risk management" means the process divided into the following three steps:

STEP 1: Hazard identification: Hazard means the intrinsic property of a chemical agent with the potential to cause harm [directive 98/24/EC]. If the workers' exposure is due to the presence of chemicals in the unsaturated soil and/or groundwater, the hazard identification means to verify their concentration levels in the involved environmental media.

STEP 2: Risk assessment: Risk means the likelihood that the potential for harm will be attained under the conditions of use and/or exposure [directive 98/24/EC]. Only after the presence of the chemical agent is verified, the employer shall proceed with the risk (exposure) assessment related to the specific agent, in compliance with the directives 98/24/EC and 2004/37/EC.

STEP 3: Reduction and control of the risk: Risk to workers' health involving chemical agents shall be eliminated or reduced to a minimum (this is just the goal of the remediation activities but workers' health shall obviously be protected also in the meantime the activities start and during them). Where the results of the assessment reveal a risk to the health of workers, some specific protection, prevention and monitoring measures shall be applied.

The proposed procedure to develop the STEP 1 is outlined in Fig. 1. When a chemical agent contaminates the unsaturated soil and/or groundwater, the legislative decree n.152/2006 requires a comparison between its concentrations measured in the contaminated media and a generic regulatory threshold limit or screening level (CSC). If the CSC is exceeded a risk assessment based on site specific parameters is required to compare the measured concentrations with the result of this assessment or site specific target level (CSR) (STEP 1.1). If the CSR (or the CSC before the site specific assessment) is not exceeded the workers can be considered as "not actually exposed" (the site is not actually contaminated). Otherwise it's possible to monitor the outdoor or indoor air and compare the analytical data with an air reference concentration (CR_{air}) (STEP 1.2). If the CR_{air} is not exceeded the workers can be considered as "not actually exposed". Otherwise, to identify the appropriate procedure it is possible to differentiate between three different types of workers:

1. Reclamation operators, i.e. workers involved in the site investigation, inspection, monitoring, sampling and clean-up action.
2. Workers for whom the chemical risk assessment, conducted on the basis of their job before the employer became aware of the soil/groundwater contamination, identified only a slight risk to the safety and health. These workers can be: administrative clerks or technicians, drivers, security guards, teachers, employees in commercial activities or services.
3. Workers for whom the chemical risk assessment, conducted on the basis of their job, before the employer became aware of the soil/groundwater contamination, revealed a (not slight) risk to the safety and health.

To protect workers' health, the following options are available:

- Option A: Perform actions to make the air concentration less than or equal to CR_{air} (e.g. applying collective protection measures and/or reducing the daily exposure frequency and/or increasing the air exchange rate).
- Option B (STEP 2): Manage the risk to the health of workers (depending on their tasks) according to the legislative decree n.81/2008 (directive 98/24/EC and 2004/37/EC transposition) duties verifying the compliance with OELs by monitoring workplace atmosphere, considering the suggestions of the National guidance document for worker protection from carcinogens and mutagens [2] where exposure to carcinogens or mutagens occurs.

In general, save particular cases, it is reasonable:

- Manage the risk to the health of the reclamation operators (type 1 workers), by selecting the Option B.
- Manage the risk to the health of the workers previously exposed to only a slight risk to the safety and health (type 2), by selecting the Option A. This is desirable especially where workplaces are similar to life places (such as offices, markets, hospitals, schools or banks).
- To manage the risk to the health of the workers already exposed to a (not slight) risk to the safety and health (type 3), by selecting the Option A or B according to the specificity of the case.

www.witpress.com, ISSN 1743-3509 (on-line)

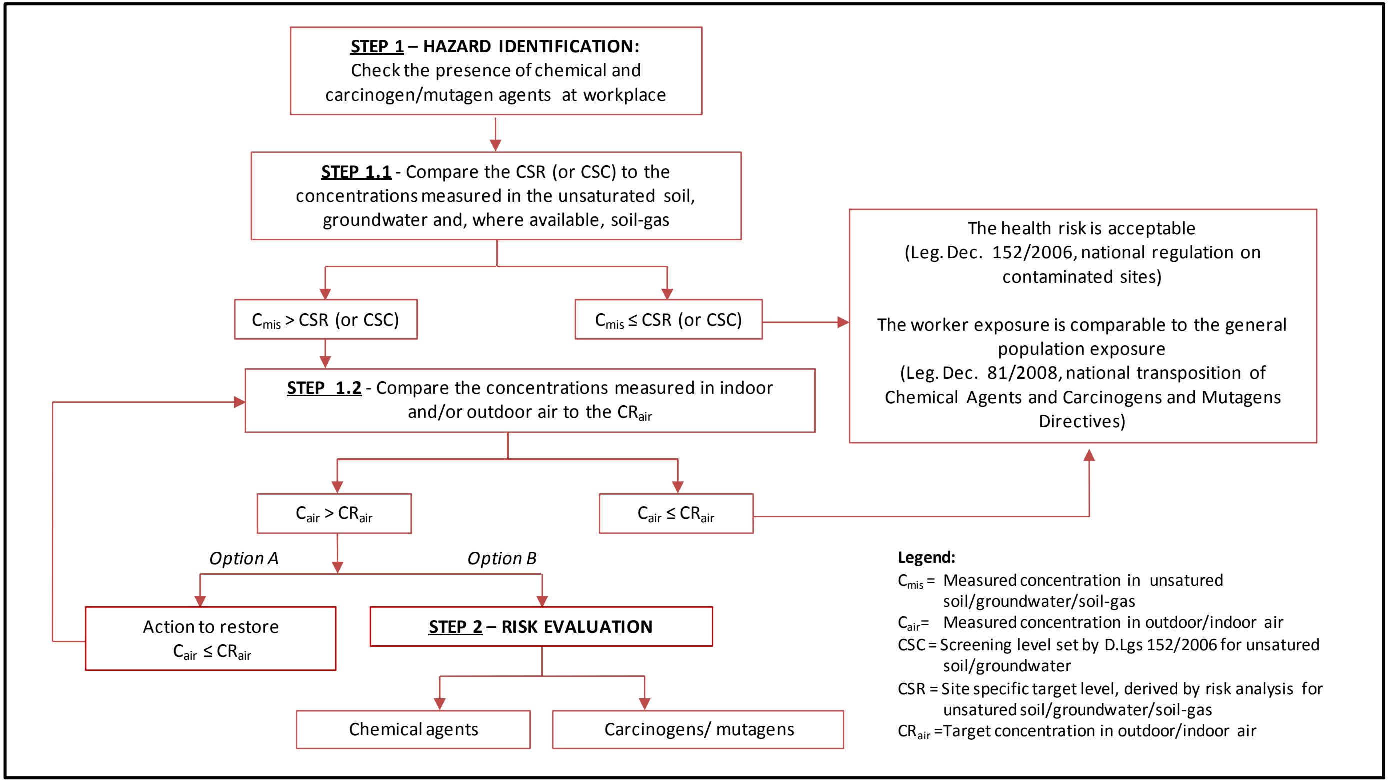


Figure 1: Procedure flow sheet for hazard identification.

In the phase of "hazard identification" it isn't necessary to distinguish between chemical agents and carcinogens/mutagens, because the CR_{air} can be reasonably considered as a reference level for the general population.

3 Reference values for chemical agent concentrations in air (CR_{air})

Reference values must be defined for concentrations of chemicals agents in air to compare with the actual values measured by environmental monitoring or estimated by quantitative models. The CR_{air} defined in the Operational Guide provides a basis for protecting workers' health to be adversely affected by inhalation of hazardous or carcinogen vapor and suspended particles. Below the CR_{air} the risk to the safety and health of workers is certainly slight or, for carcinogens or mutagens, the workers are "not exposed". To satisfy this requirement the total concentration of each soil (or groundwater) pollutant in air shall not be greater than its CR_{air}. The total concentration in air is equal to the sum of the concentration in the vapor phase and, where applicable, in the thoracic fraction (PM_{10}) of the suspended particles measured during the monitoring campaigns. The CR_{air} is valid for both indoor and outdoor air because the site of exposure does not directly affect the exposure–response relationship [3].

The criteria to determine CR_{air} (Fig. 2), provide the following steps:

Step 1: The CR_{air} coincides with the background level, when available. Background level shall be measured where the pollution level is not dominated by a single source (industry, traffic or residential heating), but is influenced by the integrated contribution from all sources upwind of the station. The position of the background measurement stations shall be locally assessed depending on the site context (rural, urban, industrial area), according to the criteria laid down by the directive 2008/50/EC on ambient air quality and cleaner air for Europe. Air quality data collected by the monitoring network managed by public or private entities and compliant with regulatory requirements are published by the National Institute for the Environmental Protection and Research [4]. Where the presence of the chemical agent is related to local sources other than polluted soil or groundwater (e.g. traffic, strongly anthropic areas) and a background level is not available, its determination should be case-specific according to criteria agreed with the Competent Authority. Finally, where the background level is lower than the calculated CR_{air} (step 3) the adoption of this latter value for CR_{air} is anyway conservative.

Step 2: CR_{air} coincides with national or international limit/target/guideline value, when available. The Legislative Decree n. 155/2010, national transposition of the directive 2008/50/EC, in order to protect human health, among the soil pollutant listed by the Legislative Decree n. 152/2006 regulates benzene, some heavy metals, particularly arsenic, cadmium, lead, nickel and also benzo[a]pyrene in the PM_{10} fraction of suspended particulate matter. For other pollutants, it is possible to refer to WHO Air quality guidelines. The pollutants of concern for soil addressed by the Air quality guidelines for Europe [3] and by the guidelines for indoor air quality [5] are mercury, chromium (VI), manganese, vanadium, styrene, toluene, 1,2-dichloroethane, dichloromethane, trichloroethylene, tetrachloroethylene, vinyl chloride, polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCB). WHO guideline values for 1,2-dichloroethane, dichloromethane and tetrachloroethylene are at present based on noncarcinogenic effects while they are all classified as carcinogens both by the UE (cat. 1B or 2) and the IARC (Group 2A or 2B). Then in specific cases the opportunity to take into account the carcinogenic effects of these pollutants should be assessed. In these cases the next steps (2 or 3) are appropriate.

Step 3: The CR_{air} is calculated applying the risk assessment procedure in backward mode that is setting the acceptable level for the human health risk and selecting the most conservative value between the ones calculated for carcinogenic and noncarcinogenic effects:

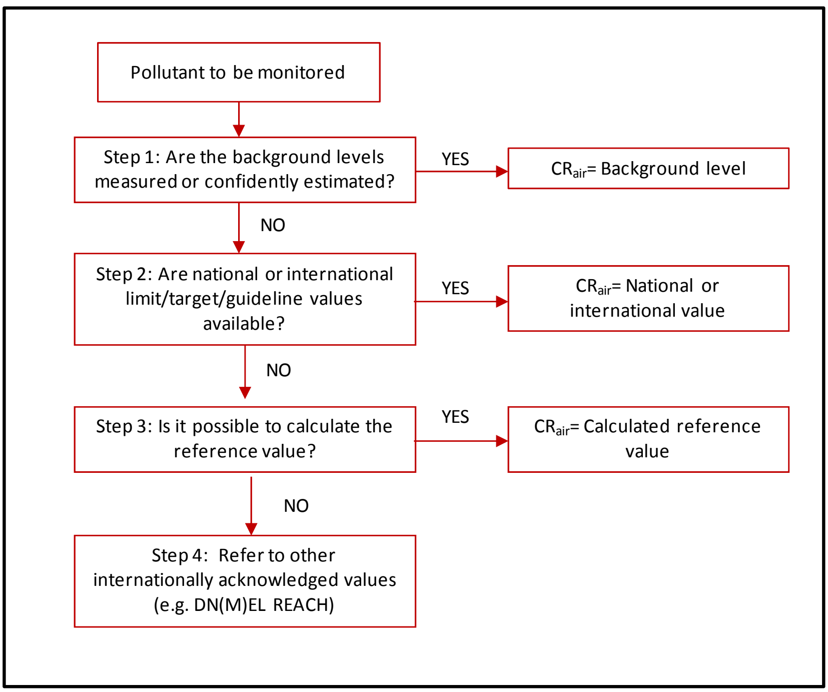


Figure 2: Procedure to define the CR_{air}.

$$CR_{air}\left[\frac{\mu g}{m^3}\right] = \frac{TR}{EM \cdot SF_{\text{inhal}}} \times 10^3 \qquad \text{carcinogenic effects} \qquad (1)$$

$$CR_{air}\left[\frac{\mu g}{m^3}\right]=\frac{THQ\cdot RfD_{inhal}}{EM}\times 10^3 \quad \text{noncarcinogenc effects} \tag{2}$$

where:

TR is the acceptable value for the individual risk from carcinogenic substances;

SF_{inhal} is the inhalation Slope Factor value for the pollutant of concern;

THQ is the acceptable value for the individual non carcinogenic risk (Target Hazard Quotient);

RfD_{inhal} is the inhalation Reference Dose value for the contaminant of concern;

EM is the effective Exposure Rate defined as the quantity of inhaled air per body weight unit, estimated by the following expression [6]:

$$EM\left[\frac{m^3}{Kg\times day}\right]=\frac{B_{air}\times EF_d\times EF\times ED}{BW\times AT\times 365\,\frac{days}{year}} \tag{3}$$

The Legislative Decree n.152/2006 sets acceptable values for the individual carcinogenic risk ($TR=10^{-6}$), the cumulative carcinogenic risk ($TR_{CUM}=10^{-5}$) and the individual and cumulative risk for noncarcinogens ($THQ=THQ_{CUM}=1$). Table 1 contains the definition and default values of the parameters to be used for EM and then CR_{air} calculations [6]. The site-specificity of the exposure factors to derive contextualized target values is anyhow recommended.

Table 1: Default exposure factors for CR_{air} calculation.

Exposure Factor (EF)		**Symbol**	**Unit**	**Industrial/ commercial**
				Adult
Body weight		BW	Kg	70
Average exposure time to carcinogens		AT_c	years	70
Average exposure time to noncarcinogens		AT_n	years	ED
Exposure duration		ED	years	25
Exposure frequency		EF	days/year	250
Daily exposure frequency		EF_d	hours/day	8
Outdoor/indoor inhalation rate by activity level	Sedentary/ Passive	B_{air} (B_o/B_i)	m^3/hour	0.90
	Moderate Intensity			1.50
	High intensity			2.50

When the calculated value results lower than the Limit of Quantitation (LOQ) of the selected analytical method, the CR_{air} should coincide with the same LOQ. The Operational Guidance contains a list of some available analytical methods with their LOQs.

Step 4: When the background level cannot be measured or confidently estimated and neither the CR_{air} is calculable as the pollutant is not carcinogenic by inhalation and an inhalation RfD (for noncarcinogenic effects) is not available, other internationally acknowledged values could be used. For example the Derived No (Minimum) Effect Level DN(M)EL estimated for the specific target, long term, systemic (or local when more precautionary) effects, by entities subjected to REACH can be considered [7].

4 Air monitoring

The environmental investigation is aimed at the comparison with the defined CR_{air}. An overall strategy shall be developed to allow the collection of samples being representative of the actual exposure of the workers by both spatial and temporal points of view.

For indoor air the monitoring strategy can be developed referring to the National Institute of Health indications [8]. For outdoor air references are available in the directive 2008/50/EC considering the exposure to pollutants derives from soil or groundwater contamination. Some indications, particularly referring to industrial sites, are reported below.

Sampling techniques. Indoor/outdoor air according to specific technical EN standards can be monitored by:

- Personal sampling: the equipment is placed on the employee and samples air in the breathing zone;
- Static sampling: the equipment is placed in a fixed location in the area of concern.

In the cases of our concern the following indications refer to environmental sampling.

Spatial distribution of sample points. The number of sampling points is strongly related to the extension of the contamination source. For outdoor air at least on sample per homogeneously polluted area should be planned. In general a point is representative of an area surface of no more than 2500 m^2 (50 m x 50 m) [6]. Where the site is contaminated by hydrocarbons, for which notable concentration gradients are expected, a lower distance (e.g. 10-20 m) is advisable. To define homogeneously polluted areas is possible to refer to the criteria for site area division laid down in the national guidelines for the application of human-health risk assessment [6]. Limiting the search to within 30 metres of the site boundary, except where a preferential pathway (e.g., utility corridor) exists that connects the site to contaminated media further than 30 metres away, is recommended [9]. Where the homogeneously polluted area is large (>5 ha) sampling locations shall be selected by reasoned criteria guaranteeing the entire area to be represented. The sampling devices shall be located where the exposure (detected contamination and workers presence) is maximum. For indoor air, buildings within 100 feet (30 m) laterally of subsurface vapor sources (or 100 feet vertically of underlying vapor sources) should be considered "near" for purposes of a preliminary analysis, under the assumption that preferential vapor migration pathways are absent [10]. At least one sampling device shall be placed away from the influence of local emissions. To characterize indoor air a sample per each room is not generally needed and a representative room on the ground floor or basement if present, where the exposure is maximum, can be identified.

Sample and monitoring duration. Each sample shall go on for a time equal to the daily exposure frequency (EF_d in Tab. 1) associated to the selected CR_{air} value. Generally sample duration shall comply with EN 689/1997 standard indications for the determination of shift values, except for specific conditions to be case-by-case assessed. The measurements to determine the environmental concentration should go on for 5-14 days [8]. Measurement campaigns should be at least one during summer and one during winter to appraise seasonal variations related to meteorological conditions and/or cycles of activity. On the basis of the initial measurement results the monitoring plan should be updated. The duration shall be associated to the selected CR_{air} value, representative of all the possible exposure conditions and particularly of the worst ones.

5 Conclusions

This paper illustrates some features of an operational guidance to be published by the Italian Workers' Compensation Authority (INAIL) to assist the employer or the supervisory authority in the management of the chemical risk to workers in contaminated sites, not still standardized.

A way to identify the presence of a risk to the workers' health by inhalation of hazardous chemical agents and/or carcinogens/mutagens from contaminated soil or groundwater is provided, to decide if the risk assessment related to these chemical agents, in compliance with the directives 98/24/EC and 2004/37/EC, is necessary. An overall procedure to manage the risk is outlined differentiating three types of workers according to their activities and tasks. The opportunity to differentiate the way to proceed in function of the eventual overlapping of environmental and other occupational exposure has been so far generally neglected in the current practice. The paper focuses then on the criteria to define the reference values for hazardous or carcinogen vapor and suspended particles in indoor and outdoor air (CR_{air}) to allow the comparison with the actual measured or estimated values. Where air measurements are carried out monitoring strategies are finally outlined. A plain tool to check the presence of chemical and carcinogen/mutagen agents at work for the inhalation exposure pathway, harmonising the environmental and occupational regulations, is so made available.

References

[1] ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale, Annuario dei dati ambientali 2012, Roma, IT, 2013, online at http://annuario.isprambiente.it/content/indice?v=10

[2] Italian Technical Coordination of the Regions and Autonomous Provinces for Occupational Safety (2002) Titolo VII Decreto Legislativo n.626/94 Linee Guida: Protezione da agenti cancerogeni e mutageni, Aggiornamento 2002

[3] WHO, Air Quality Guidelines for Europe, 2° Edition, WHO Regional Publications, European series n. 91. Copenhagen, World Health Organization Regional Office for Europe, 2000

[4] ISPRA/BRACE, Dati e metadati di Qualità dell'aria, SINAnet, National Environmental Information System, online at http://www.brace.sinanet.apat.it/web/struttura.html, last updated 21 November 2013

[5] WHO, Guidelines for indoor air quality: selected pollutants, Copenhagen, World Health Organization Regional Office for Europe, 2010

[6] ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale, Criteri metodologici per l'applicazione dell'analisi assoluta di rischio ai siti contaminati (rev. 2), Roma, IT, 2008

[7] European Chemicals Agency, Database for information on registered substances, online at http://echa.europa.eu/information-on-chemicals/registered-substances, last updated 24 January 2014

[8] ISS Istituto Superiore di Sanità, Strategie di monitoraggio dei Composti Organici Volatili (COV) in ambiente indoor, edited by the "Gruppo di Studio Nazionale sull'Inquinamento Indoor dell'ISS", 2013, online at http://www.iss.it/binary/pres/cont/ambiente_indoor.pdf

[9] BCME British Columbia Ministry of Environment, Technical Guidance on Contaminated Sites, July 2009, online at http://www.env.gov.bc.ca /epd/remediation/guidance/technical/pdf/tg04-draft.pdf

[10] USEPA, Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites, Office of Emergency and Remedial Response U.S. Environmental Protection Agency, Washington, DC 20460OSWER 9355.4-24 December 2002

Evaluation of microshock risk during a surgical procedure

G. L. Amicucci[2], E. Zennaro[1], F. Fiamingo[2] & C. Mazzetti[1]
[1]*Department of Astronautics, Electrical and Energetics Engineering (DIAEE) Electrical Engineering Section, Sapienza Università di Roma, Italy*
[2]*Department of Safety Technology (DTS), Research, Certification and Verification Sector, Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL), Italy*

Abstract

During a surgical procedure, risk assessment is important in order to prevent undesired patient's ventricular fibrillation. Even weak currents flowing through the heart of a patient are potentially able to cause such a dangerous event.

The hazard can be reduced through the adoption of suitable protection measures, chosen by means of an in-depth investigation of the microshock probability.

Such a probability is obtained by the product of the probability of ventricular fibrillation when certain fault conditions occur and the probability of occurrence of the considered fault conditions. The fault conditions here considered are able to determinate certain values of the leakage current that can flow through the patient's body.

A method for the microshock probability assessment is presented based on the leakage current estimation that is obtained by simulation of an electrical circuit model of a typical surgical layout.

The layout in question is composed of an operating table, a patient monitor and a defibrillator; all supplied by a medical IT system. Leakage currents flowing from this medical equipment to the chest of the patient, are measured in normal and in fault conditions. The permitted leakage current values are obtained by the international standard IEC 60601-1, and an estimate of the probability of

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150091

ventricular fibrillation at different values of the leakage current is obtained by the Annex A (rationale) of the same standard.
Keywords: microshock risk, defibrillator, operating table, patient monitor.

1 Introduction

Operating theatres are workplaces where the protection from electrical injuries is critical. In fact several Medical Electrical Equipment (MEE) are used by medical workers and are in contact with the patient in order to perform their function.

During open heart surgery and when catheters are in use, it is necessary to minimize leakage currents that may flow through the patient. Current as low as 10 μA through the heart may be fatal causing ventricular fibrillation (microshock).

To prevent risks, power systems supply must operate with a high degree of reliability and quality. A safe use of MEE can be accomplished by selecting proper circuit mitigating interventions [1, 2].

In literature some microshock events are reported (see for instance [3–5]). International standards give information on the ventricular fibrillation probability.

Such a probability depends on the current that flows through the heart.

During a surgical procedure or when a MEE is applied to a patient for diagnosis or therapy, a fault condition could eventually determinate values of the leakage current flowing through the patient by the MEE that are potentially dangerous. Hence, the microshock probability can be evaluated by the product of the probability of ventricular fibrillation and the probability of occurrence of the considered fault conditions, as discussed in [6].

The simulations presented in the paper have been used to quantify the microshock probability and, consequently, to identify which interventions can reduce the risk under a tolerable level.

In a previous paper [7], a method for the modeling of a safety oriented electrical circuit of a defibrillator and the results of leakage current simulations were shown. The usefulness of those simulations is explained in the present paper which extends the simulation to the electrical circuit model of a surgical layout composed by an operating table, a patient monitor and a defibrillator, all supplied by a medical IT system. The circuit model is deeply explained in section 2. In section 3 the limit values of leakage currents evaluation in fault conditions are considered. In section 4 the microshock probability is evaluated and in section 5 the results of such evaluation are presented and discussed. In section 6, some conclusion and further development of the work are formulated.

2 Surgical layout circuit model

2.1 Electrical circuit model of medical equipment

In the paper [7] the electrical circuit model of a MEE has been obtained by using electrical safety tests on a real MEE and information on electrical insulations.

The tests have been accomplished according to the procedure described in the applicable international standards [8, 9].

Medical equipment modelled in this work are a patient monitor, an operating table and a defibrillator. The first two MEEs are always involved in surgical procedures, the third equipment can be put into operation during emergencies, for example, when ventricular fibrillation occurs. So, we draw a circuit model of a typical surgical layout.

Electrical circuit models of three MEE are obtained by results of a campaign of measures accomplished by the Clinical Engineering Unit (CEU) of the hospital Campus Bio-Medico in Rome in accordance with the measurement set-up described in the international standard EN 62353 [9]. In particular, equipment leakage currents (ELCs) and applied part leakage currents (APLCs) are obtained by the direct test method described in the standard. The circuits are simulated with Multisim a software by National Instruments.

The patient monitor modelled is a class I MEE which can be supplied with 230 V AC. It is composed by six floating type applied parts (CF-type and BF-type) which can be divided in three groups considering the different functions performed. They are the ECG monitoring by CF-type electrodes, the oxygen saturation monitoring by the BF-type pulse oximetry and the blood pressure monitoring by the BF-type sphygmomanometer.

The operating table is a class I equipment with body type (B) applied part, i.e. the table top where the patient lies during the surgical procedure.

The defibrillator is a class I equipment with three CF-type applied parts which perform the ECG monitoring and two BF-type applied parts which are the defibrillator electrodes, its model was already presented in the paper [10].

The values of the electrical parameters and the simulated leakage currents of each MEE alone, i.e. considered by itself, are not reported since they don't differ significantly from those reported in [7]. The model of the complete layout, instead, is presented here for the first time.

2.2 Electrical circuit model of a medical IT supply system

There are suitable measures preventing faults which can be applied to electrical system and equipment in an operating theatre in order to reduce the microshock risk, as it is shown in [2]. The two main mitigating interventions are the medical IT system (IT-M), which supplies MEE by isolating the secondary windings of the transformer from the earth constituted by the equipotential bonding bar, and the equipotential bonding between equipment connected to the patient that avoids the voltage drop and the eventual flow of dangerous leakage currents through the patient's body.

Moreover, the international standard IEC 60364-7-710 [11] fixes equal to 500 μA the maximum admissible value of the earth leakage current of the unloaded isolation transformer. And the same standard fixes to 200 mΩ the maximum admissible value of the conductor and connection resistances between the earth terminal of the mains plug and the equipotential bonding bus bar. Finally, the standard IEC 62353 permits that the maximum value of resistance between the earth terminal of the mains plug and the protectively earthed accessible conductive parts of the MEE be equal to 300 mΩ. Hence, in the circuit model of the surgical layout used in the simulations the PE conductors comply with such admissible values and the isolation to earth of the secondary winding is modeled with two stray capacitances of each phase conductor to earth [12].

2.3 Electrical circuit model of patient

According to [13], the patient is simulated by a network of five resistances representing left arm, R25, trunk, R51, left leg, R50, right arm, R1 and right leg, R26. The sum of three resistances belonging to one side of the human body is equal to the conventional value of 1 kΩ. It is the same for the other side of the human body. Indeed a percentage of 47.2% of the total body resistance is assigned to one arm, which is mainly composed of bones, a 1.3% is assigned to trunk, assumed to be a cylinder full of saline water highly conductive with a discrete amount of bones, and a percentage of 51.5% is assigned to each leg, which is larger than the arm but with similar organic content.

Figure 1 shows the three MEE connected with the patient and supplied by a medical-IT system.

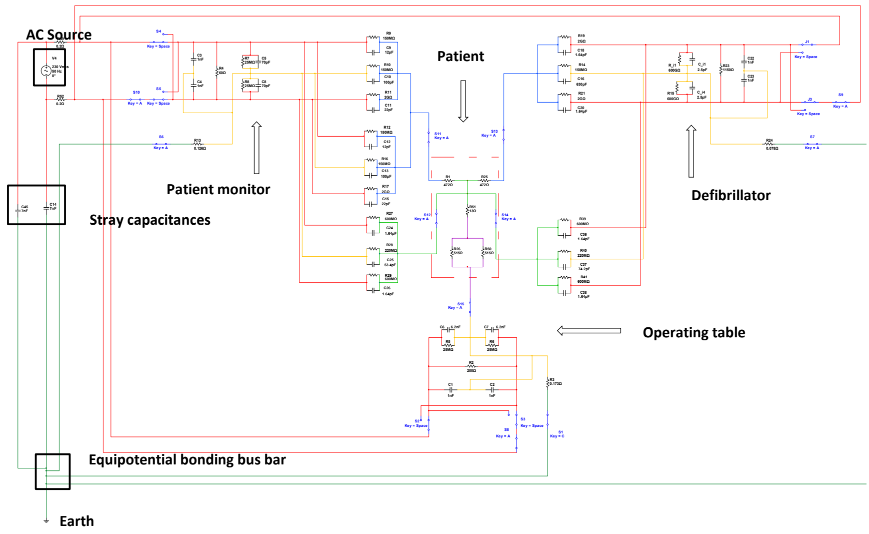


Figure 1: Electrical circuit model of three MEE in contact with the patient in an operating theatre.

3 Leakage currents evaluation in fault conditions

3.1 New limit values

Limit values of leakage current reported by international standards are based on a series of studies.

In the present paper it has been taken as a reference the relationship between the values of the leakage current with the probability of ventricular fibrillation that has been presented in [14]. Values of current flowing through the heart of the patient leading to a probability of ventricular fibrillation less or equal than 1% are not considered as eventually dangerous. However, since similar threshold limits are chosen on a probabilistic base to be effective for a large fraction of the population, some authors consider as possibly dangerous also lower values [15]. In fact, currents lower than 50 μA could be dangerous for patients, with some heart disease, during cardiac surgical procedures. In a study performed on 40 patients affected by several cardiac pathologies [16], an alternate current was given through a pacing catheter placed near the right ventricular apex. New limit values were recorded as potentially dangerous for patients. These are 20 μA, 32 μA and 49 μA. These are the threshold values considered in this paper to underline the most dangerous fault conditions that could occur during a surgical procedure in an operating theatre.

4 Microshock probability evaluation

4.1 Probability of ventricular fibrillation

According to the reference [8] some ventricular fibrillation probability values are identified and reported in Table 1.

Table 1: Relationship between leakage current values and probability of ventricular fibrillation in fraction.

Current [μA]	Damage probability
20	0.003
32	0.005
40	0.007
50	0.01
60	0.015
100	0.065
150	0.25
200	0.5
250	0.78
300	0.94
1000	1

www.witpress.com, ISSN 1743-3509 (on-line)

4.2 Probability of occurrence of undesired events

According to the standard [8] some undesired events are identified and the occurrence probability values are reported in Table 2. The probability of these events is evaluated in terms of number of surgical procedures. So a probability of 0,01 corresponds to 1 occurrence every 100 surgical procedures.

Table 2: Occurrence probabilities, in fraction, of determined undesired events.

Undesired condition	Occurrence probability
Degradation of applied part insulation	0.01
Double fault to one equipment	0.01
Single fault to two equipment together	0.01
Single fault to one equipment	0.1

The probability of occurrence of a single fault condition, as the fault of the PE conductor in a class I MEE, is considered equal to 10%, while the probability of occurrence of a double fault condition is evaluated by squaring such value (i.e. by considering the failure of two insulations, or two means of protection, as independent events).

For example, taking into account a floating type applied part, its insulation should be considered as composed by two insulations whose failures are independent; the fault probability of both could be calculated by squaring 0.1 as reported in Table 2.

5 Results

5.1 Results of leakage current evaluation

In this section the results of simulations of the circuit model shown in Fig. 1 are presented. The values of leakage current monitored at the chest of the patient are simulated in these conditions:

a) Normal condition, when three MEE operates without faults;
b) Single fault condition, when a mains part or the PE conductor linked with one MEE is disconnected;
c) Double fault condition, when the events in b) occurred together to the same MEE, or occurred singly to two of three MEE in a determined period of time;
d) Degradation of the insulations of one MEE;
e) Normal polarity of all equipment, inverse polarity of all equipment, and inverse polarity of each apparatus in turn.

Values of potentially dangerous leakage currents flowing through the resistance of the trunk, R51, are shown in Table 3 for condition c) and in Table 4 for condition d) in the case of patient monitor. There are no relevant differences if one would consider the other two pieces of medical equipment.

Table 3: Leakage currents simulated in different fault conditions.

Fault condition	Patient's chest leakage current
Disconnection of a mains part and disconnection of PE of the operating table	58,8 μA
Disconnection of a mains part and disconnection of PE of the defibrillator	29,7 μA

Table 4: Leakage currents simulated during electrical insulations ageing of patient monitor.

BF-type applied part – MP1 insulation		
Capacitance [pF]	**Impedance[MΩ]**	**Current [μA]**
12	130	1.57
600	5.3	20
900	3.5	30.2
1500	2.1	50.1
Resistance [MΩ]	**Impedance[MΩ]**	**Current [μA]**
150	130	1.57
10	10	12
0.5	0.5	223
0.051*	0.051	1020
BF-type applied part – MP2 insulation		
Capacitance [pF]	**Impedance[MΩ]**	**Current [μA]**
22	144	1.57
600	104	21
920	0.5	31.9
1450	0.051	49.5
Resistance [MΩ]	**Impedance[MΩ]**	**Current [μA]**
2000	144	1.57
150	5.3	1
0.5	3.4	221
0.051*	2.1	1020

Table 4: Continued.

CF-type applied part – MP1 insulation		
Capacitance [pF]	**Impedance[MΩ]**	**Current [µA]**
1.64	573	1.57
600	5.3	20.3
900	3.5	30.5
1500	2.1	50.5
Resistance [MΩ]	**Impedance[MΩ]**	**Current [µA]**
600	573	1.57
150	149	2.10
0.5	0.5	223
0.051*	0.051	1030
CF-type applied part – MP2 insulation		
Capacitance [pF]	**Impedance[MΩ]**	**Current [µA]**
1.64	573	1.57
600	5.3	21.7
900	3.4	31.9
1450	2.2	50.2
Resistance [MΩ]	**Impedance[MΩ]**	**Current [µA]**
600	573	1.57
150	149	1.10
0.5	0.5	221
0.051*	0.051	1020

*Value just greater than the threshold value equal to 50 kΩ signalled by the insulation monitoring device [11].

5.2 Results of microshock probability evaluation

As anticipated in section 1 the microshock probability is evaluated by the product of the probability of ventricular fibrillation and the probability of occurrence of fault conditions.

In Table 5 the results of microshock probability are reported.

The tolerable limit for the microshock probability is assumed 10^{-3}, as reported by the standard [8]. The degradation of the insulation between an applied part and a mains part, whose impedance goes down to a value of few kiloohms, lead to the greatest and not tolerable value of the microshock probability. The minimum value of the insulation resistance, leading to patient leakage current

Table 5: Microshock probability values, according to the identified fault conditions.

	Fault condition	Probability of microshock
1.	Degradation of AP insulation to 0.05 MΩ	10^{-2}
2.	Degradation of AP insulation to 0.5 MΩ	$5*10^{-3}$
3.	Double fault condition to the operating table	10^{-4}
4.	Degradation of AP insulation to 2 MΩ	10^{-4}
5.	Double fault condition to the defibrillator	$5*10^{-5}$
6.	Degradation of AP insulation to 3 MΩ	$5*10^{-5}$
7.	Degradation of AP insulation to 5 MΩ	$3*10^{-5}$

near 300 μA and to a ventricular fibrillation probability of 94%, is 380 kΩ. In this case, the microshock probability is equal to $9.4*10^{-3}$. The value reported in the first row of Table 5 has to be intended as the maximum value of microshock probability that can be reached with the minimum value of insulation resistance which is not signalled by the insulation monitoring device. In fact, the applied part insulation failure is considered to occur 1 times every 100 procedures, whatever is the severity of insulation breakdown. This hypothesis is important to underline the importance of the dielectric strength tests to each insulation fulfilled by the fabricant of the MEE. In fact, the occurrences of undesired event reported in Table 2 have been evaluated considering the independence of failure behaviour of each insulation, if it were not so, the occurrence probabilities would be greater. Also non-destructive tests on insulation resistance have to be performed before the acceptance of the equipment in the operating theatre and periodically, as required by [9]. The insulation resistance tests should be performed in addition to the leakage current measurement. In fact it can be proved by model simulations that performing the APLC test on a BF-type applied part of the patient monitor with the insulation resistance to the mains part down to 51 kΩ, the leakage current measured by the tester is 8 μA. So one cannot notice the deterioration occurred to the equipment under test. On the contrary this condition is severe and can lead to a not tolerable microshock probability during a surgical procedure, as shown in Table 5.

Another event considered is the double fault condition of the operating table. Though the microshock probability result is under the threshold of 10^{-3} an incorrect maintenance and inspection of the operating theatre could cause accidents. It is very important to maintain carefully the power supply cord to prevent its damage. For information on similar events see [17]. Moreover, if the table has an internal electrical power source it has to be disconnected from the mains source during a surgical procedure. These interventions prevent not only the microshock risk but also the burns due to the adoption of electrosurgery which are more likely to occur.

The IEC 60601-1 [8] refers that the probability of occurrence of undesired events listed in Table 2 would be less than those reported there. Improvements in design, more reliable components, better materials and the use of risk management processes would decrease the probability down to 2% for the occurrence of a single fault condition and 0.04% for the double fault condition and the degradation of the insulation of an applied part. These values would decrease the microshock probability under the tolerable limit accepted. So, failure rates of electrical insulations of medical equipment should be communicated to the responsible organizations, if it were not so, one should measure the insulation resistance before the acceptance of the medical equipment and also the interval between two inspections should be defined.

6 Conclusions

Operating theatres are locations where microshock risk has to be assessed to prevent the ventricular fibrillation due to dangerous leakage current that may flow through the patient. In this paper a method for the evaluation of the microshock probability is presented in order to investigate and to choose the mitigating interventions.

An electrical circuit model of a surgical layout composed by the electrical supply system, the patient, an operating table, a defibrillator and a patient monitor is shown. Undesired events have been identified by simulations of leakage currents flowing through the chest of the patient in different fault conditions.

The degradation of applied part insulations is the hazardous fault.

However, the microshock probability is tolerable if the occurrence of the event is equal to 0.04%. The insulation resistance values should be known before the acceptance of a MEE and they should be periodically measured to prevent the increase of the microshock probability due to the ageing of the insulation. Though the MEEs have passed the electrical safety tests, a risk for patients to be victims of electroshock remains, so by measuring the insulation resistances of a MEE it is possible to know the microshock probability related to its use during a surgical procedure.

In conclusion, this method permits the probabilistic microshock risk assessment by simply measuring the resistance of the insulations of an applied part and then by simulating the surgical layout by its electrical circuit model.

Acknowledgements

The authors are grateful to the Clinical Engineering Unit of University Campus Bio-Medico of Rome for their support during measurements and to Eng. Simone Sepe for his valid support during the model development.

References

[1] G.L. Amicucci, L. Di Lollo, F. Fiamingo, V. Mazzocchi, G. Platania, D. Ranieri, R. Razzano, G. Camin, G. Sebastiani, P. Gentile, Electrical safety during transplantation. *Transplantation Proceedings*, Elsevier, 42, pp. 2175-2180, 2010.

[2] G.L. Amicucci, F. Fiamingo, C. Mazzetti, Gli impianti elettrici ospedalieri: indicazioni costruttive e di utilizzo, in Italian, *ISPESL Ed., Monograph, Supplement to Prevention Today,* 1, 2008, pp. 19-54 –ISBN 9788889415444
[3] C.-Y. Yan, X.-J. Cai, Y.-F. Wang, H. Yu, Ventricular fibrillation caused by electrocoagulation in monopolar mode during laparoscopic subphrenic mass resection, *Surgical Endoscopy,* 25, 309-311, 2011.
[4] M.K. Chernovsky, J.E. Sipe, R.A. Ogle, Evaluation of health care operating rooms as wet/dry locations, *The final report*, The Fire Protection Research Foundation, 2010.
[5] D.H. Atkin, L.R. Orkin, Electrocution in the Operating Room, *Anesthesiology*, 38 (2), 181-183, 1973.
[6] G.L. Amicucci, F. Fiamingo, E. Zennaro, L. Poggi, Gestione del rischio per la protezione e la sicurezza dei sistemi elettrici a servizio delle strutture ospedaliere in Italian, *VII edition of VGR 2012, Valutazione e Gestione del Rischio negli Insediamenti Civili ed Industriali*, Pisa (Italy), October 3–5, 2012.
[7] E. Zennaro, C. Mazzetti, F. Fiamingo, G.L. Amicucci, Circuit model of medical equipment for electrical safety purposes, paper presented at the *WIT 5th International Conference on Safety and Security Engineering 2013*, Rome (Italy), 2013.
[8] CEI EN 60601-1 "Medical electrical equipment – General requirements for basic safety and essential performance" 3rd ed., 2007.
[9] IEC EN 62353: Medical electrical equipment – Recurrent test and test after repair of medical electrical equipment, 1st ed., 2008.
[10] E. Zennaro, G.L. Amicucci, F. Fiamingo, C. Mazzetti, Circuit model of a medical equipment for electrical safety assessment, *manuscript submitted for publication on International Journal of Safety and Security Engineering*.
[11] IEC 60364-7-710: Electrical installations of buildings – Part 7-710: Requirements for special installations or locations – Medical locations, 2002.
[12] T. Kisielewicz, G.B. Lo Piparo, F. Fiamingo, C. Mazzetti, B. Kuca, Z. Flisowsky, Factors affecting selection, installation and coordination of surge protective devices for low voltage systems, Electric Power Systems Research, ISSN: 0378-7796, vol. 113, 2014.
[13] IEC/TS 60479-1: Effects of current on human beings and livestock – Part 1: General aspects, 4th ed., 2005.
[14] A.B. Watson, J.S. Wright, J. Loughman, Electrical thresholds for ventricular fibrillation in man. *Medical Journal of Australia*, 1(24), 1179-1182, 1973.
[15] M. Laks, R. Arzbaecher, J. Bailey, A. Berson, S. Briller, D. Geselowitz, Will relaxing safe current limits for electromedical equipment increase hazards to patients? *Circulation*, 89 (2), 909-910, 1994.
[16] C.D. Swerdlow, W.H. Olson, M.E. O'Connor, D.M. Gallik, R.A. Malkin, M. Laks, Cardiovascular collapse caused by electrocardiographically silent

www.witpress.com, ISSN 1743-3509 (on-line)

60-Hz intracardiac leakage current: Implications for electrical safety, *Circulation,* 99, 2559-2564, 1999.
[17] N.M. Courtney, E.P. McCoy, R.J. Scolaro, P.A. Watt, A serious and repeatable electrical hazard – compressed electrical cord and an operating table, *Anaesthesia and Intensive Care*, 34, 392-396, 2006.

Section 2
Critical infrastructure protection

This page intentionally left blank

Quantum technology in critical infrastructure protection

M. Karol & M. Życzkowski
Institute of Optoelectronics, Military University of Technology, Poland

Abstract

Finding effective ways of critical infrastructure object protection requires more recent and more sophisticated security systems. Particularly important security aspects are information protection and perimeter security. Development of a new quantum technology, both in quantum computing and quantum cryptography, gives the necessary technology needed to build single photon optic fiber systems. The authors would like to present concepts of using single photon interferometers to protect infrastructure facilities which, in particular, take into account optical fiber transmission lines. The conducted analysis of what is available on market systems and the expected single photon sensor's properties in terms of security and information show a drop in detection. We also compared the degree of systems' complexities in terms of system security and difficulties associated with devices' construction and installation in transmission lines.

The paper presents the main principles of single-photon interference, the operation and construction of single photon systems in the detection and generation of single photons for the purpose of commercial systems. The concept will be described as perimeter protection and the protection of a transmission line by a single photon sensor. The authors discuss the proposed construction and operation of the proposed fiber optic single photon interferometer as a protection sensor. They also try to bring the possibility of using the sensor in areas other than the protection of transmission lines and compare the predicted properties of single photon sensor currently implemented solutions in the field of fiber optic sensors for perimeter protection.

Keywords: single photon, QKD, security, critical infrastructure.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150101

1 Introduction

As a critical infrastructure we must consider systems and their constituent functionally interconnected objects, including building structures, equipment, installations, services essential to safety of the state and its citizens in order to ensure the smooth functioning of public administration, as well as institutions and entrepreneurs. With a view to crisis management law, data transmission infrastructure between government departments can be assigned as a critical infrastructure requiring special protection.

Rapid development of computing power makes it difficult to generate safe encryption key and efficient encryption algorithms to protect classified information. The constant increase of the transmitted data rate increases difficulties with ensuring data safety in growing data volume transmission. In addition, technology development of quantum computers' construction creates a security risk for almost every existing encryption algorithm.

Therefore, in order to ensure classified information transmission safety it is necessary to apply "one time pad" algorithms which use an encryption key only once, and the key is of the same length as the transmitted massage. This algorithm is proved to be unconditionally safe, but its use is limited due to a required length of encryption key. Since the encryption key must be of the same length as the transmitted message, and current generation methods do not provide sufficient length of the generated key, it causes serious problems with the use of "one time pad" during broadband communications. A solution to this problem may be quantum key distribution (QKD) systems. Further development of this technology could make it possible to apply the encryption algorithm with a one-time used key. At present, the key generation rate by QKD systems goes to hundreds of Kbps. In such a case, although a bandwidth is important, the strength of a generated key is however crucial to full message safety and makes the decryption of a massage received without complete knowledge of the encryption key impossible.

Security of QKD systems is based on a quantum mechanics' basis which, according to current knowledge and theoretical assumptions, cannot be broken. Moreover, the key distribution protocol called BB84 [1] has been mathematically proven to be absolutely safe [2, 3]. It can be concluded that a combination of unconditionally secure encryption algorithms with the key generation will allow us to get a fully secure message encryption.

Unfortunately, a real implementation of this method has many limitations on side of quantum key generation methodology. A team of authors conducted a series of tests and analyses revealing opportunities and ways for current systems to protect systems from breaking their safety. Moreover, the possibility of using single photon systems in terms of critical infrastructure security was explored. In that capacity, a concept was developed and preliminary tests were carried out to monitor the state of transmission lines using a single photon interferometer. The assumption of the use of quantum mechanics' principles guarantees a possibility of external disturbances' detection in transmission lines with an accuracy exceeding currently used systems.

2 Specific properties of single-photon technology

In quantum mechanics we talk about possible states rather than exact values. In a simpler way we can say that we want to find a place where there is a particle which we are particularly interested in. But it is impossible to find the exact particle position; only the place where it can most likely to be found, but not necessarily a place where the particle is in reality. This is a consequence of the inability to make accurate measurements in accordance with Heisenberg's uncertainty principle.

Thanks to the properties of quantum mechanics, among others, it is possible in practice to use a single photon as a completely safe data carrier. Because, in accordance with Heisenberg's uncertainty principle and Bell's theorem, it can be determined whether quantum information has been eavesdropped. This is possible by coding information in a photon with the use of one of two features. Unfortunately, information coded in a single photon can be read out, but reading it gives information about eavesdropping.

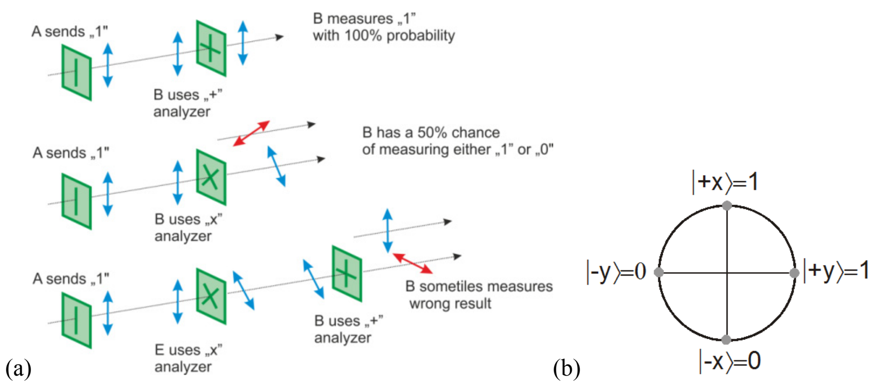


Figure 1: (a) Measurements of polarization states; (b) bit values of polarization states.

The first feature allowing the use of a single photon as a data carrier is the polarization state. Use of orthogonal polarization states for coding values "0" and "1" allows for distinguishing between these states by simple passage of a photon through a polarization beam splitter. Such approach is schematically presented in fig. 1(a). It is possible to generate such polarization state that, after passing through the same polarization beam splitter, it will pass a photon on one of two outputs with equal probability. Furthermore, coding with the use of two bases rotated relatively to each other by 45 degrees allows us to diversify a single-bit coding method by using two distinguishable states of polarization (fig. 1(b)). Using an incorrect polarization analyser will cause the appearance of transmission errors. Eavesdropping and wiretapping is revealed by an increase of quantum bit error rate measured at the receiver's signal.

Such an approach of using polarization encoding is in accordance with original assumptions of BB84 protocol. In this approach, photon bits are encoded by using linear polarization states (fig. 1(a)) and measured by using two analysers (fig. 1(b)). Since it is not possible to measure four polarization states at the same time, and the measurement with a wrong base changes the photon state with a 50% probability, the measured values may be different from the transmitted ones.

Similarly, it is possible to encode information in a photon phase by using single-photon interference. According to the principle of single-photon interference (1)(2) based on a phase difference between signals in individual interferometer arms, the probability of photon detection at different outputs changes.

$$-r^2e^{i\Theta}|\Psi> +t^2e^{i\varphi}|\Psi> = t^2 - r^2(e^{i\varphi} + e^{i\Theta})|\Psi> \quad (1)$$

$$irte^{i\varphi}|\Psi> +irte^{i\Theta}|\Psi> = irt(e^{i\varphi} + e^{i\Theta})|\Psi> \quad (2)$$

$$\Theta = \varphi: \begin{cases} 0 \\ |2irte^{i\varphi}|^2 = 4r^2t^2 \end{cases} \qquad \Theta - \varphi = \pi: \begin{cases} 2(t^2 - r^2)e^{i\varphi} \\ 0 \end{cases} \quad (3)$$

where $t|\Psi\rangle$ and $r|\Psi\rangle$ are states of photon in interferometer arms; φ and Θ are phases of radiation in interferometer arms.

In the single photon interferometer system shown in Fig. 2 for the phase difference of 0 and π, there is a certainty of photon detection on one detector (3). So the signal phase shift of π between branches is used to code bit states of "0" and "1" which correspond with orthogonal polarization states.

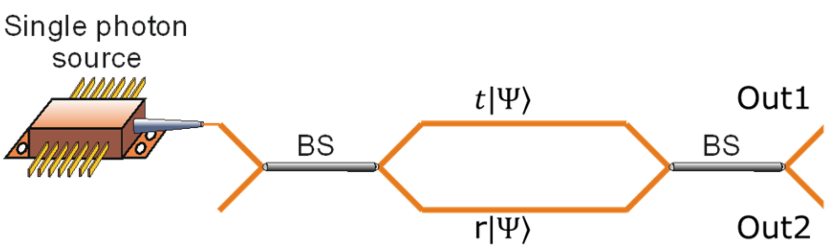
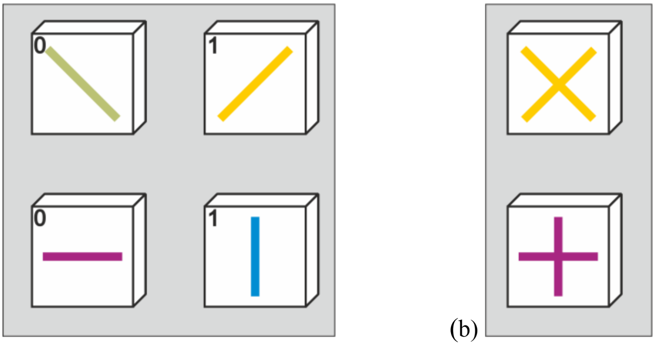


Figure 2: Single photon interferometer scheme.

A polarization coding system based on quantum mechanics is regarded as a foundation of quantum information transmission, while, at the same time, describing the technique in the most intuitive way. However, difficulties of sending a polarization state by an optical fiber transmission medium make commercial use of polarization coding a very complicated issue. Phase coding is also based on principles of quantum mechanics and single-photon interference, but systemic implementation allows to use this encoding in real commercial systems.

Information transmitted through a classic telecommunications' channel can be amplified or copied by using commercially available equipment. Quantum states of photons transmitted through a transmission medium in accordance with no cloning theorem cannot be copied without measuring the photon state, because each measurement can distort the transmitted photon state what may be giving an incorrect measurement result in the receiver. This ensures inability to eavesdrop the transmitted massage by a third party while ideal optoelectronic components are used in the transmitting and receiving devices.

Both polarization or phase changes made to a transmission medium are easy to observe. The most common effect observed in the case of a disturbed transmission line is the appearance of detection at wrong detectors. This allows for an accurate detection of disturbances in an optical fiber which transmits a photon by using a relatively simple method of signal processing and generating an alarm signal that causes repeated generation of the encryption key. This solution is currently used in available commercial devices.



(a) (b)

Figure 3: (a) Polarization states; (b) BB84 analysers.

In order to improve the properties of quantum systems, it was necessary to eliminate some of the problems associated with transmission of radiation through an optical fiber. The biggest problem in transmission is a random change occurring in transmitted light polarization. Thus, it was necessary to develop a system compensating for environmental impact to changes introduced to polarization in a transmission line. Construction of an auto-compensating phase device is shown in fig. 4. This system is composed of two devices called the transmitter (Alice) and receiver (Bob). The transmitter is built with a Faraday rotator mirror, phase modulator coupled with a random number generator, variable optical attenuator (VOA) and sync detector. The receiver consists of two single photon detectors, a sub-nanosecond laser, a phase modulator coupled to two random number generators, an unbalanced Mach-Zehnder interferometer and control system.

Although the radiation source is located in the same system as single-photon detectors, it is not a transmitting device. A transmitting arrangement is considered a device in which attenuation of a strong laser pulse to a single-photon level is carried out and one of four states is encoded by a phase modulator. The receiver's and transmitter's fiber optic elements are made of polarization maintaining components which enable an interferometric system's balance. A sub-nanosecond pulse generated by a pulse laser is initially divided into two beams using a 50/50 beam splitter at unbalanced interferometer input. In the short arm, an optical fiber is spliced with 90° optical axes' rotation ensuring orthogonal polarization states in both arms. Then, the polarizing beam splitter combines radiation from both arms to one transmission fiber. Radiation coming out from the device is in the form of two time-shifted pulses. Pulses propagate through the fiber to the receiver where an asymmetric beam splitter decouples light to a synchronizing detector. The rest of the radiation passes through a variable attenuator, an inactive phase modulator and, at the end of the fiber, is reflected from a Faraday rotator mirror. After reflection, radiation makes another pass by the phase modulator which, this time, introduces change (compatible with values generated in RNG) to the second pulse. Then, radiation passes for the second time through the variable attenuator which makes attenuation set at half value required to obtain a single photon in pulse. FRM at the system's end ensures rotating polarization causing that radiation from a shorter arm will be propagating in a longer arm and vice versa. As a result, automatic compensation of environmental influence on the optical fiber is obtained. In the interferometer's shorter arm there is a phase modulator which introduces changes to a returning pulse. Depending on phase changes, a signal is obtained at one of single photon detectors according to the single photon interference rule.

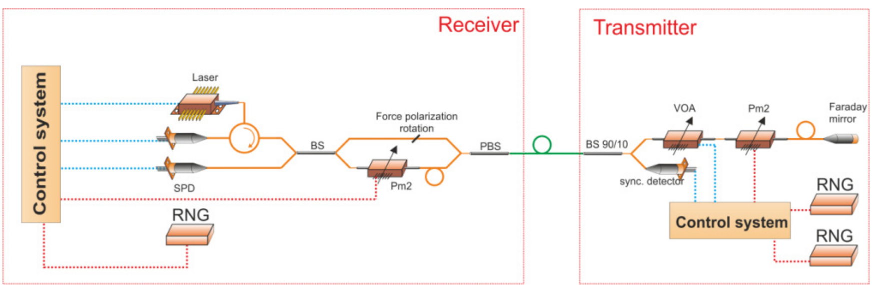


Figure 4: Auto-compensating phase system scheme.

These systems for both phase and polarization configurations have drawbacks and limitations which, for polarization configuration, are the following:

- Fiber optics change polarization stochastically;
- Reduction of speed and accuracy by polarization controllers;
- Requires the use of up to four single photon detectors;

while in systems based on phase we can distinguish the following disadvantages:

- Light polarization affects output result;
- Balanced interferometers are required;
- Backscattering (in some configurations);
- Speed of phase modulators.

3 Quantum detection limitations

When using single-photons in an optical path there are many problems associated with detection and generation systems. This is due to many factors, both technological and physical properties. The research and analysis conducted by the authors show that components used in quantum key distribution systems have a number of imperfections. Those imperfections have a significant impact on key security and generation rate.

Detectors are one of the most important components in quantum systems. At present, detectors are used in various types which achieve the best efficiency reaching up to 95% [4]. Unfortunately, they work at temperatures close to absolute zero. Therefore, InGaAs avalanche photodiodes are the most commonly used detectors which allow us to work at room temperatures using a thermoelectric cooler. Many factors have an influence on detectors' performance, starting with construction of a detecting element, detector operation temperature and control voltages. Changes in individual parameters allow us to get different photon detection efficiency with a different noise level. Currently, detection efficiency of APD diodes reaches up to 25%, but these values are still too small for telecommunication application. In addition, more "false counts" appear at higher efficiencies because of an increase in the threshold voltage, so there is no gain in usable pulse detections. An important aspect of single-photon detection is not only to obtain the highest efficiency, but also to minimize false detections. Therefore, while using detectors in systems a constructor should seek to obtain the optimal value of detection probability and detector's noise.

As mentioned before, physics' operation of detectors has an effect on single-photon detection. The most effective method to counteract these effects is the selection of control parameters of the detector. This concerns:

- the detectors' own noise;
- false counts;
- a strong possibility of blinding detector by strong laser radiation [5];
- the possibility of counting by the detector photons from the optical path not related to the transmission channel.

4 Single photon generation

A single photon source in telecommunication applications should be characterized by the following parameters:

- Emits only one photon – high p(1) emission probability, low p(2) and p(0) probability;
- Narrow spectral width – small $\Delta\lambda$;
- On demand – triggered;
- Room temperature operation;
- Low cost.

www.witpress.com, ISSN 1743-3509 (on-line)

At the moment, there is no single-photon source to meet all of these conditions. Very good methods are the following: "Heralded single photon source (down-conversion) [6]", "Emission from Nitrogen Vacancy Center in Diamond [7]" and "Quantum Dot in Micropost Microcavity [8]". The single-photon source with good generation performance requires very low operating temperatures and high costs. There are no radiation sources allowing efficient single-photon generation at room temperature. Since commercial sources are used in the operating room conditions of low cost construction, the attenuated laser pulses' method is used in available devices.

In order to obtain a single photon from a laser pulse it has to be attenuated, but the attenuation level is dependent on laser power and the expected number of photons in a pulse. According to Poisson distribution, attenuated pulse photons are generated with a certain probability depending on the expected number of pulses. To avoid the occurrence of more than one photon, it is necessary to set the attenuation system to an expected value of 0.1 photon per pulse which means that probability of an emitting photon in a pulse is approximately 9.5%. To determine the required attenuation level to reach a desired value, continuous measurements of source generated radiation are required. These measurements are shown in fig. 5. The mean value of radiation source power allows for the estimation of required attenuation level allowing us to obtain single photons with a very low probability of occurrence of pulses consisting of more than one photon.

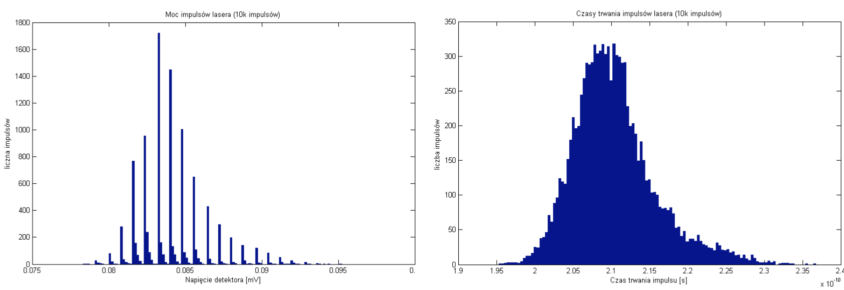


Figure 5: Pulse time and power distribution of laser pulses.

Due to the stochastics of single photon measurements' processes correct result interpretation requires a proper attitude. With a generation of laser pulses at a frequency of 100 kHz, in fact, after attenuation, only 9.5k single photon pulses per second can be used for encoding information. Further, after detection with efficiency about 20% and 1μs detector dead time, the amount of single photon pulses is reduced practically up to 900 pulses per second.

Elements responsible for encoding information are a very important component in quantum key transmission. These elements limit key exchange systems' speed by the time needed to switch between different coding states. It is also extremely important to obtain repeatable modulators' settings in order to avoid errors of incorrect coding or reading transmitted photons.

While using an optical fiber as a transmission medium a significant reduction of systems' throughput occurs caused by fiber optic attenuation. For example, the probability of a single-photon transmission at a distance of 1 km is about 63%, and the maximum theoretical range is up to 400km [5]. Moreover, when auto-compensating systems are used, there is a risk of single photons generated by partial reflection and backscatter from fiber connectors or imperfections. Elimination of this phenomenon is realized by the addition of storage fiber on the transmitting device. Also key information packets are transferred to detect reflected pulses when there is no right for photons reflected from the fiber imperfections to appear.

The impact of all components and processes for key generation efficiency significantly reduces encryption performance of quantum key exchange systems.

5 Vulnerability of QKD systems

The most spectacular attack on quantum key exchange systems was the attack [9] performed on an operating polarization system at the University of Singapore. During that attack, a method of blinding and controlling single photon detectors [10] with suitable powers' radiation was used. The attack was carried out on the basis of photons received by a duplicate of the receiving apparatus from the trusted side. The eavesdropper device using circularly polarized radiation blinds the receiver enforcing linear work of single photon detectors. Then, by using a strong pulse, the eavesdropper measurement result is forced on the receiver at the trusted side. This pulse in each case ensures detection on the appropriate detector. The attack remains undetected by regular techniques due to the use of a real receiving system as part of an eavesdropper device which allows for achieving the effect of a complete link of the quantum key distribution. The scheme of the system used to conduct this attack is shown in fig. 6.

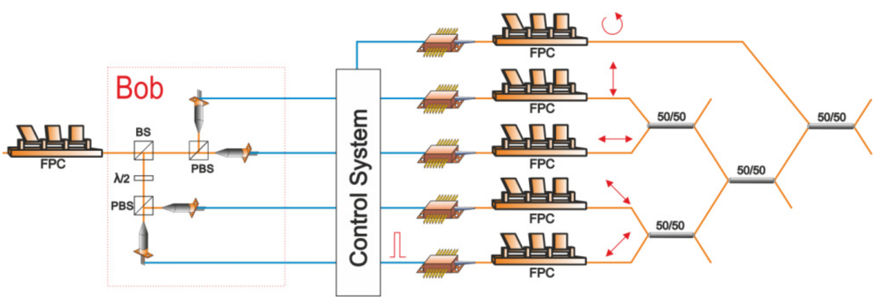


Figure 6: Scheme of QKD eavesdropping device.

Other well-described attacks are Trojan-horse attacks [11, 12]. They are carried out on the basis of sensing the phase modulator state using reflected signals within a transmitting system using the OTDR technique. In this attack the aim of the eavesdropper is not to measure a single photon state, but to get a strong light pulse identical state as the coded photon. For this purpose, the eavesdropper is plugged into a transmission line and a strong radiation impulse is sent to the transmitter. Reflection from transmitting system components passes through a phase modulator at the same time as a single photon. Consequently, the eavesdropper obtains full information about the coded signal with no need to decode the disturbance of the single photons' state.

In addition to defined and tested attacks, there are many presented theoretical methods of attacks on quantum systems. In this group, there are risks related with prepared assumptions of technologies' development, such as:

- Photon Number Split attacks which assume the use of quantum memory for storing pulses of photons with a population greater than one [13].
- the possibility to make non-destructive measurement of the transmitted photon state [14].

As shown, despite theoretical evidence of security, implementation of components in a real system remains a problem. Current implementations have limitations and weaknesses which are still detected and corrected. Patches introduced by manufacturers against individual attacks seem to be an effective solution, but they are not included in system security models. Therefore, the question is whether these systems are safe enough?

6 Conclusions

At the present moment, quantum cryptography systems can increase security of transmitted data with keeping adequate precautions. However, due to the lack of security evidence for such transmission, systems' application to classified information protection is currently impossible. Moreover, a crucial value in telecommunications is the amount of transmitted data. Current solutions significantly reduce the capacity of quantum key exchange systems. Further development of technology may improve transmission rate and its security allowing us to use security applications at a government level. Research on quantum computers can make most classical encryption systems unsafe and, thus, it can force a development of more advanced coding techniques than those used so far. Therefore, it will be necessary to develop technologies which will ensure the safety of key exchange and data encryption. This task can be performed by the technology of quantum key exchange, if the major problems of detectors and other components are solved.

Acknowledgements

The project is co-financed by the National Centre for Research and Development within the project realized for national security and defence "Fiber-optic link integrity monitoring system for protection against unauthorised access to classified information" (System monitorowania integralności łącza światłowodowego w celu ochrony przed nieautoryzowanym dostępem do informacji niejawnych), Contract no. DOBR/0070/R/ID1/202/03.

References

[1] C. H. Bennett and G. Brassard, Proceedings of IEEE International Conference on Computers, Systems, and Signal Processing, 175–179 (1984)

[2] P. Shor, J. Preskill, Phys. Rev. Lett. 85, 441−444 (2000)

[3] H. K. Lo, H. F. Chau, Science 283, 2050–2056 (1999)

[4] A. E. Lita, A. J. Miller, and S. W. Nam, Opt. Express 16, 3032 (2008)

[5] Quantum communication technology N. Gisin and R. T. Thew Electronics Letters, 46, 965 (2010)

[6] S. Fasel, O. Alibart, S. Tanzilli, P. Baldi, A. Beveratos, N. Gisin and H. Zbinden, New Journal of Physics 6, 163 (2004)

[7] C. Kurtsiefer, S. Mayer, P. Zarda, and H. Weinfurter, Phys. Rev. Lett. 85, 290 (2000)

[8] M. Pelton, C. Santori, J. Vučković, B. Zhang, G. S. Solomon, J. Plant, and Y. Yamamoto, Phys. Rev. Lett. 89, 233602 (2002)

[9] L. Lydersen, C. Wiechers, C. Wittmann, D. Elser, J. Skaar, and V. Makarov, Nat. Photonics 4, 686–689 (2010)

[10] V. Makarov, N. J. Phys. 11, 065003 (2009)

[11] A. Vakhitov, V. Makarov, and D. R. Hjelme, J. Mod. Opt. 48, 2023–2038 (2001)

[12] N. Gisin, S. Fasel, B. Kraus, H. Zbinden, and G. Ribordy,Phys. Rev. A 73, 022320 (2006)

[13] G. Brassard, N. Lütkenhaus, T. Mor, and B. C. Sanders. Physical Review Letters, 85(6):1330+ (2000)

[14] A. Reiserer, S. Ritter, G. Rempe, Science 342, 1349 (2013)

This page intentionally left blank

Optimization of the operation of a fiber optic interference-based sensor for perimeter protection

M. Życzkowski & P. Markowski
Institute of Optoelectronics, Military University of Technology, Poland

Abstract

The main purpose of the paper is to present the impact of the polarization state of light in fiber optic interference sensors on their stability and efficiency. The main application of interference-based sensors for security is the protection of wide area objects, especially perimeter protection. This type of sensor offers high accuracy of locating disturbances and a high certainty of detection. Their advantage is resistance to external electromagnetic interference, such as storms, or to influence other devices located in the detection zone. The sensitive part of the sensor does not introduce electromagnetic disturbances to the environment. An interference-based fiber sensor requires complex methods of signal detection in order to achieve the maximum efficiency. The paper describes research on the impact of polarization state of light in fiber optic interference-based sensors on stability, accuracy and efficiency in order to determine the alarm state and the disorder location. The paper presents a method to stabilize the state of light polarization in order to maintain the detection state of the maximum contrast. We determined the state of light polarization with the highest detection efficiency and stability of tested sensors. We present an interference-based sensor with a stabilized level of detection at the point of the maximum sensitivity.
Keywords: infrastructure protection, fiber optic sensor, interference-based sensors.

1 Introduction

At the time of the ubiquitous threat of terrorist attacks around the world, it is essential to ensure the security of critical infrastructure facilities. Perimeter fencing is the primary barrier in the way of an intruder while attempting

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150111

intrusion on a protected area. To ensure the quickest response of security services, fence monitoring systems are applied which are able to detect and locate the place of intrusion. Due to the fact that elements of this type of detection systems are the first line of protection, it is necessary to make information provided by the system the most certain alike in terms of sensitivity, detection and the minimum number of false positives, as well as in terms of resistance to environmental factors. By analysing the above requirements it becomes clear that the interference-based sensors are the best solution. They offer a high sensitivity, the ability to locate, as well as they are resistant to external atmospheric conditions. Unfortunately, this type of sensors require complex detection and control systems to ensure that they are up to their optimum use. By controlling and adjusting operating parameters of interference-based sensors, it is possible to adapt the system to work in variable environmental conditions with maximum sensitivity to intrusion occurrence.

The paper presents the method for automatic correction of the input state of light polarization of the double Mach-Zehnder interferometer. Correction of polarization state at the input light aims to generate and maintain interference contrast with a value close to one. The presented system is dedicated to applications in the field of security systems [1] such as perimeter security of critical infrastructure or monitoring integrity of telecommunication lines [2]. The system can successfully be used in other applications requiring detection of mechanical [3] disorders along many kilometers zone with the possibility of determining the place of disorder [4].

The presented system was tested in field conditions. The aim of the measurements was to determine the possibility of detection disorders along the fiber optic cable and stability of the system.

2 Influence of light polarization on the interference pattern

Interference pattern can be generated only by a coherent light [5]. The main parameter which determines the obtained interference pattern is phase difference of two mutually interfering light waves. The phase difference is a result of the difference in optical length of the interferometer arms. If the resultant phase difference is equal to zero, a constructive interference occurs resulting in the maximum possible light amplification. If the resultant phase difference of two interfering waves is equal to π, a destructive interference occurs and a complete extinction of the light could take place. In other cases, the observed intensity at the output can have a value between the intensity of the maximum gain and the intensity of total extinction.

In the case of light interference, polarization state is also crucial [6]. For orthogonally polarized waves interference does not occur. For the case when states of polarization of two interfering waves are non-orthogonal, it is possible to observe interference fringes. The maximum contrast of the interference can be achieved only for waves with the same state of polarization.

A qualitative parameter describing the interference pattern is the interference contrast [7]. Contrast is defined as the ratio of a difference between maximum and minimum values of light intensity and a sum of maximum and minimum values of light intensity. Mathematical relation that defines the interference contrast describes formula (1)

$$K = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{1}$$

where: K – interference contrast, I_{max} – maximum value of light intensity, I_{min} – minimum value of light intensity.

In the fiber-optic interferometer systems constructed on the basis of a standard cylindrical fiber, state of polarization changes with distance along the fiber. Wherein each fiber introduces various changes of polarization state which depend on local stress and torsion of fibers. Stress and torsion introduce significant birefringence of an optical fiber.

Through the proper selection of polarization state, interferometer system can affect the value of interference contrast. It is possible to distinguish two polarization states (mutually orthogonal) for which the contrast takes maximum values. For these states shifts of polarization in both arms of the interferometer are the same, thus, interfering waves are polarized equally at the output of interferometer. Visualization of the impact of input polarization state on the interference contrast is presented in figure 1.

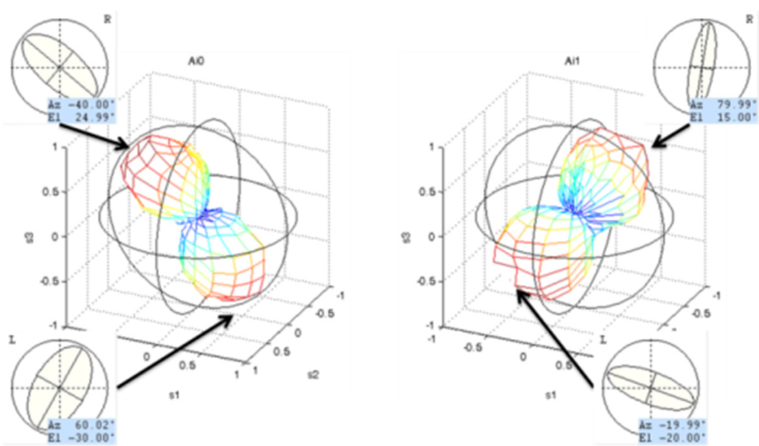


Figure 1: Influence of input state of polarization on the output interference contrast.

A change of polarization state at the input of interferometric system (for which the maximum contrast is achieved) may be caused by the change of propagation conditions. Polarization states for which the maximum contrast is achieved remain orthogonal to each other. The shift of state of polarization (for which the maximum contrast is achieved) is greater as greater is the change in propagation conditions.

3 Construction and principle of operation of the double Mach-Zehnder interferometer

The presented optic interferometer system is built on the basis of the Mach–Zehnder interferometer. An optical supply is applied at both ends of the system in the opposite direction of light propagation: clockwise CW and counter clockwise CCW. A schematic diagram of the system is shown in figure 2.

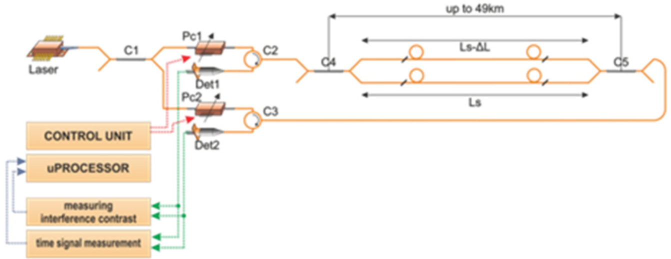


Figure 2: Schematic diagram of the double Mach–Zehnder interferometer.

The presented system can be divided into two parts: control – transmitting – receiving optoelectronic systems and passive fiber optic part. The elements of control – transmitting – receiving optoelectronic systems are: coherent light source with modulated wavelength (fiber laser THE ROCK NP Photonics controlled by a generator Tektronix AFG3021.) 2x2 3dB coupler, two polarization controllers (PCD-M02-B controlled with the NI USB 6009 card), two detectors (Thorlabs DET01CFC NI PCI-6115 with input/output block NI BNC-2110) and PC unit with LabView software. The built laboratory system is shown in figure 3.

In the presented double interferometer system both Mach–Zehnder interferometers have the same properties in terms of sensitive parts of the system. Arms of both interferometers have exactly the same length, thus the imbalance between the arms of two interferometers is the same. Sensitive parts introduce the same stress and, as a result, both systems provide the same interference pattern.

Direction of light propagation is opposite in both interferometers. Length of optical supply path and length of receiving path are also different.

Both optical systems are supplied by the same source which generates the light with a constant wavelength modulation. The optical radiation is separated by a 2x2 3dB coupler and transmitted to polarization controllers. The independent state of polarization for each direction of propagation is set to achieve the maximum contrast of interference pattern at the output. Then, the radiation is transmitted to the Mach–Zehnder interferometer – for the CW direction from polarization controller by the circulator C2 directly to the arms of interferometer, and for the CCW direction through the circulator C3, then through a fiber along the interferometer's arms. As a result, the interferometric pattern is transmitted to the detector – for the CW direction pattern is transmitted

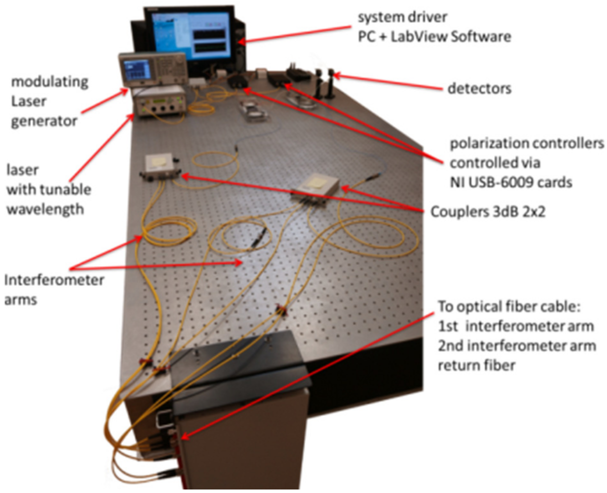


Figure 3: Operated laboratory system of double Mach–Zehnder interferometer.

through a fiber along the interferometer's arms, by the circulator C2 to detector, and for the CCW direction it is transmitted by the circulator C3 directly to the detector.

In order to perform continuous measurement of interference contrast, a modulation of the operation point is introduced to cover the entire transfer characteristics of the system. Modulation parameters should be selected according to an aligned optical line. For a system with a non-zero optical path difference relation for desired depth of wavelength modulation describes formula (2).

$$\Delta V = \frac{c \cdot \Delta\varphi}{2\pi \cdot n_{co} \Delta L} \quad (2)$$

where: ΔV –depth of wave modulation, c – speed of light, $\Delta\varphi$ – position of the middle of operating point in transfer function graph, n_{co} – refractive index of fiber core, ΔL – optical path difference of interferometer's arms.

For such defined modulation depth a function graph describing the relationship between the required retuning of the laser and the optical path difference can be plotted. Relationship between the values of optical path imbalance of the interferometer's arm and the required tuning range wavelengths of the supply system is shown in figure 4.

Selection of modulation parameters affects the stability and reliability of the measurement interference contrast pattern. According to equation (2), the modulation depth depends on imbalance of the interferometer's arms' length. An insufficient modulation depth can cause the transfer function graph to be not fully covered. It may be impossible to achieve the maximum possible contrast and the interference pattern may be unstable and highly variable. For a too high depth of modulation the operating point may cover the transfer function graph several times for one full period of wavelength change. In this case, the interference contrast reaches the maximum value for a given state of polarization, but the contrast of the interference may fluctuate.

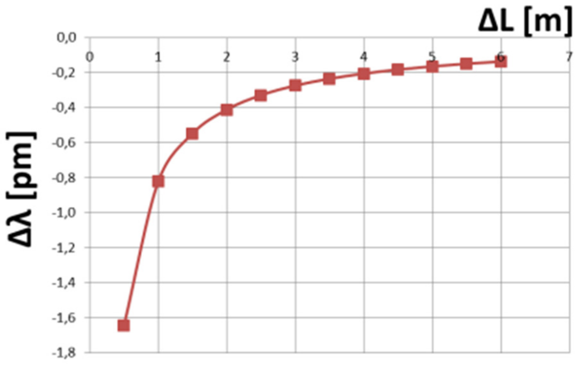


Figure 4: Depth of modulation of the input light as a function of unbalance of optical path length.

It is possible to distinguish a certain value of modulation depth for the maximum contrast and minimal fluctuations. This is exactly the value of modulation depth corresponding to the length of the interferometer's arms' imbalance as a result of the equation (2). A graph of medium contrast, standard deviation and difference of the measured maximum and minimum contrast with 1000 series of measurements for each value of voltage controlling the modulation depth for both directions at the same time is shown in figure 5.

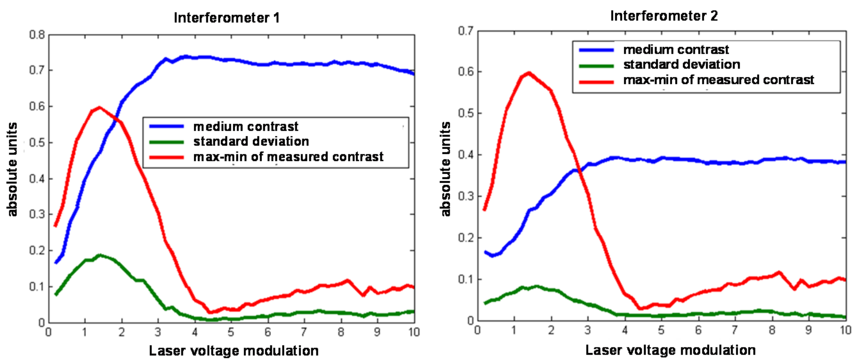


Figure 5: Medium contrast, standard deviation and difference of the measured maximum and minimum contrast with 1000 series of measurements for each value of voltage controlling the modulation depth for both directions.

For both systems it is possible to select the value of modulation depth to maximize contrast of the interference and to minimize the fluctuations. Because of that for both directions CW and CCW the value of imbalance length is identical and the modulation depth is the same for both directions. However, because two interferometers are supplied through different optical paths, an independent control of the input polarization states for both directions of propagation is required.

4 Implementation of the polarization correction state

In the described double Mach–Zehnder interferometer an alarm signal is generated based on the interference contrast. Due to the character of the system's application, the system is under continuous low frequency environmental disturbances causing small changes of values in the interference contrast. In order to improve detection parameters the maximum interference contrast is achieved by setting up the input state of polarization. All external disturbances can cause a decrease of contrast by introducing tension to the measurement channel. These changes can cause changes of polarization and phase at the end of the interferometer's arms. Changes in the range between 1 and 0.9 are categorized as noise, and the system does not respond. For the contrast values between 0.9 and 0.75, the system is set to work with environmental impact and polarization state of the input light is set to achieve the maximum contrast, thus an alarm signal is not generated. Contrast values below 0.75 generate an alarm signal and the system recognizes this type of disorder as a physical interference with the optical path. Illustration of contrast changes and the required search area for optimal value of polarization state is shown in figure 6.

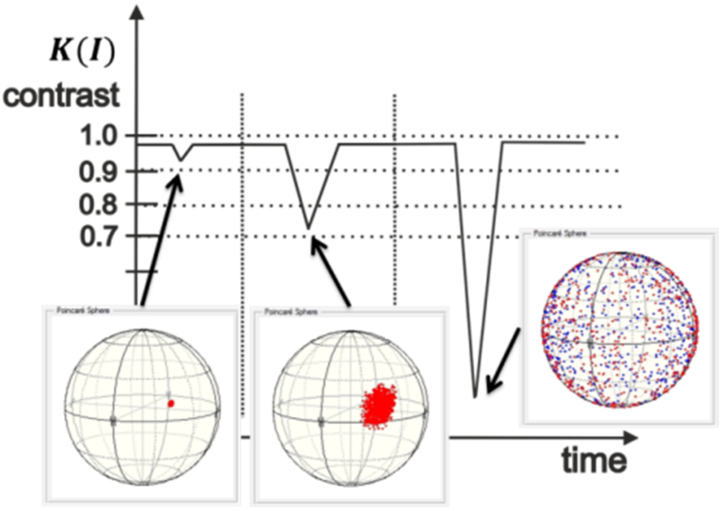


Figure 6: Contrast changes and the required search area of Poincare sphere for optimal value of polarization state.

The adjustment algorithm of the input polarization state in the described system was implemented in a LabView 2013 environment. At the time of decrease of contrast the system corrects the input state of polarization. This is accomplished by setting random polarization states of the appropriate area in the Poincare sphere. Therefore, the basis of polarization state and the corresponding interference contrast are generated. After a predetermined number of scans the state of polarization with the maximum contrast value is set. The algorithm presenting the procedure of creating the basis of polarization states is shown in figure 7.

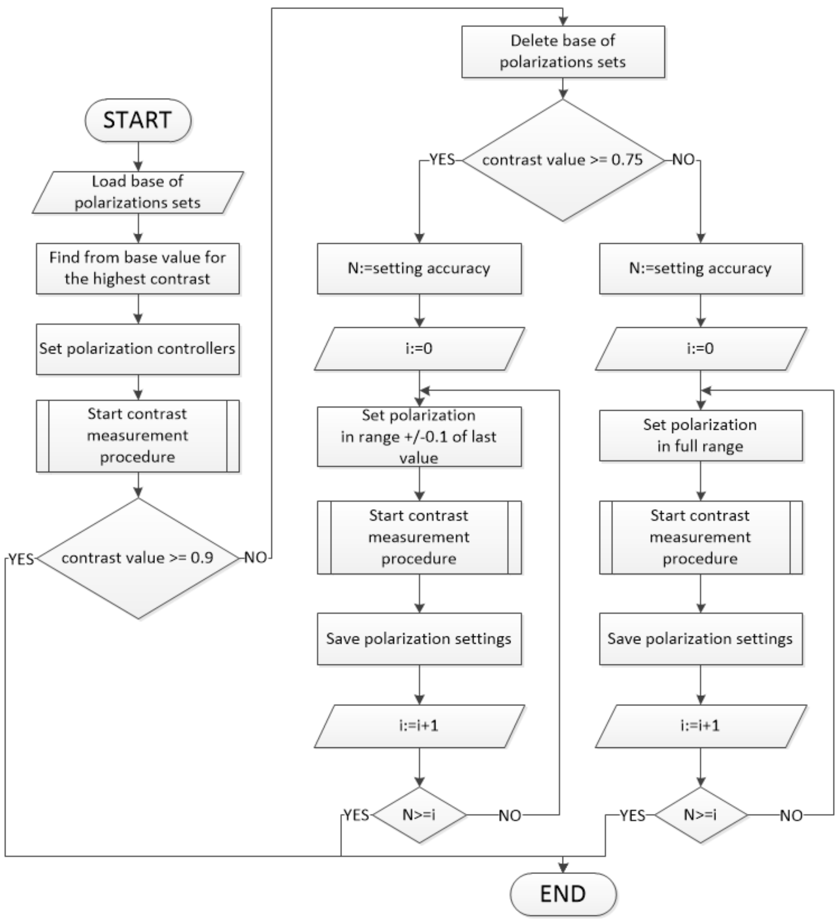


Figure 7: Poincare sphere searching algorithm to determine the base polarization states and the corresponding contrasts.

The system has been tested on the prepared test training ground built with standard telecommunication cables. Images presenting test environment and the running system are shown in figure 8.

Figure 8: Fiber optic sensor system in a double configuration of the Mach–Zehnder interferometer during field tests.

5 Conclusions

The presented system is stabilized to environmental vibrations, self-adjusting its parameters to temporary changes introduced by the environment. Therefore, the system generates an alarm signal as a response to the dynamic changes caused by a sudden appearance of external disturbances, such as physical contact with an optical fiber sensing cable. The tests demonstrate time stability of the system's operation with a proper detection of the external mechanical disturbances. In order to generate a signal suitable for measuring the contrast of the interference pattern, the system generates interference fringes with a frequency of 5 kHz. This allows to generate an alarm signal with a high probability as the frequency of signals generated by physical disturbances are in the range of 0–700Hz. Sampling rate of detection of electrical signals from the detectors was 100kS/s.

Acknowledgement

The project is co-financed by The National Centre for Research and Development within the project realized for national security and defence "Fiber-optic link integrity monitoring system for protection against unauthorised access to classified information" (System monitorowania integralności łącza światłowodowego w celu ochrony przed nieautoryzowanym dostępem do informacji niejawnych) Contract no. DOBR/0070/R/ID1/202/03.

References

[1] M. Szustakowski, W. Ciurapinski, M. Życzkowski, J. Wrobel, R. Dulski, P. Markowski, Security-orientated Plastic Optical Fiber sensor in Modalmetric Configuration, *Procedia Engineering*, **47**, pp. 916-923, 2012

[2] M. Życzkowski, M. Szustakowski, W. Ciurapinski, P. Markowski, M. Karol, M. Kowalski, Optical Fiber Sensors as the Primary Element in the

Protection of Critical Infrastructure especially in Optoelectronic Transmission Lines, *Safety and Security Engineering V*, pp. 273-283, 2013
[3] J. Dakin; B Culshaw, *Optical fiber sensors: Systems and applications*, Artech House, Boston 1989
[4] M. Życzkowski, M. Kondrat, W. Ciurapinski, Initial research of dual wavelength fiber optic perimeter sensor, *Journal de physique. IV*, **JP 129**, pp. 189-191, 2005
[5] H. F. Schouten, G. Gbur, T. D. Visser, E. Wolf, Phase singularities of the coherence functions in Young's interference pattern, *Optics Letters*, **28(12)**, pp. 968-970, 2003
[6] Nori Shibata, Akimichi Nakazono, Yoshinori Inoue, Interference between two orthogonally polarized modes traversing a highly birefringent air-silica microstructure fiber, *Journal of Lightwave Technology*, **23(3)**, pp. 1244-1252, 2005
[7] Wu Yuan, Bian Pang, Jia Bo and Xiao Qian, Fiber-optic sensor without polarization-induced signal fading, *Microwave and Optical Technology Letters*, **56(6)**, pp. 1307-1313, 2014

Intrusion detection sensors used by electronic security systems for critical facilities and infrastructures: a review

G. Yatman, S. Üzumcü, A. Pahsa & A. A. Mert
Department of Information and Security Technologies, HAVELSAN, Turkey

Abstract

This paper provides an introduction to the UFC 4-021-02 Electronic Security Systems Standard document prepared within the Unified Facilities Program of the U.S. Department of Defence, which is providing guidance to architects and engineers on how to plan and design electronic security systems for critical facilities and infrastructures. Then, this paper reviews the sensors, mainly the passive infrared-, seismic-, active infrared-, active ultrasonic-, microwave and fiber optic cable-sensors, that form the most frequently used sensors by an intrusion detection subsystem of electronic security systems for critical facilities and infrastructure protection. Lastly, this paper describes a generic perimeter electronic security system application with an unattended wireless sensor network (UWSN) and draws a conclusion by thoughts on other possible future sensor system developments.

Keywords: critical facility and infrastructure protection, electronic security systems, intrusion detection system, passive infrared sensor, seismic sensor, active infrared sensor, active ultrasonic sensor, microwave sensor, fiber optic cable sensor, unattended wireless sensor networks (UWSN).

1 Introduction

This paper provides brief information about smart sensor technologies used by the intrusion detection system, which is a subset of the electronic security system as described in Section 2 and shown in Figure 1, based on the UFC 4-021-02 Electronic Security Systems Standard Document. The unified facilities criteria (UFC) system is prescribed by MIL-STD 3007: Standard Practise for Unified

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150121

Facilities Criteria and Unified Facilities Guide Specifications. The UFC 4-021-02 document is prepared within the Unified Facilities Program of the U.S. Department of Defense and is providing guidance to architects and engineers on how to plan and design electronic security systems. In Section 3, the most frequently used sensors by the intrusion detection system for critical facilities and infrastructure protection are reviewed, which are the passive infrared-, seismic-, active infrared-, active ultrasonic-, microwave and fiber optic cable-sensors. Then, in Section 4 a generic perimeter electronic security system application with unattended wireless sensor networks (UWSN) is described.

2 Electronic security system overview

Electronic security systems (ESS) are comprised mainly of access control systems (card readers, door contacts, etc.), closed circuit television (CCTV) system, intrusion detection systems (sensors), data transmission systems and operational control and command centers. ESS is part of an overall physical protection system. As shown in Figure 1, the overall physical protection system consists of civil engineering features of fences, gates, entry points, clear zones, and standoff distances; architectural issues of construction materials, barriers, doors, windows, and door hardware; structural issues of blast resistant protection; mechanical issues of heating, ventilation, and air conditioning (HVAC) protection and redundancy, electrical engineering issues of power redundancy and lighting systems, ESS, and operational considerations such as policy, procedures, and response times [1].

2.1 Detect, delay, and respond principle

Electronic security systems act mainly on the detect, delay, and respond principle where time between detection of an intrusion and response by security forces, which should be less than the time it takes for an intruder to reach his goal, is a key factor. For that reason, the ESS designer should plan and place certain intrusion time delaying obstacles like card readers or fences as shown in the example in Section 2.2, so that the security officers be able to gain enough response time to hinder the intruder trying to achieve his purpose, after receiving the intrusion alarm generated by the ESS.

2.2 Detect, delay and respond example.

Table 1 provides an example of the times related to each detect and delay option in Figure 2 [1]. The cumulative delay times shown in this example are estimated at slightly over eight and a half minutes. Assuming a security forces response time of eleven minutes, the sequence of events shown in Table 1 allows sufficient time for an adversary to achieve his purpose and/or damage the targeted asset [1].

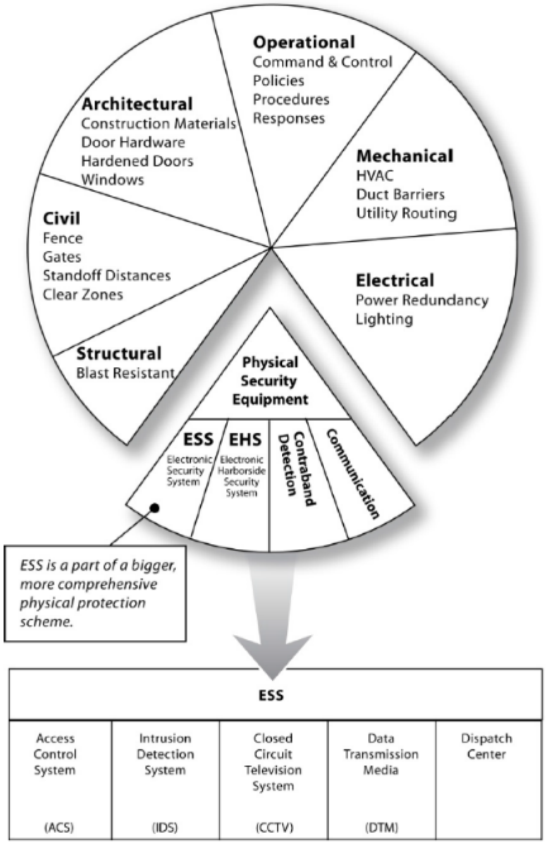


Figure 1: ESS as a part of a physical security system [1].

Table 1: Example breach events and delay time [1].

	Delay options	**Delay time**	**Detection options**
1	Climb fence	8–10 sec.	Perimeter fence detection system
2	Cross open ground (for example 600 feet)	10 feet/sec.	Microwave sensors
3	Breach building door or window or wall	1–2 min.	Door contacts or glass breakage sensor
4	Breach interior hardened door	2–4 min.	Door contacts
5	Work time in breached space	3 min.	Motion sensor
TOTAL DELAY TIME		**8 min 39 sec nominal for this example**	

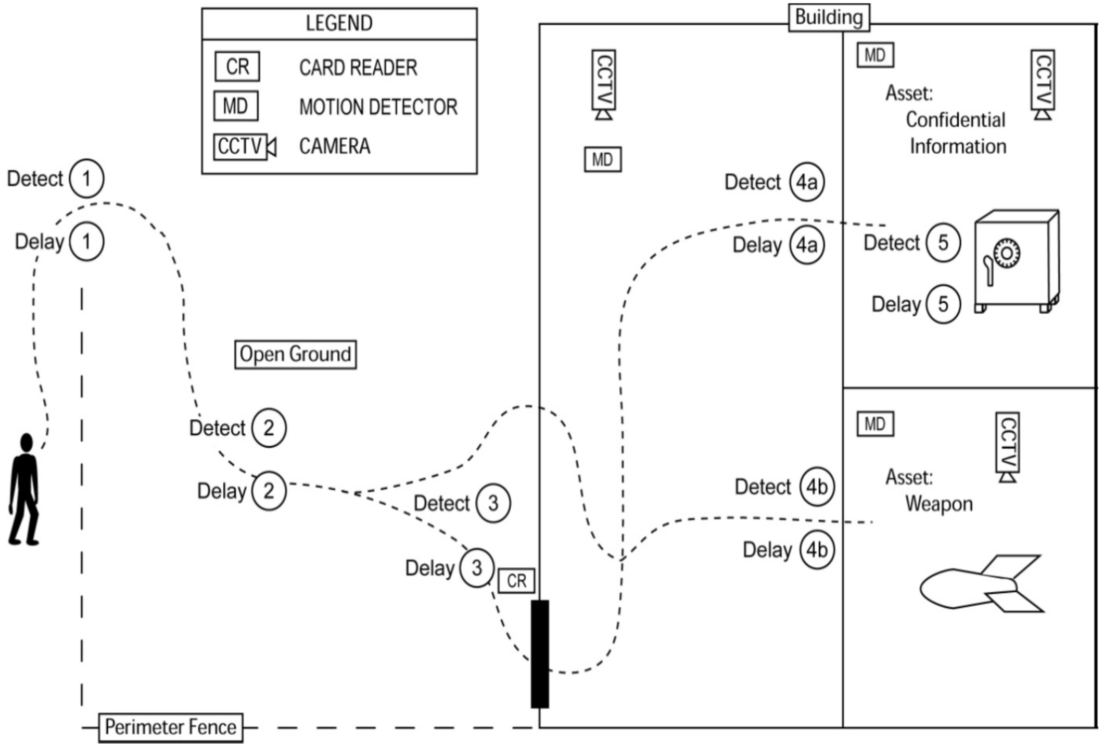


Figure 2: Example detect and delay options [1].

3 Intrusion detection system (IDS)

IDS is a subsystem of ESS as described in Section 2 of this document. The function of an IDS is to detect threatful/adversary intrusions. The detection of an intruder starts the “clock” on the detect, delay, respond timeline described previously.

The main components of an intrusion detection system are the following:

- Sensors detecting intrusion through sensing voice, vibration, motion and other physical and environmental events.
- A bidirectional data transmission media to transmit the signal of detection to a local and/or remote operational control and command center and for transmitting commands of operators to the field devices.
- Processors for automatic evaluation of the data received from sensors.
- Workstations with a user interface software for operators to monitor alarms actuated by the sensors.

In this section some of the most applied sensor types used by intrusion detection systems are presented.

3.1 Passive infrared motion (PIR) detectors

3.1.1 Detection principle

Infrared electromagnetic radiation is outside of the visible light spectrum and is emitted by all living beings and surrounding objects which can also be thought as radiated heat. The term passive for these kind of detectors refers to the fact that PIR devices are not generating any energy for detection purposes. Instead, they are only detecting the reflected heat from objects which are moving in their detection range.

Mirror or Fresnel lenses pool the rays of heat for maximum reception and transfer them onto a sensor made of pyroelectric (or thermoelectric) sensing materials. This sensing device generates a temporary electric potential when it detects a certain temperature difference which is caused by the object being warmer or colder than its environment and activates an alarm.

3.1.2 Application

Depending on the optics installed, PIR motion detectors are suitable for exterior (outdoor) and interior (indoor) surveillance.

3.1.3 Disadvantages and advantages

Structural elements inside detection area which are causing shadows are preventing detection or give rise to false alarms. The sensor is sensitive to weather. When body temperature and ambient temperature are the same, the sensor cannot differentiate and detect. Sudden temperature changes such as air turbulences or exhaust air from devices can create a moving object response which can activate false alarms.

www.witpress.com, ISSN 1743-3509 (on-line)

The detectors can be easily installed. The detectors sensitivity can be adjusted. PIR sensors are very low on power consumption and thus suitable for battery powered applications.

3.1.4 Surveillance range

Depending on the type, the range may be approx. 100 m. The width of the surveillance area can be adjusted by suitable lenses or partial masking of the optical system (from <5° to >120°) [2].

3.2 Seismic sensors

3.2.1 Detection principle

In-ground seismic sensors also named as geophones detect seismic energy vibrations created in the ground by running, crawling or walking activities above its location. The seismic energy is converted by the sensors to electrical signals.

3.2.2 Application

Depending on the product, the detectors can be used for surveillance of paved, gravelled or asphalt surfaces as well as paths or grassland [2].

3.2.3 Disadvantages and advantages

The sensors sensitivity to low frequency signals is unsatisfactory. This fact leads to decrease of the detection range.

It is a hidden installation. It is suitable for surveillance of undulating terrain because the surveillance field can be aligned to the landscape. In-ground seismic sensors installed adjacent to the perimeter fence can provide additional detection capability for protection in case the vibration sensors mounted on the fence are bypassed by tunneling or careful climbing.

3.2.4 Surveillance range

One seismic sensor has a detection range of several meters per sensor. They can be cascaded to larger systems.

3.3 Infrared light barriers (active IR sensors)

3.3.1 Detection principle

Infrared (IR) light barriers are used for linear surveillance by IR light rays on straight perimeters where no ground undulations exist. This infrared sensor system is made of two basic units, a transmitter and a receiver. The transmitter, located at one end of the protection zone, generates a multiple frequency straight line beam to the receiver unit located at the opposite end of the zone thus an infrared "fence" is created between the transmitter and the receiver. Persons or objects interrupting the light ray between the units will be instantly detected.

3.3.2 Application

The area between transmitter and receiver needs to be clear of all obstacles/ obstructions that could interfere with the IR signal.

Typically, IR light barriers are used for surveillance in conjunction with wall, single/double fence or gate barriers.

When installed on roofs, these systems detect persons climbing over.

They can also be applied as a security curtain in front of objects to be protected. It is possible to install them on roofs to protect the crest.

3.3.3 Disadvantages and advantages

The surveillance range may be affected by weather conditions such as fog, heavy rain or severe sand/dust.

Their applications are manifold and can easily be retrofitted in existing security systems.

3.3.4 Surveillance range

Different systems with varying ranges are available.

The number of multiple barrier beam stretches, from individual transmitter-receiver pairs installed one above the other generally in posts, may differ.
The height of these barrier systems range from a few centimeters to several meters [2].

3.4 Active ultrasonic sensors

3.4.1 Detection principle

The active ultrasonic sensors are motion detecting devices that work similar to radar and sonar utilizing the Doppler principle.

They emit ultrasonic sound energy into a monitored area and reacts to a change in the reflected energy pattern.

3.4.2 Application

Ultrasonic sensors are installed typically on walls or ceilings. Ultrasonic sensors can be used together with passive infrared sensors to provide a greater probability of detection.

Because these sensor systems are dependent upon reflections, or echoes, from a moving intruder, clear line of sight between the sensor and the intruder are required so that energy can be transmitted to the intruder and reflected back with no obstructions in the way.

3.4.3 Disadvantages and advantages

Excessive air motion from a fan or an HVAC system can cause the sensor to trigger [3].

They are not affected from changes in the thermal environment. The ultrasonic sensor also can detect motion behind partial obstructions.

One of the key advantages of the ultrasonic sensor is the ability to calculate the distance to the object in motion [3].

3.4.4 Surveillance range

Ultrasonic sensors can be sensitive to slight motions at nearly twice the distance than PIR sensors. The overall detection range is comparable to that of a PIR sensor.

3.5 Microwave sensors

3.5.1 Detection principle

Microwave sensors are volumetric sensors and operate by radiating microwave energy into the protected area. They consist of physically separated transmission and reception units. Changes caused by intruders in the electromagnetic field between the transmitter and receiver are detected and lead to activation of alarms.

3.5.2 Application

Microwaves can be used to monitor both exterior areas and interior confined spaces, such as vaults, special storage areas, hallways and service passageways [4]. By exterior applications, microwave sensors are used for surveillance of wide areas or long stretches in open spaces or on top of roofs.

3.5.3 Disadvantages and advantages

The sensor is not suited for tight surveillance areas. Hills and depressions require special consideration as they may constitute surveillance loopholes [2]. Thus microwave signals pass through concrete and steel, special care is required when installing these sensors near roadways or adjacent buildings where nuisance alarms may occur due to reflected microwave patterns.

Detection is extremely reliable and weather insensitive.

3.5.4 Surveillance range

The radius of the elliptically extended surveillance area may be up to 15 m in the middle. It may be up to several hundred meters long.

3.6 Fiber optic cable sensor

3.6.1 Detection principle

Fiber optic cable sensors use light for transmission and detection. The cable sensor can be fastened to or installed on the fences or can be buried underground. They register disturbance at a barrier (e.g. fence) or in the ground. The fiber optic cable must be bent or disturbed in some way, to affect the wave guide of the light being transmitted and thereby signalling a disturbance [4]. Detection is a function of stress on the ground for buried applications or on the fence fabric by e.g. cutting or climbing over the fence for fence mounted cables.

3.6.2 Application

Fiber optic cable systems are suitable for surveillance of very long distances along e.g. fences or oil and gas pipelines.

3.6.3 Disadvantages and advantages

In some cases, considerable vibration caused by environmental impacts may cause false alarms.

The system is impervious to transient voltage and lightning strikes. It is suitable for retrofitting existing fences. Depending on the system, the fibre optic sensor cable can also be used for transmission of communication data (e.g. video image data) [2].

3.6.4 Surveillance range

Depending on the product, these systems are suitable for distances up to 80 kilometers. The surveillance field of a cable is approx. one to two metres circumference around the cable routing [2]. Digital systems are able to localise alarms along the cable routing with an accuracy of several metres [2].

4 Description of a generic perimeter electronic security system application with unattended wireless sensor network (UWSN)

Today, closed circuit television (CCTV) systems are used by most of the security systems for critical facilities whereas the operation and maintenance costs of CCTV systems are high and the probability of preventing threats is low. Reasons are that these systems are dependent on the operators' recognition of potential threats through watching several screens with camera images in the operation center, and the cabling needs for the devices which is restricting the areas which can be monitored.

Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances [5].

These sensor nodes together with wireless communication infrastructure and the operation center build up an electronic perimeter security system for critical facilities/infrastructures or borderlines which can be remote operated. Remote operated unattended wireless sensor network (UWSN) systems for protecting critical facilities and infrastructures in contrast to wired systems have advantages like cost effectiveness and the extension of area to be protected. Further advantages are the lower human live risk, long operation time without maintenance need, self-organizing capability, applicability to very large areas, endurance to tough environment and weather conditions.

The sensing units in the wireless area network (WAN) system don't only transmit the information collected from field, they also deliver information from other sensors through each other to collector units. Thus, a new sensor can be easily added to the network and even if a sensor is out of order due to a malfunction, the network structure can be reconstructed again according to the present condition. Another unique feature of sensor networks is the cooperative effort of sensor nodes [5]. Sensor nodes are fitted with an on-board processor. Instead of sending the raw data to the nodes responsible for the fusion, sensor nodes use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data [5].

The general structure of a generic perimeter electronic security system with UWSN application is shown in Figure 3. A command and control center software in this structure interprets and pre analyses the incoming data from the

www.witpress.com, ISSN 1743-3509 (on-line)

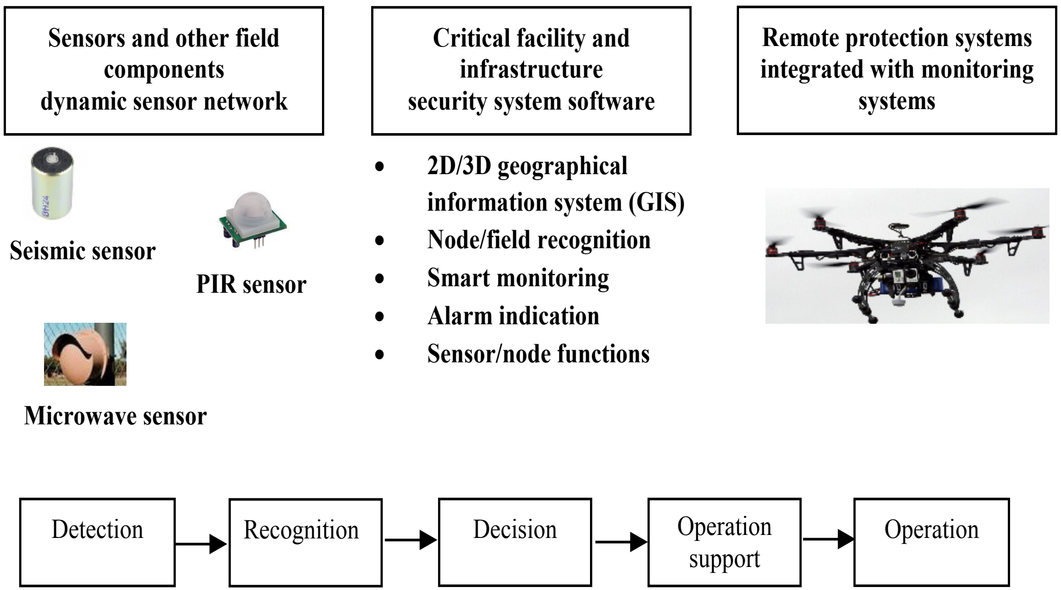


Figure 3: General block diagram of a critical facility/infrastructure electronic security system.

smart and energy effective sensors comprising the WAN system, delivers the enquiries rapidly to the units to go into action, permits upon authorization remote operation of the sensors in the system, analyses data from past events and works in interaction with other systems like a unmanned vehicle drone which can be also added to the system for surveillance from air.

5 Conclusions and future directions

As discussed in the previous sections, various types of sensors operating in wireless mesh networks can build up highly effective smart security systems. These are state-of-the-art electronic security systems which have many advantages in contrast to wired classical systems as defined. New algorithms have also been developed for the application requirements of sensor networks.

These sensor network systems can be tailored to the optimum security systems required, by selecting the suitable sensors and other subsystem components according to the environmental, field and other conditions for the area to be protected. Important design criteria for electronic security systems are described by guiding standard documents like UFC 4-021-02.

Besides being used in security applications, it is foreseen that smart sensor systems will be placed everywhere in daily life in the near future. Personal health monitoring, training and coaching systems using wireless sensors are recently advertised by some of the leading electronic device companies. Wearable sensors of these systems are attached to the body and connected to a mobile or local data receiving and computing device with user software for tracking and showing performed activities, heart rates and other information required for monitoring.

Wireless sensor networks are going to be used in the health sector, for example by placing sensors in the homes of disabled patients for monitoring their health status remotely and continuously from hospitals. These systems can also be used for monitoring environmental pollution caused, for example, by industrial facilities, by placing relevant sensors in polluted sites for detecting the contaminants in water, soil or air. These and much more wireless sensor systems are now in front of our doors and are going to enter our lives soon.

References

[1] UFC 4-021-02, *Electronic Security Systems*, U.S. Department Of Defence, Unified Facilities Program, pp. 5–7, 2013

[2] VdS 3143, *Security Manual Perimeter*, Gesamtverband der Deutschen Versicherungswirtschaft e.V. (GDV), pp. 31–38, 2012

[3] Hodges, L., *Ultrasonic and Passive Infrared Sensor Integration for Dual Technology User Detection Sensors*, Michigan State University, pp. 5–6, 2009

[4] National Criminal Justice Reference Service, *Perimeter Security Sensor Technologies Handbook*, Defense Advanced Research Projects Agency (DARPA) & The National Institute of Justice (NIJ), pp. 2–12 to 2–55, 1998

[5] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, *Wireless sensor networks: a survey*, Elsevier, Computer Networks 38, pp. 393–422, 2002

This page intentionally left blank

Section 3
Emergency response

This page intentionally left blank

A review of process safety catastrophes on the Texas Gulf Coast

R. G. Carranza
Chemical Process Engineering Consultant, Montgomery, Texas, USA

Abstract

Catastrophes related to processing facilities on the Texas Gulf Coast are reviewed. Most information is taken from the Chemical Safety and Hazard Investigation Board (CSB). The cases are condensed and presented such that only the essential material required is included. The Board's recommendations are highlighted. Statistics are presented from the Bureau of Labor Statistics and the Bureau of Economic Analysis indicating the rates of injuries and deaths in the industry. Furthermore, personal observations are made which include commentary based on the author's 25 years of industry experience.
Keywords: chemical, process, safety, CSB, OSHA, ASME, refinery, petroleum.

1 Introduction

Four different process safety catastrophe case studies are presented for review, all located along the Texas Gulf Coast: Marcus Oil, British Petroleum, Formosa Plastics, and Goodyear Tire and Rubber. Statistics from the federal government are also presented and suggest that, overall, injuries and fatalities are decreasing – that is, since 2003. And lastly, personal experience is used to shine some light on why these catastrophes are occurring.

1.1 Marcus Oil and Chemical, Houston, Texas: polyethylene wax processing facility explosion and fire, December 3, 2004

The incident at Marcus Oil [1] is interesting because it is really more political than it is technical. After an investigation by CSB, Marcus Oil is found, for the most part, not guilty of breaking any federal law; nor to be in violation of any local regulations. The industrial standards relating to this case are ASME code section VIII, State of Texas and City of Houston regulations, National Board

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150131

Inspection Code NB-23, OSHA Process Safety Management Standard, and the International Fire Code.

Marcus Oil processes high density polyethylene wax. Hexane and other hydrocarbons are extracted, stored in tanks above ground, and sold. The processed wax is pelletized for sale. When the wax (called “rag”) is separated from the lighter hydrocarbons, it is placed in tanks. The environment of the tank is made inert with nitrogen blanketing. When the rag is to be further refined and pelletized, steam coils in the tanks melt the wax and the liquid wax is flowed out of the vessel and to a pump using the nitrogen as a motive force. Tank 7 is one tank used for storing the molten rag. The process is described in fig. 1.

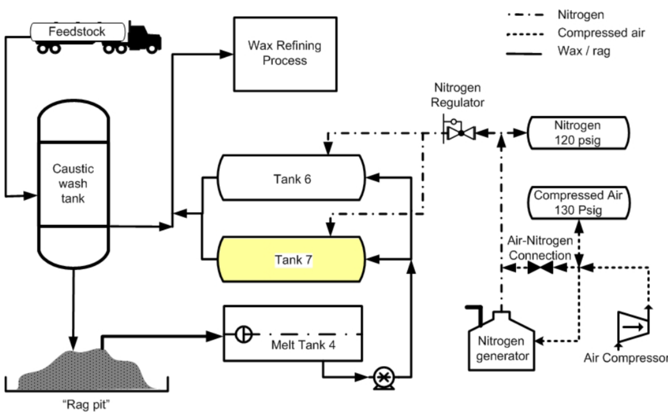


Figure 1: Schematic of Marcus Oil processing facility for polyethylene wax [1].

CSB determines that Marcus Oil alters the vessel design of several tanks on the property, including Tank 7. A 24 inch hole is cut in Tank 7 to install and maintain the steam coils. A metal plate is welded over the hole that does not adhere to ASME section VIII. The poor welding fails when the vessel is pressurized with nitrogen to 67 psig, the regulator set pressure.

Furthermore, the company’s nitrogen generator is incapable of supplying sufficient nitrogen to the system. A bypass line is connected to the company’s plant air system to supplement the nitrogen system during peak times. Thus, the oxygen content in the gas blanket over Tank 7 is 18% oxygen instead of the desired maximum of 8%.

When the plate is blown from the tank, it hits the ground and creates a spark. The molten hydrocarbon is in an oxygen rich environment and an explosion occurs. The heads on the tank are shattered and the 50,000 pound vessel is hurled 150 feet. Luckily, no deaths occur. Some local residents are slightly injured due to flying debris and concussion. Three fire fighters sustain minor injuries.

CSB discloses the following facts:

- Since the State of Texas does not require facilities to abide by ASME section VIII nor the National Board Inspection Code NB-23, the facility is not at fault. Normally these codes have guidelines regarding the construction, repair, hydrotesting, and overpressure protection for pressure vessels.
- The City of Houston does require implicitly that Marcus Oil follow ASME code, since the city has a law relating to vessels containing hazardous materials (as specified by the International Fire code) with inert gases. In other words, although polyethylene wax is not defined as "hazardous" by the City of Houston, Marcus Oil must use ASME code since the vessel utilizes inert gas. The problem is that ASME code only covers new vessels and not modified. Such being the case, the refinery is perfectly within the law to use non-certified welders, to neglect hydrotesting, and not use proper overpressure protection on the vessel. Since the vessel plate is destroyed in the explosion, it cannot be verified that Tank 7 is installed using ASME code; but, other tanks in the facility do have plates indicating adherence to ASME code – so it is assumed that Tank 7 is within code.
- OSHA Process Safety Management standard does not apply in this incident. The reason is that polyethylene is not a "flammable liquid"; and although hexane is flammable, the amount being stored at the facility is well below the 10,000 pound regulatory threshold.

1.2 British Petroleum, Texas City, Texas: refinery fire, positive material verification, July 28, 2005

This case relates to a procedural error performed during routine maintenance [2]. The plant is operating a Resid Hydrotreater Unit. High temperature hydrogen is used to remove sulfur and nitrogen as hydrogen sulfide and ammonia. Carbon steel is susceptible to high temperature hydrogen attack (HTHA) at temperatures and pressures above 450°F and 100 psia. At these conditions, hydrogen reacts with the carbon in the pipe and forms methane. Thus, low alloy steels containing 1.25-3.0 percent chrome must be used.

Low temperature hydrogen is fed into a couple of heat exchangers in series. Because of the wide range of temperatures in the process, two different types of materials must be used for the piping: carbon steel and low alloy steel (see fig. 2).

As is seen in fig. 2, elbow 1 is made of carbon steel; and elbows 2 and 3 are made from low alloy steel. The reason being temperature variation. However, when the exchangers are disassembled for maintenance in January of 2005, the contractor mistakes elbows 1 and 3 for one another. The elbows are reversed during reassembly. Carbon steel and low alloy steel are indistinguishable to the naked eye.

It is concluded that elbow 3 fails in less than 3000 hours of service due to HTHA. The result is that the hydrogen escapes from the corroded pipe and ignites. British Petroleum requires positive material identification (PMI) for new projects, but does not have a requirement for maintenance projects. PMI is easily accomplished with portable hand-held devices like an X-ray fluorescence instrument. Furthermore, the contractor is simply sloppy with respect to tagging piping components and reassembly. The entire event is entirely avoidable with proper tagging. CSB passes these recommendations to both British Petroleum and the contractor. One minor injury to plant personnel is reported and no deaths.

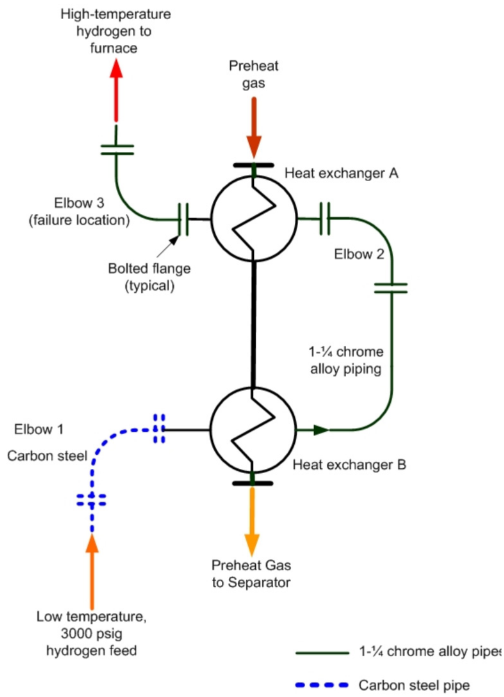


Figure 2: Elbow and heat exchanger arrangement for hydrogen preheat [2].

1.3 Formosa Plastics, Port Comfort, Texas: olefins unit fire, October 6, 2005

Formosa Plastics experiences a plant explosion and fire in its Olefins II unit. [3] The reason for the incident is damage to the process piping from a motorized vehicle. A trailer being pulled by a forklift pulls a manual valve off a strainer. Liquid propylene pools on the ground, vaporizes, and explodes. The explosion is categorized as an “unconfined, low speed, deflagration”. Fig. 3 is a schematic of the process.

Note that the schematic does not appear to be entirely representative of the situation. A C3 splitter is usually fractionating propylene from propane; thus, the tower product is propylene, but a condenser/heat exchanger seems to be missing between the tower and the pumps.

An analysis of the incident reveals several interesting points:

- When Formosa conducts a process hazard analysis of the unit, it is determined that barriers protecting process equipment from vehicular collision are necessary; but not for the process area in question because the probability of a collision is highly remote – one in twenty years. Thus, the strainer and associated piping are not protected from vehicular collision.

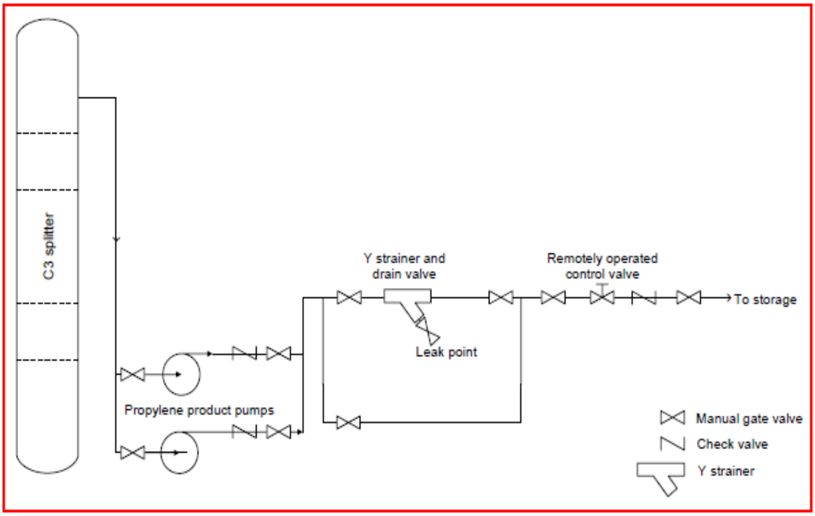


Figure 3: Process Schematic of the Formosa Unit [3].

- Within the area that is consumed with fire, there is a pipe rack that also contains a flare header. Although most of the columns supporting the rack are fireproofed, one row of columns is not. This allows the rack to fall and the piping to the flare is crimped. Propylene, instead of being vented, is allowed to feed the fire. M. W. Kellogg is hired to design the Olefins I unit in 1988 – at the same time API publishes its fireproofing guidelines, Publication 2218, which states that all flare network piping should be supported by steel columns with fireproofing. In 1996, Formosa hires M. W. Kellogg again, this time to design Olefins II. Kellogg simply uses the old Olefins I design without updating the fireproofing on the steel columns.
- An important point in this study is the fact that Formosa did not isolate the distillation column with automated shutoff valves. The check valve stopped flow from storage; and thus, did not allow the fire to be fueled from this source. However, the distillation column is a source of fuel and there is nothing to prevent the fire from being fueled by this source. CSB recommends that all vessels with large inventories of flammable materials be isolated with automated valves. Formosa only has hand valves to shutoff flow to the fire that originates from the distillation column.
- Formosa does not require employees to wear flame retardant clothing in the unit and is cited by OSHA. Formosa contests the citation. Sixteen employees are injured in the incident, one seriously.

www.witpress.com, ISSN 1743-3509 (on-line)

1.4 Goodyear Tire and Rubber Company, Houston, Texas: heat exchanger rupture and ammonia release, June 11, 2008

The explosion at the Goodyear plant killed one worker and injured six others [4]. The reason is operator error. Essentially, a heat exchanger is blocked-in during operation; the resulting overpressure ruptures the vessel, and flings debris and ammonia throughout the production unit.

The scenario revolves around a shift change, overnight:

- Fig. 4 is a schematic of the heat exchanger and the associated piping.
- Ammonia (shell side) is used as a coolant for a reactor feed (tube side).
- On the late afternoon of June 10th, an operator closes the isolation valve to the shell side relief valve in order to replace a rupture disk.
- The disk is replaced but the isolation valve is not reopened.
- Early the next morning, a worker closes the block valve upstream of the control valve on the shell side exit. The system is now completely blocked-in.
- The worker then flows steam though the tube side to clean the exchanger; however, the extra energy evaporates excessive amounts of ammonia and the exchanger ruptures.

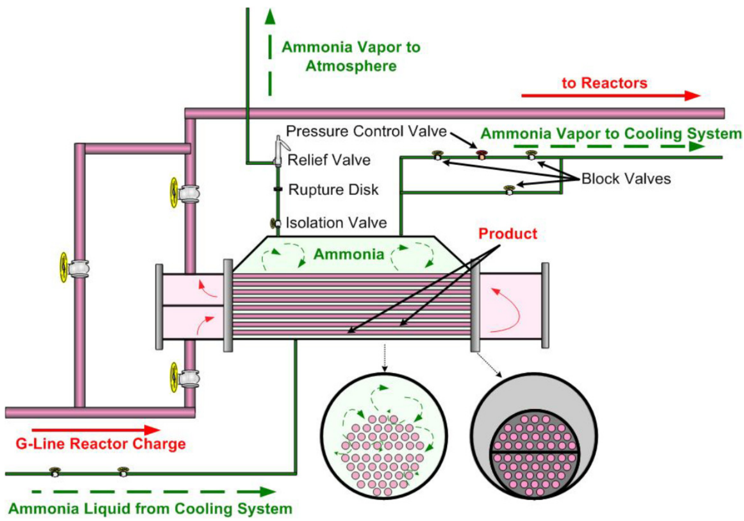


Figure 4: Process schematic of Ammonia Heat Exchanger [4].

Despite the fact that Goodyear's emergency and maintenance procedures are described in one word, "sloppy", the entire incident could have been avoided by following two guidelines provided by ASME Boiler and Vessel Code, Section VIII:

- ". . . when a pressure vessel relief device is temporarily blocked and there is a possibility of vessel pressurization above the design limit, a worker capable of releasing the pressure must continuously monitor the vessel. Goodyear's maintenance procedures did not address over-pressurization by the ammonia when the relief line was blocked, nor did it require maintenance and operations staff to post a worker at the vessel to open the isolation valve if the pressure increased above the operating limit." [4]

- ". . . over-pressure protection shall be continuously provided on pressure vessels installed in process systems whenever there is a possibility that the vessel can be over-pressurized by any pressure source, including external mechanical pressurization, external heating, chemical reaction, and liquid to vapor expansion. Workers should continuously monitor an isolated pressure relief system throughout the course of a repair and reopen blocked valves immediately after the work is completed." [4]

In the early afternoon of June 11th, the body of Gloria McInnis is found in the general area of the ruptured heat exchanger. She is part of the company's emergency response team, and procedural errors lead to an improper head count – she is mistakenly accounted for as alive and well. Her husband's main concern is whether she dies from the explosion or the ammonia. A search through the internet and the Houston Chronicle's website does not provide an answer.

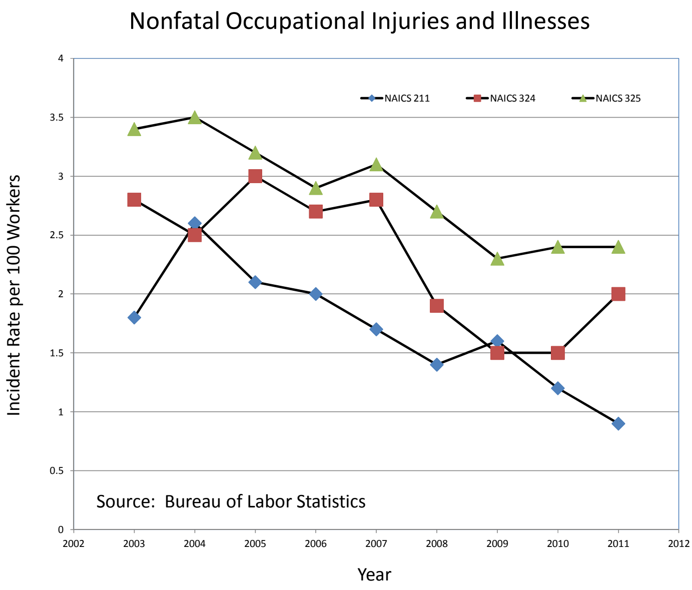


Figure 5: US nonfatal injuries and illnesses rates by industry.

1.5 Industry injury and fatality statistics

Industry statistics are provided by the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA). Historically speaking, the government uses the Standard Industry Code (SIC) for classifying industries; but sometime around the year 2000, the government makes an attempt to use a new system: North American Industry Classification System (NAICS).

This change in systems causes a break in the data. Most of the data in the 1900s is defined by SIC and data from 2000 (approximately) onward is defined by NAICS. Attempts are being made to correlate the two systems but the process is slow. For simplification, this report confines discussion to NAICS, starting at 2003.

NAICS uses 6 numbers to define industries – the first two digits define a broad industry, and the next numbers are used to specifically fix which subsector is being referred. For simplicity, and to avoid "splitting hairs", only three numbers are used in this study.

The industries studied are oil/gas, petroleum, and chemicals:

- NAICS 211 - Oil and Gas Extraction
- NAICS 324 - Petroleum and Coal Products Manufacturing
- NAICS 325 - Chemical Manufacturing

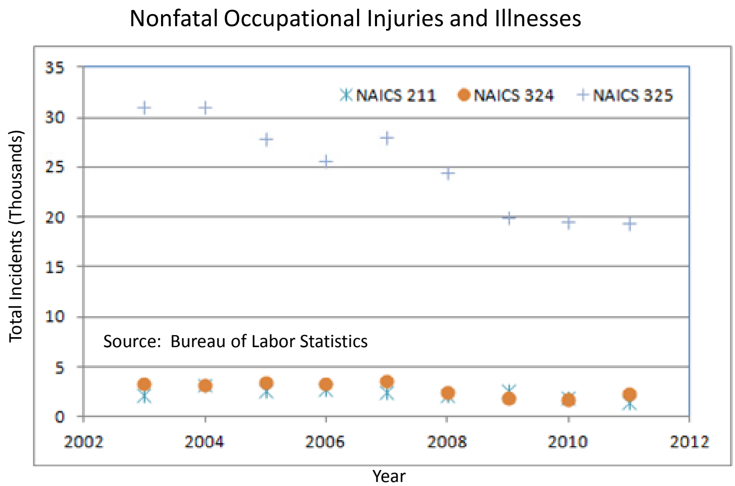


Figure 6: US nonfatal injuries and illnesses totals by industry.

Figs. 5–8 graphically indicate the course of injuries and fatalities in the USA and Texas for the selected industries. The following must be noted for clarity (per BLS):

Incident Rate per 100 Workers = Total Incidents/Total Hours Worked by All Workers * 200,000

The figure 200,000 refers to the number of hours worked by 100 workers, working 40 hours per week for 50 weeks. Closer analysis of this relationship shows that it is easily reduced to the following form:

Incident Rate per 100 Workers = Total Incidents/Average Annual Employment *100

One more note must be made for clarity. The following data are not presented in this study because BLS does not provide this data, or the data per BLS is incomplete:

- Texas injury incident rates for NAICS 211 and 324.
- Texas total injuries for NAICS 211 and 324.
- National fatal rates for NAICS 211, 324, and 325.
- Texas fatal incident rates and totals for NAICS 211, 324, 325.
- A data point for the year 2003 and NAICS 324 is missing in fig. 8.

A quick glance at figs. 5–8 makes one thing fairly clear – injuries and fatalities are trending downward since the year 2003. This is important when compared to fig. 9.

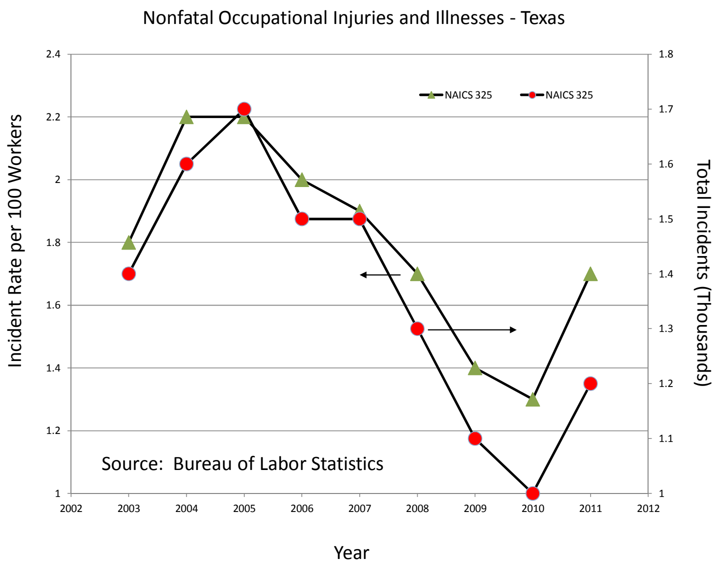


Figure 7: Texas injuries and illnesses incident rate and totals, by industry.

Fig. 9 indicates that the NAICS industries 211, 324, and 325, undergo an economic downturn between the years 2007 and 2010. Yet, injuries and fatalities do not surge upward during this period. It appears that injuries and fatalities actually decline during this period. This is important because there is a belief among people in the industry, the press, and the public at large, that ultimately what matters to corporations are profits; and that people do not matter. Figs. 5–9 do not support this belief – in general, injuries and fatalities are trending downward, particularly during economic hard times.

2 Conclusion

Despite the fact that injuries and fatalities are trending downward, the reality still remains that serious and catastrophic explosions and releases are occurring, as is seen in the cases studied in this report. Twenty five years of experience shine some light on why these terrible incidents continue to occur. Although not experimentally conclusive, the following reasons and causes are proposed for discussion:

- Rushed capital, turnaround, and maintenance schedules.
- General lack of project organization – blurred lines of authority, responsibility, and work flow.
- Many processing facilities have a resident contractor; but, it appears that this is simply "window dressing". Personal experience shows that when flaws in design are brought to the attention of the client by the contractor (flaws that will be costly with respect to vessel alterations, hydrotesting, X-ray examination, PHA reviews, squad checks, etc.), the client just simply explains the flaw away with hypothetical arguments and semantics. Of course, the contractor can only make suggestions – the contractor can be, and often is, easily replaced.
- Personnel skill sets do not match work performance requirements, for instance:

1. Mechanical engineers in a refinery maintenance department charged with leading a pressure relief valve documentation and upgrade project; and yet, do not understand the term "scenario analysis". This is clearly a job for chemical engineers.
2. Instrument technician in charge of orifice plate sizing, and does not understand why the heat capacity ratio and the molecular weight are not required in the calculations if the fluid is a liquid.
3. Instrument technician in charge of selecting liquid level and pressure instruments, when told that the pressure is a product of density, liquid height, and gravitational constant; does not understand why the gravitational constant is in the equation, "if it is a constant".
4. Refinery engineering departments selecting pressure vessels and metallurgy without employing a legitimate mechanical engineering department; rather, the piping designers and process engineering department are used.
5. Piping supervisor (skilled in computer aided design, not engineering) is named project manager and leads process engineers in a pressure relief valve study.
6. In some engineering design firms, civil and electrical engineers are doing chemical process simulation; while chemical and mechanical engineers are selecting process instrumentation, electrical switch gear, transformers, and motor control centers.
7. Electrical engineer with a background in computer circuit boards is hired as a lead instrument engineer on a petroleum refinery revamp project.

As is indicated in figs. 5–9, profits do not appear to be a driving force behind catastrophic incidents in process facilities; however, personal experience tells otherwise. Utilizing designers, with no engineering degree, who have worked their way into the office from the field, is a cheap way to do engineering; but not supportable. Furthermore, using chemical engineers to do electrical systems and using electrical engineers to do process simulation is, perhaps, a way to cut down on manpower; but again, this is unreasonable. And lastly, if resident contractors can be easily replaced by the client, one can rest assured that contractors will not press issues that the client does not want to hear - especially if the issues involve high costs.

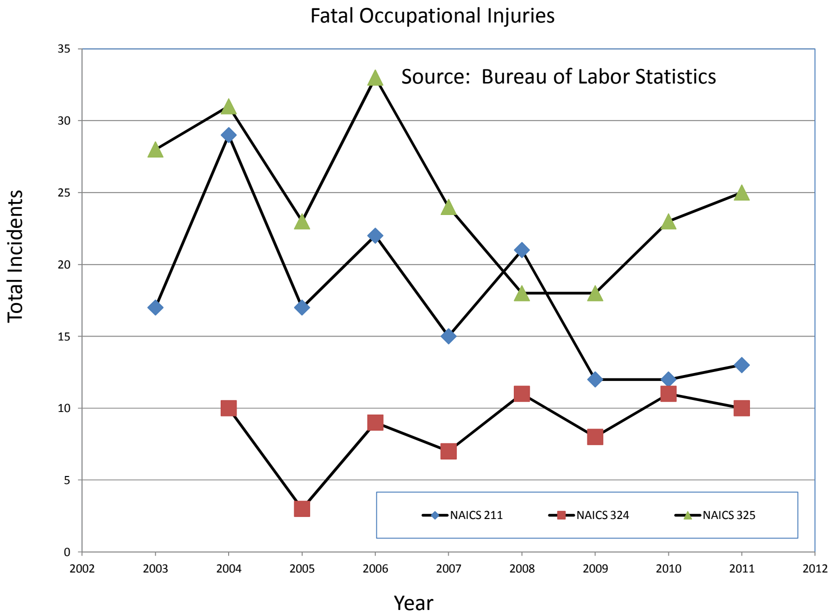


Figure 8: US fatal incidents by industry.

How do things get this way? One suggestion is democracy. A manufacturing environment is very democratic – that is, its life blood is the work produced by unskilled or semi-skilled labor where the educational level usually is not beyond high school. Much effort is made to keep the morale of the worker high; for instance, birthday parties, bowling parties, barbeque parties, pot luck lunches, etc. If there is a plant upset, the intelligentsia normally steps back and says, "let them handle it". The worker very much feels that he is in control because he "makes things go".

Yet, as is described, the manufacturing facility is becoming paralyzed by chaos. This is not surprising. Socrates claims that democracy is the penultimate step before complete chaotic collapse and complete tyranny in a state.

Professor Kenneth Harl, in his online class, "The Peloponnesian War" [5], makes a great observation:

> Aristotle, writing at the end of the 4th century B.C., noted that a state's constitution depends heavily on the military obligations of its citizens. . . . Before the advent of the navy, men from the lowest Athenian class (thetes) generally served as auxiliaries or light infantry on the battlefield. They could not perform hoplite service [hoplites are heavily armored soldiers from the propertied class, they buy their own armor, and thus; are wealthy by necessity] and were not taken seriously in the assembly. . . . Once these men became rowers in the fleet of triremes [war ships], they gained a higher position in society and could assert their political rights. . . . Thus, the development of the Athenian navy went hand in hand with the development of democracy. . .

. . . . naval advancements changed the state into a full participatory democracy with no restrictions on office-holding. To man a fleet of 200 triremes required 34,000 thetes trained as rowers. Inevitably, these men realized their importance to the defense of the state and asserted their political power.

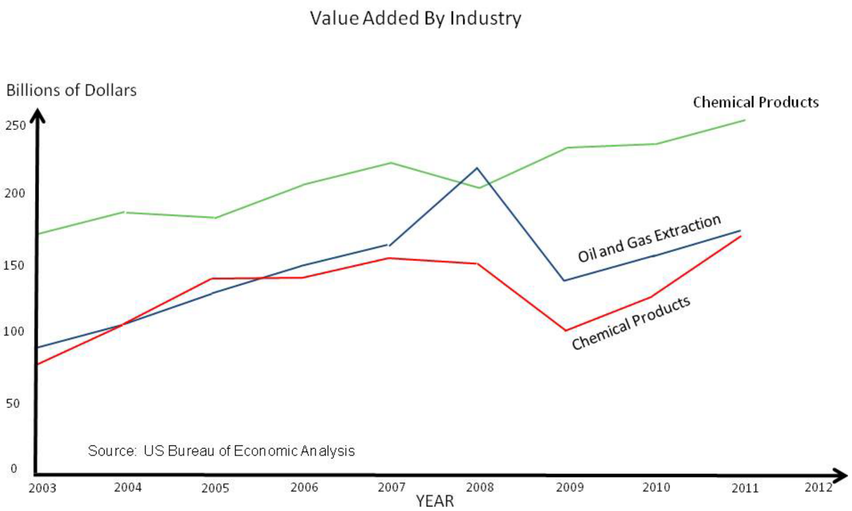


Figure 9: Value added for selected industries.

In our present day, the manufacturing facility is analogous to the great triremes of ancient Greece. Our duty, however, is to insure that the processing plants of today do not crash on the rocky coast of the beckoning sirens who promise higher profits via cheap and unqualified labor.

References

[1] Case Study, No 2005-02-I-TX, Polyethylene Wax Processing Facility Explosion and Fire, US Chemical Safety and Hazard Investigation Board, June, 2006.

[2] Safety Bulletin, No 2005-04-B, US Chemical Safety and Hazard Investigation Board, October 12, 2006.

[3] Case Study, No 2006-01-I-TX, US Chemical Safety and Hazard Investigation Board, June, 2006.

[4] Case Study, No. 2008-06-I-TX, US Chemical Safety and Hazard Investigation Board, January, 2011.

[5] Dr. Kenneth Harl, "The Peloponnesian War", The Teaching Company, 2007.

The role of citizens in emergency management systems in the Czech Republic

J. Rehacek, J. Dlabka, B. Baudisova & P. Danihelka
Faculty of Safety Engineering, VSB,
Technical University of Ostrava, Czech Republic

Abstract

Safety is one of the major priorities in European society. In order to ensure a better quality of life and to remain proactive even during emergencies, effective risk management is needed. Current trends clearly indicate a shift from a passive role of citizens as recipients of help to empowerment and effective self-protection. This paper aims to provide insights into the present state of citizen engagement in the risk management systems within the field of civil protection in the Czech Republic. An analysis of citizens' roles has been conducted and the deficiencies of the current system are discussed along with the identification of possibilities for improvement. Results indicate that the citizen's role within the Czech Republic emergency management system is rather ambiguous. On a theoretical level, stated in the strategy policy guidelines, citizens are perceived as an integral part of the system and, as such, should be empowered to self-protection. But practical implementation leads us to the conclusion that citizens are rather subjects of rescue, passive recipients of help from the side of trained professionals and the major focus is still concentrated on the public authority bodies rather than on citizens. This ambiguous state is particularly visible within the risk communication efforts and the future implications should be discussed further.
Keywords: emergency management, risk communication, civil protection, disasters.

1 Introduction

Human society has been constantly exposed to disasters and emergencies throughout its existence. Large-scale disasters and emergencies are major life events for both communities and individuals. Handling these types of events used

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150141

to be predominantly within the competences of the affected communities and individuals, but in recent decades, it is far more often a competence that is delegated to special professionals who are better trained and prepared than normal citizens to deal with all possible types of such emergencies.

Emergency management system has to serve both as a system that reflects the nature of a hazard and its possible consequences and as a system that reflects the natural behaviour of affected communities. The major issue is the dichotomy between the prescribed roles of citizens and trained professionals within the emergency management system's hierarchical structure. If the emergency management systems are biased, then they may be ineffective. Overemphasizing the competences of authorities in the event of emergencies is contrary to the requirements for resilience and sustainability, because if the system's means and resources do not meet the needs of the affected communities, then we may have a real emergency.

The main objectives of this paper are to evaluate the emergency management system in Czech Republic with an emphasis on citizen engagement and to determine whether or not the current emergency system reflect on the means, potential and needs of citizens in case of emergencies. The first part of this paper provides a review of human behavioural reactions to disasters. The second part describes the emergency management system in the Czech Republic. The third part focuses on an analysis of the national legislation and how it affects the potential role of citizens. In the fourth section, the discrepancies between optimal emergency management and the current emergency management are defined and described. The last part summarizes possible future implications.

2 Citizens' behaviour during emergency situations

In recent years, terms such as "modern disasters" or "disasters of the 21st century" have been more frequently used than ever. The number of disasters and emergencies has been increasing, but more importantly, so has their severity [1].

Smet *et al*. [1] inspected randomly chosen disasters and emergencies in which their complexity over time increases, as well as the increased likelihood that there will be events for which emergency management systems are not designed or prepared.

For such scenarios, it is crucial to incorporate and to reflect the skills, competencies and resources of the citizens to support an increase of capacity that leads to a more resilient society and sustainable emergency management systems. Many papers have been published on the topic of human behaviour during disasters and emergencies (e.g. [2–4]). The main objective is to resolve and to elucidate the misunderstandings about human behaviour during those emergencies that are reportedly confused with irrational and rather improper reactions.

Based on those findings, requirements for emergency systems that accept and are derived from behavioural science literature have been formed. It is important to have knowledge about hazards, but also to accept and to foster knowledge about the human behaviour of citizens in times of emergency. Emergency systems that do not reflect those principles are predestined to fail and have to be considered ineffective [1]. Future hazards for human society resulting from complex interactions between economical, technical and social factors represent a new challenge for redefined emergency management systems. Such systems have to establish and also recognize all possible roles taken by communities on all levels and to organize stakeholders accordingly [5].

But the question still remains, to what extent are citizens capable of self-rescue and of rescuing and helping others? According to Helsloot and Ruitenberg [4], the behaviour of modern citizens is probably still the same as that of their ancestors. Data from real emergencies indicates that most of the lives saved during emergencies are saved not by trained professionals, but by ordinary citizens. The number of people rescued by trained professionals is reported to be only one-fourth of those who need to be helped [4]. This implies that citizens are the basic units who are in large extent capable of helping not only themselves, but also others. Therefore, the individuals and the communities with their capacities, means, resources, knowledge, and relationships should be perceived as an essential and independent part of the critical infrastructure of emergency management systems [6]. The citizens are first on the scene and respond to and rescue individuals. In addition, they also protect the property from being further destroyed [2].

A study conducted by Donahue [7] states that many of the public officials perceive citizens very differently than the citizens perceive themselves. Public officials assume that people are poorly informed, unaware of how to react in case of an emergency, that citizens cannot be trusted in their overall judgment and that they are significantly less-prepared that people think they are. Public officials also tend to attribute the lack of preparedness on the procrastination, rejection and overall laziness of citizens, while the citizens claim that they lack the necessary information.

Patterns of human behaviour recorded during emergencies indicate that the claim of irrational citizens is not true. Dynes [8] formulated a hypothesis of situational altruism. This is a specific form of altruism that arises from emergency situations. Dynes claims that this behaviour originates from the presence of victims on-site and also assumes that a lack of sufficient resources in a particular situation is needed for situational altruism to be exhibited. Situation altruism is then formed as an auxiliary form of behaviour that is not observable outside of emergency situations [8].

These findings show us that there is much more going on during emergencies than is usually assumed by public authorities and some experts. There are new roles being formed, the old roles are being expanded, time-honoured organizational schemes are being changed and values are being re-prioritized. All those changes appear to be chaotic and confusing due to their very rapid progress, but acknowledging that a rational explanation exists behind those actions is essential for coping with disasters and emergencies.

Only then it can be observed that citizens generally react rationally and correctly. They seek important information and in most cases they do everything they are capable of to cope with an emergency situation. Victims of disasters do not react irrationally, they just react differently than what public officials and some experts assume [9].

That led to the conclusion that a hierarchical emergency management system is not fully effective and systems supporting and enabling decision-making at lower levels should be adopted instead. The generally-used emergency management systems that are based on bureaucracy, a top-down management and on hierarchical structure have to be improved and updated. Accordingly, bureaucratic emergency management systems display properties such as: pre-defined objectives and goals, formal structures implemented to coordinate actions and activities on all levels and a stratified division of labour in order to prevent a repetition of tasks and general confusion [10].

In addition, all procedures and principles should be designed, developed and accepted by all members of the organization in order to effectively react to the chaotic environment. Takeda and Helms [10, 11] showed that with regard to such events as Hurricane Katrina and tsunamis, bureaucratic structures are dysfunctional and ineffective.

Perrow [12] brings about the idea of non-robust systems implying "inelegant" structures. He suggests perceiving emergencies as a process of weakening the organizational systems from the point of disruption, which is the catastrophic event. Robust systems of this kind require an "inelegant" system of management and governance. This means that organizational structures should not be slim, centralized and positions in it should not be specialized. This correlates with Roux-Dufort [13] who perceives an emergency as a systemic weakening of the organizational structures to the point of disruption caused by an emergency event. Current modern technological and informational systems allow for decentralization, but they are usually designed to support centralized management [12].

So again, a better definition of roles within society is needed to be able to coordinate and to organize actors on all possible levels in order to improve coping with such threats [14]. According to the "upper echelons theory" [15], top managers structure a situation so that decisions reflect their world view. They oversimplify the world in order to understand it. Roux-Dufort [13] perceives their arrogance as a result of the difference between the complexity of the situation and what managers perceive as simplified reality.

Dynes [3] made a distinction between classic bureaucratic crisis management systems based on paradigm C^3 (chaos, command, control) and effective crisis management, where continuity should be emphasized over chaos and coordination and cooperation should be more significant than command and control [3]. For emergency planning, it is possible to define theoretical applicable fields [16]. List of potential factors affecting emergency response is defined by Thévenaz and Resodihardjo [17].

Emergency planning is also often biased (burdened), which leads to a loss of effectiveness, meaning that preparations are focused on situations that do not reflect reality. One example is panicked behaviour, which is far less common than people think it is [18–21]. For example, preparedness in the USA is perceived as an opportunity on the individual level and includes activities such as being informed about relevant risks, preparing emergency communication plans and preparing tools for helping each other during emergencies. In some cases, it has been proved that people who do not have trust in the government have a 50% probability that they will obey government orders [22].

To ensure that people are able to take care of themselves, they need applicable and actual information upon which they can base their decisions. Without that information, people will still make decisions and judgments, but those decisions will be reasonable and appropriate only from the subjective point of view and will stand up to the viewpoint of experts. Disaster risk management structures come into consideration in cases of residents who are unable to help themselves or cannot be rescued by fellow citizens [23]. In their study, Di Mauro *et al.* [24] showed that people do have an interest in preparation and prevention activities with regard to Seveso facilities, but this is hindered by insufficient risk communication and low awareness about risks. Murphy [25] states that emergency management systems in communities should not stand against government-induced emergency management systems, but should complement them.

3 Analysis of the roles of citizens in emergency systems

The analysis has been conducted by reviewing of strategic documents and through the Czech national legislative related to the civil protection. There are many acts and decrees related to the citizen protection and to the emergency system. In the selected documents there have been systematically searched parts and key words describing primarily or secondarily rights and obligations of citizens and structures by which they are included to the emergency system. The findings of the analysis have been compared to the findings described above. The differences are discussed along with outlining of their common cause.

Regarding the strategic documents, there is one major document strictly related to the civil protection. It is the conception for population protection, which is being processed in multiyear interval. In the conception for years 2006 to 2013 [26] has been explicitly stated: “Basic element of civil protection system is informed and educated citizen, who can react on taken precautions, will contribute to self-protection and to protection of others”.

In a more recent conception [27], this statement is no longer present, but civilians are perceived as part of a system which needs to be educated and informed as well as to be given a set of responsibilities. There is however stated that civilians are responsible partly for their own safety. Generally civilians are being taken into account as autonomous unit, who is able to react individually and contribute to its own safety.

The Czech Republic, due to its rather convenient geographical location and thanks to its natural conditions, is not commonly affected by major disasters with extreme consequences in life losses. Of the most notable ones over the past 20 years are floods, windstorms and landslides. In spite of the effects on property and the need for substantial evacuations during the floods of 1997 and 2002, there is no experience with any other large-scale disasters with an acute threat to a large number of people.

The national civil emergency system is fairly new and modern. Civil protection has undergone massive development. Initially, during the cold war, the civil protection system was built mostly as a protection against consequences of war, as in (not only) other communistic countries. After 1989 change of regime to democratic, the civil protection system was slightly updated, but there was only partial effort to focus more specifically on this matter. This changed after 1997 when large-scale floods showed everyone that the systems were inefficient, which led to completely new legislative packages that defined emergency and crisis situations, competencies etc. The basic structure of the new system was profiled in 2000.

The emergency system is two-tiered – generally, there is emergency planning and preparedness with crisis planning. The first case of preparedness is for "emergency situations", which means natural phenomena along with industrial emergencies [28]. Preparedness is mainly defined as cooperation between rescue units on all levels, called the integrated emergency system (IRS). Cooperation is defined as joint operations and chain of command and covers the area of emergency planning. In the Czech Republic, the government level has two basic types of emergency plans – external emergency plans of nuclear [29] or chemical facilities [30] and the emergency plans of entire regions [29]. Procedures during the management of emergencies focus mostly on onsite management, which is the equivalent of an incident command system [31, 32]. On higher levels, cooperation is managed by information and operation centres – these are communication centres for emergency calls located in most cases in main regional fire stations [28].

The second tier is called crisis management, which focuses on situations that are beyond the capabilities of solely-integrated rescue systems [33, 34]. Crisis management is mainly on the local or regional level and only in some cases at national level. Within this system is a crisis management staff, which consists of regular officials who should be organizing anti-crisis activities and measures in times of crisis. Legislatively, crisis management enables actions that would otherwise not be possible (such as work obligations, closing entry to areas and restrictions on the right to strike).

The role of citizens as described in law is defined in both emergency management system and crisis management system independently. Within the emergency management system, the role of the citizens is defined by the responsibilities, rights and obligations of citizens in general and also by the institutes that act as a secondary units of the IRS in cases of emergencies [28]. It is explicitly stated that an integral part of the IRS are "civil protection organizations", non-governmental organizations (NGOs) and civic associations, all of which could be of help in rescue and response activities. Their participation is planned only before emergencies and they are activated only if their assistance is needed. By legal rights, those subjects are obliged to obey orders from the incident commander [28].

The main principle of citizen integration in the emergency preparedness system and in emergency plans is to inform and educate citizens of the possible risks and threats and to inform them about planned measures [28, 35]. In addition, in an emergency, they must obey orders from the legal authorities responsible for coordinating IRS (the incident commander in most cases). Citizens are, within preparedness efforts, perceived as a value that should be protected and also a part of the IRS, which means they have an obligation to obey direct orders. Legislation clearly states that there is a right to be informed about risks in the time before any emergency, but only before the event occurs [28]. Warnings and information received during an emergency is an integral part of emergency plans, but only marginally mentioned in law. The executive decree [29] also explicitly states that part of coordination is securing of the closure of the event surroundings and forbidding entry by everyone who is not necessary.

In developed emergency plans [29, 30], the most attention is focused on a description of the territory along with the hazard, on a list of allocated forces and resources and in the end, specific actions to be taken. Emergency plans do not include citizens as autonomous units. They can participate in rescue operations, but only if they are coordinated by someone from IRS (the incident commander) or to be controllably rescued (being evacuated, sheltered, etc.).

Crisis management is the difference between emergency situations and crises given by the policy decision. The state of a crisis is a situation where an emergency situation goes beyond the possibilities of IRS and for which authority is needed to declare a state of crisis that will allow officials to take extraordinary precautions. In the Czech Republic, there is a total of 4 states of crisis [33, 34, 36]. Two of them are civil and usable during civil emergencies [34] and two of them are military-based, which focus on threats to democracy [33] and/or on war [36]. The main task of crisis management is to preserve the functionality and continuity of state administration. The measures are mainly based on the economical level (the planned duty of defined subjects to provide services and resources), keeping those subjects functioning (critical infrastructure protection) and last but not least, on defined management systems.

Managing a crisis situation is taken care of by crisis management staffs, which are defined on all levels of state administration and they consist of elected officials and public servants from different levels. The chair of the crisis staff is typically the highest-ranking authority (Mayor, Governor, etc.). Crisis staff can be used even in an emergency (as a command for IRS) to coordinate large-scale emergencies, but this option is not often used [34].

The role of citizens in this system is also very limited. Citizens are perceived passively as someone who should be protected or coordinated; this is the same as in the case of emergencies. Citizens have the right to be informed about information needed for crisis management and planning, and supposed to tolerate limitations derived from crisis actions to be taken, to carry out the work obligation and to provide material means. The term "voluntary assistance" is an extended form of assistance when addressing an emergency situation. Local emergency authorities may decide that citizens have to do a certain job in a certain place for a certain period of time [34].

Crisis planning doesn't include its functioning citizens to be active parts at all. Sections of crisis plans that are formed from descriptions of danger or defined precautions include only lists of institutions and entrepreneurs conducting commercial activities suitable for aiding the defined means described above [37]. First and foremost, these are subjects of critical infrastructure, but the idea is not to involve everyone who can help, but rather manage the provision of resources and services in an emergency situation. The crisis plan itself does not include any option to incorporate local, non-governmental organizations or the community.

4 Major issues identification

The main question is why is there such a discrepancy between academic findings and the current state in the Czech Republic? One factor is a lack of major disasters, so the updated management systems have not yet been needed for large-scale sudden crises, and without this experience, it is hard to develop functioning structures.

The Czech Republic, because of its favourable geographical location, is spared from many large-scale disasters such as earthquakes, hurricanes and large landslides. In the past 20 years, there has been only one type of disaster that has led to disaster risk management improvement: floods. With regard to the findings listed above, these possible problems have been identified:

1. The system is optimized for small-scale emergencies and disasters, not for crises and emergencies that are beyond the experience of the IRS. Saying that the IRS is ineffective is an overstatement and is not true. Only the IRS structure meets the needs and situations that do not go beyond its common possibilities or assets.
2. Citizens are perceived as passive receivers who have to be cared for. Safety and security in the Czech Republic is mostly understood as a granted service to be provided to citizens.
3. Authorities responsible for crisis and emergency management ignore human behaviour in emergencies. In crisis and emergency plans, as well as in legislative and methodological documents, there is no mention of how the specific behaviour of citizens is to be taken into account. The absence of such practice is obviously the reason for this situation, but according to Dynes [3] it is the main obstacle to reaching effective crisis management.
4. The system is too bureaucratic and non-transparent. The two-step emergency and crisis management system is to some extent confusing and is not easy to understand it due to complicated and overlapping competencies. There are too many plans and the goal for managers is mostly to meet legal requirements. The whole system of emergency planning is strongly derived from military practice what is according to Dynes [3] neither appropriate nor effective.
5. There is no further practice with risk communication with the citizens during emergencies and preparedness. Communication is conducted only as a legal requirement but, it does not reflect human behaviour. It is in contrast with well-functioning specific early warning and information systems in floods preparedness [38], which only confirms the prerequisite

that experience and closeness to the issue is a major factor for enhancing the system and that sufficient information activities and warning is of great importance for the ability to cope with disasters.

6. Science and research in crisis management appear to be internalized and derived from experience, which leads to oversimplifying the adaptation of legal requirements without further analysis. Even though there is a wide range of experts and academics in this field, the field is perceived as mostly technical and socio-economic and psychological components are being ignored or at least not employed sufficiently.
7. The positive message is, that new Conception of Citizens Protection till 2020 put emphasis on citizen active participation and stakeholder involvement, as well as on communication and education system improvement.

5 Discussion and conclusions

New emerging threats, such as terrorism, new types of (or a combination of) global-change induced disasters, along with low probability threats lead to the question whether or not the Czech Republic is, along with other countries, facing new challenges properly. It leads to questioning the effectiveness and functionality of the prevention and response system for emergencies for which we are not yet prepared and for which current resources would probably not be sufficient. This further leads to question about whether the emergency management system still works as a rather bureaucratic hierarchical structure without considering human behaviour rather than reflecting real crisis (situations that we are not accounted for) which requires constant revisions, searching for better solution and learning from others.

With current systems in the EU, it is not necessary to address the protection of territories within each member state. A promising solution is to renounce hierarchic structures and to use the incident command system and incident command management instead, which will guarantee a sustainable life of the citizens [39]. It is needed to accommodate a shared philosophy of disaster and/or emergency preparedness, which is the same for the EU [39].

First, citizens have to be taken into account as a part of complete systems, as they have the responsibility and also the ability to rescue themselves and to help to rescue others. It is possible and appropriate to let them participate and to engage them not only in the preparedness phase, but also in ongoing disasters [40]. A crucial tool for achieving these goals is a functioning effective risk communication system.

One of the possible ways to improve risk communication is to employ modern information technologies. A high level of engagement during emergencies is not a new thing, but thanks to information technology, the roles are far more transparent and there are many more opportunities for citizen to be put into action [41], including active management. Modern technologies allow for more active engagement of citizens if there is better access to the Internet and with

www.witpress.com, ISSN 1743-3509 (on-line)

incorporating mobile technologies, mobile phones, text and multimedia messages especially when combined with GPS [41].

A hopeful solution would be an avoidance of hierarchical and pseudo military structures and not using incident command systems and incident command management. Better employing of NGOs could be one solution, too.

Acknowledgement

The contribution has been supported by the Program of Security Research of the Czech Republic 2010–2015 as a part of Project No. VG20132015131.

References

[1] Smet, H., Lagadec, P., Leysen, J., Disasters out of the box: a new ballgame? *Journal of Contingencies and Crisis Management*, 20 (3), pp. 138–148, 2012.

[2] Perry, R.W., Lindell, M.K., Understanding citizen response to disasters with implications for terrorism. *Journal of Contingencies and Crisis Management*, 11(2), pp. 49–60, 2003.

[3] Dynes, R.R.., Community emergency planning: false assumptions and inappropriate analogies. *International Journal of mass Emergencies and Disasters*, 12 (3), pp. 141–158, 1994.

[4] Helsloot, I., Ruitenberg, A., Citizen response to disasters: a survey of literature and some practical implications. *Journal of Contingencies and Crisis Management*, 12 (3), pp. 98–111, 2004.

[5] Olsen, O.E., Kruke, B.I., Hovden, J., Societal safety: Concept, borders and dilemmas. *Journal of Contingencies and Crisis Management*, 15 (2), pp. 69–79, 2007.

[6] Barnes, J., Newbold, K., Humans as a critical infrastructure: Public-private partnerships essential to resiliency and response. *First IEEE International Workshop on Critical Infrastructure Protection*, Los Alamitos, CA, USA, pp. 75–83, 2005.

[7] Donahue, A.K., Ready or not? How citizens and public officials perceive risk and preparedness. *Public Management Research Conference*, Syracuse, New York, June 2–4, 2011.

[8] Dynes, R.R., Situational Altruism: Toward an Explanation of Pathologies in Disaster. *Assistance Research presentation, Xiii World Congress of Sociology*, Germany, 1994.

[9] Quarantelli, E.L., Community crises: an exploratory comparison of the characteristics and consequences of disasters a riots. *Journal of Contingencies and Crisis Management*, 1 (2), pp. 67–78, 1993.

[10] Takeda, M.B., Helms, M.M., "Bureaucracy, meet catastrophe": Analysis of Hurricane Katrina relief efforts and their implications for emergency response governance. *International Journal of Public Sector Management*, 19 (4), pp. 397–411, 2006.

[11] Takeda, M.B., Helms, M.M., "Bureaucracy, meet catastrophe": Analysis of the tsunami disaster relief efforts and their implications for global

emergency governance. *International Journal of Public Sector Management*, 19 (2), pp. 204–217, 2006.

[12] Perrow, C., Organizing to reduce the vulnerabilities of complexity. *Journal of Contingencies and Crisis Management*, 7 (3), pp. 150–155, 1999.

[13] Roux-Dufort, C., Is crisis management (only) a management of exceptions? *Journal of Contingencies and Crisis Management*, 15 (2), pp. 105–114, 2007.

[14] Olsen, O.E., Kruke, B.I., Hovden, J., Societal safety: Concept borders and dilemmas. *Journal of Contingencies and Crisis Management*, 15(2), pp. 69–79, 2007.

[15] Hambrick, D.C., Mason, P.A., Upper echelons: The organization as a reflection of its top managers. *Academy of management review*, 9 (2), pp. 193–206, 1984.

[16] Herzog, R.J., A model of natural disaster administration: naming and framing theory and reality. *Administrative Theory & Praxis*, 29 (4), pp. 586–604, 2007.

[17] Thévenaz, C., Resodihardjo, S.L., All the best laid plans…conditions impeding proper emergency response. *International Journal of Production Economics*, 126 (1), pp. 7–21, 2010.

[18] Quarantelli, E.L., Panic behaviour in fire situations: Findings and a model from the English language research literature. *Fourth Joint Panel Meeting of the United States Japan Panel on Fire Research to be held in Tokyo*, Japan, 1979.

[19] Quarantelli, E.L., The sociology of panic. *International encyclopaedia of the social and behavioral sciences*. Pergamon Press: New York, pp. 11020–11030, 2001.

[20] Quarantelli, E., The behaviour of panic participants. *Sociology and Social Research*, 41(3), pp. 187–194, 1957.

[21] Quarantelli, E.L., The nature and conditions of panic. *American Journal of Sociology*, 60(3), pp. 267–275, 1954.

[22] Lasker, R.D., *Redefining readiness: Terrorism planning through the eyes of the public*. University at Albany, School of Public Health, Centre for Public Health Preparedness, 2005.

[23] Scholtens, A., Jorritsma, J., Helsloot, I., On the Need for a Paradigm Shift in the Dutch Command and Information System for the Acute Phase of Disasters. *Journal of Contingencies and Crisis Management*, 22(1), pp. 39–51, 2014.

[24] Di Mauro, C., Bouchon, S., Torretta, V., Industrial risk in the Lombardy Region (Italy): What people perceive and what are the gaps to improve the risk communication and the participatory processes. *Chem. Eng. Trans*, 26, pp. 297–302, 2012.

[25] Murphy, B.L., Locating social capital in resilient community-level emergency management. *Natural Hazards*, 41 (2), pp. 297–315, 2007.

[26] Ministry of Interior, Conception of Population Protection till 2013 with a possible overlaps until the year 2012. Government of Czech Republic: Praha, 2008.

[27] Ministry of Interior, Conception of Population Protection till 2020 with a possible overlaps until the year 2030. Government of Czech Republic: Praha, 2013.

[28] Parliament of the Czech Republic, Act No. 239/2000 Coll., on integral rescue system and on the amendment of some laws, as amended. Collection of Laws of the Czech Republic, 2000.

[29] Ministry of Interior, Decree No. 328/2001 Coll., on certain details of providing of integrated emergency system. Collection of Laws of the Czech Republic, 2001.

[30] Ministry of Interior, Decree No 103/2006 Coll., which designates fundamentals for designating an accident planning z one and the scope and method of preparing an external emergency plan. Collection of Laws of the Czech Republic, 2006.

[31] Alexander, D., *Principles of emergency planning and management*. Oxford University Press, Oxford: New York, 2002.

[32] Bigley, G.A., Roberts, K.H., The incident command system: High-reliability organizing for complex and volatile task environments. *Academy of Management Journal* 44 (6), pp. 1281–1299, 2001.

[33] Parliament of the Czech Republic, Constitutional Act No. 110/1998 Coll., on security of the Czech Republic, as amended by the Constitutional Act No. 300/2000 Coll. Collection of Laws of the Czech, 1998.

[34] Parliament of the Czech Republic, Act No. 240/2000 Coll., on crisis management and on the amendment of some laws, as amended. Collection of Laws of the Czech Republic, 2000.

[35] Ministry of Interior, Decree No. 380/2002 Coll., on the preparation and implementation of civil protection. Collection of Laws of the Czech Republic, 2002.

[36] Czech National Council, Act No. 1/1993 Coll., Constitution of the Czech Republic. Collection of Laws of the Czech Republic, 1993.

[37] Government of the Czech Republic, Government Decree No. 462/2000 Coll., which implements the provisions of Sec. 27(8) and Sec. 28(5) of Act No. 240/2000 Coll., on Emergency Management and Amendment to Some Acts. Collection of Laws of the Czech Republic, 2000.

[38] Höppner, C., Buchecker, M., Bründl, M., Risk communication and natural hazards. *CapHaz project. Birmensdorf, Switzerland*, 2010.

[39] Boin, A., Ekengren, M., Preparing for the world risk society: towards a new security paradigm for the European Union. *Journal of Contingencies and Crisis Management*, 17 (4), pp. 285–294, 2009.

[40] Roberts, N., Public Deliberation in an Age of Direct Citizen Participation. *The American Review of Public Administration*, 34 (4), pp. 315–353, 2004.

[41] Palen, L., Liu, S.B., Citizen communications in crisis: anticipating a future of ICT-supported public participation, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, New York, USA, pp. 727–736, 2007.

Challenges for integrated early warning and disaster management in the UAE

A. Al Hmoudi & Z. Aziz
University of Salford, UK

Abstract

In the UAE, there are deficiencies in the use of technology in the exchange of information and reliance on the National Centre for Meteorology and Seismology Monitoring and Warning (NCMS). The new centre is affiliated to the Ministry of Presidential Affairs and it is established in coordination with concerned authorities. It is networked with similar centers in the region for the sharing of information and intervention at times of need. It also provides meteorology monitoring with advice and warning on storms. However, members of the community are uninformed and do not know the procedures carried out in the event of the arrival of early warning signals. The UAE is vulnerable to the possibility of tsunami activity. Early warning systems (EWS) within the UAE face various socio-technical challenges. Moreover, there are shortcomings in the training process and scenarios with individuals and institutions of civil society. Natural disaster management is not only about shelters and distribution of blankets, medicines and evacuation operations. It is also about education, awareness generation, mitigation strategies, community participation and lifestyles.
Keywords: early warning, challenges, community, natural hazards, disaster management, NCMS, communication.

1 Introduction

The United Nations International Strategy for Disaster Reduction (UN/ISDR) identified the use of custom-made caution messages for all inclusive groups as one of the four vital elements of early warning systems. Despite this, the element is seldom accounted for by hazard observation and early warning systems (EWS). In corporation with climate change-related vulnerability and risk assessment, the assessment of the risks should encompass both climate scenarios

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150151

and a combination of hazard and vulnerability scenarios. This is a move to provide a solid decision making set up. (Birkmann *et al.* [1]). As highlighted by Renn and Walker [2] risk communication is considered a key element by the Integrated Risk Governance Structure in relation to risk control. Effective risk communication should serve the purpose to educate stake holders and the society in general the basis of risk and equip them with ability to make proper decisions in relation to risk. Effective communication between all the stake holders involved is considered a vital mechanism in approaching risk and should in relation improve awareness and effectual approach to risks (Chang-Seng and Jury [3]). According to Grasso *et al.* [4], the UN certainty of data should be efficiently conversed to the users. In addition, the people at risk should be timely warned on UN certainties (Birkmann *et al.* [1]; Chang-Seng and Jury [3]; DKKV and ISDR [5].The degree of consideration given to natural hazards such as floods, tropical storms and weather related hazards such as heavy precipitation and heat waves in comparison to slowly creeping hazard processes, for instance, salinisation and rises in sea-level, the main consideration lies on the natural hazards. In addition even lesser consideration has been given to accumulated shocks from non-extreme events (Birkmann *et al.* [1]). The major challenge in improving the ability of societies to manage environmental shocks and creeping environmental changes, is to craft an integrated structure that takes into account all relevant hazards without sidelining UN connected systems. This all inclusive approach should offer synergies and cost efficiencies, for instance in data gathering and processing, and in public preparedness endeavors. Additionally, it should aid in the enhancing and upholding warning abilities for the less frequent hazards, such as tsunamis (Basher [6]).

EWS within the UAE faces various socio-technical challenges: Firstly, the role of communities within EWS is not clearly defined. Also, members of the community are uninformed and unaware of Federal plan, and as results do not know the procedures carried out in the event of the arrival of early warning signals. Dhanhani [7] has highlighted how lack of an end to end and people-centered approach on EWS, low levels of preparedness and a general lack of knowledge regarding the emergency management plans. Secondly, the UAE has a huge expatriate population who do not speak Arabic. The presence of other languages, such as English, Persian, Hindi, and Urdu create significant communication challenges. As identified by Al Ameri [8], there are significant weaknesses in the transfer of understandable warning messages and preparedness information to those at risk and there are no networking and communication among the NCMS and other stakeholders.

2 Reviewing the National Center of Meteorology and Seismology in the UAE

The center is affiliated to ministry of presidential affairs which is the authority concerned with meteorology and seismology affairs. It represents the country as a member in the world organization for meteorology and seismology. The center provides services to the public, governmental bodies, research centers, media, and aviation and decision makers. The federal decree number 6 of 2007 was promulgated to establish and regulate the National Center of Meteorology and Seismology (NCMS [9]). Main fields of the National Center of Meteorology and Seismology: the introductory handout issued by the National Center of Meteorology and Seismology illustrates that it is concerned with the following fields (NCMS [9]). Meteorology and Early Warning: the center works within the global system of the World Organization of Meteorology in international and regional collaboration with member states of the above mentioned organization. It performs its tasks through the following organizations and abilities:

1. Weather networks: the center operates and maintains 59 automatic weather stations all over the world, 5 weather radars and upper atmosphere layers station.

2. Communication network: all meteorological information is to be collected and exchanged through local, regional and international communication networks. The Center is connected with the following main circles: Abu Dhabi/Muscat, Abu Dhabi/Jeddah, satellite circles and uses MSS system to collect and redistribute data.

3. Weather forecasting includes: main forecasting center, numeral forecasting center, in which a high resolution (HRM) model and its applications (SWAM – MAM) are used while (Visual Weather) is used to follow weather changes, flight forecasting and naval forecasting centers.

4. Rain-making applications: the center has two flights working in rain-making project and assisted by 5 earth radars. Many good experiments have been conducted in this field. This field is one of the main activities of the center.

5. Climatic studies: the center reviews and processes climatic data, and prepare climatic studies and reports serving activities in different countries, especially those concerned with studies and researches such as universities, research institutions and entities concerned with applied sides and establishing climatic information bank.

6. In an earthquake's field: the center, through a network of five stations for monitoring strong and weak movement of earthquakes, conducts monitoring works. Such stations are the same as those stations used in earthquakes monitoring network for nuclear experiments comprehensive banned area. Also, the center is specialized in earthquake engineering studies, applied geology and the effect of soil on earthquakes waves.

2.1 Research, developing and training fields

The center is to perform scientific research, especially applied ones in forecasting and seismology; to participate in the universities, research institutes and related studies; to train the needed technical cadres to work in forecasting and seismology.

2.2 Technical services field

A department was established in the center for delivering technical services for managing databases and systems; creating, developing and analyzing databases programming; managing and maintaining communication lines and networks; maintaining forecasting and earthquakes equipment and devices. The center should work to provide all the developed devices and equipment for every section coping with the new developed technologies.

3 Methodology

According to the four elements of an early warning system explained previously, the second stage is disaster observation. The National Center of Meteorology and Seismology plays a vital role with respect to observation, weather forecast and prediction process, which is the essence of early warning system. The researcher has focused on explaining and studying the National Center of Meteorology and Seismology in Abu Dhabi which, subjects to ministry of presidential affairs. A random sample was taken from the center's staff to determine how staff understands their role and needs of early warning system, and the availability modern technology means to early warning system and natural disaster observation.

3.1 Survey results

The study was conducted on a sample consists of (40) persons from workers in the National Center of Meteorology and Seismology, in UAE. Researcher followed certified scientific approaches and frames in selecting the sample for study. Results are as follows:

Table 1: Sample age groups.

Age group	20–30	31–40	41–50	51–65
Percentage	(14%)	(29%)	(14%)	(43%)

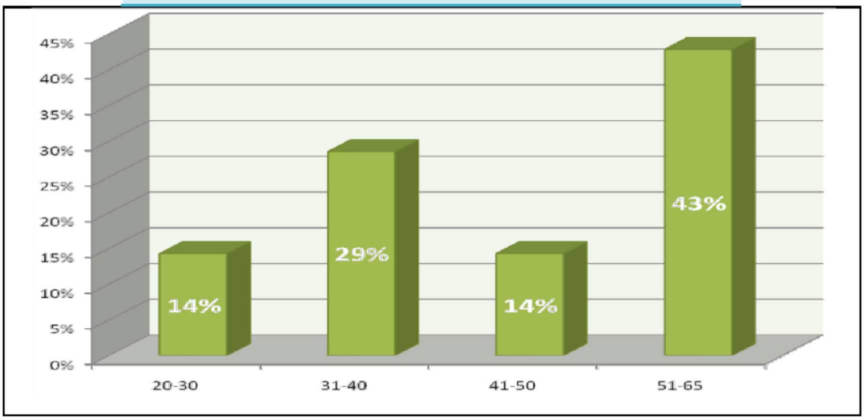
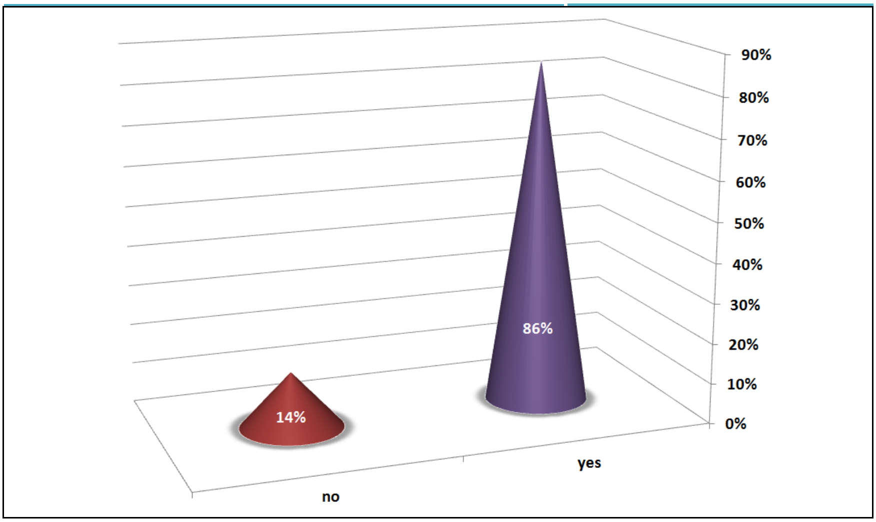


Table 2: Satisfaction average with current weather forecast pattern performance and efficiency.

Satisfaction average with current weather forecast pattern and efficiency	Yes	No
Percentage	(86%)	(14%)



The study showed that 6 persons (86%) from the sample of study are satisfied with current weather forecast pattern performance and efficiency. On the other hand, only one person, (14%) from the sample is not.

The study showed that 6 persons (86%) of the studied sample are satisfied with the current tsunami forecast pattern performance and efficiency. While only one person (14%) is not.

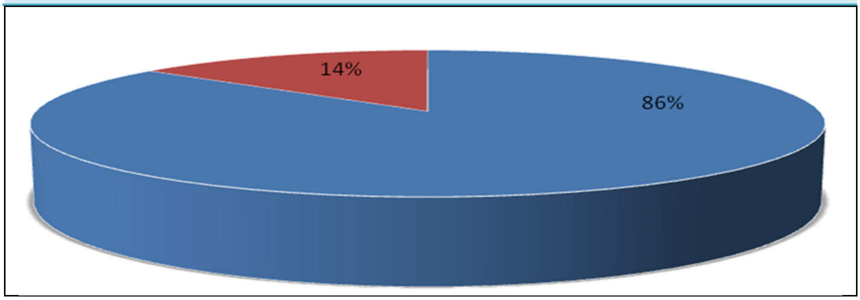
The researcher found, after his visit to the National Center of Meteorology and seismology; the best way of coordination between the Center and the Department of Emergency and Public Safety, is by exchanging field visits to get familiar with the work nature of each other, and exchanging data and experience. Researcher suggests appointing a deputy from the Centre in the Central Operation room in the General Directorate of Abu Dhabi Police, to provide the required information about weather updates and to explain its details, as he is the specialized person for weather conditions observation.

4 Challenges of EWS pertaining to new environmental shocks in the UAE

The policy lessons that can be emulated from existing EWS and monitoring in the context of dissimilar and exposed target groups in the National Center of Meteorology and seismology (UAE) are sum up as follows.

Table 3: Satisfaction average with current tsunami forecast pattern performance and efficiency.

Satisfaction average with current Tsunami forecast pattern performance and efficiency	Yes	No
Percentage	(86%)	(14%)



- So as to prop up resilience building, the focus on EWS should not only be hazards but also on the notion of exposure. There is need for EWS to be improved so that people are not only warned before the event of a hazard impacts a society, but also have a say in making sure that the livelihoods/lives at risk are secure from the gradual changes that are brought by climate changes.
- There is need for information on hazard pattern changes to be merged with knowledge and forecasts about the development of vulnerabilities. The combination of the two will present the foundation of high quality EWS.
- There is no sustainability in isolated or individual hazard, especially in the context of dealing with the challenges related to climate change. This calls for the need to give an explanation for rapid and gradual hazards simultaneously (for example, the potential significance of storm surges and sea-level rise)
- Top-down, technocratic, expert-driven and linear EWS alone are not effective at reducing damage and saving lives. A mixed institutional approach that includes both formal and informal phases is frequently indispensable. In such a scenario, the system does not control the people at risk but the people are an essential part of the system, thus creating a people-cantered approach. This entails combining different types of knowledge in EWS, especially by connecting scientific and traditional knowledge.
- The development process of EWS entails a multi-disciplinary approach. This approach must recognize all the stakeholders in the community and along the chain. It must also strive to build partnership and dialogue instead of being based on a top-down alert process.

- The human assets and preparedness approaches connected to a EWS are especially imperative in low-technology places.
- There is supposed to be a change towards working, relating and communicating 'with' the community as opposed to 'for' the community.
- The shift of EWS technologies in dissimilar societal and cultural settings raises the question of robust and the abilities of the societies' to uptake such complicated technologies devoid of deal with the digital divide governance problem.
- In addition, the new technologies and communication platforms like Face book and Twitter and the internet generally have to be understood better. This is in terms of their role in enlightening and warning people in situations of calamity.
- The effectiveness and sustainability of a EWS is driven by the systems of governance, which is economic, political and socio-technological.
- The founding and development of EWS should be an essential objective of both rural and urban planning ad connected sectors.
- So far, EWS have been very effective in identifying sudden-onset hazards at the same time creeping societal tipping points and environmental changes that are imperative dynamics in decisions to migrate. In terms of displacement, EWS have not been adequately well thought-out, or at least have gotten not as much of interest compared to hazard detection
- Currently, climate services are under development through the GFCS (Global Framework for Climate Services). In this situation, the lack of effective climate services around the world restricts the current abilities and prospects in the use of climate information for EWS.

5 Summary

Early warning is to give the opportunity of time to prepare and to reduce the confrontation of the victims, and reduce the economic and social losses in the United Arab Emirates. National Centre for Meteorology and Seismology in the UAE the national main responsible for the establishment of an early warning system in the state, in coordination with the concerned authorities, including the Ministry of Interior represented emergency management; public safety and civil defense. And coordination between them contributes to overcoming the challenges facing early warning in the UAE.

References

[1] Birkmann, J., Chang Seng, S.D., Surez, D. (2011). Adaptive Disaster Risk Reduction in the Light of Climate Change, Ed DKKV.

[2] Renn, O. and Walker, K. (2007) Lessons learned: a re-assessment of the IRGC framework on risk governance. In: Renn, O. and Walker, K. (eds.) *the IRGC Risk Governance Framework: Concepts and Practice*. Springer, Heidelberg and New York, pp. 331–367.
[3] Chang-Seng, D. and Jury, M. (2010): Tropical cyclones in the SW Indian Ocean. Part 2: structure and impacts at the event scale. In: Meteorology and Atmospheric Physics. vol. 106, no. 3, pp. 163–178.
[4] Grasso V.F., Beck J. and Manfredi G. (2007). Automated decision procedure for earthquake early warning, Journal of Engineering Structures, 29 (Issue 12), pp. 3455–3463.
[5] ISDR. (2009). "Reducing Disaster Risks through Science: Issues and Actions. Report of the ISDR Scientific and Technical Committee". Global Platform for Disaster Risk Reduction, in Geneva, Online 10/03/2010 http://www.preventionweb.net/globalplatform/2009/background/documents/SD-03-ENGScientific-Technical-Committee.pdf.
[6] Basher, R. (2006). Global early warning systems for natural hazards: Systematic and people-centered. In: Philosophical Transactions of the Royal Society 364: pp. 2167–2182.
[7] Dhanhani, H. (2010) Evaluation of the Response Capability of the United Arab Emirates to the Impact of Natural Hazards.
[8] Al Ameri, F. (2010). Implementing an Effective Public Warning System in Abu Dhabi UAE. Coventry University (MSC-Disaster Management).
[9] National Center of Meteorology and Seismology (NCMS), (2013). Ministry of Presidential Affairs, UAE.

Section 4
Security surveillance systems

This page intentionally left blank

Infrasonic fluidic oscillator for use in anti-terrorist warfare

V. Tesař[1] & E. Smyk[2]
[1]Institute of Thermomechanics ASCR, Czech Republic
[2]UTP University of Science and Technology, Poland

Abstract

The authors investigated a new approach to improving the effectiveness of detecting trace amounts of illegal substances, such as those on clothing of persons who have come into recent contact with explosives. An annular synthetic jet, generated by a simple and inexpensive non-moving-part fluidic oscillator operating at infrasonic frequencies protects the sample on its path – from the clothing surface to the inlet in an analyser – and prevents its dilution and escaping into the atmosphere.
Keywords: anti-terrorist warfare, synthetic jet, impinging jet, infrasonics.

1 Introduction

Terrorism is among the severest problems our civilisation is now facing. The success of terrorists is due to the economic factors favouring them [1]. It is cheaper by several orders of magnitude to launch a terrorist attack than to prevent it by deploying, maintaining, and manning large-scale protection systems and organisations. Prevention requires detection and early warning so effective that potential attackers are deterred. Among the detection and screening methods, the most expeditious is discovering on a person's clothing even the minutest traces of illegal substances – ranging from detecting concealed explosives to single out those persons who were merely present in a room where the illegal materials were handled. Standard detection uses trained dogs but this will not suffice in the near future. It is not fully reliable and training and keeping dogs by dedicated personnel at the vast numbers likely to be needed is economically untenable. Replacement by technological solution is necessary and of particular promise are ideas offered by fluidics – the technique of handling and controlling

WIT Transactions on The Built Environment, Vol 151, © 2015 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150161

liquid and gas flows without the action of moving components. Fluidic solutions are inexpensive and in collaboration with microelectronics provide means shifting the current economic disbalance at least slightly away from terrorism.

2 The task

Substituting the dog-based detection activities by a technological solution needs solving several development steps. First, the detection has to be extremely sensitive. Dogs on average can detect explosives at concentrations in air as low as 1 ppb (parts per billion) – depending on composition and vapour pressure of the particular explosive. Nevertheless, sufficiently sensitive multi-spectral sensors became already commercially available at a reasonable price [2, 3] – an achievement mainly thanks to microelectronics but in a non-negligible measure also to microfluidics [2].

Effort now focuses on efficiency of sample acquisition and delivery to the sensor. Progress in this direction can significantly relax the demands placed on the analyser sensitivity. Two areas are in need of improvement: (a) It is necessary to remove more effectively the detected substances from the interrogated surface. The limit is posed by the demand of the procedures being not overly unpleasant to public. (b) Also handling the samples must be more effective, in particular preventing their dilution. The main problem is anthropometric variance of screened persons. It results in a gap the sample has to traverse between the interrogated surface and the inlet into the sensor. Helpful information has been in the meantime acquired by research into the details of the method applied by dogs in their detection job [2] – and the possibilities of emulating them by fluidics. To release the detected substances from the interrogated surface, dogs use jets of exhaled breath. In the subsequent half-period this alternates with the sniffing inhalation phase, during which the advantage dogs possess is their ability to move their head so as to place the snout to the proper position relative to the interrogated surface. Suggested mechanical means analogous to dog's head positioning – e.g., moving pipes with end pads landing on the person's clothes – are not practically acceptable.

Perhaps least inconvenient – and already accepted by the general public – is locating the detectors in portals (Fig. 1) to be walked through. The versions currently in use have simple nozzles generating air jets directed at particular locations on the screened person. Unfortunately, such simple jets do not handle the samples properly. They blow them away from the detection position and let them escape into the atmosphere. Attempts at improvement increase the sample amount by increasing the aerodynamic power supplied to the nozzle – without real success. The jets, powerful to the level of unpleasantness, do release more substances but let them escape. In portals nowadays available [3] the collectors taking the sample into the analyser are positioned in the lintel top beam of the portal. The transport of the sample to the collector relies on thermal convection currents. Unfortunately, these currents generated by body heat are slow so that the screened person cannot simply walk through the portal at a normal pace. Also, they tend to be unreliable since the slow currents may be easily diverted by

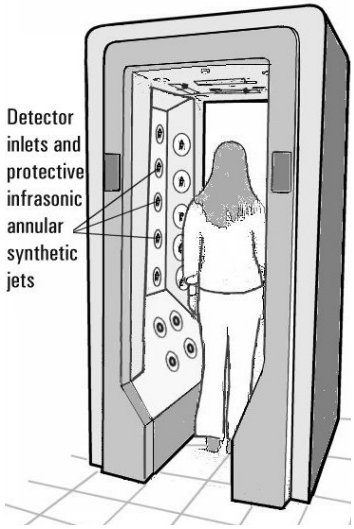


Figure 1: An example of a portal for detecting minute traces of illegal substances on a person's clothing.

unpredictable horizontal air flows (e.g. room draughts or person's motion). Not answered is the dilution of the sample by mixing with the surrounding air.

The collector inlets should instead be placed near the sample releasing nozzles and the sample has to be driven into them by another, preferably aerodynamic mechanism – e.g. a horizontal air flow. The problem of how to generate this flow is made more difficult by the inevitable separation distance to be travelled by air flows between the person's clothes and the portal side wall.

Anthropometric statistics say [4] that an acceptably small percentage – a mere 5% – of men in the USA have a shoulder breadth more than 510 mm while the minimum distance is defined by 5% of Hong Kong women who have their shoulder breadth less than 355 mm. Air flows generated in the portal have to travel the difference distance between these values. It is estimated that distance 155 mm on each side of the portal will be able to handle 90% of the grown-up population. The remaining extreme cases – as well as children and pet animals – should be handled by auxiliary detectors hand-held by attendants, which have to be present anyway to supervise the screening.

3 Failure of steady-flow annular jet

There seemed to be a solution meeting the requirements: the annular impinging jet (as shown in Fig. 2). The impact on the stagnation circle on the investigated surface would generate the requested releasing of the sample. Simultaneously, the return flow from the centripetal stagnation point (on jet axis) would provide the sample transport to the detector inlet. There was a belief that this flowfield will form an aerodynamically impenetrable and yet mechanically unobtrusive barrier, preventing sample dilution by mixing with external atmospheric air.

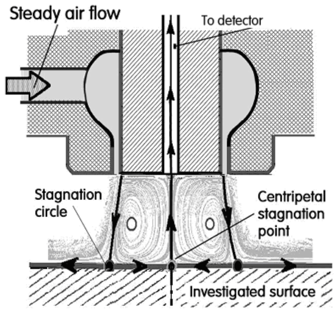


Figure 2: Unsuccessful annular air jet. The tasks to perform are: 1) agitating the surface and release the sample; 2) generating a flow from surface to detector inlet; 3) protecting this flow from escaping and diluting. The failure occurred whenever the nozzle-to-surface distance was more than ~3 nozzle exit diameters.

Unfortunately, attempts at implementing this idea were unsuccessful. A nozzle of reasonable diameter cannot generate an annular jet reaching far enough – not so much because of the loss of jet momentum but mainly due to the coalescence into the stagnation point S terminating the annular character (Fig. 3(a)). The change of the centripetal surface flow into the centrifugal pattern is related to the metamorphosis phenomenon in [5]. Computation results,

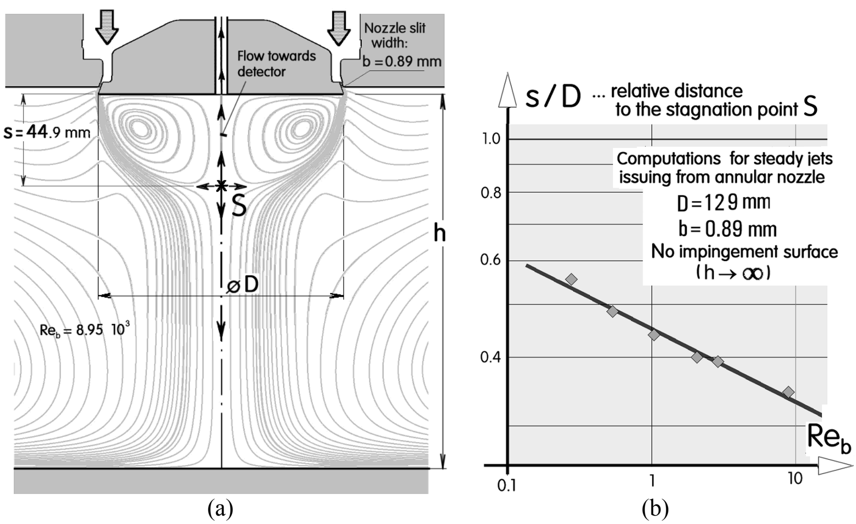


Figure 3: (a) Computed pathlines of steady annular show the loss of annular character. The recirculation region reaches only to the point S and not to the surface. (b) Computed distances s of the stagnation point S from the nozzle. Very low Reynolds numbers Re_b may seem to be helpful but are impractical.

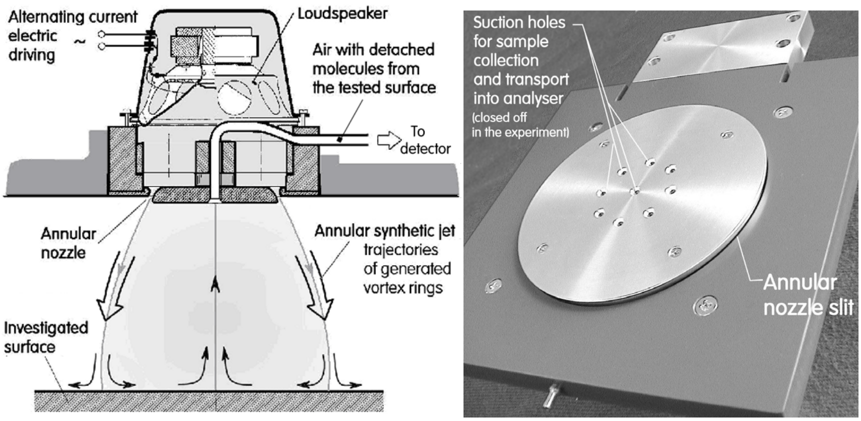
like those in Figs. 3(a) and (b), have shown that obtaining the stagnation point at the requested distance 155 mm from the nozzle (Sect. 2) – with reasonable dimensions of nozzle outer diameter D and slit width b – is out of the question. Admittedly, the results in Fig. 3(b) apply to $h \rightarrow \infty$, i.e. absence of impingement wall with which the s/D ratio increases somewhat, but the increase is much less than what is needed. Experiments have also shown problems with hysteresis [16].

4 New idea: protective annular synthetic jet

Synthetic jets are generated by fluidic rectification effect [7–9] from an alternating outflow and inflow through a nozzle [10]. They consist – at least over a certain distance from the nozzle [18] – of successive pairs of individual vortices. The jet is "*synthesised*" from them. In the unusual annular nozzle case they were first proposed for the discussed detector application in [17]. Another unusual feature of this proposal is generation of the periodic flow by means of a no-moving-part fluidic oscillator. The device thus becomes simple (Fig. 7(a)) and reliable. The generated jet is of the hybrid-synthetic jet character [11, 12], i.e. with non-zero time-mean flow in the nozzle. This is an important factor, helpful to generating the overall flowfield character similar to Fig. 2. The character of consisting of individual vortices make them capable of reaching very far without the coalescence, because the vortices are radially pressure-balanced already at their formation and thus their motion trajectory, as was observed in visualisations [9, 10], is not prone to the coalescing effect. Another factor of importance for the discussed application is the low-frequency pulsatile character (as opposed to high-frequency turbulence) promoting the release of the illicit material traces from the screened textile surface.

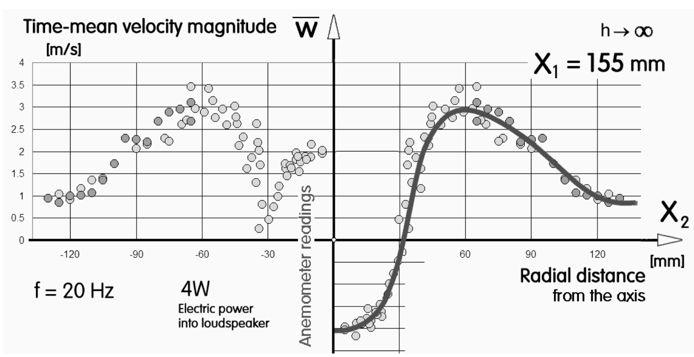
Existing studies of synthetic jets are aimed at control of fluid flow past bodies, usually by generation of streamwise vortices [19]. This use calls for a rather high driving frequency [20]. In the discussed application, however, operation in audible frequency range would cause inconvenience. To avoid it, the device is operated at an inaudible infrasonic [14] frequency, in practice ≤ 20 Hz. Another unusual feature is the attempt to increase the reach of the jet by inclining the nozzle exit direction away from the nozzle axis and centrebody protruding above the outer part of the annular nozzle.

To verify the assumptions, hot wire anemometer measurements were performed using laboratory model (Figs 4(a) and (b)) together with numerical unsteady flowfield computations. Because of the large number of unknowns, it was decided to perform separate experiments with the annular synthetic jet – which was for this purpose generated by a loudspeaker (Fig. 4(a)) – and with the infrasonic oscillator. In both cases the flows were studied by means of hot-wire anemometer. Interpretation of anemometer data is somewhat complicated by their inability to discriminate between the flow direction out from the nozzle and back into it. Avoiding inconvenience by operation at infrasonic frequencies has led to question whether the low frequency would not lead to extremely poor performance. In one of the earliest experiments, the probe was traversed at a short distance from the nozzle to measure the velocity profile at various driving frequencies from 5 Hz to 65 Hz (Figs 6(a) and 6(b)). It was established that at the frequency 20 Hz and with electric input power only 4 W the actuator did operate quite efficiently (improvement of the efficiency was not substantial at higher frequencies – Fig. 6(b)) and did not generate an audible disturbance.



(a) (b)

Figure 4: (a) Solution: synthetic annular jet – here in the configuration for laboratory tests, driven by a loudspeaker. The alternating outflow and inflow generates a system of vortex rings moving towards the interrogated surface. (b) Photograph of the actuator model with 129 mm nozzle diameter. Note the centrebody protruding slightly (4.15 mm) above the nozzle slit, which is inclined outwards.



(a) (b)

Figure 5: Time-mean velocity profile at X_1 = 105 mm axial distance from the nozzle: (a) absolute values measured by hot-wire anemometer; (b) fit to data with correct sign. Velocity maxima at a quite large radial distance X_2 show lack of coalescence.

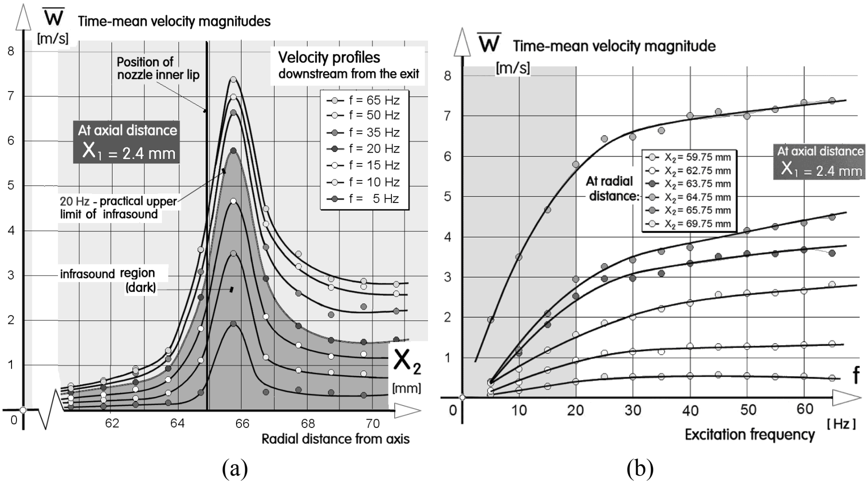


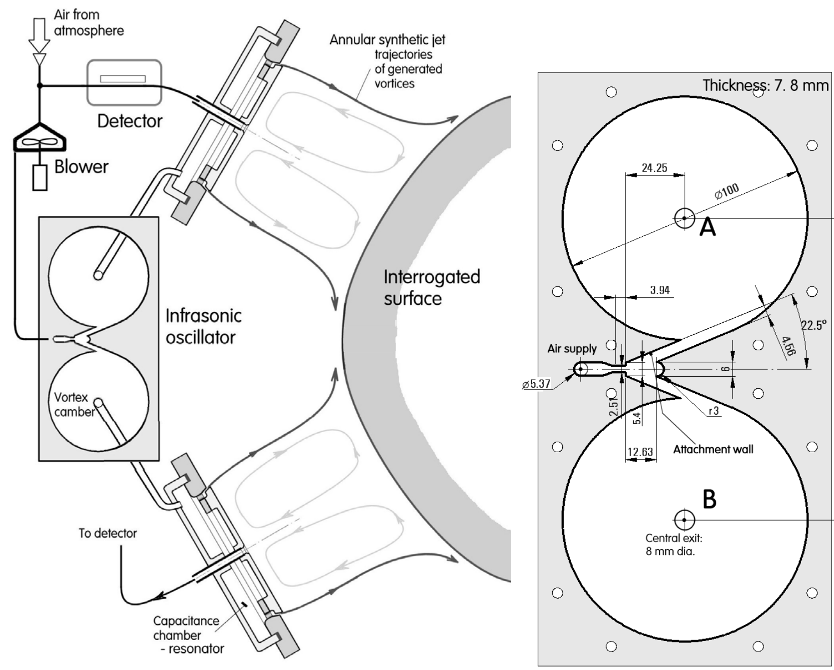
Figure 6: (a) Profiles of time-mean velocity at a small axial distance X_1 = 2.4 mm obtained at different driving frequencies (with constant loudspeaker driving power 4W). The requirement of inaudible noise limits the operation to the shaded region; (b) Dependence of velocity peak (a) on frequency. Beyond the infrasonic 20 Hz, the velocity growth with frequency is much slower.

The fundamental factor is the size of the protected region occupied by the stationary vortex ring in front of the nozzle. Measured velocity profiles, such as their typical example presented in Fig. 5, have shown that the boundary of the protected volume – which is coincident with the loci of velocity maxima in the profiles – indeed does extend far beyond the requirements. Recognisable velocity maxima were measured at axial distances from the nozzle more than X_1 = 155 mm. The non-zero velocity on the axis (presented as negative in Fig. 5 to account for the probe inability to indicate sign change) is actually indicative of the presence of the flow from the investigated surface towards the detector inlet.

5 Infrasonic oscillator

Fluidic oscillators are mostly designed by providing a fluidic amplifier with feedback loops. This traditional setup ceases to be useful if the task is to generate oscillation at very low, infrasonic frequency – which is requested in the discussed anti-terrorist application to avoid the screened persons' exposure to the annoying acoustic signal. Low frequency means long feedback channels which may be difficult to stow and the hydraulic losses inside them may be so strong that the feedback signal reaches the amplifier input at a too weak level.

The oscillator tested in the course of developing the anti-terrorist detector is therefore based on a wholly new idea. There is a vestigial fluidic jet-deflection diverter amplifier, which does not possess any control nozzle, being switched by the load-switching mechanism. Instead of the travelling-time delay in a long

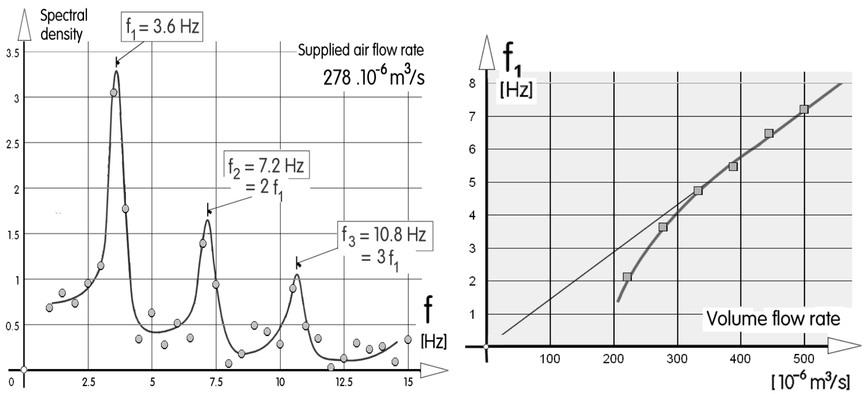


(a) (b)

Figure 7: (a) Schematic representation of two actuators generating two annular two synthetic jets driven by common infrasonic fluidic oscillator; (b) Cavities of the fluidic oscillator model as used in the feasibility tests.

feedback channel, the low frequency is achieved by using the spin-up time in vortex chambers.

A drawing (with dimensions) of the oscillator used in the feasibility testing is presented in Fig. 7(b). Cavities were made by laser-cutting in a 7.8 mm thick plate of PMMA. Air from the supply inlet (diameter 5.37 mm) is lead into the nozzle (of 2.51 mm width) from which it issues as an air jet between two attachment walls (mutually inclined by 45 deg). The jet attaches to one of them by the Coanda effect and is led into the corresponding vortex chamber. Let us assume it enters tangentially the upper vortex chamber A, generating there a rotational flow governed by the law of conserving the moment of momentum. This means that as fluid goes to the central exit and the radius of rotation gradually decreases, the local rotational speed gradually increases. In the end it attains a magnitude so high that the resultant centrifugal force opposes the input flow into chamber A so strongly that it cannot be any more overcome by the Coanda effect. The air jet separates from the attachment wall and is switched to the other one, leading into the vortex chamber B, where the rotation has in the meantime stopped. After the switching, the rotation in the chamber B increases in intensity. It finally attains a magnitude so high that the resultant centrifugal force opposes the input flow into the chamber B so strongly that it cannot be any more overcome by the Coanda effect and the air jet is switched back.



(a) (b)

Figure 8: (a) An example of oscillator frequency spectrum measured by hot-wire anemometer in one of the two output terminals; (b) Dependence of the dominant frequency f_1 (cf. Fig. 8(a)) on the supplied air flow into the oscillator model.

The oscillation frequency values seen in Fig. 8(b) are very low, indeed in the infrasonic range. In Fig. 8(a) is a spectrum of the output signal measured in one of the oscillator's two output terminals by a hot-wire anemometer. There are in this spectrum three local peaks of which the one at the lowest frequency f_1 is clearly dominant. The other two smaller peaks are at frequencies which are integer multiples. As usual in most fluidic oscillators, the frequency tends to be proportional to the supplied flow rate, i.e. there is a constant Strouhal number. Included in Fig. 8(b) are two data points obtained by measurements at very low flow rates, at which there are some friction effect causing a decrease of the Strouhal number – again a phenomenon known from other fluidic oscillators.

6 Conclusions

Annual synthetic jets were demonstrated both experimentally and by numerical solutions to fulfil the requirements – especially the long axial reach towards the interrogated surface –requested for capability to transport trace substance samples from the surface to the entrance into the analyser. The closed boundaries of the active region prevent dilution by external atmospheric air and the pulsatory character helps in detachment of the sample. The low frequency makes the device practically inaudible.

Acknowledgements

Gratefully acknowledged is institutional support RVO: 61388998 and also support by grant Nr.23-046S from the GAČR – Czech Science Foundation.

References

[1] Jain, S., Mukand, W. (2004) The economics of high-visibility terrorism, *European Journal of Political Economy*, Vol. 20, p. 479

[2] Tesař V. (2007) *Pressure-Driven Microfluidics*. Artech House Publishers, Boston – London

[3] Settles G. S. (2006) Fluid mechanics and homeland security, *Annual Review of Fluid Mechanics*, Vol. 38, p. 87

[4] Ruff C. (2002) Variation in Human Body Size and Shape, *Annual Review of Anthropology*, Vol. 31, p. 211

[5] Tesař V., Trávníček Z. (2008) Excitational metamorphosis of surface flowfield under an impinging annular jet, *Chemical Engineering Journ.,* Vol. 144, p. 312

[6] Tesař V., Trávníček Z. (2006) Apparatus for collection of samples from the surface of examined objects, in Czech language, *Patent Application No. PV 2006-214*, Patent Office of the Czech Republic

[7] Tesař V. (1984) Law governing entrainment of surrounding fluid during alternating inflow into and outflow from an orifice – in Czech, *Czechoslovak Patent Office Application PO 86-84,* Prague, Czech Republic

[8] Tesař V., Zhong S.(2003) Efficiency of synthetic jet generation, *Transactions of the Aeronautical and Astronautical Society of the Republic of China, Zhongguo Hangkong Taikong Xuehui Huikan*, Vol. 35, No.1, p. 45

[9] Tesař V., Trávníček Z. (2005) Pulsating and Synthetic Impinging Jets, *Journal of Visualization*, Vol. 8, No. 3, p. 201

[10] Trávníček Z., Tesař V. (2003) Annular synthetic jet used for impinging flow mass transfer, *Internat. Journ. of Heat and Mass Transfer,* Vol. 46, p. 3291

[11] Tesař V. (2007) Configurations of fluidic actuators for generating hybrid-synthetic jets, *Sensors and Actuators A: Physical*, Vol. 138, p. 394

[12] Trávníček Z., Vít T., Tesař V. (2006) Hybrid synthetic jets as the nonzero-net-mass-flux synthetic jets, *Physics of Fluids*, Vol. 18, p. 081701-1

[13] Tesař V., Hung C.-H., Zimmerman W. (2006) No-moving-part hybrid-synthetic jet actuator, *Sensors and Actuators A: Physical*, Vol. 125, p. 159

[14] Gavreau V. (1968), Infrasound, *Science Journal*, Vol. 4, Issue 4, p. 33

[15] Tesař V., Kordík J. (2013), Effective hydraulic resistance of a nozzle in an electrodynamic actuator generating hybrid-synthetic jet – Parts I and II, *Sensors and Actuators: A Physical*, Vol. 199, p. 379, 391

[16] Trávníček Z., Tesař V. (2013), Hysteresis in annular impinging jets, *Experimental Thermal and Fluids Science,* Vol. 44, p. 565

[17] Tesař V. (2014), Fluidic oscillator, *Czech Patent Appl.* PV 2014-903, Dec. 2014

[18] Tesař V., Kordík J. (2010), Time-Mean Structure of Axisymmetric Synthetic Jets, *Sensors and Actuators: A. Physical,* Vol. 161, p. 217

[19] Tesař V., Kordík J., Daněk M. (2008) Lift and Separation Control on Wind Turbine Blades by Vortices Having Streamwise Oriented Axes, *Proc. of* "*Fluid Dynamics 2008",* ISBN 978-80-87012-14-7, Inst. of Thermomechanics AS CR, v.v.i., Prague

[20] Tesař V., Zhong S., Fayaz R. (2013) New fluidic oscillator concept for flow separation control, *AIAA Journal,* Vol. 51, p. 397

www.witpress.com, ISSN 1743-3509 (on-line)

This page intentionally left blank

Early warning system for the prevention and control of unauthorized accesses to air navigation services infrastructures

A. Accettura[1], G. Carelli[2], F. Di Maio[2], S. Donarelli[1], F. Garzia[1,3] & M. Lombardi[1]
[1]*Safety & Security Engineering, SAPIENZA, University of Rome, Italy*
[2]*ENAV, Italian Provider for Air Navigation Services, Italy*
[3]*Wessex Institute of Technology, UK*

Abstract

Early warning systems are fundamental instruments for the management of critical situations since they are able to signal in advance any anomaly with respect to ordinary situations.

The purpose of this paper is to present an early warning system, based on artificial neural networks, for the prevention and control of unauthorized accesses to the air navigation services infrastructure in Italy.
Keywords: air navigation services, early warning, neural networks.

1 Introduction

Air navigation services represent a very delicate mission for the security of air transport. This mission is made through integrated systems [1–4] that represent a critical infrastructure whose access, both from the physical and logical point of view, must be accurately checked and controlled. In fact, any unauthorized intrusion inside the control system could generate catastrophic consequences.

This research, whose field is the security of control of air transport, starts from the need to reveal any kind of unauthorized access into the sites which belong to the Italian Provider for Air Navigation Services (ENAV) both from the physical and logical point of view.

The proposed goal is reached using a proper artificial neural network (ANN) able to supervise the different accesses, and to give an early warning in cases of

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150171

anomalies. Anomalies are defined in the case of badge and computer username or password unauthorized use that are given by a proper Security Operation Centre (SOC).

The ad-hoc-designed ANN is trained using data such as badge owners, login codes, ENAV site number (ENAV has different sites located in different zones of Italy), date and hour of the access and so on, both in normal and early warning conditions.

Once the ANN is properly trained, it is able to analyse all the access data to the flight assistance system. Any time it reveals a suspect access, it immediately generates an early warning to the security operators to allow them to check the suspect accesses to avoid unauthorized intrusions that could negatively interfere with the normal activity of flight assistance.

The proposed ANN based system is capable to be trained constantly, so that it can learn new suspect access configurations, guaranteeing a high level of protection and security to the air navigation services provider system of ENAV. The purpose of this paper is to illustrate the ANN based system, its design, its implementation and the interesting obtained results.

2 ENAV

ENAV is Italian Provider for Air Navigation Services that is supervised by the Minister of Economy and Minister of Infrastructures and Transport.

It is composed of different central sites and numerous local sites such as 4 control centres (named ACC, located in Rome, Milan, Padua and Brindisi) and 40 airport structures, divided by tipology.

ENAV provides the following air navigation services (ANS):

1) air traffic services (named ATC, FIS, ALRS, ATAS);
2) aeronautical information services;
3) meteorological services;
4) communication, navigation and surveillance services.

3 The Security Operation Centre

The Security Operation Centre (SOC) has been created and managed by ENAV, which is the only European provider equipped with such a security governance structure.

The SOC is the physical and logical place for all the information (coming from all the controlled infrastructures); necessary to monitor the security converge.

The purpose of the SOC are:

1) to monitor, in a proactive way, the security infrastructures by means a supervision and control activity of all the devices that ensure protection to ENAV personnel and to operative sites. It supervises and controls all the systems/devices that perform air traffic control functions;
2) to prevent and manage incidents in an efficient way;

www.witpress.com, ISSN 1743-3509 (on-line)

3) to contribute to the government and management of security providing services and data related to the behaviour of security systems.

The SOC services are summarized in fig. 1.

SOC structure can be divided into two macro-areas:

1) SOC IT for the information, networks, and systems protection;
2) SOC PA for the centralized management of the physical security.

The SOC IT works in the internal perimeter of the E-Net and on the related services, aided by high-qualified personnel and properly differentiated according to professional profile, application field, working time.

The main units that compose the SOC IT are represented by:

1) SOC SIG that supervises the information security of management information systems;
2) SOC ATC that supervises the ENAV information operative system and the security of the information of SOC devices;
3) SOC E-Net that manages and monitors the operative traffic on the E-Net (just IP traffic);
4) SOC IAO that manages the inter-domain events as second level for the control of the SIG, ATC, E-Net events in terms of quality assurance, resilience and forensic services.

ACTIVITIES	DESCRIPTION	TIMEFRAME SERVICES
Real Time Device Monitoring	Real time monitoring of IT and IT related security events affecting IT infrastructures through specific tools able to detect and analyze potential security breaches or suspicious activities intended to exploit vulnerabilities	H24 7x365
Incident Management	Processes and actions to deal with security incidents	H24 7x365
Vulnerability Assessment	Continuous vulnerability assessment through specific indicators and controls	9:00 – 18:00 mon-fri
Security Intelligence	Conducted in a transparent and continuous manner, information sharing	9:00 – 18:00 Mon-Fri
Policy Management & Enforcement	Managing rules both for security devices and for personnel	9:00 – 18:00 Mon-Fry
Technical & Executive Reporting	Analysis support and actions with the purpose of enhancing decision management	9:00 – 18:00 Mon-Fry
Policy Compliance	Verification of policy (both laws/regulations and internal rules, referring also to best practices.	9:00 – 18:00 Mon-Fry
Fault Management	Troubleshooting and support for contingency planning	H24 7x365
End Point Protection	Security services for endpoints	9:00 – 18:00 Mon-Fry

Figure 1: SOC services.

4 Access control and early warning

It is evident that it is very important to control the physical and the logical access to the system and every anomaly must be immediately signaled (early warning) to avoid that the intruder could make dangerous operation on the air navigation system.

An example of anomalous physical access is represented by the use of the same entrance badge in two different sites at the same time or in a too restricted time with respect to the physical distance of the two considered sites.

It is therefore clear that is very important to have an early warning system [3] that signals any anomalous access to the security personnel to activate all the necessary security procedures to prevent any attack to the air navigation system.

5 The early warning system

The early warning system must check continuously every physical and logical access to the SOC and signal any anomalous access.

From this point of view, an Artificial Neural Network (ANN) that is capable to learn all the data related to normal and warning condition has been used.

The physical access to the sites is made by means of a badge while the logical access to the system is made through a login.

In the case of physical access, the SOC receives the following data: <date>, <time>, < site identification code>, <user identification code>.

In case of logical access, the SOC receives the following data:
<date>, <time>, < site identification code>, <username>.

It is therefore important to check the following pieces of data:

1) badge – badge;
2) badge – login;
3) login – badge;
4) login – login;

to reveal any anomalous non matching between the name of the operator, time, and physical distance between the sites.

The following normal/warning modality are considered:

1) the entrance of the same user in the same site at any time interval (normal);
2) the entrance of two different users in two different sites at any time interval (normal);
3) the entrance of the same user in two different sites of the same city after a proper time interval depending on the physical distance between the two sites (normal);
4) the entrance of the same user in two different sites after a too reduced time interval (warning).

6 The artificial neural networks

Artificial neural networks (ANN) actually find a lot of applications in different fields such as:

1) electronics: process control, machine vision, voice synthesis, linear and nonlinear modelling, signal analysis;
2) robotics: trajectory control, vision systems, movement controller;
3) telecommunications: image and data compression, noise reduction,
4) security: face recognition, voice recognition and other biometrics applications, new sensors;
5) defense: weapon steering, signal and image identification, radar and image signal processing, object discrimination and recognition;

and other fields such as aerospace, insurance, banking, manufacturing, automotive, medical, financial, entertainment.

The common element of their field of applications is the need to classify a given element as belonging to one or more given classes.

One of the main referring model for the reproduction of human intelligence is the so called 'Connectionism' that postulates the logic equivalence between any structured knowledge and a proper neural network. The Connectionism allows to develop a new form of artificial intelligence based on a sub-symbolic computation instead of the symbolic computation that represents the typical application field of the classical artificial intelligence. The Connectionism originates from the study of the working mechanisms of the central nervous system of biological organisms.

The human brain is composed of neurons that are cells whose purpose is represented by information processing. Each neuron is connected with the other by means of a central body called an axon and by numerous terminations called dendrites. The connection points between the neurons are called synapses which show an excitatory behavior if they allow the electrical pulses to pass or an inhibitory behavior if they stop these pulses.

Each neuron behaves as an adder of the pulses generated by nearby neurons: if the sum overcomes a certain threshold the neuron actives letting the information to proceed along its path.

The connections between neurons can be modified allowing the memory effect to take place.

Artificial neural networks imitate this mechanism generating a knowledge database by means of the modification of the connections of a net that can learn from direct experience modifying its internal state to adapt to the solution of a particular problem.

The modeling of the behavior of neural networks is quite complex and generally uses the approach of the dynamic systems and the related concepts such as cycles, strange attractors and equilibrium points.

Neural networks are particularly useful when the law related to a certain phenomenon is not known in a deterministic way but it is necessary to reproduce it.

www.witpress.com, ISSN 1743-3509 (on-line)

Neural networks are very useful when:

1) it is necessary to generalize the knowledge acquired on a restricted base to a wider base;
2) a certain situation changes with time;
3) data are not complete, uncertain or influenced by errors;
4) great tolerance to troubles or malfunctions is necessary;
5) it is necessary to find rapidly a heuristic solution to a particular problem;
6) a phenomenon rapidly changes and short adapting times are requested;
7) a high computational parallelism is requested;
8) a proper algorithm is not known;
9) qualitative or incomplete data are present;
10) the problem is data intensive instead of number crunching;
11) it is necessary to produce knowledge for an expert system.

For all these reasons neural networks represent a useful and flexible tool for a lot of situations.

The elementary computation element of this kind of technology is represented by the neuron, which is a cell that receives one or more input value and produces one or more outputs that depends on the input values (as shown in fig 2).

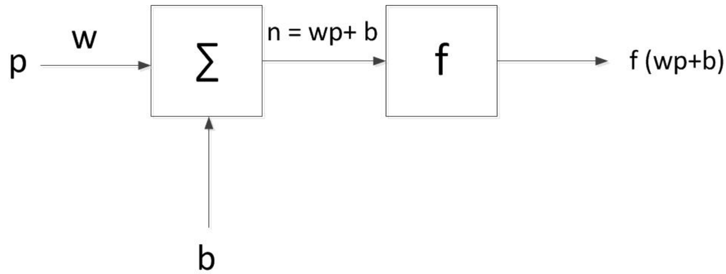


Figure 2: Single input neuron.

Considering a single input–single output neuron, if p is the input and w is the weight, the product wp reaches the Σ unit where it is summed to a bias value b, that can be considered as an input of value equal to 1 and whose weight is equal to b. The computed quantity n=wp+b reaches the transfer function f that calculates the output of the neuron a=f(wp+b).

The parameters w, p and b are adjustable and they can be adapted so that the neuron exhibits an interesting or desired behaviour.

Therefore an elementary neuronal cell performs simple operations such as additions and multiplications which can be easily executed by low computation capabilities devices. Their strength relies on their organization in massively parallel architectures.

The elementary cells can be connected in different way to form a neural net that can be trained to do a particular job adjusting properly their weights and/or their biases (supervised learning) or letting it learn by itself (unsupervised learning that is typical of the self-organizing nets).

The transfer function of the neuron can have different expressions that are: step (symmetric and asymmetric), linear (with saturation or without saturation), sigmoidal (logarithmic or tangential), triangular, radial and others. If the neuron has more inputs:

$$\mathrm{p} = \left[p_1, p_2, ..., p_R\right] \tag{1}$$

each of them is multiplied by the weights:

$$\mathrm{w} = \left\lfloor w_{1,1}, w_{1,2}, ..., w_{1,R} \right\rfloor \tag{2}$$

and the sum unit executes the dot product **wp**, adding the bias b to give:

$$w_{1,1}p_1 + w_{1,2}p_2 + ... + w_{1,R}p_R + b \tag{3}$$

that is the argument of the output transfer function.

An example of multiple input neuron is shown in fig. 3.

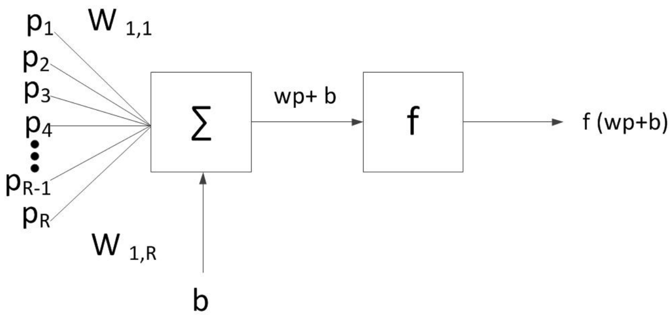


Figure 3: Multiple input neuron.

Two or more multiple neurons can be combined to generate a layer of neurons. Considering a layer composed of S neurons, each element of the input vector **p**, composed of R elements, is connected to each neuron input through the weight matrix **w**. The j-th neuron weights properly its inputs, performing a dot product and adding the j-th bias to generate its scalar output n(i). The various values n(i) taken together, form a vector **n** composed of S elements. Each element of the vector **n** represents the input of the transfer function of the relative neuron. At the output a column vector **a** is obtained.

Generally, the number of inputs R is different from the number of neurons S.

An example of a layer of neurons is shown in fig.4.

In a layer of neurons the weight matrix **w** has the following form:

$$\mathrm{w} = \begin{bmatrix} w_{1,1} & w_{1,2} & \cdots & w_{1,R} \\ w_{2,1} & w_{2,2} & \cdots & \\ & & & \\ w_{S,1} & & \cdots & w_{S,R} \end{bmatrix} \tag{4}$$

where the row indices indicate the destination neuron of the weight and the column indices indicate which source is the input for that weight. For example, the weight labeled with (3,2) expresses the strength of the signal from the second input element to the third neuron.

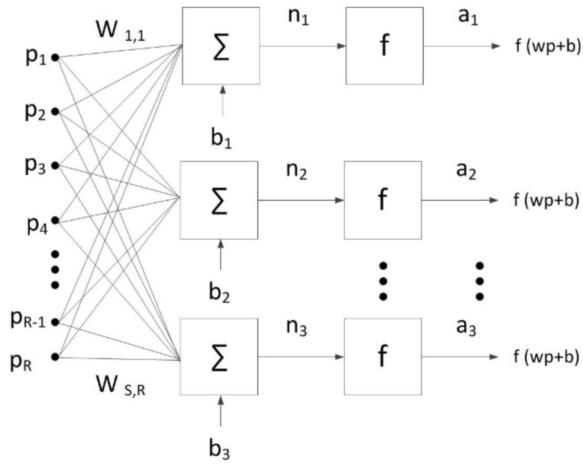


Figure 4: Layer of neurons.

When we deal with a multiple layer net we deal with different weight matrixes **w**, different bias vectors **b**, and different output vectors **a**, each of them referring to the relative layer.

In this situation, the first layer is called the input layer, the network output is called the output layer and the intermediate layers are called hidden layers.

Multiple layers nets can perform complex functions. For example, a two layer net, where the first layer is sigmoid and the second layer is linear, can be trained to approximate any function with a finite number of discontinuities.

Networks with biases are able to represent relationships between inputs and outputs easier than networks without biases. In fact a neuron without a bias will always have a net input to the transfer function equal to zero when all of its inputs are zero while a neuron with bias can learn to have any net transfer function net input under the same conditions by learning an appropriate value for the bias.

An example of a neural net with an input layer, a hidden layer and an output layer are shown in fig. 5.

7 The ANN used for the proposed system

The ANN used for our system is a Feed-Forward, characterized by the presence of one or more hidden layers that connect the input neurons with the output neurons. The learning algorithm is represented by the back propagation that calculates, at any learning step, the output and compares it with the expected value, trying to minimize the mean squared error (MSE) calculating the gradient of the error with respect to weight of the neurons to modify them successively. A sigmoid function has been considered as activation function of the neurons.

Since only a single layer ANN has been considered, the critical factor to be focused is represented by the number of neurons the hidden layer.

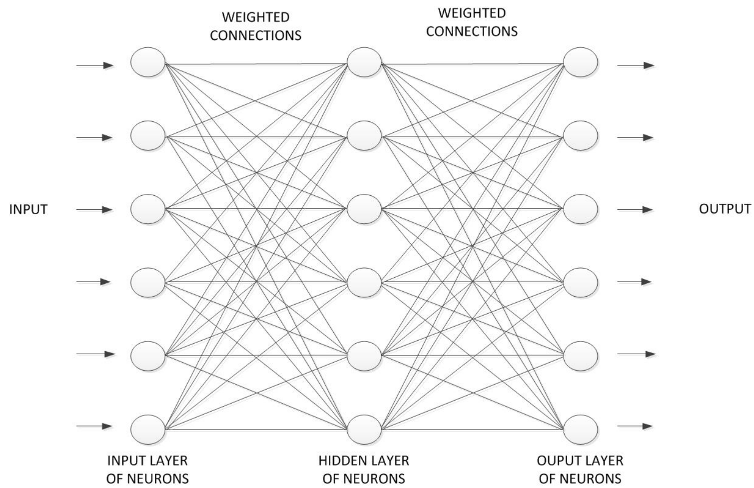


Figure 5: Example of neural network with an input layer, a hidden layer and an output layer.

8 Results

The ANN has been trained and then tested using a variable number of neurons of the hidden layer (8, 9, 10, 12, 13, 15), evaluating the performances of the different ANN by means of MSE that represents the most significant parameter for our purpose.

In fig. 6, the MSE results during the training phase obtained for different values of the number of neurons of the hidden layer are shown.

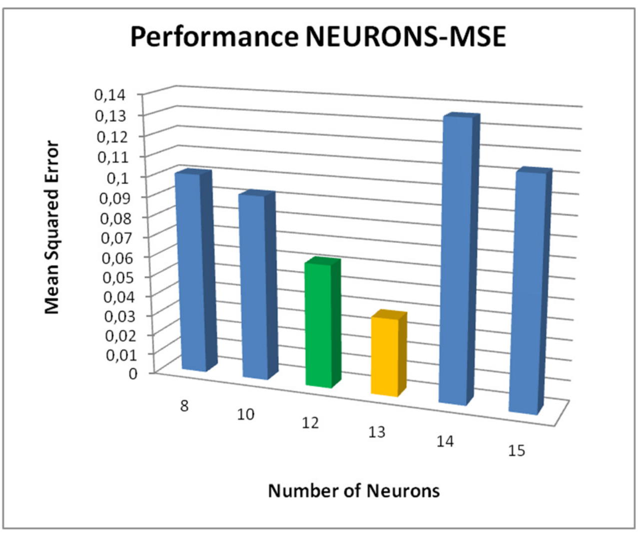


Figure 6: Mean squared error versus number of neurons of the hidden layer.

From fig.6 it is possible to see that the ANN characterized by 13 neurons in the hidden layer is the network that presents the lower MSE and, for this reason, this is the network that has been used.

Once selected the number of neurons of the hidden layer, it is necessary to check the generalization capacity of the selected network.

The input data has been divided into 3 different groups:

1) training set;
2) validation set;
3) generalization test set.

Different attempts of division of the data set were made to find the optimal values that ensure the best generalization capacity that has resulted to be:

1) training set: 65% of data set;
2) validation set: 15% of data set;
3) generalization test set: 20% of data set.

9 Conclusions

Early warning systems are fundamental instruments for the management of critical situations since they are able to signal in advance any anomaly with respect to ordinary situations.

In this paper, an early warning system, based on artificial neural networks, for the prevention and control of unauthorized accesses to air navigation services infrastructure in Italy, has been studied, finding and optimal ANN capable of solving this delicate problem.

The system is very flexible since it can rapidly trained any time a variation in the users database occurs, due to the great flexibility of neural networks.

It is also very easy to be implemented since it needs a reliable PC, connected to the SOC network, where the ANN can run and perform its early warning functionality.

The system can obvious be further developed, studying new and more performing ANN architectures but this is out of the scope of the present work.

References

[1] Garzia, F., Sammarco, E., Cusani, R., "The integrated security system of the Vatican City State", International Journal of Safety & Security Engineering, WIT Press, Vol. 1, No. 1, pp. 1-17, 2011.

[2] Contardi, G., Garzia, F., Cusani, R., "The integrated security system of the Senate of the Italian Republic", International Journal of Safety & Security Engineering, WIT Press, Vol. 1, No. 3, pp. 219- 246, 2011.

[3] Garzia, F., Cusani, R., "The integrated safety/ security/ communication system of the Gran Sasso mountain in Italy", International Journal of Safety & Security Engineering, WIT Press, Vol. 2, No. 1, pp. 13-39, 2012.
[4] Garzia, F., Sammarco, E., Cusani, R., "Vehicle/people access control system for security management in ports", International Journal of Safety & Security Engineering, WIT Press, Vol. 2, No. 4, pp. 351-367, 2012.

This page intentionally left blank

A biometric iris recognition system based on principal components analysis, genetic algorithms and cosine-distance

V. Nosso[1], F. Garzia[1,2] & R. Cusani[1]
[1]*Department of Information, Electronics and Telecommunication Engineering – SAPIENZA – University of Rome, Italy*
[2]*Wessex Institute of Technology, UK*

Abstract

Iris recognition is regarded as the most reliable and accurate biometric identification system available. The present work involves the development of a novel technique in order to improve the performance of iris recognition systems. We have used for our experiments a publicly available iris recognition system. Tests on CASIAv3 image database have resulted in a 2% accuracy improvement with respect to traditional methods; a significant one in iris recognition.
Keywords: iris recognition, PCA, genetic algorithms, cosine distance, biometrics.

1 Introduction

The iris, that is the unique human internal organ visible outside, is a sort of muscle that trimmers the pupil diameter, controlling the light amount that gets into the eye, reaching the retina where it is converted into electrical pulses that reach the brain to be analysed and understood. The mean iris diameter is equal to 12 millimetres while the diameter of the pupils, varies from 10% and 80%.

The iris is a stratified structure, composed by a layer of strongly pigmented epithelial cells that do not allow light penetration, a layer of muscles that trimmer the pupil opening, a layer of blood vases enriched by radials grooves that are little folds whose depth varies as a function of pupil dilatation.

Each iris is characterized by a complex pattern whose combination of randomness and complexity gives it a mathematical uniqueness with a collision

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150181

probability just equal to zero. In fact, the two iris patterns of the same person are different and independent and the same is valid for the eyes of the homozygote twins. This is due to the fact that iris patterns are epigenetic, since they start from a given genetic configuration and they develop during pregnancy independently from the genetic component.

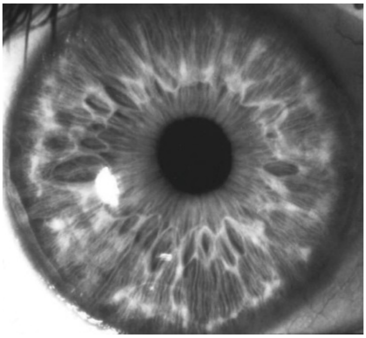


Figure 1: A picture of an iris.

It has been calculated [1] that the probability of existence of two similar iris patterns is about 10^{-78}.

The experiments related to the determination of the statistical properties of iris patterns [2, 3] have shown that they are characterized by a binomial distribution with $\dot{\rho}$=0.5 and 249 degrees of freedom that confirm that the collision probability of two iris pattern on the same iriscode is about 10^{-78}.

The iris pattern, once stabilized, remains the same for the whole life unless some particular degenerative pathologies occur.

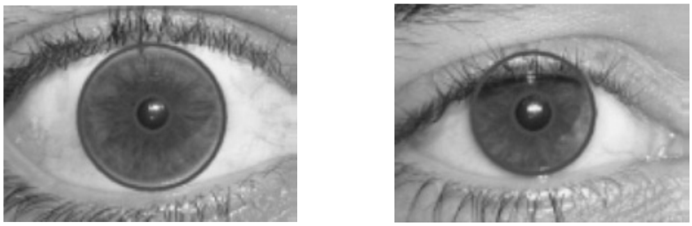
The present work proposes a novel technique for improving iris recognition systems accuracy through principal component analysis (PCA), genetic algorithms (GAs) and cosine-distance (CD).

A publicly available iris recognition system [4] has been used for system developing and comparative testing. Tests on CASIAv3 [5] image database have resulted in a 2% accuracy improvement with respect to existing systems that represents a significant result in iris recognition field characterized by high accuracy and recognition rate.

2 Iris acquisition

During iris acquisition, disturb such as cilia and eyelid can partially occlude the image (as shown in fig. 2), and it is necessary to apply a proper mask to avoid a noisy acquisition.

After this operation it is necessary to make a proper segmentation to individuate the internal and external contours of the iris.



(a) (b)

Figure 2: (a) Clear iris image; (b) partially occluded iris image.

3 Iris normalization

Once the external and the internal contours of the iris are individuated, a proper transformation from polar coordinates (r,θ) to Cartesian coordinates (x,y) is made using the following [6]:

$$\begin{aligned} x(r,\theta) &= (1-r)\,x_p(\theta) + r \cdot x_i(\theta) \\ y(r,\theta) &= (1-r)\,y_p(\theta) + r \cdot y_i(\theta) \end{aligned} \tag{1}$$

where $r \in [0,1]$, $\theta \in [0,2\pi]$, $(x_i(\theta), y_i(\theta))$ and $(x_p(\theta), y_p(\theta))$ are the coordinates of the iris and the pupil, respectively, along the direction individuated by θ. In this way, the annular structure of the iris becomes a normalized rectangular structure (as shown in fig. 3).

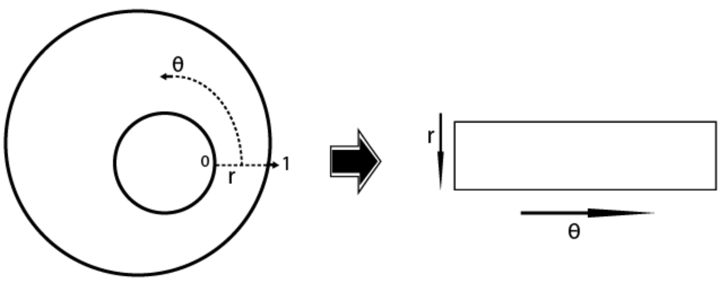


Figure 3: Normalization of the iris structure.

4 Iris coding

Once the iris is normalized, it is necessary to code it.

From this point of view, a proper binary code is derived quantifying the phase response of a texture filter [6], represented by the 2D Gabor filter that is:

$$H(r,\theta) = e^{-j\omega(\theta-\theta_0)} e^{-(r-r_0)^2/\alpha^2} e^{-j(\theta-\theta_0)^2/\beta^2} \tag{2}$$

where α and β vary with an inverse proportion with respect to the frequency ω to generate a set of quadrature pair frequency-selective filters centred in the position (r_0, θ_0).

Then the angle of the phasor represented by complex coefficient over 4 levels (one for every quadrant of the complex plane) is quantified, generating for every (r_0, θ_0) a couple of bit $(h_{\Re}, h_{\Im})$ according to:

$$\begin{aligned} h_{\Re} &= \begin{cases} 1 & \mathrm{Re}\left(\int_{\rho}\int_{\psi} e^{-j\omega(\theta_0-\psi)} e^{-(r_0-\rho)^2/\alpha^2} \times e^{-j(\theta_0-\psi)^2/\beta^2} I(\rho,\psi)\, d\rho d\psi \right) \geq 0 \\ 0 & otherwise \end{cases} \\ h_{\Im} &= \begin{cases} 1 & \mathrm{Im}\left(\int_{\rho}\int_{\psi} e^{-j\omega(\theta_0-\psi)} e^{-(r_0-\rho)^2/\alpha^2} \times e^{-j(\theta_0-\psi)^2/\beta^2} I(\rho,\psi)\, d\rho d\psi \right) \geq 0 \\ 0 & otherwise \end{cases} \end{aligned} \tag{3}$$

From eqs (3), it is possible to see that every bit represents the sign of the imaginary or real part of the projection of a location on the adopted filter.

It is evident that only phase information is considered since this information are more significant with respect to the amplitude information that depends on the contrast, the light and the camera gain.

The compensation of the eventual angular shift is made during the comparison phase by means of a circular shifting of the code since this operation corresponds to an angular rotation of the image. At the end of the operation, the code that gave the best score is considered since it corresponds to the best alignment.

5 The principal components analysis (PCA)

The principal components analysis (PCA) is a well-used technique for the selection and reduction of the dimension of a set of features. It is based on the correlation principle that allows us to find an orthogonal projection base that allows a reduction of the dimension of features arrays and the reduction of the features themselves.

In our case, PCA is used to calculate the projections on the axes in the multidimensional space of the features considering the differences of the iris samples that are in the database.

The used PCA procedure allows a good generalization capability in the reconstruction of a signature when the latter is compared with another signature that has not been used in the training phase.

6 Genetic algorithms (GAs)

Genetic algorithms offer the great advantage of evolving their behaviour to match with the behaviour of the final users, using a mechanism that is very similar to the one used by nature. Different genetic algorithm can be used to achieve the desired purpose, each characterised by peculiar features.

Genetic algorithms are considered wide range numerical optimisation methods, which use the natural processes of evolution and genetic recombination. Thanks to their versatility, they can be used in different application fields.

GAs are particularly useful when the goal is to find an approximate global minimum in a high-dimension, multi-modal function domain, in a near-optimal manner. Unlike the most optimisation methods, they can easily handle discontinuous and non-differentiable functions.

7 The proposed system

The proposed system applies the PCA, the GAs and the Cosine distance in different phase of the process to increase the recognition accuracy with respect to the existing systems.

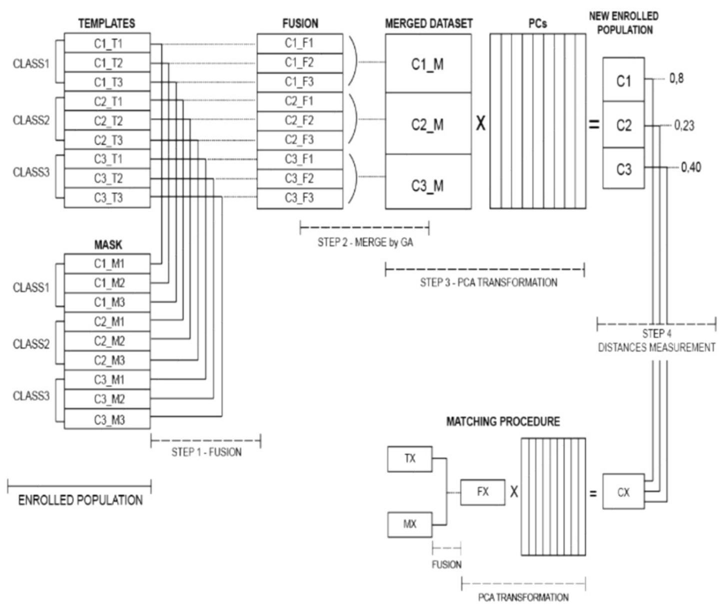


Figure 4: Scheme of the proposed system.

www.witpress.com, ISSN 1743-3509 (on-line)

During the step 1, every iris template of each class is associated a proper mask used during the segmentation phase, to avoid losing precious information, the mask is fused with the template itself provided that the mask does not cover more than 30% of the iris. The fusion operation in made in a simple way: if a binary value of both templates and mask is equal to 1, the final value is equal to 0.5, otherwise the value of the templates remains unchanged (0,1). In this way a new fusion template composed by (0, 0.5,1) is generated, considering also the masking effect of celia and eyelid.

During the step 2, the dataset, composed by different pre-processed vectors per class, is processed to obtain a single representative vector per class. The most useful tool is represented by genetic algorithms (GAs).

In fact, since each class is represented by a certain number of templates of the same iris (that in our case is equal to 3), if PCA is applied to all classes, not only the inter-classes differences are exalted but also the intra-classes differences are exalted, leading to possible problem in the recognition phase.

For this reason, before the PCA phase, a proper merging phase, to obtain a unique vector representative of the all vectors that compose the class itself is applied.

After different attempts, the fitness function (to be minimized) has been chosen to be:

$$\sqrt{intramean} - extramean \tag{4}$$

where intramean and extramean are, respectively, the intra-class mean of the distances and the extra-class mean of the distances obtained from the considered vector over the database in the actual state of processing. The square root operated on the first term is due to the need to individuate the vector that better represents the considered class and for this reason it is necessary to give more importance to the similarity related to the template belonging to the same class more that to the non-similarity between vectors belonging to different classes. Further, the PCA tends to exalt the difference between vectors belonging to different classes. For this reason, a fitness function that balance the above effect is considered.

During the step 3, once that each class is represented by a unique vector, thanks to the GAs computation of step 2, a PCA transformation is applied to increase the differences between the different classes and reduce the dimensionality of the space where the different vectors can be located. The transformation is done through a rotation of the referring system based on the main components individuated by means of the PCA. The same transformation is done on the test template during the comparison phase to project them on the same referring system.

During the step 4, a proper distance metric to calculate the distance between the templates is used. Since after the PCA transformation the templates are not more binary, it is not possible to use the Hamming distance. From this point of view, the cosine distance has been used since it is able to measure the degree of similarity more that the degree of difference such as Euclidian distance. The similarity is defined as:

$$\text{similarity} = \cos(\theta) = \frac{A \cdot B}{\|A\| \|B\|} \quad (5)$$

where A and B are the two considered vectors (or templates).

Since it represents the angle between the two vectors, it is evident that is measure the "direction similarity".

The cosine distance is therefore defined as:

$$1 - \cos(W_1, W_2) = 1 - \frac{\sum_{i=1}^{n} p_i q_i}{\sqrt{\sum_{i=1}^{n} p_i^2 \sum_{i=1}^{n} q_i^2}} \quad (6)$$

where p_i and q_i, are the components of templates W_1 and W_2 respectively.

It is now necessary to choose a proper threshold to be used in the comparison phase. In this case, the original database is considered, calculating all the distances between every training template and every class (that is the vector that, after the above operation, represents each class). In this way, a couple of distribution (intra-class and extra-class) is obtained. The segment that connects the mean of the two distributions is divided into 100 sub-segments and, for every value individuated on the extremes, a proper threshold of the same value is individuated. The accuracy (defined as 100- ((FP%+FN%)/2) where FP% are the false positive in percentage and FN are the false negative in percentage), calculated using this threshold over the distributions, can be chosen as the one that has produced the best results overall.

8 Results

The CASIAv3 database [5] has been used that has been divided into 3 database composed by 60 classes composed by 7 images each (dataset 60-7), 100 classes composed by 7 images each (dataset 100-7), 200 classes composed by 7 images each (dataset100-7).

We first randomly selected three templates for every class to represent the class itself: as consequence, we divided the dataset in two subsets, the enrolled set, which contains these templates, and the test set, containing the templates not selected to be enrolled.

As a first step, we analysed the enrolled set: matching every possible pair of templates belonging to the set we extracted distances distribution; we then searched for the threshold which gave the best accuracy, obtaining the results shown in table 1.

After enrolled population analysis we produced a new couple of distributions (intra/extra class, as usual) matching every template in the enrolled set with every template in the test set; we then use the previously selected threshold to calculate the accuracy on these distributions (we also searched iteratively for the ideal threshold to apply on these distributions), obtaining the results shown in table 2.

Table 1: Enrolled population analysis (Hamming distances).

	Dataset60-7	Dataset100-7	Dataset200-7
Distribution features			
Intra-class mean	0.3	0.29516	0.30111
Extra-class mean	0.46998	0.47039	0.47026
Intra-class variance	0.0037689	0.0032847	0.036776
Extra-class variance	0.00024137	0.0021465	0.0022221
Classification rates			
Best accuracy found (for threshold)	97.0778% (0.41728)	97.6616% (0.4213)	96.5504% (0.4296)
Intra good classifications	170 on 180 (94.44%)	287 on 300 (95.66%)	565 on 600 (94.16%)
Extra good classification	15884 on 15930 (99.7%)	44397 on 44550 (99.6%)	17791 on 179100 (98.93%)

Table 2: Enrolled vs. test statistics (Hamming distances).

	Dataset60-7	Dataset100-7	Dataset200-7
Distribution features			
Intra-class mean	0.31433	0.30869	0.31516
Extra-class mean	0.47304	0.47338	0.47344
Intra-class variance	0.0036829	0.0031889	0.0037369
Extra-class variance	0.00020572	0.00018924	0.0001912
Classification rates			
Accuracy found (for threshold)	96.1982% (0.41728)	97.4731% (0.4213)	96.5955% (0.4296)
Intra good classifications	666 on 720 (92.5%)	1141 on 1200 (95.08%)	2248 on 2400 (93.666%)
Extra good classification	42436 on 42480 (99.9%)	118637 on 118800 (99.86%)	475328 on 477600 (99.5243%)
Ideal rates			
Best accuracy found (for threshold)	96.6066% (0.43971)	97.7163% (0.4388)	96.8401% (0.4386)
Intra good classifications	686 on 720 (95.27%)	1163 on 1200 (96.9167%)	2284 on 2400 (95.166%)
Extra good classifications	41603 on 42480 (97.9%)	117037 on 118800 (98.516%)	470501 on 477600 (98.5136%)

www.witpress.com, ISSN 1743-3509 (on-line)

Considering the developed system, again, as a first step, we analysed the enrolled set as before: just consider in this case we refer to the "new enrolled population", obtaining the results shown in table 3.

Table 3: Enrolled population analysis (cosine-distance).

	Dataset60-7	Dataset100-7	Dataset200-7
Distribution features			
Intra-class mean	0.042722	0.057206	0.071277
Extra-class mean	0.73227	0.74645	0.65646
Intra-class variance	0.0055536	0.0068622	0.0067554
Extra-class variance	0.0098361	0.0059322	0.0042718
Classification rates			
Best accuracy found (for threshold)	99.7081% (0.38749)	99.8064% (0.4569)	99.6914% (0.4399)
Intra good classifications	179 on 180 (99.4444%)	299 on 300 (99.6667%)	597 on 600 (99.5%)
Extra good classification	10617 on 10620 (99.9%)	29684 on 29700 (99.9461%)	119260 on 119400 (99.8827%)

After enrolled population analysis we matched every template of this population against every template belonging to the test set (produced as the enrolled was) producing a new couple of distributions; we then used the previously selected threshold to calculate the accuracy on these distributions (we also searched iteratively for the ideal threshold to apply on these distributions), obtaining the results shown in table 4.

From tables 1–4 it is possible to see how the performance of the proposed method are superior with respect to the performances of the classical method.

9 Conclusions

In the present work a new technique to improve the performance of iris recognition systems has been studied and tested. We have used for our experiments a publicly available iris recognition system. Tests on CASIAv3 image database have resulted in a 2% accuracy improvement with respect to traditional methods, a significant one in iris recognition.

www.witpress.com, ISSN 1743-3509 (on-line)

Table 4: Enrolled vs. test statistics (cosine-distance).

	Dataset60-7	**Dataset100-7**	**Dataset200-7**
Distribution features			
Intra-class mean	0.11581	0.13958	0.18129
Extra-class mean	0.72704	0.74253	0.65458
Intra-class variance	0.0094728	0.085181	0.010802
Extra-class variance	0.0098429	0.0059258	0.0041061
Classification rates			
Accuracy found (for threshold)	98.697% (0.38749)	99.2121% (0.4569)	98.8188% (0.4399)
Intra good classifications	234 on 240 (97.5%)	394 on 400 (98.5%))	782 on 800 (97.75%)
Extra good classification	14145 on 14160 (99.9%)	39570 on 39600 (99.9242%)	159021 on 159200 (99.8876%))
Ideal rates			
Best accuracy found (for threshold)	98.8806% (0.403)	99.3851% (0.4953)	98.8706% (0.4605)
Intra good classifications	235 on 240 (97.9167%)	396 on 400 (99%)	784 on 800 (98%)
Extra good classifications	14138 on 14160 (99.8%)	39509 on 39600 (99.7702%)	158788 on 159200 (99.7412%)

References

[1] Flom, L.; Safir, A., "Iris Recognition System", US Patent 4.641.349, Feb 1987.

[2] Daugman, J., Downing, C., "Epigenetic Randomness, Complexity, and Singularity of Human Iris Patterns", Proceedings of the Royal Society, Biological Sciences 268, pp. 1737-1740, 2001.

[3] Daugman, J., "The importance of being random: Statistical principles of iris recognition", Pattern Recognition, Vol.36, N.2, pp. 279-291, 2003.

[4] Libor Masek, "Recognition of Human Iris Patterns for Biometric Identification", the University of Western Australia, 2003.

[5] Institute of Automation - Chinese Academy of Sciences, “Note on CASIA-IrisV3”, http:/www.CBSR.IA.AC.CN/irisdatabase.htm, 2006.
[6] Daugman, J., “New Methods in Iris Recognition”, IEEE Transactions on systems, man, and cybernetics—part b: cybernetics, vol. 37, pp. 1167-1175, 2007.

www.witpress.com, ISSN 1743-3509 (on-line)

This page intentionally left blank

Harmless screening of humans for the detection of concealed objects

M. Kowalski, M. Kastek, M. Piszczek, M. Życzkowski
& M. Szustakowski
Military University of Technology, Institute of Optoelectronics, Poland

Abstract

Multispectral screening systems are becoming more popular because of a wide range of applications. Terahertz and infrared radiation have unique properties applicable to the field of surveillance and security systems. One of the most significant applications of multispectral screening systems is the prevention of terrorist attacks. Visual detection of objects hidden under clothing of a person is one of the most challenging problems of threat detection. There are many solutions to the problem; however, the most effective utilize multispectral surveillance imagers. We investigate the possibility of harmlessly detecting objects covered by various types of clothing in three spectrums – visible, infrared and terahertz. The terahertz range of electromagnetic radiation has considerable potential to detect hidden objects because it penetrates clothes. The infrared imagers are also very useful in searching for concealed objects because infrared cameras can detect small temperature differences on the surface of clothing. Radiation from these three ranges is harmless to humans. We present the detection methodology using infrared and terahertz imagers as complementary sensors to provide image data for a multispectral threat detection system. Possible ways of using the results are also presented.
Keywords: THz imaging, object detection, harmless screening.

1 Introduction

A need to build highly efficient security systems for the detection of items covered with fabrics is a very urgent topic for researchers. Because of increased concern over terrorist attacks on aircraft, sensitive security scanners have been developed to screen passengers more effectively. Some of these scanners use

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150191

ionizing radiation like X-rays, which is a type of radiation that can cause cancer and other health problems [1, 2]. In order to scan people effectively without harmful effects other imaging techniques might be employed. We consider two ranges of radiation as potentially useful for detection of hidden objects and unconditionally harmless to humans.

One of the solutions is a terahertz (THz) imager [3, 4]. Practical, real-time imaging in the terahertz band is of great interest for the screening of people, particularly the detection of dangerous objects at standoff range [5–7]. The terahertz waves offer great possibilities in the field of concealed objects detection because can penetrate various materials and are not harmful to humans [8]. However, the main difficulty in the THz imagers is low spatial resolutions and low image quality [8].

Another possible solution is a high resolution infrared camera. Because of the fact that infrared cameras can detect the temperature differences on the surface of the object, it is justified to investigate the possibilities of applying these type of imagers for detection of hidden items [9]. Both infrared and terahertz imagers are not harmful to humans.

A range of scanners using non-ionising radiation are currently being developed and assessed for security screening purposes. There are two types of this technology. Active scanners emit waves to produce an image. Passive scanners detect natural radiation emanating from the person. We focus on using passive imagers operating in the room temperature.

2 Methodology of imaging

Due to the fact that the thermal camera measure the relative temperature of objects and because during the measurements an object is covered with material, it measures the relative temperature of the surface of covering material. A thermal camera can be used to detect an object covered with a fabric only in certain conditions. The main condition is a value of temperature difference between an object and a surface of the covering material. In order to detect the temperature difference, the thermal sensitivity of an infrared imager should be as low as possible [9, 10].

The radiation distribution detected by the passive terahertz imager is proportional to the relative temperature of a target and is directly related to the absolute amount of THz radiation emitted by a target.

In normal operating conditions, the hidden object is heated by a human body (because of direct contact between the object and the human body), therefore the value of temperature difference between a covering material and an object may decrease. This fact should be considered in order to evaluate the potential of an infrared and terahertz cameras to detect hidden object.

However, the main difficulty in the THz imaging systems is low image quality due to low sensitivity and a small number of pixels in detecting modules of cameras.

Considering the fact that even THz images with low pixel resolution still provide valuable information, it is justified to combine them with the high-resolution images from a visible camera [11, 12]. Image fusion is a process of combining two or more images, or it can be defined as the process by which several images or parts of images (features) are combined into a single image. This process allows us to combine the most interesting elements of images from various spectral ranges into one image.

The theory for performing visual tasks using cameras is described by Johnson's criteria [13]. The criteria define the conditions of an imager for the detection, recognition and identification of an object. Because of the relatively small pixel and spatial resolutions of modern terahertz cameras, it was not possible to recognize the object for detection based on the terahertz image [11]. The investigation into new non-destructive methods for the recognition of detected objects led to the concept of the methodology of multispectral detection [11, 12]. The methodology is presented in Fig. 1.

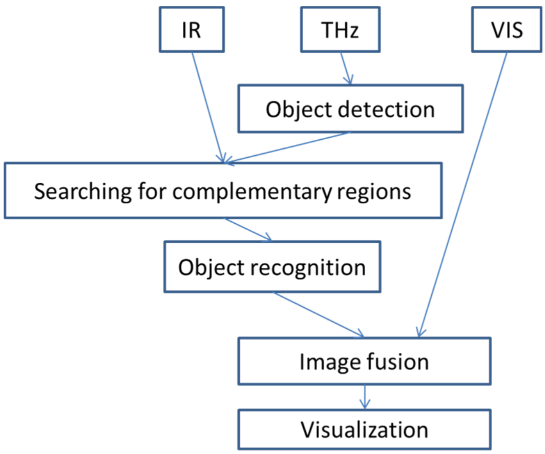


Figure 1: Methodology for detection and recognition of objects in multispectral systems.

3 The experiment

The experiment based on the detection methodology, presented in Fig. 1, employed three cameras operating in the visible, infrared and terahertz spectral ranges to detect, recognize and finally visualize the object. The methodology assumed that the terahertz camera was the primary sensor providing image data for the detection of objects, because of its proven capability of imaging through textiles. During the analysis of a terahertz image, regions with anomalies were considered as potential places to hide an object. The infrared image was searched to locate the complementary regions. The infrared image was exploited to achieve better quality imaging of an anomaly detected using the terahertz image. We investigated the potential to recognize the detected object by the analysis of the infrared image. In the last part of the methodology, the object – detected or identified – was extracted and fused with the visible image to provide the operator of the potential security system with clear and understandable visualization of the threat. The visible image operator enabled the person carrying the detected object to be identified.

In order to investigate the possibilities of detection of objects covered with various types of fabrics, the measurement methodology was developed. The measurement methodology consists of methods and algorithms used during the measurements as well as the hardware setup. The measurement setup consists of several devices – four cameras, two thermoelements (stuck to object and human body) and a thermo-higro-barometer. The cameras were selected to cover very wide range of spectra. The four cameras employed during the measurements – visible light (VIS) camera, passive terahertz (THz) camera and two infrared cameras are commercially available. In order to provide a controllable and uniform background of measurement scene, a photographic fabric was used.

Complementary images acquired with the four cameras are presented in Fig. 2.

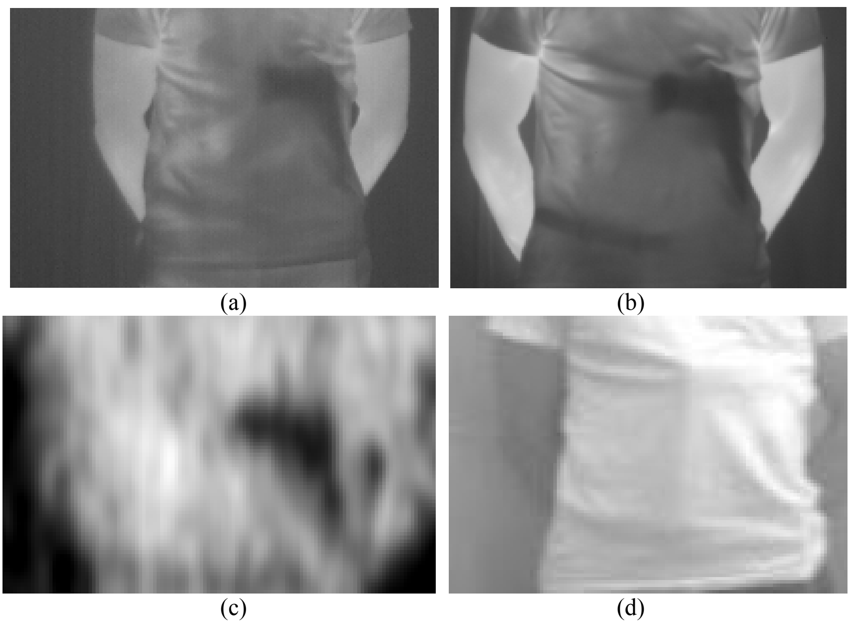


Figure 2: A human with concealed gun registered in (a) long-wavelength infrared (b) mid-wavelength infrared (c) terahertz and (d) visible range.

In order to investigate the possibilities of detection of hidden object in the terahertz range, the TS4 camera from ThruVision was employed. The cameras is operating at 250 GHz and offers a resolution of 124x271 pixels [14]. The possibilities of detection of hidden objects in infrared range were investigated using two cameras. The first infrared camera used during the measurements is a

www.witpress.com, ISSN 1743-3509 (on-line)

long-wavelength infrared (LWIR) camera P640 from FLIR supplied with uncooled microbolometer detector working in the range of 7.5–13 μm and with a resolution of 640x480 pixels. The thermal sensitivity of the LWIR camera is 55 mK at 30°C [15].

The second infrared camera is a mid-wavelength infrared (MWIR) SC5600 camera also manufactured by FLIR. The camera is supplied with cooled microbolometer detector (3–5 μm) with resolution of 640x480 pixels. The thermal sensitivity of the MWIR camera is typically 20 mK [15].

Organization of measurement sessions is presented in Fig. 2. During the measurements, several configurations with various objects (guns, knives, dynamite) and clothes (shirt, T-shirt, sweater) were prepared. A measurement of one single configuration took 30 minutes.

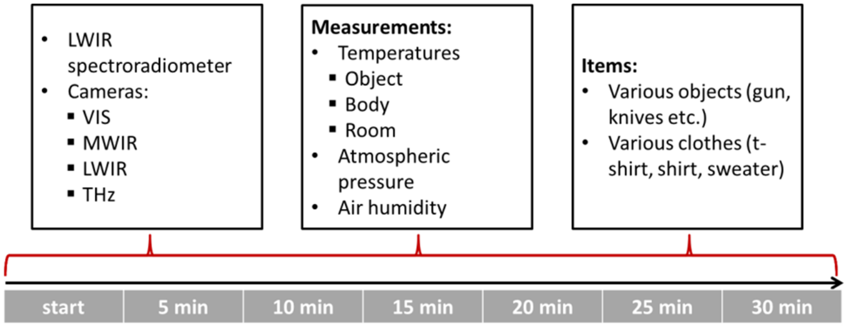


Figure 3: Measurement methodology.

The distance between a human and a set of measurement devices is 5m and is constant during the measurements. A set of data from cameras (four images) and thermoelements were collected every five minutes. For every five minutes, the data package with images, values of atmosphere parameters (air temperature, humidity and pressure) and values of body and object temperatures was collected.

4 Experimental results

Selected images registered with four cameras (LWIR, MWIR, THz and VIS) and with test object (a gun) and one type of clothing (shirt) are presented in Figs 4, 5 and 6 respectively.

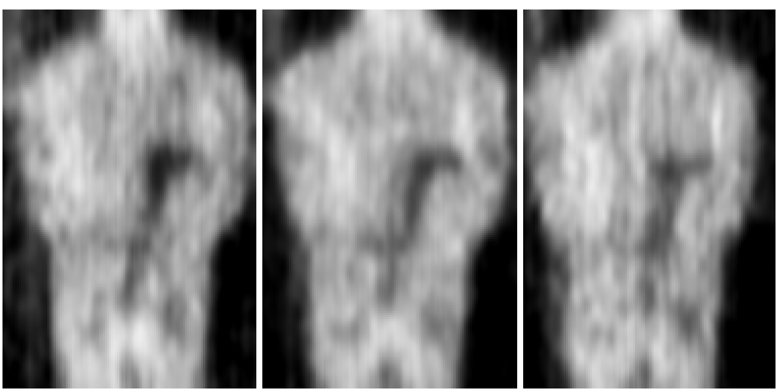
Images presented in Figs 4–6 were acquired at specified time intervals; at the beginning of the experiment, and after 15 and 30 minutes. Each experiment lasted 30 minutes. Experimental data from cameras were collected every 5 minutes. Before starting the experiments, the test objects and clothes were allowed to reach thermal equilibrium with the environment.

(a) (b) (c)

Figure 4: Images acquired by LWIR camera presenting a man wearing a shirt with a pistol, (a) at the beginning of the measurement session, (b) after 15 minutes, (c) after 30 minutes.

(a) (b) (c)

Figure 5: Images acquired by MWIR camera presenting a man wearing a shirt with a pistol, (a) at the beginning of the measurement session, (b) after 15 minutes, (c) after 30 minutes.



(a) (b) (c)

Figure 6: Images acquired by THz camera presenting a man wearing a shirt with a pistol, (a) at the beginning of the measurement session, (b) after 15 minutes, (c) after 30 minutes.

According to the results presented in Figs 4–6, the contrast of the concealed object decreased during the experiment as a result of direct contact between the body and object. Because of the transfer of energy between the two, both endeavor to achieve thermal equilibrium. The temperature difference between the object and the body decreased. Therefore, the ability to detect the concealed object with the infrared and terahertz cameras depended on the temperature parameters of the observed objects and this became less effective during the experiment. Comparison of the images indicated that in the case of the terahertz images the contrast in temperature between the hidden object and the body was higher than in the case of LWIR images and did not decrease rapidly with time.

To present the numbers in comparable manner, pixel values have been normalized using the following equation:

$$L(x,y) = \frac{I(x,y)}{\max(I)}, \tag{1}$$

where *L(x,y)* is the value of a normalized pixel, max(*I*) is the maximum pixel value in the image, and *I(x,y)* is the value of a pixel before normalization.

Subjectively, a location of the hidden object is visible in every image except the images acquired with visible light camera. It can be noticed that the visibility of the concealed object decreases during time. It is a result of decrease of temperature difference between the object and the human body. It should be noted that the ability to detect a concealed object with a camera depends on the type of clothes material and the thickness of clothing.

Comparing images registered with two thermal imagers it can be noticed that the hidden object is more distinct in the images registered with the MWIR camera.

However, to evaluate the capabilities of imager to detect a hidden object it is justified to process images in order to extract the hidden object. Image processing is an inevitable element of any surveillance security system. In the case of a system for detection of concealed objects, the system operator should be provided with a clear and understandable information [16]. The examples of binary images are presented in Fig. 7.

(a) (b) (c) (d)

Figure 7: Processed images after binarization; (a) LWIR image, (b) MWIR image, (c) THz image, (d) VIS image.

www.witpress.com, ISSN 1743-3509 (on-line)

The processed images presented in Fig. 7 show the possibilities of extraction of detected object. The processed VIS image presented in Fig. 7(d) confirms that it is not possible to detect a concealed object with a single visible light camera. However, the VIS image can be utilized in the image fusion process [lit]. Processed thermal and terahertz images presented in Fig. 7(a)–(c) show the detected object. However, the image processing algorithms need to be improved because of the artifacts remaining in the images after processing.

5 Conclusions

The purpose of the studies was to investigate the possibilities of using various cameras operating in different spectral ranges for detection of concealed objects. In the article, we presented the measurement setup consisting of medium wavelength infrared (MWIR), long wavelength infrared (LWIR), THz and visible cameras and the initial results of measurements with various types of clothing and test objects. The basic idea of the measurements was to identify the possibility not only to detect the object covered with textiles but also to identify the object. The methodology of detection assumes that terahertz camera was the primary source of image and we investigated a possibility to use infrared image to identify the detected object by analysis of the infrared image.

The presented results indicate how the changes of temperature values of human body and the object can influence the camera's ability of detection of the object covered with fabrics. The results presented in the article confirm the fact that it is possible to detect a gun covered with a shirt placed on a human body using a thermal and terahertz imager in certain conditions.

The results indicate that during the measurements the intensity of pixels presenting the concealed object decreases due to the fact, that during the measurements, the hidden object is heated by a human body and the value of temperature difference between a covering material and an object decreases.

References

[1] Rez, P., Metzger, R. I., Mossman, K. L., The Dose From Compton Backscatter Screening, *Oxford Journals: Radiation Protection Dosimetry*, 45(1): pp. 75-81, 2011.

[2] Brenner, D.J., Are X-ray backscatter scanners safe for airport passenger screening? For most individuals, probably yes, but a billion scans per year raises long-term public health concerns*,* *Radiology* **259(1)**, pp. 6-10, 2011.

[3] Jansen, C., Wietzke, S., Peters, O., Scheller, M., Vieweg, N., Salhi, M., Krumbholz, N., Jördens, C., Hochrein, T., Koch, M., Terahertz imaging: applications and perspectives, *Appl. Optics* **49(19)**, pp. E48–E57, 2010.

[4] Kemp, M.C., Millimetre wave and terahertz technology for the detection of concealed threats: a review, *Infrared and Millimeter Waves*, pp. 647-648, 2007.

www.witpress.com, ISSN 1743-3509 (on-line)

[5] Palka, N., Identification of concealed materials, including explosives, by terahertz reflection spectroscopy, Opt. Eng. **53(3)**, pp. 1-6, 2014.
[6] Lee, Y.S., *Principles of Terahertz Science and Technology*, Springer, New York, 2008.
[7] Zhang, X., Xu, J., *Introduction to THz Wave Photonics*, Springer, New York, 2010.
[8] Kowalski, M., Palka, N., Piszczek, M., Szustakowski, M., Hidden Object Detection System Based on Fusion of THz and VIS Images, *Acta Phys. Pol*. A **124(3)**, pp. 490-493, 2013.
[9] Kastek, M., Piątkowski, T., Dulski, R., Chamberland, M., Lagueux, P., Farley, V., Multispectral and hyperspectral measurements of soldier‘s camouflage equipment, *Proc. SPIE* 8382, p. 83820K, 2012.
[10] Kastek, M., Piątkowski, T., Trzaskawka, P., Infrared imaging Fourier transform spectrometer as the stand-off gas detection system, *Metrology and Measurement Sys*. **18(4)**, pp. 607-620, 2011.
[11] Kowalski, M., Kastek, M., Palka, N., Polakowski, H., Szustakowski, M., Piszczek, M., Investigation of concealed objects detection in visible, infrared and terahertz ranges of radiation, *Phot. Lett. Poland* **5(4)**, pp. 167-169, 2013.
[12] Kowalski, M., Kastek, M., Polakowski, H., Palka, N., Piszczek, M., Szustakowski, M., Multispectral concealed weapon detection in visible, infrared, and terahertz, *Proc. SPIE* 91020, pp. 91020T-91020T-7, 2014.
[13] Johnson, J., Analysis of image forming systems, *Image Intensifier Symposium*, pp. 244-273, 1958.
[14] ThruVision, www.digitalbarriers.com/products/thruvision/
[15] FLIR, www.flir.com/
[16] Kowalski, M., Palka, N., Piszczek, M., Szustakowski, M., Processing of THz images acquired by passive camera, *Phot. Lett. Poland* **4(3)**, pp. 97-99, 2012.

www.witpress.com, ISSN 1743-3509 (on-line)

This page intentionally left blank

Section 5
Safety and security: water, wastewater and waste plants (Special session organised by E. C. Rada)

This page intentionally left blank

Safety and reliability in biogas plants

V. Torretta[1], S. Copelli[2], S. Contini[1] & E. C. Rada[3]
[1]*Department of Biotechnologies and Life Sciences, Insubria University, Italy*
[2]*Department of Science and High Technology, Insubria University, Italy*
[3]*Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy*

Abstract

In the last ten years, everyone has been talking about biogas plants: politicians, ecologists, technicians, economists, laymen and experts. In other words: biogas has become fashionable. The energy crisis of the next few years shall be the shortage of fuel for the daily needs of millions of people and biogas plants seem to be a promising solution to help in solving this problem. Biogas plants are complicated enough to require both a total involvement with their specific technology and an accurate risk assessment for design purposes. With particular reference to this last feature, the number of accidents involving biogas plants has been too many to ignore. Frequent accident causes are: leakage in the storage tank and/or in the biogas distribution network, formation of flammable mixtures during maintenance operations, accidental release of H_2S, effluent discharge and developing of high pressure inside the digester. Biogas plants are often operated wrongly, deficient in technological details and incorrectly scaled-up. Moreover, all these mistakes are repeated over and over again. Therefore, there is the pressing need for a quick procedure to assess the reliability of these plants in order to operate them safely. In this work, a simple but accurate risk assessment has been carried out on a case study biogas plant using a fault tree analysis applied to the top event "fire in the digester" (one of the main causes of accident in this plant's typology). Results have shown that the overall risk (considering one year of mission time) is less than 10^{-8}. This value is acceptable considering that, near these plants, the number of inhabitants does not exceed 100 persons.
Keywords: biogas plants, risk assessment, unconfined explosions, fires, safety.

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150201

1 Introduction

Biogas is produced from a wide variety of waste in anaerobic digesters [1–4]. Anaerobic digestion is a process which transforms organic matter into gases such as methane and carbon dioxide. There are several processes for the production of biogas, depending on the type of organic waste used [5, 6]. In fact, biogas can come from several different types of raw materials: sewage sludge, food waste, manure (from cows, pigs etc.), residues from agriculture, distillery by-products and organic fraction of municipal solid wastes [7–10].

Both the total amount and the quality of the produced biogas depend on the sort of used raw materials [11]. Moreover, the involvement of different raw materials requires different processes, which unavoidably mean different sorts of upgrading or removing techniques. Therefore, it appears very difficult to fix a global yield in order to study all uses of biogas or to clearly identify hazards and risks in a biogas plant.

Despite all these criticalities, biogas is a fast-developing energy resource in Europe because it represents a valorisation of wastes and can be easily produced all over the world for a great variety of applications: transport, stationary energy use, heat and combustion. In 2010, European primary energy production from biogas benefited an annual growth of 31.3% up to reach a production of $20.9 \cdot 10^9$kg [12].

The main emerging risks related to the quick development of biogas, which is flammable, toxic, and possibly pathogen (microbiological hazard), are: 1) leakage in the storage tank and/or in the biogas distribution network, 2) formation of flammable mixtures during the digester maintenance operations, 3) accidental release of H_2S (especially in mixtures of septic wastes), 4) accidental effluent discharge, 5) overflowing sewage systems or storm-water control due to exceptional downpours, presence of dangerous products in the raw material used to produce biogas, overflow, freezing of valves and high pressure inside the digester. All these risks are enhanced by different features concerning biogas plants, such as:

- the diversity of employed processes (from wastewater treatment to solid waste treatment, or biomass valorisation by farmers) together with the absence of reference documents clearly defining, at international level, the state of the art regarding safety;
- the lack of clear regulations and standards regarding the safety of biogas production and use, and the lack of enforcement of the existing occupational health and safety regulation (including ATEX);
- the lack of organised communication channels to share the experiences (near-misses, accidents, and also positive experiences) between the industry players, but also with the usual stakeholders such as authorities, insurance companies and the public.

In order to improve both the knowledge and the global safety of biogas plants, this work reports a simple but accurate risk assessment that has been carried out on a case study biogas plant (the real plant is located in Italy). In particular, a fault tree analysis has been applied in order to quantify the probability of occurrence of the top event "fire in the digester" which is one of the main causes of accident in this plants typology. Results arising from this study have shown that the overall risk (considering one year of mission time) is under 10^{-8} y^{-1}. This value can be considered acceptable since, generally, near these plants, the number of inhabitants do not exceed 100 persons (in most cases, 10 persons is the maximum number).

2 Description of the plant

The quantitative risk assessment (QRA) reported in this case study concerns the design phase of a biogas plant sited in the north-east of Italy. In accordance with the desired configuration, the plant will produce biogas through anaerobic digestion of white meat cattle slurry (about 1,600 animals), as well as manure produced by chickens raised on broilers with straw (about 150,000 units). The biogas produced will be then processed in an internal combustion engine for the production of electricity. Part of the energy produced during the combustion process will be also recovered through the heating of water used within the company and for the production of warm milk for veal calves and for the maintenance of mesophilic conditions (about 38–39°C) within the digester. It is also estimated a daily production of biogas of around 1,150 Nm^3/day (with a methane v/v percentage of approximately 50%).

The plant object of the present study is constituted of several parts, listed below:

a) Sump for the collection of the slurry coming from manure of calves;
b) Pre-tank, equipped with a trap door, intended for the manual daily loading of poultry manure;
c) Pumping room (located in a container);
d) Emergency flare;
e) One digester, insulated and heated, with two immersion stirrer, covered with a double plastic sheeting hood;
f) Ducts for the biogas transport to the co-generator;
g) Water storage tank used by the fire-fighting network;
h) One 100 kWe co-generator;
i) Tank for the storage of the digestate;
j) Solid-liquid separator;
k) Accumulation stall for the separated solid;
l) Storage tank for the clarified fraction of the digestate;
m) Nitrification and denitrification tanks for the clarified fraction of the digestate.

All these constitutive parts of the plant have been reported in Figure 1, which shows the actual planimetry of the plant.

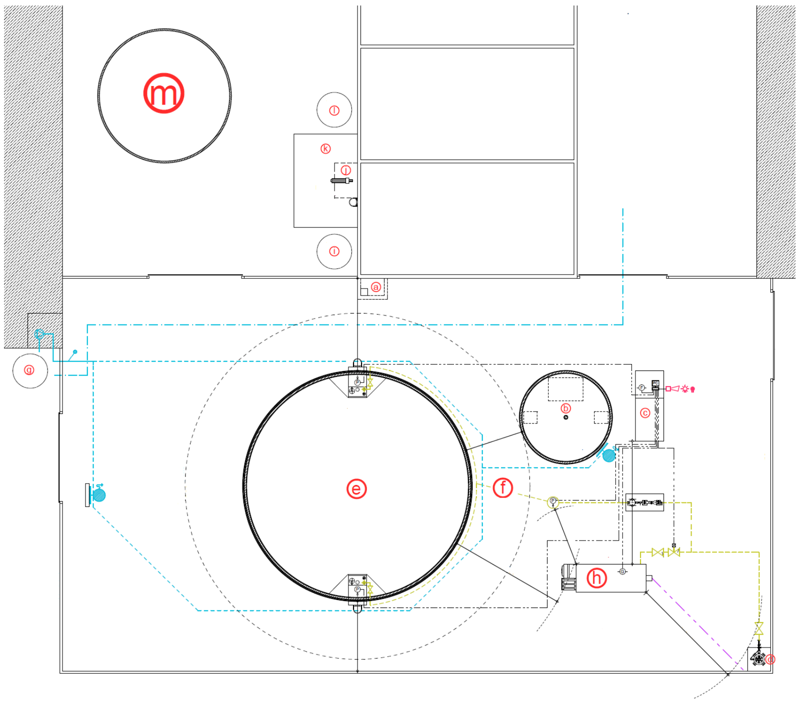


Figure 1: Planimetry of the case study biogas plant.

3 Risk assessment in industrial plants

3.1 General methods for risk assessment

Referring to technology, risk analysis is a scientifically structured discipline, that is a set of methodologies for the determination of the so-called "risk function", sufficiently developed and systematised at conceptual level. The ultimate goal is always to take the lead in a decision making process [13].

The estimate of the risk arising from the exercise of a particular industrial activity is generally performed with a methodology that, starting from statistical data derived from the history of accidents actually occurred in plants similar to the one under study, will complete a series of specific analyses, related to a particular facility and the site where it is installed, in order to obtain a sufficiently accurate estimate of the risk. In the case of mature and widespread technologies, the statistics of accidents can be so broad as to allow the direct realistic estimate of the risk or, at least, the probability of occurrence of conceivable accidents. The determination of the consequences depends very much on the site, for what concerns the aspects of meteorology and hydrology, population distribution, etc.; therefore, it is generally necessary an adaptation of the statistical data to the particular case study. If you do not have a statistic sufficiently complete to be referred to, an analytical methodology to perform a risk assessment on a theoretical basis can be employed.

The risk in the performance of an industrial activity results from the use of potentially hazardous materials. The starting point of a risk analysis is always the identification of hazardous substances and the process that they undergo in the system under study. This procedure is usually referred to as hazard identification.

The protection system (more or less sophisticated) of the plant comes into play at this point, to prevent or, at least, limit the possible effects of an accidental event. Therefore, the adverse event occurs only if you have, at the same time, the failure of the process system and the failure of the protections that the system provided to confine the incident.

Considering the physical and chemical phenomena involved in an accident you are able to evaluate their effect on individuals, economic systems, social systems, etc., through:

a) an identification of the events that contribute to the risk;
b) an estimate of the probability of occurrence of such events and their consequences;
c) a determination of the risk function and its use for decision making.

To develop such an analysis, a thorough knowledge of the system and the industrial process implemented in it has to be acquired for the search of those failures which may constitute the source of accidents (initiating events).

The risk analyst must then develop a model of the system that allows the identification of the possible states of the latter arising from each initiating event. To estimate the probability of occurrence of each state of the system, we can make use of appropriate techniques such as fault tree analysis.

The next step is the determination of all accidental scenarios associated with each degraded state of the system (sequence of events), possibly "filtered" by the effect of the available protection systems. At this point, in order to identify the consequences for each category of accidents, it is necessary to develop an environmental impact model that describes the magnitude of the consequences of each scenario. In this phase, the possible implementation of an external emergency plan can take a decisive role for the mitigation of the consequences of the accident. Finally, after determining the probability of occurrence of each accidental event, the integration of all results, (defined as an estimate of the magnitude and frequency of occurrence) on the entire spectrum of the categories of accidental scenarios, allows for the determination of the function associated with the risk linked to the activity in question. Normally, on the basis of this risk function, decision-makers (political or technical, depending on the stage at which the study is actually applied) take the appropriate decisions.

3.2 Fault tree analysis

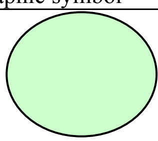
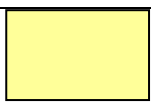
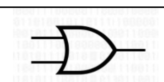
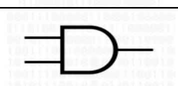
Fault tree analysis is a technique suitable for both determining the credible modes of occurrence of an undesired event (called, top event), caused by a complex concatenation of other events (qualitative analysis), and estimating the frequency of occurrence of undesired event on the basis of frequency of occurrence of the events that cause it (quantitative analysis [14]). It is a deductive methodology particularly suitable for the analysis of complex systems whose development can be easily decomposed into a succession of more simple events, and therefore it is well suited to the analysis of industrial installations.

Once all the systems (and their parts) have been identified, it is necessary to continue the analysis of the chain of systems, subsystems, equipment, etc., up to the failure of the individual components for which we are in possession of sufficient information on the probabilities of failure to be used in the evaluation.

These are combined through logical operations (and/or), also called logic gates, going from bottom to up, until you get to determine the probability of the top event. The fault tree analysis allows you to treat the contribution to risk arising from human error, as well as other causes of failure common to several subsystems. Clearly, it is possible to use fault trees also for qualitative analysis. In this case, there is the advantage of highlighting the main causes of an accident (e.g., whether failures of equipment or human error) so that you can focus on preventive measures to reduce the probability of the accident itself.

The representation of a fault tree uses some symbols with standardised meanings; the main graphic symbols are summarised in Table 1.

Table 1: Graphic symbols for fault tree analysis.

Graphic symbol	Meaning
	***Primary events:*** these events, for one reason or another, are not further investigated; if you want to perform a quantitative analysis to estimate the frequency of occurrence of the top event you need to know the frequency of occurrence of these primary events, for example, estimating it through a historical analysis.
	***Intermediate events:*** these are events that occur before or after another event and represent the cause of the next event; they are connected to the events preceding or following them by gates.
	***OR-gate:*** so that the output of the gate takes place, it is sufficient that one of the inputs to the gate itself (which may be any number greater than 1) occurs.
	***AND-gate:*** so that the output of the gate happens, it is necessary that all the inputs to the gate itself (which may be any number greater than 1) occur.

3.2.1 Quantitative risk analysis

The quantification of a fault tree has essentially the aim of quantifying the reliability *R(t)* of a system, that is the probability that, in correspondence of an allotted time interval (also called mission time, t), a system performs properly the function for which it was built. From this definition it is clear that the reliability of a system is inversely proportional to the mission time: the longer the time of the mission, the smaller results to be the reliability of the system (or it is more likely that the system fails).

www.witpress.com, ISSN 1743-3509 (on-line)

It is important to note that the quantification of the fault tree is an operation valid for orders of magnitude; in other words, the results cannot be compared on the basis of small differences. For example, 1.5 and 4.1 are essentially the same number while 3.5 to 0.12 are two numbers significantly different. It follows that no unnecessarily high accuracy is required in the input data (i.e., in the estimate of the probabilities of occurrence of the primary events).

3.2.2 Primary events quantification

For a system whose modes of failure can be represented in a fault tree, the information contained in *R(t)* are usually summed in the following functions: the unavailability *q(t)*, which is the probability that the system is not able to perform its function (because it is broken) at time *t*, and the frequency of occurrence *W(t)*, which is the number of times that the system is not expected to be able to perform its function in its mission time.

To quantify a fault tree is first necessary to calculate these quantities for all primary events that have been identified in the construction of the fault tree itself.

If the component involved in the primary event is not repairable, the component is no longer able to perform its function at time *t* if it is spoiled before the same time *t*; its unavailability therefore coincides with its unreliability, namely:

$$q(t) = \lambda t \tag{1}$$

where λ is the failure rate, that is, the frequency with which a system fails (or the fraction of the components that fail per unit of time, y^{-1}) and *t* is time, y.

If the component is repairable, its unavailability no longer coincides with its unreliability, since, even if the component had spoiled before time *t*, may still perform its function at time *t* in the case where it has been repaired. In this case, it is possible to demonstrate that the unavailability reaches an asymptotic value equal to:

$$q(t) = \frac{\lambda T_D}{1 + \lambda T_D} \approx \lambda T_D = \frac{\lambda}{\mu} \tag{2}$$

where T_D is the mean repair time, that is the time necessary to repair the component, and $\mu = 1/T_D$ is the repair rate, that is, the frequency with which a component can be repaired. For practical purposes, the unavailability can be approximated by the probability that the component has failed in the time interval T_D previous than the instant of time considered (therefore, resulting failure at time *t*).

3.2.3 Minimal cut sets and top event quantification

A minimal cut set (MCS) is the minimum combination of primary events, which is necessary and sufficient to ensure the occurrence of the top event; in equivalent terms, the top event occurs if all the events in a MCS occur simultaneously. Then, the unavailability of a MCS is the probability that, at time *t*, all the system components are not able to perform their function; therefore, this probability coincides with the probability of occurrence of the top event due to the considered MCS. Since the individual events involved in a MCS are all independent, the overall probability that all events occur simultaneously is given by the following relation:

$$q(t) = \prod_{i=1}^{n} q_i(t) \tag{3}$$

where n is the order of the MCS (the number of events that involves the MCS) and $q_i(t)$ is the unavailability of each component of the MCS.

The frequency of occurrence of the MCS, which coincides with the frequency of occurrence of the top event in the mission time (T) because of the MCS considered, is then calculated as:

$$W(t) = \int_o^T \left[\sum_{i=1}^{n} \left(\left(\prod_{\substack{j=1 \\ j \neq i}}^{n} q_j(t) \right) \lambda_i \right) \right] dt \tag{4}$$

A top event can occur if anyone of the MCS that can cause it occurs. The likelihood of the top event in a given interval of time can thus be calculated as the union (logical OR) of the probability of occurrence of each MCS that can cause the top event itself.

4 Case study risk assessment

In accordance with the purposes of the present work, we proceeded with the drafting of the fault tree concerning the top event “occurrence of fire within a gasometer for the production and containment of biogas”.

For what concerns the layout of the plant and its functioning, reference has been made to the planimetry shown in Figure 1.

Figure 2 shows the graphical representation of one of the sub-tree (E10) concerning the top event cited above. Observing the tree, it can be derived clearly the chain of events (defined as failure) such as to generate the occurrence of a fire within the gasometric dome due to that specific sequence of failures.

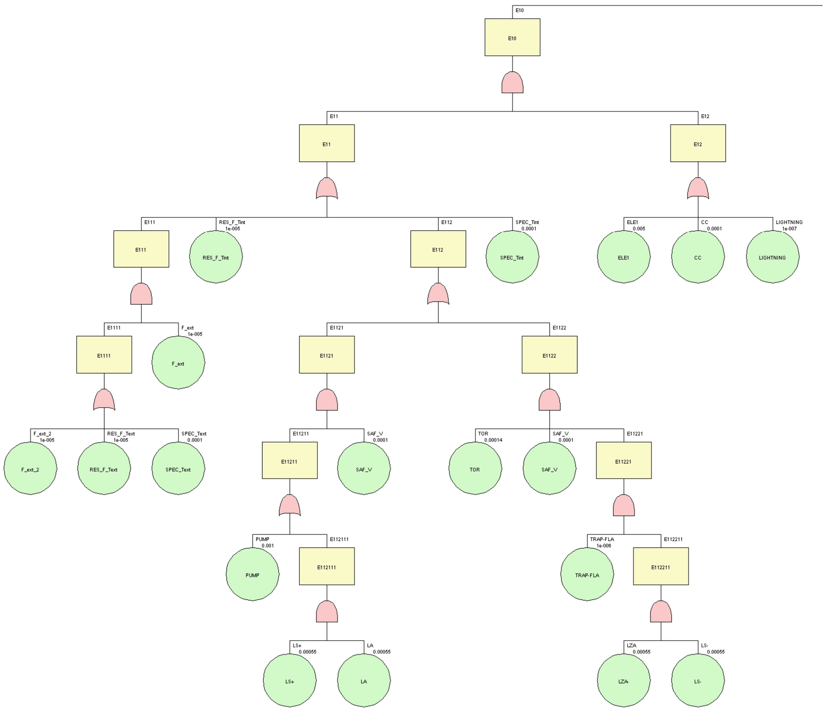


Figure 2: Sub-tree E10 for the top event: “fire in the digester”.

In particular, the top event takes place in the case where at least one of the following final intermediate events occurs:

- E10: formation of a flammable mixture within the gasometric dome because of accidental mixing between biogas and air and the simultaneous presence of an ignition source (spark, flame welding, etc.);
- E20: explosion of the gasometric dome due to the propagation of a fire (not readily extinguished) in the adjacent stables;
- E30: formation of a flammable mixture within the gasometric dome due to a malfunction in the desulfurization unit (which blows air inside the gasometric dome from the outside);
- E40: flashback from the cogeneration plant.

In order to perform the quantitative calculation of the frequency of occurrence of the top event, we have expressed all the causes originating the intermediate events (final or not) until you get to the primary events (rupture of simple components such as valves, level controllers, etc.), for which it has been possible to estimate the relative unavailability and frequencies of occurrence in accordance with appropriate databases (relative to similar systems).

It is important to emphasize that, within the scheme of the fault tree, the presence of all the protective devices useful in order to avoid a fire or an explosion of the gasometric dome has been considered.

Performing the analysis of all MCS, it is possible to observe that minimal cut sets of order higher than 5 do not exist and, moreover, there are no MCS of order 1 (this is extremely positive because there are no events that, alone, can cause the top event). Among the MCS of order 2, we have the combinations of events in which, due to exceeding of the fatigue strength of the inner sheeting hood (RES_F_Tint) or its production out of specification (inner sheeting defective, SPEC_Tint), there is the formation of a flammable mixture inside the gasometric dome that can be triggered by a short circuit (CC), improper maintenance of the electrical service (ELE1) or lightning strikes in the vicinity of the dome (LIGHTNING). Among the MCS of order 3 (16 different), there are events in which the formation of a flammable mixture within the gasometer is given by the failure of components such as the pump of the water trap used for the collection of the condensate (PUMP), the safety valve of the dome (SAF_V), the concentration meters of hydrogen sulphide (MIS_H2S) and oxygen (MIS_OX), etc. while the trigger is through the classic CC, ELE1 and LIGHTNING events. In only one case a MCS of order 3 (n ° 16) does not involve an ignition source of the types previously cited: it is the accidental scenario in which a flashback from the co-generator occurs because of the simultaneous breakage of both the flame trap and the two emergency low level switches of the water trap.

Of particular interest is the unique MCS of order 5: it expresses the combination of events that lead to the top event due to the development of a fire (not promptly extinguished) in the stables adjacent to the gasometric dome and its subsequent propagation to the dome itself. In order to compute the probability of occurrence of such a MCS is, however, required the calculation of the probability that the wind (WIND) blows towards south during the development of the fire itself. This estimation cannot be obtained from any database as it is closely related to the location of the site in which the plant is constructed. Therefore, to assess the mean wind direction during of year of mission time, meteorological data from two different weather stations (located near the plant site) has been collected.

Analysing such data, it can be reasonably assumed that the wind blows at the southern quadrant with a probability of about 50% during the year.

As regards the retrieval of all failure rates and unavailability, Dossier Ambiente manuals [15] have been taken as a reference. Moreover, it has been considered a repair rate equal to 1 day^{-1}.

Table 2 shows, in a schematic way, all the data necessary for the quantification of the fault tree. Referring to the database shown in Table 2, it can be possible to proceed with the calculation of the probability of occurrence of the top event.

Table 2: Database for failure rates, repair rates and unavailability.

Primary event code and description	Failure rate [y^{-1}]	Repair rate [y^{-1}]	Unavailability [-]
CC: short circuit	-	-	$1\cdot10^{-4}$
ELE1: electric sparks due to improper maintenance	-	-	$5\cdot10^{-3}$
FAIL-ANT: stables sprinklers failure	-	-	$1\cdot10^{-2}$
LIGHTNING: lightning in the vicinity of the dome	-	-	$1\cdot10^{-7}$
F_ext: external factors on internal sheeting	-	-	$1\cdot10^{-5}$
F_ext_2: external factors on external sheeting	-	-	$1\cdot10^{-5}$
FIRE_STA: fire in the stables	-	-	$1\cdot10^{-2}$
LA: failure of the low level alarm	$2\cdot10^{-1}$	365	$5.5\cdot10^{-4}$
LS+: failure of the high level switch	$2\cdot10^{-1}$	365	$5.5\cdot10^{-4}$
LS-: failure of the low level switch	$2\cdot10^{-1}$	365	$5.5\cdot10^{-4}$
LZA: failure of the ultimate low level alarm	$2\cdot10^{-1}$	365	$5.5\cdot10^{-4}$
MIS_H2S: failure of the H_2S controller	$5\cdot10^{-3}$	365	$\sim1\cdot10^{-5}$
MIS_OX: failure of the O_2 controller	$5\cdot10^{-3}$	365	$\sim1\cdot10^{-5}$
PUMP: failure of water trap pump	$4\cdot10^{-1}$	365	$1\cdot10^{-3}$
RES_F_Text: overcoming of the external sheeting fatigue resistance	-	-	$1\cdot10^{-5}$
RES_F_Tint: overcoming of the internal sheeting fatigue resistance	-	-	$1\cdot10^{-5}$
SAF_V: failure of the dome safety valve	-	-	$1\cdot10^{-4}$
SPEC_Text: external plastic sheeting out of specific	-	-	$1\cdot10^{-4}$
SPEC_Tint: internal plastic sheeting out of specific	-	-	$1\cdot10^{-4}$
TOR: failure of the flare valve	$5\cdot10^{-2}$	365	$1.4\cdot10^{-4}$
TRAP-FLA: failure of the flame trap	-	-	$1\cdot10^{-6}$
WIND: wind direction towards south	-	-	$5\cdot10^{-1}$

5 Results and conclusions

Analysing the fault tree generated for the incidental event "fire in a gasometer", it has been showed that the probability of occurrence of the top event (considered a mission time equal to 1 year) is of the order of 10^{-8}. This value lies within the zone of acceptability of the risk (considered as individual risk), as the limit value of unacceptability is equal to 10^{-6} (given in accordance with the recommendations of Italian fire-fighters). It can be also noted that the presence of ignition sources such as short circuit or incorrect maintenance of the electrical service weigh significantly within the MCS in which they are involved, respectively 17% and 83%, for the purposes of the occurrence of the top event.

Other events that are of considerable importance are the resistance to fatigue and the possibility of abnormalities in the inner sheeting hood (about 50%), followed by failure of concentration controllers of H_2S and oxygen in the dome (1.23%) and breakages of the pump in the water trap and the safety valve of the dome (0.49%).

References

[1] Salvi, O., Delsinne, S., Evanno, S., Biogas - A European Perspective on Safety and Regulation. *Journal of Risk Analysis and Crisis Response*, **1(1)**, 1–20, 2011.

[2] Divya, D., Gopinath, L.R., Merlin Christy, P., A review on current aspects and diverse prospects for enhancing biogas production in sustainable means. Renewable and Sustainable Energy Reviews, **42**, 690–699, 2014.

[3] Boontian, N., Optimization of the anaerobic digestion of biomass: A review. *Romanian Review Precision Mechanics, Optics and Mechatronics*, **43**, 48–54, 2013.

[4] Kasiri, S., Mah, F., Zhang, C., Haveroen, M., Ellsworth, S., Ulrich, A., Anaerobic processes, *Water Environment Research*, **84(10)**, 1217–1285, 2012.

[5] Rada, E.C., Ragazzi, M., Ionescu, G., Merler, G., Moedinger, F., Raboni, M., Torretta, V., Municipal solid waste treatment by integrated solutions: energy and environmental balances. *Energy Procedia,* **50**, 1037–1044, 2014.

[6] Torretta, V., Ionescu, G., Raboni, M., Merler, G., The mass and energy balance of an integrated solution for municipal solid waste treatment. *WIT Transactions on Ecology and the Environment,* **180**, 151–161, 2014.

[7] Rada, E.C., Ragazzi, M., Torretta, V., Laboratory-scale anaerobic sequencing batch reactor for treatment of stillage from fruit distillation. *Water Science & Technology*, **67(5)**, 1068–1074, 2013.

[8] Callegari, A., Torretta, V., Capodaglio, A.G., Preliminary trial application of biological desulfonation in anaerobic digestors from pig farms. *Environmental Engineering and Management*, **12(4)**, 815–819, 2013.

[9] Martinez, S., Torretta, V., Minguela, J., Siñeriz, F., Raboni, M., Copelli, S., Rada, E.C., Ragazzi, M., Treatment of slaughterhouse wastewaters using anaerobic filters. *Environmental Technology*, **35(3)**, 322–332, 2014.

[10] Nardin F., Mazzatto, F., Mapping of biomass fluxes: a method for optimizing biogas-refinery of livestock effluents, *Sustainability*, **6(9)**, 5920–5940, 2014.

[11] Trulli, E., Torretta, V., Influence of feeding mixture composition in batch anaerobic co-digestion of stabilized municipal sludge and waste from dairy farms. Environmental Technology, Doi: 10.1080/09593330.2014.994045. In press.

[12] Observ'ER. The State of Renewable Energies in Europe. http://www.energies-renouvelables.org/

[13] Di Mauro, C., Bouchon, S., Torretta, V., Industrial Risk in the Lombardy Region (Italy): what People perceive and what are the gaps to improve the Risk Communication and the Participatory Processes. *Chemical Engineering Transactions*, **26**, 297–302, 2012.

[14] Vaseley, W.E., Goldberg, F.F., Roberts, N.H., Haasl, D.F., *Fault Tree Handbook*, U.S. Nuclear Regulatory Commission Washington D.C., 1981.

[15] Dossier Ambiente, http://www.amblav.it/dossier.aspx

Reliability analysis and assessment of the explosion risk in a hybrid collector

S. Copelli[1], E. C. Rada[2], M. Ragazzi[2], V. Torretta[3] & M. Schiavon[2]
[1]*Department of Science and High Technology, Insubria University of Varese, Italy*
[2]*Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy*
[3]*Department of Biotechnologies and Life Sciences, Insubria University of Varese, Italy*

Abstract

Dust removal from a gas stream is a common problem in many industrial processes (e.g. power, cement, steel plants, etc.). In the last decades, plant managers more and more often have had to face the necessity of improving de-dusting systems in order to meet more stringent law requirements, inspired by the principle of the "maximum safety technologically feasible", but also pushed by the increased penetration of environmental issues into public opinion, and its meaning in terms of company image. Budgets for these improvements play a role in a general asset management strategy: de-dusting, being often an operation having low influence on production performances, is seen more as a "necessary cost" than a profit generator. The trend for companies, especially in the actual economical scenario, is to reuse existing de-dusting plants, enhancing their efficiencies rather than install new plants that would involve costs for the decommissioning of obsolete equipment. The obvious economic benefits of retrofits are counterbalanced by technical disadvantages. In particular, a systematic assessment of safety issues is required, not limited to the safety-oriented design of new machines, but extended in the evaluation of the impact that changes in process conditions (induced by the new equipment) can have on the existing ones.

In this work, explosion problems in the de-dusting section of a cement plant have been considered. Particularly, using fault tree analysis, it has been evaluated

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150211

the changing in the overall risk (considering one year of mission time) of explosion referring to a hybrid-like collector realised by introducing a Fabric Filter (FF) downstream with respect to an Electrostatic Precipitator (ESP). Results have shown that a chain of failures in the FF section may affect relevantly the risk of explosions occurrence in the collector leading to the unavoidable need for the introduction of mitigation actions into the system.
Keywords: cement plants, risk assessment, explosions, safety, hybrid collectors, retrofit.

1 Introduction

Cement manufacturing is one of the largest mineral commodity industries in the United States, with an estimated production capacity of greater than 73 million tons annually [1]. On the contrary, in European countries, a huge decrease in cement consumption has been registered during the last five years. Particularly, in 2012, there has been a 22.1% (with respect to 2011) decrease in the manufacturing of cement and this trend seems to continue [2].

The new regulation on Solid Recovery Fuel (SRF) from municipal solid waste (MSW) can change this trend and give a higher speed to this sector and decreasing the dust problem but increasing the chlorine or the heavy metals ones [3–6].

Essentially, the most important part of a cement manufacturing process is the kiln, a horizontal steel cylinder, lined with firebrick and slightly sloped downward from the raw material feed to the fuel feed supply. Typically, a kiln rotate slowly (maximum 1-3 rpm), heating the raw material mix to obtain very hot, marble-sized chunks known as “clinker”. Once out of the kiln, the clinker undergoes a cooling process. When sufficiently cool, the clinker is ready to pass through a series of grinding and milling processes providing that gray powder known as cement.

The cement industry is very capital intensive. Some of the major pieces of equipment include pulverisers, dust collectors, electrostatic precipitators, and rotary kilns. Energy costs can account for up to 40% of the total cost of cement manufacturing. Currently, over 90% of the installed capacity uses coal as primary fuel for the kiln burner. Conversion to coal was started in the 1970s. Unfortunately, the use of coal as fuel is very dangerous because of the possible triggering of fire and explosions during cement manufacturing.

Moreover, the cement industry has to face another relevant problem: atmospheric dust emissions. These emissions became in the last years the most studied problem in terms of urban pollution independently if they are produced from industrial processes, from traffic or from cooking or domestic heating [7–10].

Dust removal from a gas stream is a common and quite cheap operation required in many industrial processes but, in the last decades, more and more stringent law requirements have forced this common operation to become very expensive. Budgets for introducing improvements (or new units) in the already existing de-dusting equipment play a fundamental role in the general asset management strategy: in fact, de-dusting, being often an operation having low influence on production performances, is unavoidably seen more as a “necessary cost” than a profit generator. Companies’ trend, especially in the actual economical scenario, is to reuse existing de-dusting plants, enhancing their efficiencies rather than install new plants that would involve costs for the decommissioning of obsolete equipment. Unfortunately, the obvious economic benefits of retrofits are counterbalanced by technical disadvantages and possible safety related problems. In particular, a systematic assessment of safety issues, not limited to the safety-oriented design of new machines, but extended in the evaluation of the impact that changes in process conditions (induced by the new equipment) can have on the existing ones, must be done.

In this work, we have focused on the relevant problem of the triggering of explosions in the de-dusting section of a cement plant. Particularly, using fault tree analysis, it has been evaluated the changing in the overall risk (considering one year of mission time) of explosion referring to a case study where a hybrid-like collector is realised by introducing a Fabric Filter (FF) downstream with respect to an already installed ElectroStatic Precipitator (ESP). Results have shown that failures in the FF section may affect relevantly the risk of an explosion occurrence in the collector itself leading to the unavoidable need for the introduction of mitigation actions into the system.

2 Description of the hybrid-like collector

Hybrid collectors are abatement systems that have been designed specifically to take into account all the factors affecting their operational efficiency. Because of this fact, they have very high collection efficiency, and they represent the best technology currently available in order to fully comply with the limit values laid down by specific authorizations issued by the competent bodies.

The hybrid collection system treated in this case study has been realised by a retrofit operation consisting of an addition of a fabric filter downstream an already installed electrostatic precipitation section.

Given the particular system design, the amount of dust emitted into the atmosphere is considerably lower than that allowed by the strict environmental standards in force.

Hot gases (about 300°C), coming from the pre-heating section of the kiln, are partly used to dry and ventilate both the coal and the crude feed mills but, while the gases of the coal mill are filtered independently, the dusty gases used in the kiln are mixed with the gas coming from the pre-heater in a tower (called “conditioner”) where they are cooled (till about 160°C) and humidified with water spray; the amount of dosed water is regulated by a computer as a function of the gas temperature.

Then, the conditioned gases enter the electrostatic section of the hybrid filter, whose design is such as to allow a very low gas velocity (in order to favour the separation of the dusts from the gaseous stream). The operating principle of an electrostatic precipitator is based on the effect of ionization of a neutral gas (corona effect) when it passes through a strong electric field formed by issue (negative polarity) and precipitation (or collector) electrodes (positive polarity). Thanks to the very high applied voltage (in this case, 65 kV), the issue electrodes emit electrons by photoelectric effect and charge the dust particles of which the gas to be de-dusted is rich; in this way, the charged dust particles will be attracted by the precipitation electrodes (or plates). The dust settles on the plates so that, periodically, they have to be "shocked" in order to be kept clean and fully operative. Particularly, an electrostatic precipitator can remove dust particles as small as 1 μm with an efficiency exceeding 99%.

Immediately then, the partially de-dusted gases pass through another section: the fabric filter.

A fan located downstream of the fabric filter aspires the air flow to be de-dusted, causing its entry in the lower part of the filter; hence, the gas going up meets the rows of bags and passes from the outside to the inside of their tissue cylinder.

The particles suspended in the gas are retained on the outside of the bags thanks to both the structure of the fabric fibers and a layer of particulate laying outside the fabric of each bag (which is capable of retaining even the finer particles).

The collapse of each bag on itself, given by the outside-inside air flow, is prevented by a basket that keeps roughly the shape of a tube.

The de-dusted air inside of each bag is now aspired and removed by the filter in the upper part of the chamber to be sent to the chimney, always thanks to the fan cited above. Approximately every 8 min, in order to avoid the clogging of the filtering surface because of an excessive deposit of dusts, an air jet at high speed is blown inside of each bag: such a jet, impacting against the filtering surface, causes a sudden expansion of the bag and allows for the detaching of the crust of dust that has been formed on it. This cleaning system is called "pulsed jet" and has the advantage of not having to exclude the bags from the filtration system during cleaning operations; the air jet is provided instantly through solenoid valves from dedicated storage tanks, whose operating pressure is about 6 bar, and acquires a high speed through the venturi ducts placed on the basket of each bag. To maintain continuous filtration during the cleaning operation, the air is fed to a row of bags at a time, allowing the other rows to continue to carry out their activity. The detached material falls into the hoppers at the bottom of the filtering chamber and, then, it is extracted by means of a worm screw and returned to the kiln by means of conveyor belts.

All these constitutive parts of the plant have been reported in fig. 1, which shows a simple sketch of the de-dusting unit.

3 Risk assessment in cement plants

3.1 General risk assessment procedure

When talking about Quantitative Risk Analysis (QRA), we referred to as a set of methodologies and structured procedures having the aim of determining (both qualification and quantification) the so-called "risk function", which is a fundamental tool in a decision making process.

The estimate of the risk is generally performed starting from statistical data derived from the history of accidents occurred in plants similar to the one under study: in this case, accidents in cement plants. On the contrary, the determination of the consequences of accidental events involving the plant under study depends very closely on the location of the industrial site (at least for what concerns the aspects of meteorology and hydrology, population distribution, etc.) and, therefore, it is generally necessary an adaptation of the statistical data to the particular plant.

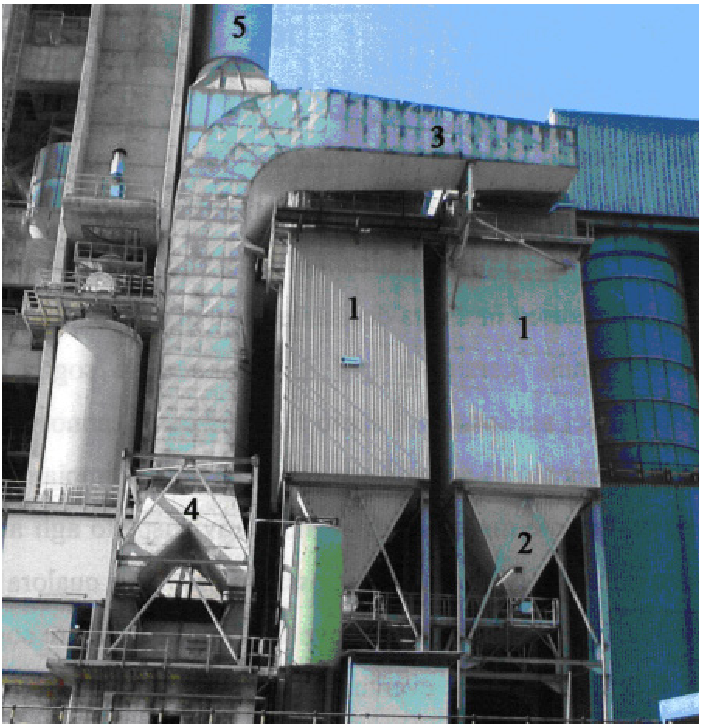


Figure 1: Sketch of the case study hybrid collector. 1) Final sections of the fabric filters; 2) hoppers; 3) de-dusted air duct; 4) fan; 5) bottom of the chimney. The ESPs are located behind the fabric filters.

In most cases, the risk linked with whatever industrial activity results from the use of chemicals or other potentially hazardous materials [11, 12]. Therefore, the unavoidable starting point of a risk analysis is always the so-called "hazards identification" procedure. Protection systems installed into the plant in order to prevent or, at least, limit the possible effects of accidental events, must to be taken into account during this evaluation step. In fact, it is important to specify that an accidental event can occur only if, at the same time, there is a process anomaly (caused by a variety of reasons) and the failure of all the related protection systems occurs.

The next step of a risk analysis is the determination of all accidental scenarios associated with the previously identified hazards, possibly filtered by the effect of the available protection systems.

Then, considering all the phenomena involved in an accident (both physical and chemical), it is possible to evaluate its effects on environment, workers, people living in the neighbouring of the facility, etc., employing the procedure constituted by the following steps:

a) identification of all the events that may contribute to the occurrence of that accident;
b) estimation of the probability of occurrence of such events and their consequences;
c) quantitative determination of the risk function related to the considered accidental event (and its use for decision making).

It is important to underline that, in order to use such a procedure, a thorough knowledge of the considered industrial plant and its processes has to be acquired for the search of those failures that may trigger an accident (initiating events).

For what concerns the estimation of the probability of occurrence of an accidental event, it is possible to employ dedicated techniques such as fault tree analysis.

Finally, after determining the probability of occurrence of each identified accidental event, the integration of all results allows for the determination of the function associated with the risk linked to the activity in question.

3.2 Fault tree analysis for QRA

Fault tree analysis is a widely used technique capable of both determining all the credible modes of occurrence of an undesired event (called, top event), caused by a complex concatenation of other events (qualitative analysis), and estimating the frequency of occurrence of the undesired event on the basis of the frequency of occurrence of the events that cause it (quantitative analysis [13]).

It is a structured procedure that requires a deep knowledge of all the components of the analysed system; particularly, the chain of intermediate events leading to the occurrence of the top event must be decomposed (through the use of logic gates) until reaching the "roots" of the tree, which are constituted by the so-called "primary events", that are events for which the probability of occurrence are always known (e.g., from databases).

Therefore, going from the bottom (roots or primary events) to the top (top event) of a fault tree, it is possible to quantify the so-called reliability function, *R(t),* of a system, that is the probability that, in correspondence of an allotted time interval (also called mission time, t), a system performs properly the function for which it was built. From the *R(t)* function, it is also possible to calculate both the unavailability function, *q(t)*, which is the probability that the system is not able to perform its function (because it is broken) at time *t*, and the frequency of occurrence, *W(t)*, which is the number of times that the system is not expected to be able to perform its function in the mission time. Of course, before quantifying a fault tree, it is necessary to determine these quantities for all primary events that have been identified in the construction of the fault tree itself.

Then, it is possible to quantify the entire tree by using a variety of methods. One of the most simple and known is the Minimal Cut Sets (MCS) method. Particularly, a MCS is the minimum combination of primary events which is necessary and sufficient to ensure the occurrence of the top event; in other words, the top event occurs if all the events in a MCS occur simultaneously. Therefore, the unavailability of a MCS coincides with the probability of occurrence of the top event due to the considered MCS. Since the individual events involved in a MCS are all independent, the overall probability that all events occur simultaneously is given by the following relation:

$$q(t) = \prod_{i=1}^{n} q_i(t) \tag{1}$$

where n is the order of the MCS (the number of events that involves the MCS) and $q_i(t)$ is the unavailability of each component of the MCS.

A top event can occur if anyone of the MCS that can cause it occurs. The likelihood of the top event in a given interval of time (mission time, T) can thus be calculated as the union (logical OR) of the probability of occurrence of each MCS that can cause the top event itself, using the following relation.

$$W(t) = \int_o^T \left[\sum_{i=1}^{n} \left(\left(\prod_{\substack{j=1 \\ j \neq i}}^{n} q_j(t) \right) \lambda_i \right) \right] dt \tag{2}$$

where λ is the failure rate, that is, the frequency with which a system fails (or the fraction of the components that fail per unit of time, y^{-1}) and t is time, y.

As it is well known, the quantification of a fault tree is always an operation valid for orders of magnitude. It follows that no unnecessarily high accuracy is required in the estimate of the probabilities of occurrence of the primary events.

4 Case study: de-dusting system retrofit

In accordance with the purposes of the present research, the authors focused on the relevant problem of the triggering of explosions in the de-dusting section of a cement plant. Using fault tree analysis, it has been evaluated the changing in the overall risk (considering one year of mission time) of explosion referring to the case study where a hybrid-like collector is realised by introducing a Fabric Filter (FF) downstream with respect to an already installed ElectroStatic Precipitator (ESP).

The drafting of the fault trees concerning the top event "occurrence of an explosion in the de-dusting section" both before (ESP) and after (HYBRID FILTER = ESP + FF) the retrofit operation was taken into account.

For what concerns the layout of the de-dusting section (before and after) and its functioning, reference has been made to the plant sketch reported in figure 1.

Figure 2 shows the graphical representation of a fault tree realised for the plant configuration before the retrofit operation, that is, considering the de-dusting section of the plant as constituted by the ESP (and its related instrumentation) only. Observing the tree, it can be derived clearly how an explosion of the ESP can be triggered as a consequence of different chains of events (all intended as failures).

In particular, the top event takes place in the case where both of the following final intermediate events occurs:

- E10: development of an overpressure higher than 6 bar inside the ESP chamber;
- E20: failure of the rupture disk installed on the ESP.

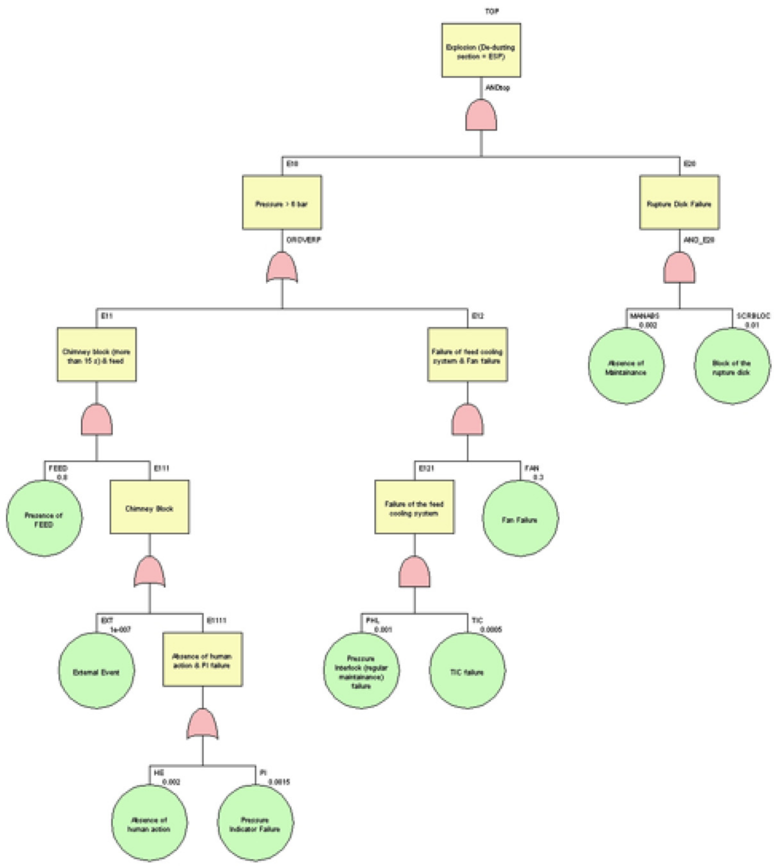


Figure 2: Fault tree for the top event "explosion in the de-dusting section" evaluated before the plant retrofit.

It is important to state that, within the scheme of the fault tree, all the protective devices present into the plant section object of the analysis have been considered.

Performing the MCS analysis, it is possible to observe that there are 4 MCS: 3 of order 4 and 1 of order 5. Among the MCS of order 4, we have all the combinations of events in which, due to the presence of external factors causing the blockage of the chimney (EXT), the feed to the de-dusting unit (FEED), the absence of a scheduled and correct maintenance activity (MANABS), the blockage of the rupture disk installed on the ESP (SCRBLOC), the absence of a human action as a consequence of the sounding of the high pressure alarm (HE) and the breakdown of the ESP pressure indicator (PI), a pressure overcoming the maximum threshold value can be reached causing a physical explosion of the ESP chamber.

For what concerns the MCS of order 5, it involves the following combination of events: fan breakdown (FAN), absence of a scheduled and correct maintenance activity (MANABS), block of the rupture disk installed on the ESP (SCRBLOC), pressure interlock (PHL) and temperature controller failure (TIC) on the water spray feeding line that constitutes the cooling system available for the hot dusty gases exiting the kiln and addressed to the de-dusting system.

In order to determine all failure rates and unavailabilities, Dossier Ambiente manuals [4] have been used. Table 1 contains all the data necessary for the quantification of the fault tree.

Table 1: Database for failure rates, repair rates and unavailabilities. Case study: before the plant retrofit.

Primary event code	**Failure rate [y^{-1}]**	**Repair rate [y^{-1}]**	**Unavailability [-]**
EXT	-	-	$1\cdot10^{-7}$
FEED	-	-	$8\cdot10^{-1}$
MANABS	-	-	$2\cdot10^{-3}$
SCRBLOC	-	-	$1\cdot10^{-2}$
HE	-	-	$2\cdot10^{-3}$
PI	$3\cdot10^{-1}$	200	$1.5\cdot10^{-3}$
FAN	-	-	$1\cdot10^{-2}$
PHL	-	-	$1\cdot10^{-3}$
TIC	$1\cdot10^{-1}$	200	$5\cdot10^{-4}$

Quantifying the fault tree using a simple numerical probability calculation involving the computation of all MCS, a value of the probability of occurrence of the top event equal to $5.6\ 10^{-8}\ y^{-1}$ has been found. Such a value can be located in the acceptability zone for what concern both individual and societal (<100 inhabitants) risk. Therefore, just from this analysis, the system does not require to be integrated with redundant protection devices in order to improve the reliability of the de-dusting section.

Successively, the authors proceeded with the generation of the fault tree concerning the top event “occurrence of an explosion in the de-dusting section”, now constituted by a fabric filter installed after the exit of the already existing ESP (that is, considering a retrofit operation).

In this case, the generated fault tree is too wide to be reported here but it is possible to briefly summarise the main results arising from its detailed analysis. Particularly, 7 different minimal cut sets can be observed: 3 of order 3, 3 of order 4 and 1 of order 5.

Among the MCS of order 3, quite dangerous, we have all the combinations of undesired events and failures in which, due to the absence of a regular and correct maintenance activity on the rupture disks of both the fabric filter and the electrostatic precipitator (MANABS), the blockage of the rupture disks (SCRBLOC), the breakdown of the cleaning air timing system (TEMP), the absence of cleaning air (NOAIR) and the failure in closed position of the exiting valve of the fabric filter (VALCLO), a pressure overcoming the maximum threshold value can be reached causing a physical explosion of the hybrid –like collector.

Among the MCS of order 4, we have all the combinations of events previously determined for the ESP unit alone (even if with some little variants): blockage of the chimney (EXT), presence of feed to the de-dusting unit (FEED), absence of maintenance activity (MANABS), block of the installed rupture disks (SCRBLOC), absence of human actions even if a high pressure alarm is sounding (HE) and breakdown of the hybrid filter differential pressure indicator (PI). Finally, regarding the MCS of order 5, we can observe that it is the same involved in the plant configuration before the retrofit operation (this is because it involves only failures of equipment located upstream of the ESP and the fan).

As previously done, to determine all failure rates and unavailabilities, Dossier Ambiente manuals [14] have been used. Table 2 contains all the data necessary for the quantification of the new fault tree.

Table 2: Database for failure rates, repair rates and unavailabilities. Case study: after the plant retrofit.

Primary Event Code	**Failure Rate [y^{-1}]**	**Repair Rate [y^{-1}]**	**Unavailability [-]**
EXT	-	-	$1 \cdot 10^{-7}$
FEED	-	-	$8 \cdot 10^{-1}$
MANABS	-	-	$2 \cdot 10^{-3}$
SCRBLOC	-	-	$1 \cdot 10^{-2}$
HE	-	-	$2 \cdot 10^{-3}$
PI	$3 \cdot 10^{-1}$	200	$1.5 \cdot 10^{-3}$
FAN	-	-	$1 \cdot 10^{-2}$
PHL	-	-	$1 \cdot 10^{-3}$
TIC	$1 \cdot 10^{-1}$	200	$5 \cdot 10^{-4}$
NOAIR	-	-	0.1
TEMP	-	-	0.05
VALCLO	-	-	0.05

Quantifying the fault tree using a classical numerical probability calculation involving the computation of all MCS, a value of the probability of occurrence of the top event equal to $3.8*10^{-6}$ y^{-1} has been found. Such a value is located in the non-acceptability zone for what concern the societal risk (<100 inhabitants) and at the boundary of the acceptability region if an individual risk is considered.

5 Conclusions

Analysing the two fault trees generated for the undesired event "explosion in the de-dusting section of a cement plant", it has been showed that the probabilities of occurrence of the same top event (considered a mission time equal to 1 year) are, respectively, $5.6 \cdot 10^{-8}$ y^{-1} and $3.8 \cdot 10^{-6}$ y^{-1}, before and after the performing of a retrofit operation consisting in the addition of a fabric filter downstream an electrostatic precipitator (in order to improve the de-pulverisation performances of the unit to meet with new more stringent regulations on threshold dust emission values).

While in the first configuration the risk can be considered acceptable (and the system does not require to be integrated with redundant protection devices in order to improve the reliability of the de-dusting section), in the retrofit configuration the risk follows within the non acceptability zone. Therefore, the system requires to be integrated with redundant protection devices in order to improve the reliability of the retrofit de-dusting section.

This simple study confirms that each process or piece of equipment change must be fully evaluated from the safety and reliability viewpoint before being introduced into an already existing plant because it can imply the increase of the risk function.

References

[1] Explosions in Cement Plants. www.fike.com/

[2] http://www.greenreport.it/

[3] Rada, E.C., Squazardo, S., Ionescu, G., Badea, A. Economic viability of SRF co-combustion in cement factory, *UPB Scientific Bulletin*, series D, **76(3)**, pp. 199-206, 2014.

[4] Ragazzi, M., Rada, E.C. RDF/SRF evolution and MSW bio-drying, WIT *Transactions on Ecology and the Environment*, **163**, pp. 199-208, 2012.

[5] Cioranu, S.I., Grigoriu, M., Ragazzi, M., Rada, E.C., Ionescu, G. Assessment of alternatives for RMSW treatment for Valcea County, Romania, *Revista de Chimie*, **65(3)**, pp. 257-261, 2014.

[6] Sarc, R., Lorber, K.E., Opmberger, P., Rogetzer, M., Sipple, E.M. Design, quality, and quality assurance of solid recovered fuels for the substitution of fossil feedstock in the cement industry, *Waste Management and Research,* **32(7)**, pp. 565-585, 2014.

[7] Taiwo, A.M., Harrison, R.M., Shi, Z. A review of receptor modelling of industrially emitted particulate matter, *Atmospheric Environment*, **97**, pp. 109-120, 2014

www.witpress.com, ISSN 1743-3509 (on-line)

[8] Torretta, V., Rada, E.C., Panaitescu, V., Apostol, T. Some consideration on particulate generated by traffic, *UPB Scientific Bulletin*, series D, **74(4)**, pp. 214-248, 2012.
[9] Seltenrich, N. Take care in the kitchen: Avoiding cooking-related pollutants, *Environmental Health Perspectives*, **122(6)**, pp. A155-A159, 2014.
[10] Sari, D., Bayram, A. Turkey and assessment of the impact on local/regional air-quality, *Science of the Total Environment,* **488-489(1)**, pp. 429-436, 2014.
[11] Capodaglio, A., Callegari, A., Torretta, V. Comparative application of different risk assessment models and implications on resulting remediation options, *Environmental Technology* **35(6)**, pp. 759-765, 2014.
[12] Hansler, R.J., Gooijer, L., Wolting, B.G. Acute inhalation toxicity in quantitative risk assessment-methods and procedures, Chemical Engineering Transactions, 31, pp. 751-756, 2013.
[13] Vaseley, W.E., Goldberg, F.F., Roberts, N.H., Haasl, D.F., *Fault Tree Handbook*, U.S. Nuclear Regulatory Commission Washington D.C., 1981.
[14] Dossier Ambiente, http://www.amblav.it/dossier.aspx

Water supply systems security: novel technologies for the online monitoring of unforeseeable events

A. G. Capodaglio & A. Callegari
Department of Civil Engineering and Architecture,
University of Pavia, Italy

Abstract

Nowadays, the demand for more efficient and comprehensive online water monitoring technologies is spurred by more stringent regulatory constraints placed on water companies to provide high quality drinking water, increasing water resources scarcity, forcing water suppliers in many areas of the planet to rely on marginal water bodies, and the threat of hostile actions by political extremists and terrorists groups, that may willingly and deliberately cause contamination of an otherwise safe supply. Traditionally, quality parameters associated with drinking water provision were monitored using routine grab samples followed by laboratory analysis. This approach only allowed the capture small data sets, mostly unrepresentative of the true variance at the source, and allowed potentially important events to occur undetected. This paper examines state-of-the-art technologies for the online monitoring of water quality in supply water systems.
Keywords: online monitoring, drinking water, system security, water quality, inorganic pollutants, organic pollutants, biological pollutants.

1 Introduction

Safe and reliable drinking water supplies are nowadays a concern of strategic significance worldwide. In many areas of the globe, the demand for high quality freshwater far exceeds available supply already. It is estimated, for example, [1] that over 2 million deaths each year are currently caused worldwide by pathogenic bacteria exposure linked to the consumption of unsanitary water. Beijing, China's capital, has reached a 3.6 billion m^3 water consumption [2], far more than the 2.1 billion m^3 locally available.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150221

The combined weight of: more stringent constraints placed on water companies to provide high quality drinking water, increasing water resources scarcity in many areas of the planet, reliance on marginal water bodies for supply, and the threat of hostile actions by political extremists and terrorist groups, that may willingly and deliberately cause contamination of otherwise safe supplies, are recent issues that have spurred demand for more efficient and robust online water monitoring technologies.

Availability of micro-biologically safe drinking water, is probably the most effective and economical way to ensure public health. In addition to “traditional” microbiological contamination by human waste, contamination of water sources by pesticides and herbicides is a growing problem worldwide. During the last two decades, studies revealed the growing presence of hazardous contaminants in wastewater effluents, including pesticides [3], natural and synthetic hormones [4], plasticizers, personal care products and pharmaceuticals compounds [5, 6].

A recent study estimated that there are 1415 human pathogens, about 12% are considered to be emerging ones. Their number continues to grow, on average at the rate of one new pathogen each year, as evidenced by relatively recent emergencies [7]. Such pathogens include organisms that can be transmitted directly through water or by water-related vectors; while a high proportion of water-borne disease is caused by classical pathogens such as *Salmonella typhi* and *Vibrio cholerae*, their spectrum is expanding.

As far as deliberate human hostile actions on urban water supplies, although none has been reported to date, in January 2002 the FBI circulated a reserved bulletin warning water industry managers that al-Qaida terrorists may have been studying American water-supply systems in preparation for new attacks [8].

Traditionally, quality parameters associated with drinking water provision were monitored using routine grab samples followed by laboratory analysis. This approach only allowed to capture small data sets, mostly unrepresentative of the true variance at the source, and allowed potentially important events to occur undetected. It is clear, that, in view of what just reported, this can no longer be considered a satisfactory procedure, and that online monitoring of water supplies, for a larger number of parameters than currently available, is quickly becoming an unavoidable choice [9].

2 Definition and rationale for online monitoring

Online monitoring is defined as the unattended sampling, analysis and reporting of a parameter; it produces a sequence of data at much greater frequency than is permitted by manual (grab) sampling, and it also allows real-time feedback for either process control, water quality characterization for operational or regulatory purposes, and/or for alert/alarm purposes.

Online monitoring can be carried out at onsite as well as in remote locations, and will deliver measurements at intervals of seconds-to-minutes. Clearly, online instrumentation must be placed at representative locations in the water system, and must be periodically maintained by qualified technical personnel.

www.witpress.com, ISSN 1743-3509 (on-line)

Monitoring requirements can be defined in relationship to:

- source water quality: (a) variability, in space and time (very low for groundwater, low for lakes, high for rivers); (b) vulnerability (type and location of possible contaminating activity), time-of-travel of a contaminant to the intake, effectiveness of barriers, control options after an alarm;
- water treatment: process optimization options and response times, sampling frequency must allow adequate process control;
- distribution systems: minimization of deterioration of water quality over time and distance, early detection of cross-connections and water losses; in addition, it must be considered that online monitors could have different sensitivity and selectivity according to the matrix and range of concentrations analyzed.

A multibarrier approach to drinking water quality protection, such as those that are mostly used by facilities worldwide, is based on the concept that contaminants must be subject to as many points of control/treatment (barriers) as possible, prior to tap. The ideal location for control of contaminants is as close to the (potential) source as possible. A source water with low vulnerability is therefore characterized by few potential contaminant activities, transit time longer than that required for laboratory analysis, and the presence of multiple physical barriers between contaminating activities and point of intake. In a source water with moderate vulnerability, online monitoring of surrogate parameters (such as TOC. DOC, UV_{254}, pH and conductivity) may be considered to keep track of potential pollution. In a high vulnerability water source, online monitoring of chemical-physical-biological parameters (turbidity, pH, conductivity, redox, fish toxicity) and surrogate parameters in addition to specific indicators (e.g. VOCs, phenols and specific toxicity tests) may be preferred. This is summarized in Table 1. This could list parameters for which online monitoring technology may not be widely available, nor field proved at the moment, but that may be useful for the given purpose.

The availability of real-time analytical information is one of the key benefits of online instrumentation: this information must however be conveyed to the appropriate user by means of a data collection and transmission system which is often referred to as SCADA, which consists of the individual online instruments, connected to Programmable Logic Controllers (PLCs) or Remote Telemetry Units (RTUs), that convert instrument outputs to the desired units, compare them to criteria set by the user, and generate signals for alarm or control to other process equipment. A host computer that can be used to visualize or store data, or to further utilize them for specific purposes, almost always complements these systems.

Table 1: Online monitoring in multibarrier drinking water system (AWWA [9]).

Activity	Monitoring strategy	Objectives
Contaminant source identification	Surrogate parameters (TOC, DOC, UV_{254}, pH, conductivity); specific parameters (related to known sources of contamination); biotest and toxicity tests	Define potential contamination in relation to vulnerability of source water
Monitoring of discharges into the source water	Specific organic/inorganic contaminants	Identify water pollution accidents
BMPs/protection of water source	Hydrological parameters; environmental parameters (solar radiation, O_2, Chl)	Prevent source deterioration; environmental management
Drinking water quality protection	Specific organic/inorganic contaminants; treatment-related parameters (Q, turbidity, pH, TOC, DOC, etc.); biotests/toxicity	Allow appropriate responses to contaminant presence (intake shut-up, additional treatment, treatment adjustment)
Emergency response	Specific organic/inorganic contaminants; biotests/toxicity	Drinking water pollution control; risk management; treatment modification

3 Online monitoring instrumentation overview

Generally speaking, online monitoring instrumentation can be divided in:

- Physical monitors (Turbidity, particles, color, conductivity, TDS, hardness, alkalinity, acidity, streaming current, radioactivity, temperature, redox potential);
- Inorganic monitors (pH and DO, disinfectants, such as chlorines and ozone, metals, fluoride, nutrients, cyanide);
- Organic monitors (carbon and hydrocarbons, UV adsorption, VOCs, pesticides, disinfection by-products);
- Biological monitors (nonspecific, algae, protozoa, pathogens);
- Hydraulic monitors (flow, level and pressure).

This paper will focus on the four former classes, discussing for each basic operating principles, and evaluation of the technology for online applications in the water distributing system.

3.1 Physical monitors

A wide array of technologies can be used for monitoring physical parameters, among them: light scattering/blocking (turbidity, particles, SS), light absorbance (color), electrochemical (conductivity, hardness, Redox), electrophoretic (streaming current), chemical tritration (alkalinity, acidity, hardness) and other (radioactivity, temperature) (Table 2).

Table 2: Physical online monitors technology.

Application	Most appropriate technology	Other technologies
turbidity		
Low turbidity raw water; clarified water; filter effluent	Single beam (tungsten or LED) turbidimeter; modulated 4-beam turbidimenter	Particle counters; particle monitors EMERGING TECHNOLOGIES Laser light source (660 nm) and improved optics turbidimeters
High turbidity raw water	Ratio turbidimeter; modulated 4-beam turbidimeter	
Filter backwash	Transmittance turbidimeter; surface scatter; ratio turbidimeter; modulated 4-beam turbidimeter	
Color		
	Online colorimeter; spectrophotometer	
TDS		
	2-electrode conductivity probe; electrodeless (toroidal) probes	
Hardness		
	EDTA tritration online; ion-specific electrodes (ISE)	
Alkalinity		
	Online alkalinity tritrator	

3.2 Inorganic monitors

Inorganic monitors technologies used in online mode to detect influent and effluent water quality, and for treatment process control are listed in Table 3.

Online monitoring of inorganic constituents is still in the early phase for many elements of interest to drinking water concerns. For metals, available technology is an adaptation to automatic operation mode of complex colorimetric methods developed for laboratory applications, and therefore turns out to be expensive and/or complex to operate, nor still suitable for installation in remote or unmanned sites. For many metals of interest in drinking water systems (As, Cd, Pb, Hg, Se, Zn), online monitoring technologies do not exist at all. Some promise for future application comes from developments in optode technology, coupled with miniaturized spectrophotometry.

3.3 Organic monitors

The technology for online monitoring of organic compounds includes TOC analyzers, UV absorption and differential spectroscopy; it is much more developed than that for inorganics, for this reason, although neither EU nor US regulations require online monitoring of these substances, many drinking water utilities routinely use online organics monitoring to some degree.

Table 3: Online inorganic monitor technology.

Parameter	Currently applied technology	Other technology developments (not currently /commonly available)
DO, pH chlorine, nitrate, fluoride	Ion-selective electrodes (IESs); membrane electrode sensors for DO (polarographic or galvanic)	Fiber-optics chemical sensors (FOCSs or optodes) for pH, DO; iodometric DO measurement
Chlorine and compounds	Colorimetric (DPD); iodometric, polarographic membranes and amperometric methods; absorbance (spectrometric) for ClO_2	ClO_2: iodometry, amperometric meth. I, DPD, amaranth, chlorophenol red, LGB dye, ion chromatography
Iron, manganese	x-ray fluorescence (complex); colorimetry	
Ammonia, nitrite, nitrate	Colorimetric, FOCS (ammonia) ion sensitive gas membrane electrodes	
Phosphorous, cyanide	Colorimetric, FOCS (cyanide)	

Most organic compounds found in water absorb UV radiation: with a UV spectrometer it is therefore possible to estimate their concentration. Initially, a UV light source with the single wavelength of 254 nm was used for such measures, however, in recent years, instrumentation reading the entire UV–VIS spectrum (200–750 nm) has been developed and marketed [10]. UV absorption is a well-defined and commonly used methodology; evidence shows strong correlation between these measurements and organic carbon concentration measured with standard methods such as TOC or others (Figure 1). In addition, it has been shown that other parameters can be measured indirectly by correlating their concentration values to UV absorption in the full spectrum (Figure 2); several commonly sought organic compounds have typical absorption spectra that make their identification quite easy with appropriate instrumentation (Figure 3).

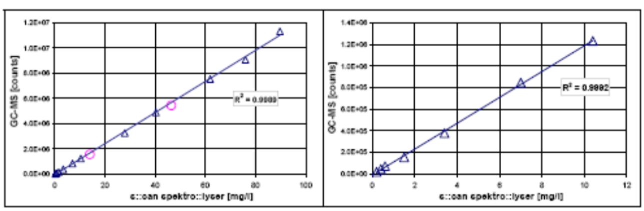


Figure 1: Calibration for benzene of online UV-VIS spectrometer against GC-MC laboratory methods, in distilled water (L) and groundwater (R) (S-can [10]).

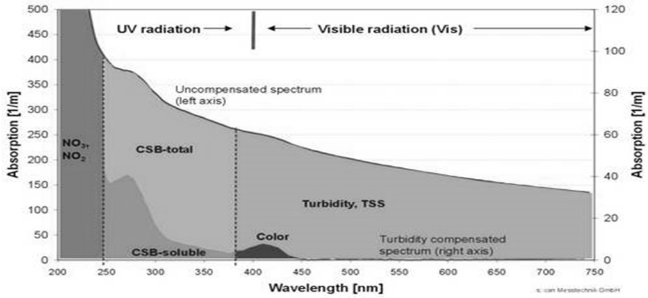


Figure 2: Correspondence between spectral absorption areas and quality parameters (courtesy S-can [10]).

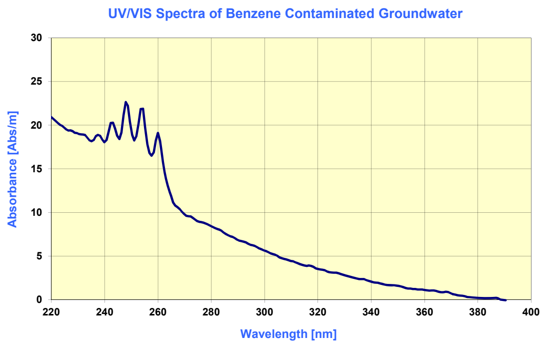


Figure 3: Typical spectral absorption image of benzene in water (S-can [10]).

Hydrocarbons in general are probably the main class of water pollutants found in surface and ground water (i.e., source water for drinking water systems). Methods for online hydrocarbon detection include: fluorometry, reflectivity, light scattering and turbidity measurement, ultrasonic methods, electrical conductivity, spectroscopy, gas-phase detection (after volatilization), resistance-based sensors; some of these methods, however, give just an indication of the presence/absence of oil on the water surface.

Volatile Organic Compounds (VOCs), including, among the others, aromatic compounds, halogenates and trihalometanes, are compounds that evaporate when exposed to air and can be of health concern when found in drinking water systems (trihalometanes are disinfection by-products – DBPs – that can be precursors to the formation of carcinogens). Their presence in drinking water can be a symptom of accidental pollution in the source water, of treatment failure/deficiency, or of incorrect disinfection procedures.

Current online monitoring technologies for VOCs include purge-and-trap gaschromatography with flame ionization (FID), electron capture (ECD) or photoionization detectors or mass spectrometry (MS). Detection limits for different substances vary according to the detector method.

Pesticides, including insecticides, fungicides and herbicides comprise triazines and phenlylurea compounds; they are monitored in drinking water systems in order to: detect accidental pollution in source waters, and check the effectiveness of treatment specifically designed to remove such substances. Online monitoring of pesticides can be carried out using composite techniques, such as:

- high pressure liquid chromatography (HPLC)/diode array (DA) detection, consists of extraction and enrichment, chromatographic separation and DA detection;
- gas chromatography (GC), consists of extraction and enrichment, GC separation and mass spectrometer (MS) detection;
- liquid chromatography/mass spectrometry, consists in extraction and enrichment, LC separation and MS, thermospray, electrospray or particle beam detection.

Each technique is capable to optimally detect a group of compounds, for example, HPLC /DA can be used to analyse; atrazine, chlortoluron, cyanazine, desethylkatrazine, diuron, hexazinone, isoproruton, linuron, metazachlor, methabenzthiszuron, metobrorumon, metolachlor, metoxuron, monolinuron, sebutylazine, simazine and terbutylazine.

In theory, any analytical laboratory method can be adapted for use as online measurement, provided that the requirements for consumables and manual intervention can be minimized: current online systems are often a “robotized” adaptation of known offline laboratory procedures, however, not always this solution is the most efficient one. A series of novel technologies, such as optochemical sensors, biosensors, and microbiological sensors are being tested for organics and hydrocarbon analysis. Advances already in use include differential UV spectroscopy for DBP detection and microphase solid-phase extraction (SPE) for the analysis of semivolatile organics [11].

3.4 Biological monitors

There are two basic types of biological monitors currently in use: those that use biological species as indicators of presence of contaminants (e.g. toxic chemicals), and those that screen for presence of biological species of concern (e.g. nuisance algae, pathogens). In common US terminology, the term *biomonitor* usually indicates the former, and is in fact used as synonymous with *toxicity monitor*. In EU terminology, biomonitor refers generally to all types of biologically-based systems.

At the present time, many existing biological monitors are quite new and can be considered experimental/unique applications. Table 4 shows an overview of the most common types of online biological monitors. Sensitivity of test organism to individual compounds must be determined initially.

Online biological monitors are a very active area of R&D due to increasing regulatory and public demand pressures. While bacterial-based systems show great sensitivity and ease of operation, and development in this area will likely derive from improved fingerprinting of organisms and maintenance cost reduction, most advances can be expected from protozoan monitor technology, with techniques in UV absorption/scattering analysis that may soon allow automated detection of *Cryptosporidium* and *Giardia*. Also, molecular techniques initially applied to the recognition of the genomic sequence of specific organisms in clinical applications [12] have also shown great potential for use in the detection of pathogens in water, and are producing extremely interesting results that could lead to widespread online use in the very next future.

Table 4: Online biological monitors.

Technology	Measurement	Comments
Fish tests	Swimming pattern Ventilation rate Biolelectric field Avoidance patterns	Low sensitivity Sophisticated requirements Requires exotic "electric fish" species Interpretation complex
Daphnid tests	Swimming activity Behaviour	Good performance, no determination of causes
Mussel tests	Shell positions/opening	
Algae tests	Fluorescence (photosynthesis)	Commercial monitors available
Bacteria tests	Luminescence Respiration of nitrifiers	Commercially available, toxicity data for over 1000 compounds
Chlorophyll-a	Fluorometry	Interference w/pigments, diss. organics, sensitive to environmental variables
Chlorophyll-a and algal absorption	Reflectance radiometry	Commercial systems available
Protozoan monitors	Concentration; centrifugation Laser scanning cytometry Particle characterization UV spectroscopy Multiangle light scattering; nucleic acid molecules and magnetized microbeads	By filtration on membrane cartridge with modified blood cell separators, minimal operation time; analysis possible within 3 minutes, particles must be confirmed by trained operator; measure particle size/distribution, high number of false positive and negative results; online system, unlabeled parasites, differentiation problems; successfully tested in lab; oocysts detected within 20 minutes, not fully automated

3.5 Indirect monitoring: "fingerprinting"

Chemical fingerprinting describes the use of a unique chemical signature, isotopic ratio, mineral species, or pattern analysis to identify different chemicals. Optical fingerprinting by UV, VIS, and NIR absorption spectroscopy can be effectively achieved by low-cost and compact spectrometric devices, which can also be linked to an online diagnostic system, to directly identify some compounds (e.g. benzene) present in the water or to give an indication of the possibility of the presence of related compounds.

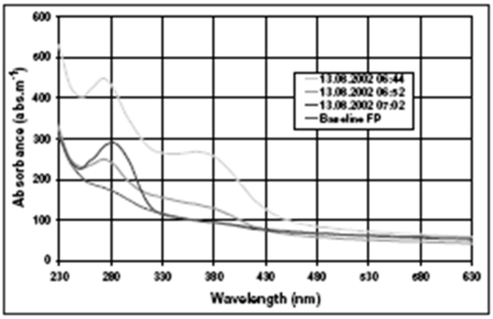


Figure 4: Optical fingerprinting of water indicating rapid quality changes.

In optical fingerprinting, a wide portion of the UV, VIS and NIR spectrum can be monitored simultaneously at high measurement frequency (minutes or fractions thereof); Figure 4 shows the spectral fingerprint of a typical municipal wastewater, in the range 230-630 nm, together with three other spectral readings from the same source that were recorded within 18 minutes from the first. These show clearly different features, indicating a pronounced change in water quality. Although this alone will not, in general, indicate the compound or compounds responsible for the change (they will need to be further investigated, if a definite answer is desired), but that can nevertheless trigger an alert to the system's operator, indicating deviation from routine conditions.

4 Upcoming technological developments

4.1 Early detection of contaminants

The existence of *Escherichia coli* (*E. coli*) in drinking water is an important indicator of faecal pathogens and potential micro biological contamination. Currently available detection methods in drinking water distribution networks are inadequate, for multiple reasons: first of all, current methods are time consuming meaning that contamination will already have reached end-users before results are available; secondly, current sampling and analysis procedures lead to detection success rates of only 5 to 25% maximum. Research by scientists from Dutch KIWA shows that by using a network of on-line sensors, success rate can be increased to 80% [13]. The core of the LabOnline system is based on a combination of a concentrator unit and a sensor system using disposable chips, protecting the sensor system from cross-contaminations and guaranteeing reliable measurements. Initially designed for E.coli, the system is capable of detecting a broad group of microbiological contaminants like bacteria and viruses. KIWA also developed a sensor technology for pesticides based on an integrated optic chip, a biochemical transduction layer, (micro)-fluidics, electronics and data acquisition/system control software, called Optiqua MobileLab. The Optiqua MobileLab sensor for detection of pesticides will have low cost per analysis, detection of five pesticides (Simazine, Atrazine, Glyphosat, AMPA, BAM 2,6-dichlorbenzamide), detection of additional pesticides (at later stages), on site detection, prompt analysis results (minutes), high resolution (e.g. detection limits 0,05 µg/).

4.2 Micro analysis system for water pathogen monitoring

Knowledge of microbial genomes led to the development of molecular methods for detection of microbial pathogens in clinical specimens as well as. A wide array of molecular techniques has been applied to the study of microbiological water quality. Application of molecular techniques, such as PCR (Polymerase Chain Reaction) has generated valuable information on the occurrence, diversity, and biology of pathogens in water [14]. In addition, molecular methods demonstrate rapid detection and enhanced specificity compared to other analytical methods. A micro analysis system for water pathogen monitoring consists of a micro polymerase chain reaction (PCR) chip integrated with a continuous-flow microarray able to reduce analysis time from 24 hrs to several hrs as compared with the existing EPA approved methods was presented by Yong *et al.* [16]. Pathogens are detected by the micro analysis system through DNA amplification, followed by direct transfer to a microarray for detection. In addition to single-species monitoring, the system shows potential in simultaneous monitoring of a range of pathogens.

4.3 Two-dimensional GC screening for new contaminants

Comprehensive two-dimensional gas chromatography (GCxGC), is a technique in which all the eluted compounds from a first column are submitted to a new separation in a second column with different selectivity. Contrary to gas chromatography (GC) which employs only one chromatographic column, GCxGC uses two columns, coupled in series, with a modulator at their junction. Due to its principle, GCxGC offers a much better capacity of separation and better sensitivity than conventional GC (3-5 fold higher than GC); therefore some compounds can be detected at the ng/L level. This technique can be applied [15] to the screening of wastewater and effluents samples. A large range of drugs (antidepressors, antibiotics, anticoagulants…), personal care products (sunscreens, antiseptics, cosmetics…) and carcinogens can thus be found in water and waste water samples. In addition to the above mentioned micropollutants, a wide variety of nitrogen aliphatic and aromatic structures that could act as DBP (disinfection by-products) precursors, can also be uncovered.

4.4 Molecular online detection of waterborne pathogens

A molecular technique, based on polymerase chain reactions to detect pathogens was proposed [17] to improve PCR diagnostics for routine analysis purposes, focusing on the processing of the sample, which is crucial for the robustness and the overall performance of the method. Objectives in sample preparation are to increase the concentration of the target organisms to the practical operating range of a given PCR assay; and to produce a purified DNA extract that would be representative of the initial water sample and would be free of PCR-inhibitory substances. This can be achieved by means of a two-step UltraFiltration (UF) procedure by using prototype hollow fiber UF cartridge, and a commercial UF centrifugal concentrator.

5 Discussion and conclusions

This paper overviewed existing instrumentation applicable to water supply online monitoring, and examined a few state-of-the-art technologies. It is clear that technological development in this field is very rapid, and that astonishing advances are anticipated in several areas (fingerprinting, optochemical sensors, biosensors, molecular techniques). Software applications, together with new generation sensors, are also contributing to the identification of otherwise difficultly monitored parameters.

In spite of the high technology being developed, monitoring costs are bound to become a lesser and lesser part of a water utility budget due to the fact that automation and technological simplification will abate the human cost factor (maintenance and other labour forms) and reduce significantly the complexity of procedures (with those, of reagent requirements, etc.).

Proper interpretation and use of the growing mass of water quality data that will become available through new technologies will allow better management of water resources, and water treatment and distribution facilities.

References

[1] WHO. Emerging issues in water and infectious disease. World Health Organization, Geneva, 2003.

[2] Beijing Water Authority. Data on water distribution and use in Beijing, China. Press Release, 2013.

[3] Öllers, S., Singer, H.P., Fässler, P. and Müller, S.R. Simultaneous quantification of neutral and acidic pharmaceuticals and pesticides at the low-ng/l level in surface waters. J. Chromatogr. A 911, (2), 225, 2001.

[4] Kolpin, D.W., Furlong, E.T., Meyer, M.T., Thurman, E.M., Zaugg, S.D., Barber, L.B. and Buxton H. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: A national reconnaissance. Environ Sci Technol 36, 1202, 2002.

[5] Daughton, C.G. and Ternes, T.A. Pharmaceuticals and personal care products in the environment: agents of subtle change? Environ. Health Perspect 107, (6) 907, 1999.

[6] Jones, O.A.H., Voulvoulis, N. and Lester, J.N. Human pharmaceuticals in the aquatic environment, Environ. Technol. 22, (12), 1383, 2002.

[7] Cunliffe D.A. Emerging Enteric and Potentially Waterborne Pathogens in the Region. Proceedings, Singapore International Water Week Conference, June, Singapore, 2008.

[8] IonLife website (ionlife.org). "How safe is our water? The threat of terrorism" Jan. 31, 2002.
[9] Awwa. Online Monitoring for Drinking Water Utilities. Cooperative Research Report. (E. Hargesheimer, O. Conio and J. Popovicova, Eds.) AWWA Research Foundation, Denver, CO., 2002.
[10] S-can company website http://www.s-can.at. S-can Gmbh, Vienna, Austria, 2014.
[11] Yongtao Li, E.J. George, E.M. Hansen, J.J. Toma, M. Werner and P.D. Smith. SPE Twin-PAL. Online in situ monitoring of semivolatile organic compounds in water. Proc. AWWA Water Quality Tech. Conf., Salt Lake City, UT., 2000.
[12] Bej, A.K. Molecular based methods for the detection of microbial pathogens in the environment. *J Microbiol Methods*, **53**, 139-40, 2003.
[13] Koerkamp M.K., M. van Wijlen. Next generation sensors for detection of pesticides and E.coli in water. Proceedings, Singapore International Water Week Conference, June, Singapore, 2008.
[14] Loge, F.J., Thompson, D.E., & Call, D.R. PCR detection of specific pathogens in water: a risk-based analysis. *Environ Sci Technol*, **36**, 2754-9, 2002.
[15] Semard G., Z. Do-Quang, A. Bruchet. Screening of emerging contaminants in wastewaters using advanced GCxGC-TOFMS. Proceedings, Singapore International Water Week Conference, June, Singapore, 2008.
[16] Yong C.K., I.K. Lao, R. Murthy, H.M. Ji, C.Y. Teo, Christope Lay, H.H. Feng, W.T. Liu. Micro analysis system for water pathogen monitoring. Proceedings, Singapore International Water Week Conference, June, Singapore, 2008.
[17] Courtois S., K. Sebti and Z. Do-Quang. Universal concentration for large volumes of water samples before molecular detection of waterborne pathogens. Proceedings, Singapore Intl. Water Week Conference, June, Singapore, 2008.

This page intentionally left blank

Section 6
Human factors

This page intentionally left blank

An investigation into HSE educational programs in the USA

M. Albuti[1] & G. Reniers[1,2,3]
[1]*Research Group ARGOSS, Faculty of Applied Economic Sciences, University of Antwerp, Belgium*
[2]*Safety and Security Science Group, Faculty of Technology, Policy, and Management, Delft University of Technology, The Netherlands*
[3]*Faculty of Economics and Management, Campus Brussels, Belgium*

Abstract

As the demand for safety professionals in industry is ever more increasing, companies are becoming keener on having candidates that have precise knowledge in HSE management and its elements. The knowledge, much desired by companies, is neither technical nor managerial but a balance of both. A handful of universities in the United States have created 'Safety' programs that acquire program graduates the knowledge needed for industry. The 'Safety' educational programs are somewhat new compared to most programs offered in universities. The educational programs investigated in this study are accredited by national and international educational boards. Those educational boards require those programs to be continually improved to ensure students are attaining the objectives and goals set for the programs. Our investigation shows in what way the 'HSE' needs of industry are met in the 'Safety' educational programs that are offered in the United States. The reporting prevails gaps that were found, similarities and differences in programs, interpretation of the findings, and finally recommendations.
Keywords: safety education, HSE education, HSE management, safety management, PDCA, hazard identification, operational control, risk assessment, training for safety and health, crisis management and disaster preparedness.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150231

1 Introduction

Regular students (not coming from the industry) graduating from HSE programs in the USA need to have well rounded knowledge regarding HSE (Health, Safety, Environment) and the accompanying models and systems. HSE educational programs are indeed designed to cover certain key HSE elements that are useful in industry. Our study investigates these HSE key elements, with their applicability within the industry in mind. As this field is rather new and educational programs are under continuous improvement, this investigation will identify the similarities and differences between programs and what are believed to be shortcomings when assessed from the industrial perspective. Students starting a job and joining the workforce in an industrial sector, sometimes seem to be lacking in a certain element of HSE. Although academic institutions provide the most important generic elements required for HSE management systems, those HSE elements that graduates often seem to be lacking, are those elements that are implemented and operated differently in each company.

Educational programs need to satisfy the needs of certain goals and objectives. The method to identifying the goals of such educational programs is the result of several cycles of analysis and improvement. The Accreditation Board for Engineering and Technology (ABET, 2015) [1], puts it this way: “The program must regularly use appropriate, documented processes for assessing and evaluating the extent to which the student outcomes are being attained. The results of these evaluations must be systematically utilized as input for the continuous improvement of the program. Other available information may also be used to assist in the continuous improvement of the program.”

In the remainder of this paper, an overview of the HSE elements that HSE departments in the industry operate and live by, is first drafted and looked at. Second we investigated if educational programs are covering those elements that are adopted in HSE departments in industry.

2 Methodology

The selection criteria for determining the programs to be analyzed in our study, were the following. Programs can, and do, often have different names but having similar goal(s) and are also characterized by a different level of contents depth. A program could be called ‘safety management’ in one institute and ‘Occupational Safety and Health’ in another institute, but could have similar program goals and objectives, and they will both be considered. However, the programs should be under the same category for accreditation, which is ‘Safety’. They should not be purely technical or managerial, but a mix. Furthermore, the programs considered are of a bachelors’ level and if the academic institute did not offer this bachelors’ option, then the Masters’ level was chosen.

After finding 50 HSE educational programs within the United States (CHEA Database) [2], only 13 passed the selection criteria for HSE management programs explained above. Most of the programs are strictly technical engineering programs, and therefore did not fit the criteria. Although 17 programs are accredited as "Safety" programs by the Council for Higher Education Accreditation in the United States, 4 of the 17 programs did not pass because they are safety programs but they either have one highly specific focus, such as radiation protection, emergency management, or because they are not the level of degree we are investigating ('associate degree'). Out of the 13 programs, 9 are ABET certified programs [3]. ABET [4] mentions that "Accreditation provides an opportunity for academic institutions to demonstrate they are committed to maintaining their programs' quality and that their programs are performing at the level required by the professions they serve. Programs undergo periodic accreditation to ensure that they continue to meet quality standards set by the profession. The result provides lasting benefits to students, the institution, employers, the professions, and society as a whole."

The study included all possible 'core electives', which are non-obligatory courses offered in the educational program. Since the required courses are not enough to complete the study program, students are obligated to complete a few electives of their choice from a designated list that is set by the faculty. Some programs offer more core electives than others.

3 Research results

HSE departments in the industry develop, follow and implement management systems. Those management systems could be adopted from one or more generic management systems that are tweaked and modified for the needs of the company. Lyons and Plisga [5] have stated "One of the key recommendations was that companies should have safety management systems that control a company's operations from top to bottom. The systems were recommended to include the elements of ISO 9001 (a standard for management of quality in organizations)."They all have one common item which is the use of the cycle of continuous improvement. The continuous improvement cycle is also known as the plan-do-check-act (PDCA) cycle. As Maruta [6] refers to Imai's words, "The PDCA cycle was initially employed as a tool for product quality control, and then it was recognized as a tool for production process improvement." Mukherjee [7] also describes it in a highly manner by stating "The PDCA cycle keeps on rectifying the errors and assures that they do not repeat again and again. This ensures that the PDCA cycle puts an organization on the path of continues improvement." It is obvious that the first key element of any HSE educational program should be to become acquainted with the use of different management systems and with the PDCA cycle.

'Planning' is the first phase of the PDCA loop. In relation to the Planning phase, an educational program may include courses that cover elements of policy, hazard identification and risk assessment. Planning also includes knowledge about, and familiarization of, legal and other requirements, such as industry standards, which are also key elements of adequate HSE within the chemical industry. The 'Do' phase should, amongst others, include structures and responsibilities, safety training, awareness, and communication. Document and data control, operational control, and emergency preparedness and -response including crisis management, is also part of the 'Do' phase within the PDCA loop. The 'Check' phase includes elements such as inspection, auditing, testing incident reporting and verifying the corrective/preventive actions and measures that have been taken in the previous phase. The 'Act' phase from the continuous improvement cycle includes analysis of what is being reported and taking actions upon it.

Courses related to the PDCA loop are important for HSE educational programs, since they form the basis for effective management systems within organizations in the industry. Table 1 provides coverage of learning elements found within the investigated/selected educational programs. The table shows the number of universities that offer HSE programs completely covering the element related to the PDCA loop. This table for example shows that 12 of the 13 selected HSE educational programs cover the element of 'management systems', and all programs cover the element of 'hazard identification and risk assessment' and 'operational control'. 'Legal' is not covered by one of the HSE educational programs. 'Incident investigation/corrective and preventive action' is an element that is fully covered by 11 of the programs investigated. Surprisingly maybe, only about half of the programs cover the elements of 'safety and health training' and 'emergency preparedness/crisis management'.

Table 1: Number of universities/educational programs that cover the PDCA element.

Element	**Number of programs covering the element**
management systems	12/13
hazard identification/risk assessment	13/13
legal and other requirements	12/13
operational control	13/13
training for safety and health	8/13
emergency preparedness/crisis management	6/13
incident investigation/corrective and preventive action	11/13
Other (e.g., communication, document control, etc.)	8/13

From Table 1 it can be observed that not all programs cover all elements. Figure 1 further displays the numbers obtained when dividing the number of courses by the number of programs that are offering the PDCA element. This way, it is possible to have an idea of the level of contents' depth of an element in the educational programs. For example, on average there are 4.85 classes that cover the element of 'operational control' in an educational program. Hazard identification/risk Assessment has an average of 3.08 courses per educational program, 'management systems' 2.33 courses.

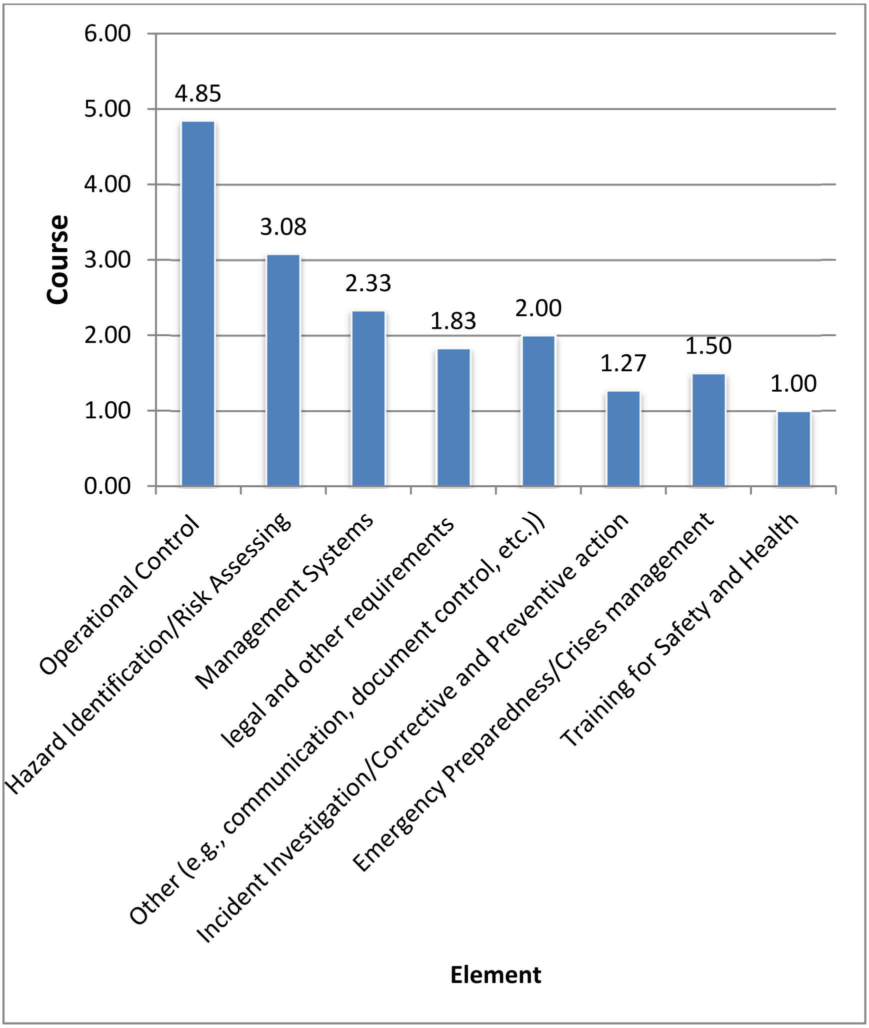


Figure 1: Average number of courses covering each element.

A university has several ‘colleges’, depending on its size, how much staff it has, its facilities, and its funding. A university could thus have separate colleges for engineering and for technology, but it also could have one college for engineering, science, and technology all at once. Our study indicated that HSE educational programs were offered and accredited in one of the following colleges: ‘engineering’, ‘science’, ‘health’, or ‘technology’. In order for the program to be accredited it must have full time faculty members dedicated to the program, with one faculty member being the program administrator in charge.

4 Conclusions

This study identifies and investigates HSE educational programs in the United States. Going through curricula and programs, most have been identified as technical HSE programs that did not qualify for our investigation. We found that HSE educational programs in the USA have a clear trend of including courses on ‘operational control’ and on ‘hazard identification / risk assessment’. This trend shows the focus on the engineering and technical elements. Since all programs are in an engineering, technology, health, or science college, it logically contains very technical faculty, and therefore the focus would evidently be on technical elements.

Elements such as ‘safety training’ and ‘emergency preparedness and crisis management’ are not always included in courses within the program, which represents a shortcoming of the current situation. A course in ‘safety training’ requires less technical and more managerial teachings, and hence, faculty members would need extensive background in training how to train. This also includes ‘emergency preparedness and crisis management’, where faculty must be very specialized in order to teach and fully explain the technicalities of this element. Companies do include these elements in their HSE management system, therefore all programs investigated should have these elements integrated in them because they are elements that could be taught and would not vastly differ from organization to the other.

Based on the findings of our study, we may conclude that an expert who is very knowledgeable in operational control and hazard identification is much easier to find than someone who can flawlessly create and manage HSE training programs or who has the specified expertise to create and maintain a crisis management program. Consultants with specific experience are therefore paid to help organizations around the globe to maintain those two elements. It can thus be recommended to put more emphasis on safety training and on crisis management in available and accredited HSE educational programs in the USA.

Future research includes a similar analysis of educational programs within the UK and also continental Europe. Furthermore, other topics such as cybersecurity can be considered to be investigated, as well as a comparison between European programs and US programs.

References

[1] Accreditation Board of Engineering and Technology (ABET). Criteria for Accrediting Applied Science Programs, 20015-2016. http://www.abet.org/asac-criteria-2015-2016
[2] CHEA Database of Programs Accredited By Recognized U.S. Accrediting Organizations. CHEA Database of Programs Accredited By Recognized U.S. Accrediting Organizations. http://www.chea.org/search/actionProg.asp
[3] Accreditation Board of Engineering and Technology (ABET). Find Accredited Programs. http://main.abet.org/aps/AccreditedProgramSearch.aspx/AccreditationSearch.aspx

[4] Accreditation Board of Engineering and Technology (ABET). Why Accreditation Matters to Programs and Institutions. http://www.abet.org /accreditation-matters-programs-institutions
[5] Lyons, W.C. & Plisga G.J, (eds). *Standard Handbook of Petroleum & Natural Gas Engineering,* Elsevier Inc., Oxford, 2005.
[6] Maruta, R., Maximizing Knowledge Work Productivity: A Time Constrained and Activity Visualized PDCA Cycle. Knowledge and Process Management, 19(4), pp. 203-214, 2012.
[7] Mukherjee, P.N., Prentice-Hall of India, Private Limited., *Total Quality Management*, New Delhi – 110001, p. 234, 2006.

www.witpress.com, ISSN 1743-3509 (on-line)

This page intentionally left blank

Analysis of the relation between safety perception and the degree of civil participation as a tool of sustainable development

J. Betáková[1], M. Lorko[1], J. Dvorský[2] & M. Škoda[1]
[1]*Dubnica Institute of Technology, Slovakia*
[2]*University of Žilina, Slovakia*

Abstract

Building an advanced society based on sustainable values is inherently linked with terms such as freedom, justice, progress, independence, democracy and, not least, safety. Provided the citizens face the consequences of public decision-making, their involvement into all the stages of the developmental process of the objective area is obvious and legitimate that makes the potential for its higher transparency and effectiveness. The study deals with a deep analysis of the relation between safety perception and the level of civil participation.
Keywords: environmental management, spatial management, sustainable development.

1 Introduction

Cities are the driving force of the European economy. Generally, they are considered to be a creativity and innovation accelerator within E.U. terms. Approximately 70 per cent of the E.U. population lives in metropolitan areas generating about 70 per cent of the E.U. gross domestic product. That's also the reason why the urban development integrated policy plays a significant role; being the prerequisite for the implementation of particular development policies in the context of European strategy of sustainable development.

In this context, the Leipzig Charter on Sustainable European Cities (2007) is based on the presumption that municipalities must mobilize the public and private sector, unify their interests and set controlling measures for the implementation of integrated regional development. Within these processes, engagement of all economic actors, concerned subjects and the general public is

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150241

of great importance; taking into account local needs, terms and respecting the principle of subsidiary. Resulting from it, increased attention has been paid to civic participation recently, which is a generally inseparable part of democratic regimes, with respect to the problems associated with democracy. It's a complex phenomenon that can be defined as active participation of citizens in solving the social problems, as well as in managing the public affairs. It is not limited just to the subjective acceptance of public affairs in private, but it also assumes citizen involvement in public affairs through concrete acts.

2 Security and its spatial impact: theoretical determination of the terminology

Society's concern in the problems connected with the urbanization process is a permanent phenomenon. It's provable that the degree of citizen participation in public affairs is closely linked with the perception of safety within the particular environment. In this context, it should be recognized that the safety either as an objective status or subjective feeling of the individual represents an essential prerequisite for sustainable territorial development. Finka and Kluvánková-Oravská [1] state that on the one side, the interest of the general public, academia and the third sector in the issue of safety is gratifying, but on the other side, safety becomes a political issue that causes many measures and activities aimed at safety to lead to fragmentation of sources and efforts into partial and often counterproductive solutions in order to declare the political sphere concern in the problems of common people. We often forget complexity, spatial and temporal coherence of safety problems. The consequences are being solved instead of the reasons of particular problem origin.

In this context, Ivančík [2] points out that the security of each referential subject or individual, group or state is limited by safety environment and, from an economic point of view, by resources available within the entity. Trigilia [3] defines a safe environment as the one in which individual reference entities pursue their security interests in the interaction with sources, respectively bearers of security threats. From the economic theory point of view, security is an estate that can be public or private. If the security is being ensured as a public estate, it's ensured by particular subjects and institutions belonging to the public sector. Šimák [4], Klučka [5] and Hudáková *et al.* [6] characterize the public sector as a part of social reality, or a subsystem of particular spheres of social life in public ownership where, from political point of view, the decisions are made in public elections and public control is applied here, while the purpose of public sector functioning is the fulfillment of public interest and administration of public affairs. The public sector is the product of state public policy. In this context, Beneš [7] points out that public administration is an inseparable part of the public sector that determines the complexity of legally qualified activities performed by executive bodies of public administration and public legal entities. Spatial security represents the problem that is generally known and accepted, but it lacks a clear definition of this term. In this context, Hamalová and Belajová [8] and ESDP [9] state that, traditionally, the policy of urban security is being interpreted in the context of some security partial problem and certain generally appointed interpretation is absent. In this context, probably the most integrated definition of urban security is provided by Finka [10, 11] who defines it as any kind of human security within public places of a built-up area.

3 Public participation as a tool for the creation of public affairs

Citizen participation in public affairs, so-called cons or co-decision, makes presumptions for improving the quality of all-society development in the territory where it takes place. Šikula [12] states that civil participation presents a large social concept having multidisciplinary character and society-wide impact. Based on the principle of subsidiary, partnership and trust, it makes presumptions for the implementation of practical needs and experience of citizens who live in a particular territory, respectively participate in its development in some way. Strussová and Petríková [13] (see also [14]) point out that, if there's an assumption the citizens will face the consequences of public decisions, their involvement in all the stages of this development process is obvious and legitimate and that makes the potential for higher transparency and effectiveness of the whole process. Citizens' participation and involvement into creation, realization and control of these processes increase their sense of control over environment, their independence, self-determination, responsibility, while, on the other side, decrease disposal, anonymity and feelings of vagueness resulting in losing their feeling of security within a particular environment.

Participation of particular subjects in the creation of development processes of territorial development increases the citizens' identification with a particular space and makes the feeling of fellowship to this territory and motivation to beneficial behavior for the development of all the community, as well as the territorial unit concerned. It often counterweighs the opinions and decisions of more powerful bodies participating in the development of a particular territory. Based on an allegation by Pirošík [15], we claim that participation is an effective tool for achieving the most effective public decisions. Although public participation is from a formal point of view, legally established in many acts, such as the Constitution of the Slovak Republic, Law of Municipalities, administrative procedure, Law of Free Access to Information, so-called info law, Law of Regional Development, Law on Construction, Waste Act, Clean Air Act, Act on Environmental Impact Assessment, etc., and more, it has a specific historical background in the environment concerned, it has not become an homogeneous part of Slovak political culture, yet. Zemanovičová and Gyárfášová [16] and Lin [17] point out the model of public involvement into public decision-making in which the citizen represents an active element within the participial model of public administration in the way that, besides delegating the rights to deputies, he/she tries to be responsible and advocates and makes institutions necessary for the effective operation of parliamentary democracy within the democratic environment through lobby forming.

The World Bank study entitled Participation in Practice: The Experience of the World Bank and Other Stakeholders, 1996, diagnoses barriers of enforced participation in planning the developmental projects as follows:

- Lack of governmental commitment to pass participial approach;
- Unwillingness of the administrative apparatus of the project to give up the control over project activities and directives;
- Lack of project workers' incentives and skills that would encourage them to pass participial approach;
- Limited organization ability at a regional level and insufficient investments in building community opportunities;
- Late participation take off;
- Disbelief between the government and involved entities at a regional level.

Responsible public officials and representatives often underestimate the effectiveness of the implementation of methods and tools of public participation in decision making processes. They perceive it as a threat to their influence and power. These negative attitudes can be subject to various reasons.

4 The survey methodology

In our study, we focus our attention on citizens' participation, respectively, their associations, in the creation of public affairs, their participation in public decision-making and the security perception in the territory of the Euro region Biele-Bíle Karpaty. The goal of the presented research study is to draw attention to the analysis of facts and development trends within the development of civic participation and its barriers in the Euro region Biele-Bíle Karpaty in public affairs, in context with security perception by the citizens of the Euro region Biele-Bíle Karpaty; both the Czechs and the Slovaks. The main goal was to generate connections and relationship of public participation in its creation and evaluation, as an entity which this indicator directly refers to. The main goal of the research was to analyze facts of security perception by inhabitants of the Euro region Biele-Bíle Karpaty of both Czech and Slovak parties. Acquiring, collecting and the assessment of selected data and valid information on subjective security perception, as a category of life quality of the Euro region inhabitants from the point of view of particular target groups will make the basis for the optimization of a communicative strategy of local self-governments aimed at effective participation of inhabitants and entities participating in the development of public affairs of the territory concerned in the context of development policies of regional sustainable development.

The basic framework for studying the problem is formed by relations between territorial development continuity and the actual use of territorial potential of the territorial structure. A partial goal of research was to analyze the facts:

- Use of the participation potential of Euro region Biele Karpaty by its inhabitants, from both the Czech and Slovak sides;
- Identification of the most significant forms of partnerships contributing to the realization of social and economic development of Euro region Biele Karpaty;
- Analysis of security perception as the category of life quality, as well as the value system of individual actors of this development process from the point of view of particular target groups.

Methodology of logical research has been applied in the paper, e.g. comparative method, analytic-synthetic method at examining the particular tools of spatial management, respectively, an analytic-synthetic method at making conclusions.

Research methodology is based on the principle of a multilevel complex analysis of selected activities and factors affecting the development of settlement structure. The processing itself has been divided into three developmental stages:

- Analysis of theoretical knowledge and practical experiences compatible with the implementation of selected tools of spatial management and their territorial impacts on the development of settlement structures;
- Analysis, quantification and application of qualitative methods at assessment of synergic and cumulative impacts in the context of sustainable development and the system of planning mechanisms;
- Summary of conclusions for practical application of progressive approaches to assessing the developmental potential of a settlement unit.

The comprehensive survey has been carried out within the project KEGA No.005 DTI-4-2014 sectorial integration of spatial impacts of the safety management of environmental risks on a research specimen of 360 respondents in the Czech Republic, respectively 360 respondents from the Slovak Republic in the period from May 2014 to June 2014. Data collection has been done by electronic on-line survey, as well as by standardized questionnaire (so-called exploration method), thus it was the collection of primary data. The on-line survey procedure was as follows:

- Questionnaire in final form was programmed into web form and placed on the Internet and social networks;
- After successfully testing the questionnaire, the respondents addressed by e-mail containing the survey web address, as well as log-in data;
- During the on-line survey, we could check information on the survey state, quota-repletion, respectively continuous statistics at any time, being a significant advantage of processing. Data collection was closed up after filling the specimen and quotas;
- Collected data were checked with regard to the consistency, seriousness and logic reference of the answers. Wrong answers (conversations) were deleted. Statistic signs of respondents were added to data and they were consequently processed using a statistics program.

5 Methodology of diffusion analysis of selected participation barriers

Using the diffusion analysis of particular barriers within the Czech and Slovak Republics, we can determine whether the perception of selected barriers in these countries is identical. Particular respondents' replies were expressed by the scale where number 1 represented the smallest influence, to the largest influence, expressed by the number 10. Diffusion analysis processing is numerically demanding, therefore it was carried out with the support of statistical software STATGRAPHICS Centurion XV [18].

Selected barriers of participation of self-government and public administration:

1. Lack of governmental commitment to pass participial approach;
2. Unwillingness of the administrative apparatus of the project to give up control over project activities and directives;
3. Lack of project workers' incentives and skills that would encourage them to pass participial approach;
4. Limited organizational ability at a regional level and insufficient investments in building community opportunities;
5. Late participation take off, skepticism of getting some changes;
6. Disbelief between the government and involved entities at a regional level.

Diffusions analysis of selected barriers plays a significant role in assessing the survey and discussion in a particular field. Diffusion analysis of selected barriers consists of the following stages:

- Define *selected characteristics* (medium value, diffusion) from subject case study in selected barriers of the countries.
- Make a decision on the suitability of the use of *parametric* or *non-parametric* test in diffusion analysis of the barriers with regard to the conditions set on their realization.
- Determine if medium values of selected barriers between particular countries are identical by *testing* the diffusion hypotheses of selected barriers using the parametric F-test and non-parametric Kruskall–Wallis test.

6 Methodology of diffusion analysis of selected participation barriers

Elementary characteristics in the given field of research, such as medium value and diffusion, are shown in the tables below.

www.witpress.com, ISSN 1743-3509 (on-line)

Table 1: Medium values of participation barriers of self-government and public administration.

Barriers	SK	CZ
1.	6.25	5.98
2.	2.79	3.08
3.	4.24	1.16
4.	1.23	2.69
5.	5.61	4.41
6.	2.08	5.71

Table 2: Participation barriers' diffusion of self-government and public administration.

Barriers	SK	CZ
1.	0.45	0.78
2.	1.28	1.97
3.	2.08	0.94
4.	2.19	0.56
5.	1.16	1.37
6.	1.58	0.67

Diffusion analysis is carried out using the parametric F-test, respectively non-parametric Kruskall–Wallis test. The parametric test can be performed subject to the following two conditions:

- Homoscedasticity – identity of participation barriers' diffusion of self-government and public administration in particular countries. Results are summarized in Table 3.
- Value normality – probable model of normal value diversion of barrier assessment of self-government and public administration between countries. Results are summarized in Table 4.

The non-parametric Kruskall–Wallis test can be performed subject to the presence of diffusion homoscedasticity. However, risk values in particular sectors are not distributed normally.

Table 3: Bartlett's test for verifying the homoscedasticity.

Barriers	Bartlett's test [P-value]
1.	0.085
2.	0.457
3.	0.614
4.	0.147
5.	0.226
6.	0.071

Table 4: Pearson's χ^2-test for verifying the normality of barrier values.

Barriers	Pearson's χ^2-test [P-value]
1.	0.251
2.	0.741
3.	0.047
4.	0.009
5.	0.014
6.	0.189

The results of Bartlett's test say that there is 95% probability of accepting the hypothesis of identical diffusions of selected barriers from self-government and public administration. Pearson's χ^2-test says that there is 5% importance of barriers 1st, 2nd and 6th being normally distributed. In such barriers are all the assumptions for realization parametric F-test of diffusion analysis filled. As the P-value of Pearson's χ^2-test within the 3rd, 4th and 5th barriers are lower than significance level 0.05, we refuse hypothesis on normal distribution in given barriers of self-government and public administration. Assumptions for realization of the non-parametric Kruskall–Wallis test of diffusion analysis of barriers of self-government and public administration are fulfilled in these barriers. Barriers' diffusion analysis results with the help of a parametric and non-parametric test are compiled in Table 5 and 6.

Table 5: Parametric F-test for barriers' diffusion analyses.

Barriers	F-test [P-value]
1.	0.015
2.	0.144
6.	0.039

www.witpress.com, ISSN 1743-3509 (on-line)

Table 6: Non-parametric Kruskall–Wallis test barriers' diffusion analyses.

Barriers	Kruskall–Wallis test [P-value]
3.	0.047
4.	0.002
5.	0.098

Interpretation of the results of barrier diffusion analysis of self-government and public administration from tables 5 and 6 is as follows:

We accept the hypothesis, probable in 95%, that the following medium values of barrier assessment between Czech and Slovak respondents are identical. They are:

- Unwillingness of the administrative apparatus of the project to give up control over project activities and instruction;
- Too late participation start; disbelief that something can change.

From a statistical point of view, there are no significant differences in the assessment of the barriers of self-government and public administration (0.05 significance). Other barriers of self-government and public administration are statistically important in their diffusion difference assessment of Slovak and Czech respondents.

7 Survey assessment and discussion

Practical implementation of current public participial activities into the processes of territorial management has developed into the stage when it has become the part of most national systems of settlement development and territorial planning. The legal system of developed democracies covers and ensures specific conditions of citizen participation, with respect to their associations, in public decision making through the laws becoming tools of practical public participation in decision making processes. It's not only creation of the conditions for public participation, but more active and purposeful engagement into decision making processes with public consequences. The citizens gets the legal right to be informed sufficiently about administrational activities and subjected coherence of decision making processes and activities, has the right to present his opinions and reflections. This way he gets into the position of being an equal partner with all participants in these processes. Targeted and meaningful implementation of participation methods and tools increases the feeling of control over the environment, independence, self-determination and responsibility, decreases disaffection, anonymity and the feeling of irrelevance, and finally, participation increases population identification with the territory where he lives.

Assessment views of respondents on solved problems from both countries, in spite of all-society changes and twenty years of independent existence of both republics, are surprisingly closely related. According to our opinion, historical roots and territorial cohesion has a strong impact on the point of view on solved problems.

As research results show, the most respondents assessed critically "game rules" having been established in the new society during twenty years.

Question: **Do you think that your life quality has improved in comparison with your ancestors before 1989?**		
	SK [%]	***CZ [%]***
Yes	26	22
No	30	28
It is still the same	37	26
I'm not able to judge the state objectively	7	24
Question: **Does the new situation open new possibilities for you "to have a good time"?**		
Yes	31	25
No	37	32
The same	26	26
I'm not able to judge the state objectively	6	17

As far as equality of the citizens before the law is concerned, only one fourth (26%) thought that they are getting better than what their ancestors had before 1989. On the other hand, more than two thirds considered the situation as the same (37%) or even stated that equality before the law has decreased (30%). Concerning prevalence of positive evaluation of the state of political rights and freedoms, it's obvious that, according to respondents, the problem consists not on paper, but in applying equality before the law in everyday life. A similar problem is, according to the predominant part of the publicity, even a limited chance to gain solid social status based on honest work. Only less than one third of respondents (31%) thought that the new era gives them better possibilities than the generation of their parents, while almost two thirds hold the view that they get either the same (26%) or even worse (37%).

This process has been proved in its wider context in losing civil interest in public affairs. In this historically-spatial cohesion, we understand civil participation in the subject territory as a process implementing the points of view of all interested subjects into administration, development, management and use of the subject territory. It's the process of enhancement of own ideas and realization of the conditions, helping to form settlement identity and fellowship with the local community.

Practically, responsible workers and representatives of public administration and self-governments often underestimate the effectiveness of implementation of methods and tools of participation of the mentioned publicity into decision making processes; they perceive it as a threat, wasting time, power or influence. That's the reason why we focused our attention in our research on the perception of potential barriers of particular subjects' participation in public affairs.

8 Conclusion

In the end, we can confirm the basic axiomatic question of the survey, making the platform for searching for the answers and relations on the question if the extent of citizen participation in public affairs is closely related to the perception of security of a particular environment confirmed this cohesion in particular space works and is dominantly linked to perception of life quality of citizens and stakeholders of various developmental processes. It has an important impact on the creation of developmental decision making. Municipalities gain the citizens for their decisions by making space for civil participation, whereby on one hand it creates potential for conflict elimination within the community, on the other hand, interactive bonding between the citizens and self-government creates conditions for many innovative ideas and important feedback that contributes to strengthening the community and consequently to decreasing corruption behavior within self-government. In this context, we would like to point out the statement by Lin [17] that civil participation has the processional character bearing democracy process of the society and its public life. It transforms personal and group interests of regional and local communities with public interests. Thus, it is an interactive process of change in which the environment and the citizen itself are changing and the citizen stops being careless towards his/her settlement and social environment and takes responsibility for activities in his/her surroundings.

Acknowledgement

The authors would like to thank the Ministry of Education of the Slovak Republic for its support on the grant project KEGA Project no. 005DTI-4/2014.

References

[1] Finka, M., Kluvánková-Oravská,T., 2010. *Koncept polycentricity v súčasnej teórii a praxi spravovania územia*, In*: Prognostické práce, 2010*, vol. *2*, no. *1*, pp. 23-37, Prognostický ústav SAV Bratislava, 2010, ISSN 1337-9666

[2] Ivančík, R. 2012. Bezpečnosť z pohľadu ekonomickej teórie. In Politické vedy. [online] Fakulta politických vied a medzinárodných vzťahov – UMB, Banská Bystrica Roč. 15, č. 3, 2012. ISSN 1338-5623, s. 100–124. Dostupné na internete: http://www.fpvmv.umb.sk/userfiles/file/3_2012/IVANCIK.pdf

[3] Trigilia, C. 2001. *Social Capital and Local Development. In European Journal of Social Theory*, 4(4), London: Sage Publications, 2001, *Available from: http://est.sagepub.com/content/4/4/427*

[4] Šimák L., 2004. *Krízový manažment vo verejnej správe*, Fakulta špeciálneho inžinierstva, Žilinská univerzita v Žiline, Žilina 2004 ISBN 80-88829-13-5

[5] Klučka, J. *Ekonomická efektívnosť v projektoch bezpečnosti*. Zborník z 15. vedeckej konferencie FŠI, Žilina, 2010, str. 371-374, ISBN 978-80-554-02024-0

[6] Hudáková, M., Bugánová, K., Lusková, M. *Small and Medium-Sized Enterprises Business Risks in Slovakia.* In: *WMSCI 2014:* The 18th World Multi-Conference on Systemics, Cybernetics and Informatics, Orlando, Florida, USA, 2014. ISBN -13: 978-1-941763-05-6. p. 45

[7] Beneš, M., 2006. *Konkurenceschopnost a konkurenční výhoda*, Working Paper č.5, Centrum výskumu komerční schopnosti české ekonomiky, Brno, 2006. ISSN 1801-4496

[8] Hamalová, M., Belajová, A., 2011. *Komunálna ekonomika a politika*, vyd. Sprint dva, Bratislava 2011, ISBN 978-80-89393-38-1

[9] ESDP – European Spatial Development Perspective (ESPD), *Forwards balanced and Sustainable development of the Territory of the European Union*, European Communities 1999, ISBN 92-828-7658-2

[10] Finka, M. 2001. *Interdisciplinárne aspekty vývoja priestorovej kvality systémov osídlenia.* Bratislava: Road, 2001, ISBN 80-88999-09-X

[11] Finka, M., 2006. *Koncept polycentricity v súčasnej teórii a politike priestorového rozvoja*, In: Petríková, D., Finka, M., trajektórie územného rozvoja, Spectra 2006. ROAD Bratislava, ISBN 978-80-88999-31-7

[12] Šikula, M. *Dlhodobá vízia rozvoja slovenskej spoločnosti*, A Long-Term Vision of the Slovak Society Development. Second (unchanged) edition. Bratislava: ÉÚ SAV 2010. 274 s. Druhé, nezmenené vydanie. ISBN 978-80-7144-168-7

[13] Strussová, M., Petríková, D., 2009. *Možnosti a predpoklady občianskej participácie v udržateľnom sídelnom rozvoji*, Sociológia 41, 2009, č. 4, ISBN ISSN 1336-8613

[14] Sustainable Development of the Territory of the European Union, European Communities 1999. ISBN 92-828-7658-2

[15] Pirošík, V. 2004. Protikorupčné ustanovenia v novele správneho poriadku. In.: Pod lupou. Newsletter Transparency International Slovensko.

[16] Zemanovičová, D. Gyárfášová, O. 2000. *Korupcia na Slovensku z hľadiska spravovania vecí verejných.* Bratislava: Centrum pre hospodársky rozvoj – Transparency International Slovensko. In: Róbert Vico – vydavateľstvo, 2000. ISBN 80-967382-5-9

[17] Lin, 2001. Social Capital: *A Theory of Social Structure and Action*, Cambridge University Press, New York, ISBN 978-521-47431-3

[18] STATGRAPHICS: *Software Statgraphics Centurion XV. 2014*. [online] [cit. 25 March 2014]. Available: http://www.statgraphics.com/support/download_center.aspx

Analysis of the human risk factor which affects the reliability and safety of machinery

G. Hotta[1], D. Ishibashi[1], Y. Ohbuchi[2] & H. Sakamoto[3]
[1]*Department of Mechanical Engineering,*
Ariake National College of Technology, Japan
[2]*Creative Engineering and Design Education Center,*
Kumamoto University, Japan
[3]*Graduate School of Science and Technology,*
Kumamoto University, Japan

Abstract

It is an important matter to decrease the mean time to repair (MTTR) in order to improve the reliability of machinery. When the factory workers repair as non routine operations, there is no operation manual. Therefore, the repairing quality depends on the maintenance engineer's skill or the operator's skill. However, in the non-routine operations, the correlation of the maintenance engineer's experience and the decrease of MTTR does not necessarily exist. This is an important problem in optimum maintenance planning. So, an analysis of the influence of the human factor on the reliability of machinery is desired. In this research, we make an action model for coping with the failures of maintenance engineers, and analyze the human factor which affects the reliability of machinery. In addition, we consider the improvement of the reliability of machinery by reducing the MTTR.
Keywords: MTTR, infrequent operation, human factor, risk-taking situations, psychological tests, risk reduction.

1 Introduction

Production facilities keep their reliability by check and maintenance. The routine check and maintenance procedure is generally carried out based on a check manual. In the case of the breakdown of newly installed machinery, the repair manual sometimes cannot be found in the operation text. In the initial failure

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150251

period of the Bath Tub Curve in particular, this tendency is notable. When there is mention that "it is easy to repair" as a measure of the reliability in the mechanical equipment, it is indispensable to reduce the MTTR by the immediate restoration of a breakdown at a production site. As there is no repair manual in non-routine work, the repair operation is completely the responsibility of the maintenance and operating engineer. This operation largely depends on the engineer's skill and experience [1]. However, in non-routine operations, the correlation of the maintenance engineer's experience and the decrease of MTTR does not necessarily exist [2]. This is an important problem in optimum maintenance planning. In this research, an analysis of the influence of the human factor on the reliability of machinery was carried out and the reliability improvement of machinery by reducing the MTTR and the repair time was discussed.

2 Action model of the maintenance engineer during the breakdown

2.1 Conventional study about reliability and human risk

Past research on the influence of the human factor on the reliability of machinery is as follows: 1) the quality engineering analysis about the reliability of software in the design review process [3]; 2) the occurrence pattern of human error in the marine vessel's engine problems [4]; 3) the system's reliability analysis on the relation between human behavior and machinery breakdown, etc. In the conventional study, human error is defined as a factor of the reliability in a model of a manually operated machine and its countermeasure is considered. In this research, we paid attention to the individual personality and behavioral characteristics of the maintenance engineer and not to human error as the risk factor affecting the reliability of the machine. These are pre-behavior, current behavior and post-behavior at time of the breakdown.

2.2 The influence of a personal behavior model on reliability

According to a Japanese preservation society, the operating engineer's behavior at time of breakdown was classified into the following three parts: 1) planning, 2) action and 3) evaluation [6]. These are termed pre-behavior, current behavior and post-behavior at breakdown. Evaluation is the report of the cause of breakdown and the repair treatment, and the collection of the information for the prevention of recurrence. As the reliability of a mechanical system is decided by the combination of these three behavior items, we define each behavior element of a maintenance engineer as $K1$, $K2$ and $K3$. A machine causes N time breakdown during a fixed period, and we assume that different maintenance engineers can handle the breakdown. The set of the choices for repair behavior were given to maintenance engineers of N person. We assign the number to each maintenance engineer of N person and consider the next assembly.

www.witpress.com, ISSN 1743-3509 (on-line)

$$I = \{1,\ 2,\ 3,\ \cdots,\ N\}$$

The behavior choices (a,b, ・・・) which a maintenance engineer decides, exists in each behavior element Kn (n =1,2,3). So the next system is formed.

$$K^I_n = \{a^I_n,\ b^I_n,\ c^I_n \cdots\} \quad (n=1,\ 2,\ 3\cdots) \tag{1}$$

As a result, the repair time at each behavior element is determined when a maintenance engineer selects the repair behavior. For example, when he selects the behavior of KI (plan) stage, the assembly T_{KI} of all repairing time is represented as the following system.

$$T_{KI}{}^I = \{ t_{KI}{}^1,\ t_{KI}{}^2,\ t_{KI}{}^3 \cdots \} \tag{2}$$

When we assume the assembly which collects the repair time as the result of executing all of the three behavior elements to be R^I.

$$\overline{R^I} = \{(T_{K1}{}^1 + T_{K2}{}^1 + T_{K3}{}^1),\ (T_{K1}{}^2 + T_{K2}{}^2 + T_{K3}{}^2),\ \cdots\} \tag{3}$$

Because selecting from a number of repair method candidates becomes a decision making problem, the maintenance engineer's behavior affected on R^I can be considered in the cases of the following two types (4) and (5).

$$u(R_{work} - \overline{R^I}) > p \cdot u(R_{work} - R_{loss}) + (1-p)\, u \cdot R_{work} \tag{4}$$

$$p \cdot u(R_{work} + R_{loss} - \overline{R^I}) + (1-p)\, u(R_{work} - \overline{R^I}) > u \cdot R_{work} \tag{5}$$

Here, $\overline{R^I}$ is the average maintenance time, R^I_{loss} is lost time by judgment error, R^I_{work} is the standard working hour, and the probability of judgment error is p.

Equation (4) shows the action of the risk avoidance and Equation (5) shows the action of risk orientation. In this study, we calculate the utility function u shown in Eqs. (4) and (5), which is obtained by experiment and we examine whether the behavior of a maintenance engineer is risk avoidance type or risk orientation type. However, as there is a report that even the person of the risk evasion tendency has a tendency to become the risk orientation type in group [7], we also investigated the change in the action pattern in the group behavior.

2.3 Risk behavior model of the maintenance engineer

The professional attribute and individuality of the maintenance engineer are generally different. So assembly R_I in repairing time about Eq. (3) has too many elements. Therefore, the searching of utility function u which satisfies equation (4) is not practicable. Here, the professional attribute means his experience and skill and the individuality means inherent characteristics like his strong and weak points and his reactive response, etc. So we simplify the behavior model and make the following suppositions for checking the utility function by experiment easily: i) the maintenance engineer's professional attribute is uniform; ii) the maintenance engineer's professional individuality depends on preference strength between 3 elements K_1, K_2 and K_3 of a behavior model, because the professional attribute and individuality of the maintenance engineer are generally different for every individual; iii) the operation is non routine works. To avoid the complexity, supposition i) was installed according to the study of Hirose *et al*. [8]. The preference strength [9] of ii) means the different priority order of three behavior patterns by strong and weak points.

Figure 1 shows the analysis of a "close call" report by a chemical company in Fukuoka Prefecture, Japan. The first action of the employee after touching the breakdown valves is indicated. From this figure, it is found that the employee takes a different action respectively, and these actions are classified into the following three behavior patterns; the guess, the action and the information gathering. From the response behavior for the breakdowns, it is guessed that there are the different behavior patterns by each employee.

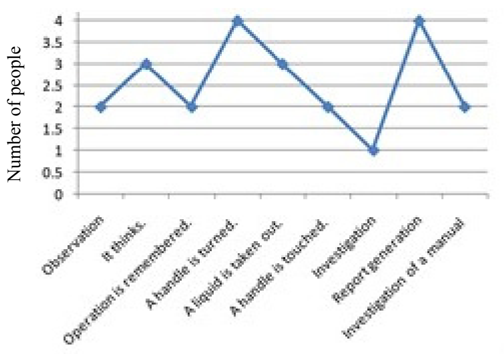


Figure 1: Action after touching the broken valve for the first time.

The supposition iii) is the necessary condition to fill the supposition ii). There is each behavior pattern of the maintenance engineer by the preference order of three action elements from the above mentioned supposition. The effect of the behavior pattern on the repair time is examined, and the estimation of the utility function u become possible.

3 Behavior pattern check of the maintenance engineer

3.1 Presumption of behavioral pattern by the maintenance engineer's preference

In order to study the behavior patterns that structure the preference relation among the behavior elements, the following survey questionnaire, mentioned in this paper as experiment (1), was carried out on 63 driver license holder 3rd grade students of the Department of Mechanical Engineering of Sojo University.

"Please select at least two of the following (1), (2) or (3) items. If you think you have merits for one item, indicate the corresponding number, and if not, write a 0. (1) I can predict the risk to some extent; (2) I can avoid dangers even when sudden; (3) when informed by another person of a dangerous experience, I use this safety information as a new lesson."

From the questionnaire's results, 11 kinds of behavior patterns have been distinguished by preference relation and named respectively I-type–XI-type. The number of persons corresponding to each type is given in Table 1 in field "number of person (1)" and the preference relations are represented by mathematical symbols.

Table 1: Difference of the repair time by an action pattern.

Type	Preference relation	The number of People [%]		
		(1)	(2)	(3)
I	①~②~③	10	10	11
II	①≻②≻③	25	13	26
III	②≻①≻③	9		16
IV	②≻③≻①	13	18	0
V	③≻②≻①	5		0
VI	①≻③≻②	19	5	21
VII	③≻①≻②	0		0
VIII	①≻②~③	0	0	0
IX	②≻①~③	13	26	21
X	③≻①~②	0	3	0
XI	①~②~③	6	25	5

In addition, when only two items were selected, it is clear that the remaining item has a very low preference order and therefore a preference relation is used among the three. And when all the items are equivalent (all set to 0 or blank) they are assumed to be indiscriminate.

The preference relations obtained from the questionnaire of experiment (1) are displayed in Figure 2 overlaying the number of person. The preference relations obtained from the questionnaire of experiment (1) are displayed in Figure 2 overlaying the number of people. By comparing the numbers of people of experiment (1) it can be seen that there are more less behaviors of types XI and IV (but also V). Since type XI corresponds to an unconscious behavior and type IV denotes inattention they are considered to be failures.

3.2 Comparison of the behavior pattern and a member of society

From experiment (1) we could distinguish 11 types of behavior patterns. Here we check if such patterns also apply to factory workers using the following case method. The case method was first applied on 36 students of the Mechanical Engineering Department of Ariake National College of Technology. The case method consists of: (1) plan before operation (prevision of risks); (2) safety measures during the operation (risk aversion); and (3) report of the experienced risks (transmission of risk knowledge). The resulting priority order was compared with the one of experiment (1) to see to what extent they correspond.

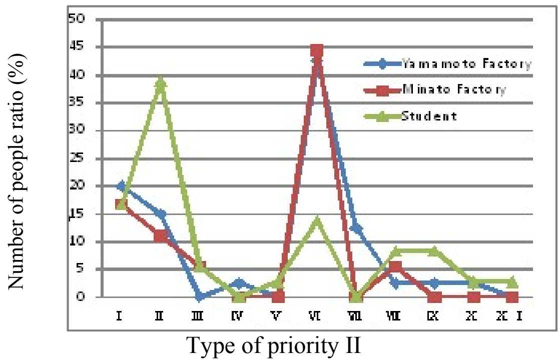


Figure 2: Comparison of a worker and a student in a case method result.

Then, we did the same with 40 employees of a factory of Yamamoto Co. (which produces cans, and includes large machinery), and 18 employees of Ltd. Harbor handicraft (which includes small machinery). Those two enterprises have been chosen because both because the daily manufacturing work includes the production of a large part of low-volume non-standard products. The results of these new experiments are given in Figure 2. This figures first shows that an enterprise worker is roughly equivalent to a student, which validates using a student as a model of an enterprise worker performing non-regular tasks. However, the characteristics of response to danger prove to be different between students and professionals. As seen in Figure 2, the students chose in majority behavior type II when facing a danger whereas for both enterprises the workers chose behavior type IV that give priority to the transmission of information about the experienced risk over the prevision of risk. In other words, communication among the partners is emphasized in the professional world.

3.3 Comparison of the action patterns in a student and a member of society

During a survey, the employee tends to answer taking into account their manager. Hence, in order to ascertain the authenticity of the survey results, we imposed the machine operations used for the experiments with the 40 employees of the Yamamoto Corp. factory. Figure 3 shows the experimental apparatus: a hand stamper used for printing on paper. The subject prints "一" on paper with a stamp. "Λ" is printed by the paper already. He can print the character as C according to the "A". We requested that he did this using his non dominant hand.

(a) (b)

Figure 3: Experimental apparatus: (a) manual stamper; (b) printer character.

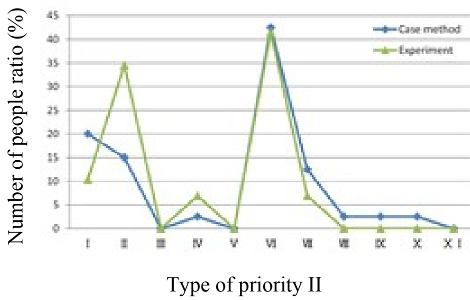


Figure 4: Comparison with the results so far and the questionnaire after the experiment.

The characteristics of the task were obtained through the observation the operation and the questionnaire filled out after work. The questionnaire consisted of giving the preference order among (1) before the task, the planning of the operations to apply; (2) during the task, the avoidance of failure; (3) after the task, the transmission of information to the next worker. The results of this experiment are shown in Figure 4. This figure also shows the results of the previous experiments, and shows that in both cases, type VI was the most selected behavior, the following one being type II. The behavior characteristics of risk presumption and risk avoidance were both significant in the case of non-regular work when the worker acted as an individual, but the prevention of risk proved to be stronger when the worker acted as an employee. When a risk was known to be possible, types VII and X, those who postpone risk avoidance, formed about 50% of the prevision of risk behaviors.

www.witpress.com, ISSN 1743-3509 (on-line)

4 Change in action pattern in grouping

4.1 Change in individual action in a group

Nowadays, work organizations become more and more collective, so the number of interactions within workplace groups is increasing.

Thus, the employees in industrial fields are acting as members of an organized group rather than as individuals, and their management too requires to be performed collectively rather than independently. Hence we studied the change in behavior patterns depending on the number of individuals in a group for the cases of experiment (2). For that purpose, we made 5 groups of 3 manufacturing staff of the studied Yamamoto Corp. Using the same basic framework as for Figure 3, three different print patterns were to be performed with 3 manual stampers. The same experiment was also done with 10 different persons individually to be compared with the result of the groups afterwards. Each individual worker had to operate 2 or more manual stampers and an award was to be given if 2 or more stamps had been printed out beautifully. The other rules (3 and 4 items) were similar.

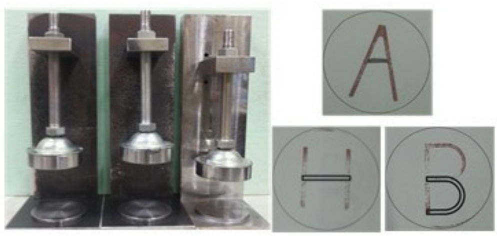


Figure 5: Experimental apparatus: (a) manual stamper; (b) printer character.

The questionnaire to fill out after work as an addition to the 3 and 4 items, included (1) the obtained awards, (2) the operation during the experiments and (3) which of aspect of the effort about quality insurance was the staff most aware of.

4.2 Experimental results

The result of the group work experiment is given in Figure 6. In the figure it can be seen that individual workers favor behavior type II whereas group workers prefer behavior type IV, which confirms that the tendency toward risk presumption increases in collective work. Furthermore, Figures 7 gives the results of the questionnaire about what is the worker aware of during the experiments and shows that numerous individual workers were aware of the impact of the effort on the quality insurance, whereas the worker in-group focused more in obtaining the award rather than the quality insurance, which was the original objective of working in a group. Consequently, when an individual worker is put into a group, there is an increase of the risk presumption and a decrease of the motivation which is a dangerous tendency.

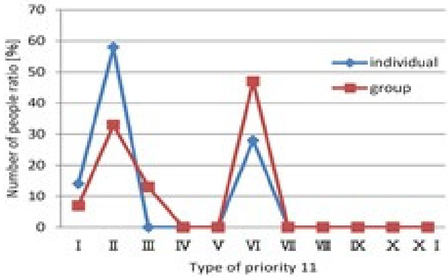


Figure 6: Questionnaire results after the experiment.

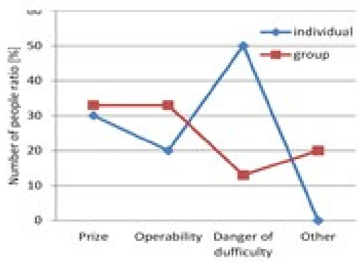


Figure 7: Consciousness during experiment.

5 Evasion of risk orientation by grouping

Experiments presented in the previous section show that when performing non-regular tasks, the behavior pattern of each individual varies a lot, and that there is a tendency toward risk-oriented behavior when working in a group. It is therefore necessary to analyze quantitatively the change in behavior pattern for an individual when working in a group in order to understand it, and improve the prevention of labor accidents. For that purpose, a new experiment was performed. 25 employees of the Yamamoto Corp. factory where divided into 6 groups of 3 people, and the remaining 7 were set to work alone. The task considered for the experiments (as illustrated in Figure 8), consisted of putting beans onto a plate using chopsticks within one minute. Each single bean put onto the plate scored one point, but when two beans were put at one time the score was doubled to four points. During the experiment, each member of a group was set to work separately from the others so that he could not see the skills of his co-workers. With this experiment, each subject had to choose before a safe behavior (taking

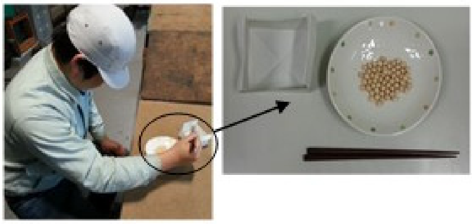
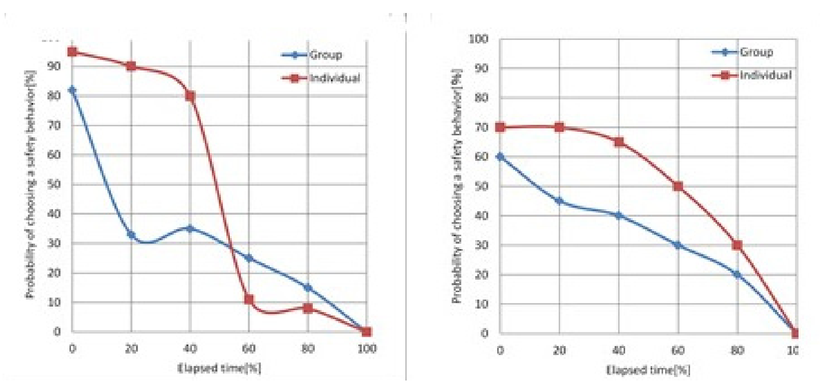


Figure 8: During the experiment.

beans one by one) and a risk-taking behavior (taking beans two by two).When choosing the safe behavior the risk of failure is low, but the reward is low too. By contrast, when choosing the risk-taking behavior, a large score will be achieved if performing well, but it is possible to lose a lot of time due to numerous failures. During the experiments, the number of people choosing the risk-taking behavior were checked every ten seconds.

In addition, a questionnaire was given to the workers that asked them to indicate the behavior they choose for every time period of ten seconds. Figure 9 gives the results of this experiment. As seen in the figure, the employees that were not in a group tend to adopt a safe behavior at the beginning and then switch to a risk-taking behavior from the second half of the period, whereas the opposite is true for the in-group employees. Also, while individuals and group workers both chose to some extent a safe behavior, there is a higher probability for the group workers to be aware that they are following a risk-taking behavior. When comparing Figures 9(a) and 9(b), which represents, respectively, the observations result and the questionnaire results, it can be seen that the employees tend to think they are adopting a safe behavior while actually following a risk-taking behavior. It can also be seen from the figure that, even when aware of their behavior, in-group employees tend more toward a risk-taking behavior than individual employees.



(a) (b)

Figure 9: Experimental results: (a) observations during the experiment; (b) questionnaire results after the experiment.

6 Conclusion

In the reliability improvement of the mechanical equipment, it is necessary to decrease the entire MTTR by the shortening of one repair time. MTTR depend on a human factor like the preparation beforehand and the capability of the repair, etc. So, we proposed a concrete model of a human factor in this study, and the verification experiment was carried out. Here, as the model, the utility function based on the preference choice of the means was used. The preference alternatives consist of three action elements of plan, action and evaluation, which actions are the behaviour of the maintenance engineer who encountered the breakdown. How the restoration time changed by each maintenance engineer's priority choice was examined by the experiment. In three action elements, the individual difference for priority choice of behavior was recognized in a student. First of all, these three action elements were classified into 11 kinds of action patterns by the priority order. Next, the student was made to experience a mock breakdown, and 11 kinds of action patterns changed by grouping was examined. As a result, the risk orientation behavior by grouping increases, and the decrease of MTTR is obstructed. Then, the maintenance engineer has to receive the education to be conscious enough of the risk orientation before the maintenance engineer takes the action in order to improve the reliability of the mechanical equipment by decreasing MTTR. As mentioned above, a quantitative understanding of the correlation of the risk orientation of the maintenance engineer and the decrease obstruction of MTTR is important. An additional verification is scheduled in order to obtain the correlation by an additional experiment in the company in the future.

References

[1] H. Sugimoto, "*Maintenance Work and Safety for Production Machine"*, Reliability Engineering Association of Japan, Vol. 25, No. 7, pp. 690-694 (2003).

[2] F. Baba, "*Research on the stable equipment maintenance activities based on the PDCA cycle —The information link and division by class of a production activity as the foundation —*", Yokohama International Society Study Research, Vol. 2, No. 2, pp. 210-211 (2012).

[3] K. Esaki, S. Yamada, M. Takahashi, K. Ihara, "*A Quality Engineering Approach to Human Factors affecting Software Reliability in Design Process*", The Journal of the Institute of Electronics, Information and Communication Engineers Vol. J83-A, No. 7, pp. 875-882 (2000).

[4] M. Najamura "*Analysis of Human Errors in Marine Engine Accidents*", Research Reports of the Yuge National College of Maritime Technology Vol. 34, pp. 14-19 (2012).

[5] T. Matuoka, "System reliability analysis in consideration of h*uman action and an equipment failure —Approach by the GO-FLOW technique—*", http://www.mech.utsunomiya-u.ac.jp/safety/gf_mmi.htm (2013).

[6] Japan Society Maintenology, "*Examination about a preservation program and an inspection*", The Data of Investigative Commission about the State of the 20th Inspection, pp. 6-11 (2006).

[7] I. Atunobu, "*Theory of decision making*", Kyoritu Shuppan Co. Ltd, pp. 4-7 (1983).

[8] F. Hirose, D. Takeda, J. Fujimoto, "*A Study on Measurement of Individual Hazard Perception (Part 3) — Development of Measurement Method of*

Individual Hazard Perception—", Report of research: Y10012 of Central Research Institute of Electric Power Industry, pp. 1-4 (2011).
[9] S. Terano, "*A Guide to System Engineering*", Kyoritu Shuppan Co. Ltd, pp. 168-172 (1996).

Oneiric stress and safety and security at work: the discovery of a new universal symbol

A. Accettura[1], M. Aufiero[2], A. Anghileri[2], A. Briccola[2], G. Canevaro[2], N. Catelli[1], M. Cavalleri[2], R. Cusani[1], E. De Lucia[1], F. Borghini[1], F. Garzia[1,3], M. Lombardi[1], P. Luraschi[2], M. Paddeu[2] & G. Rossi[1]
[1]*Safety and Security Engineering, SAPIENZA, University of Rome, Italy*
[2]*Sicuritalia S.p.A, Italy*
[3]*Wessex Institute of Technology, UK*

Abstract

Cox and Griffiths define as psychosocial risks at work "*those aspects of the planning, organization and management of work, which, along with their environmental and social contexts, may affect mental and physical health of the employees, directly or indirectly producing stress*". Therefore, a more effective approach to occupational safety and security should include integrated risk management through the identification of any work stress related problem. The purpose of this paper is to analyze the possible correlation of risk at work with the modification of sleep, and inside it, the specific function of dream activity.
Keywords: occupational safety and security, work related stress, dream activity.

1 Introduction

The four main protagonists of our research are:

a) risk at work: over the years '70–'80 the public opinion started to pay attention to "health prevention and protection", then has moved its focus to the so-called "health promotion". In this new context, the health of workers is intended not only as the absence of disease or injury, but rather as the existence of a physical and psychological well-being state. In the mid 80s, the theme of risk at work gets the interest of the psychological sciences, and finally in recent years the organizational sciences too have focused its economic variables and business aspects. Today, organizational well-being commonly means the ability of an

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150261

organization to promote and maintain workers' physical, psychological and social well-being for all its levels and roles. On 1986 the International Work Organization defined the concept of psychosocial risks later perfected by Cox and coworkers as "*those aspects of the planning, organization and management of work, which, along with their environmental and social contexts, may affect mental and physical health of the employees, directly or indirectly producing stress*" [1, 2]. Therefore, psychosocial risks can directly and indirectly affect both physical and mental health through the experience of stress and its psychopathological work-related consequences: burnout [3] and mobbing [4].

b) stress: the term stress is known for centuries (starting from 1300–1400) with regard to the tensions of a material. As soon as an external force stresses an object, it begins to react starting from a deformation up to its breakup. Nowadays the term "stress" is often improperly referred to situations and events that cause discomfort or disturbance. However, we cannot avoid stress because it is the body's physiological response to every request of modification made on it. This behavior, also referred as "General Adaptation Syndrome", is a non-specific reaction to any request (stressor) from the external or internal environment, involving all the biological systems of the body. The individual may well adapt to a stressor for the short term (eustress); but prolonged and/or overly intense exposure to stressor can produce negative reactions of adjustment (distress). The subjective attribution of value to events, justifies the distress coming from individual sensation of not being able to respond to requests or not to be up to expectations [5].

c) sleep and dream: starting with the premise that we, on average, spend one third of our lives sleeping, the importance of sleep continues to be underestimated. Since the beginning of history, and likely even earlier, sleep and dreams have always interrogated the intelligence by taking on a sacred, spiritual, and ultimately therapeutic value. In modern times, we are constantly learning more about both the micro and macrostructures of sleep by the analysis of the EEG and correlating them to all the major functional organic parameters (Polysomnography). About 27% of the general population manifests sleep disorders for physical illness or invasive therapies [6].

d) oneiric activity and stress at work: the abuse of the term stress can easily lead up us to fail to distinguish it from simple fatigue. However, while fatigue can be resolved with a quality rest or drugs, on the other hand the real distress, which is derived from an unconscious and pathogenic conflict, can only be resolved with a psychodynamic psychotherapy. Needless to physically tire ourselves in the hope of finally being able to rest. Insomnia, which is divided into the initial, intermediate and terminal types, is a phenomenon often due to certain mental disorders, like anxiety and depression; but sometimes, in proportion to the extent of our fatigue, we repeat night-time awakenings in order to fall back asleep and so reproduce the initial deeper and more restful stages of sleep (III–IV). While it is well known that we all dream every night during the REM stages of sleep, we sometimes reawake only with an either pleasant or unpleasant feeling left behind by the dream itself, without remembering any of its contents. More typically, however, fragments or complete stories of ordinary or extravagant contents remain in our minds. Whatever the case, it has been clinically proven that we only remember the parts of the dream that need to be brought from the unconscious to conscious level. This allows the true meanings of these symbolic elements to be processed and to be finally included in the free and complete expression of our Personal Identity. The contents of dreams are always used by the individual exclusively for their value in terms of symbolic personal or universal meaning, and never represent themselves. The references, therefore, are never explicitly in play, and the subjects employed as symbols must be unequivocally excluded from any hypothetical responsibility for the unconscious conflict in progress. This is particularly true also when we, as creators of the dream, represent ourselves as protagonists of situations that in reality we would avoid. Furthermore, in our conscious experience there is an inevitable contrast between the need for safety and security and the limits imposed by space, time and emotional ties. These constraints do not exist in the unconscious, and we can achieve our goals freely, by discovering that there is another way to interpret reality in which the experience regains its original symbolic meaning and ceases to be neurotic or dissociative. One of the significant symbols that is universally used to deal with the actual stress acquired from our relationship with safety and security is that of the thieves. These "professionals" of hazardous unpredictability are often adopted as the feared protagonists of our dreams. In this sense, the goal of the dreams' creator (the real Ego) is to disavow the declared uncertainty of the actor (the presumed Ego), which is often derived from an anxious expectation induced from the outside, as is thus seen as a cause for distress. In the particular case of security guards, who are required to expose themselves to risk in order to protect others, the universal symbol of the criminal overlaps with that of the goal of their own work, or rather the referent for guaranteeing survival. This coincidence, which represents a typical case of symbolic fusion, risks of confusing the sense of our personal security with that of protection required by the customer. The oneiric representation of such characters, therefore, is aimed at distinguishing between the fear for one's own survival and the empathy felt for the customer, as well as to ease the pressure of this stressful and ambiguous distinction. In short, when faced with a dream in which the presumed Ego fears the presence of thieves, kidnappers, or criminals, this situation can be described as one of stress due to vicarious traumatization. In fact, the real Ego of the dreamer not only doesn't fear these symbols as personal referents of unpredictability, but since they also represent the fear of his customers, or rather of those who expect something of professionally valid from him, his positive self-esteem is also increased by this professional expectations. Finally, in addition to confirm their irreplaceable adaptogenic role, the psychodynamic processing of these oneiric representations in clinical practice employs them as credible evidence for the existence of the unknown part of ourselves represented by the real Ego, which serves as the immutable and irreplaceable guide to both the discovery and the full expression of our Personal Identity [7]. Based on the above four references, the aim of our investigation-search was to gather preliminary information on the existence of correlations between sleep variables, including any particular dream, and the risk of stress related work accidents recognizable in sentinel events as in factors of content and context.

2 Method

The research carried out by our team was divided into five stages.

Step 1: to find a company interested in participating in the study.
The proposal to cooperate with our study was accepted by Sicuritalia S.p.A., an Italian organization, founded in 1956, leader in the field of security services and facility management. Sicuritalia is the only Italian company that handles the security services through a coordinated and unified management. The four main areas of its private, fixed or dynamic security services, all equipped with the most advanced technology, are: private security systems; surveillance; investigation; private intelligence and security informatics. In addition, Sicuritalia carries out activities of Facility Management, for storage, handling and the best use of corporate assets and occupied spaces. To directly organize and coordinate its customers Sicuritalia uses a software call “GSS Web” that, monitoring in real-time the activities contracted, allows the creation of a common data base and great homogeneity of the procedures.

Step 2: collection of the documentation for a comparative analysis.
For this purpose were carried out the following two activities:

a) selection of samples between 6 homogeneous macro tasks present in the risk assessment document of Sicuritalia: clerk; operational center attendant; monitoring and first responder service; anti-theft service; sampling values service; head of security service.

b) application and analysis of data related to the selected samples organized for homogeneous groups. In particular, the assessment of work related stress data, referring to the three-year period 2011–2013, associated with anonymous personal data.

Step 3: preparation of questionnaires to administer to the sample.
To better investigate the sample, already characterized by a medium-level of stress, it was proposed the administration of Pittsburg Sleep Quality Index

(PSQI) (modified in 15 item) test.
Step 4: administration of questionnaires to staff.
Step 5: study and analysis of the collected data with the Statistical Package for Social Science (SPSS).

3 Materials

a) The questionnaire administered to the two selected samples (operational center attendants and monitoring-first responder staff) was divided into two parts. Part 1: anonymous personal specifications of individual employees' age; school attendance; sex; nationality (if non-Italian specifying how many years in Italy); position in job seniority; length of service in the company. Part 2: modified PSQI. About the latter, the scales for the evaluation of sleep disorders, by exploring the symptoms and not the etiology, are commonly addressed to point out primary and secondary dissonnie only. The most recent scales, validated versus polysomnographic data, are considered rapid and non-invasive screening tools to identify patients with sleep disorders to submit, if necessary, to more complex and in-depth investigations. In particular, the Pittsburgh Sleep Quality Index – PSQI [8] is a self-assessment scale that discriminates between "good" and "bad" sleepers and provides an easy-to-use list of self-explanatory elements for the clinician and researcher. It provides also a rapid assessment, clinically useful, of the different conditions that may impair the quality of sleep, because it derives its item from clinical experience of sleep disorders. The test takes into consideration the last month and so permits to distinguish transient from persisting sleep problems. In order to properly carry out our research work, the original PSQI test (15 item, 5 of which, reported, for clinical information only, by the eventual bed partner, do not enter in the total score) has been modified in 15 item all evaluated by the compiler. In fact, the original PSQI basement was complemented by 4 item dedicated to investigate the possible dream representation of works elements (number 12-13-14) or thieves (number 15) as an expression of symbolic referents. The overall score of the PSQI is grouped into 7 composite item, rated on a scale from 0 to 3, whose sum can go from 0 to 21, with a score higher than 5 considered indicative of sleep disorders. In particular, these composite 7 item represent: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disorders, the use of hypnotic drugs and noise during the day. In this respect, the authors are particularly satisfied to have standardized a valid and reliable psychometric tool for monitoring the sleep quality.

b) Data collected from the company's injury and disease register.

c) Demographic indicators of working forces engaged for qualification in the farm, including assessments of turn-over and full results of work stress risk assessments – related (breakdown of accident indices, context and content factors), both organized as the previous data for homogeneous groups.

4 Preliminary analysis of normalcy

To perform preliminary analysis of normalcy on our samples were separately used frequency functions of Statistical Package for Social Science (SPSS) [9]. In particular, we carried out a:

a) reliability analysis of PSQI (Cronbach's α calculation). From the results obtained by using SPSS we found a Cronbach's α of 0.851 for central operational personnel, and of 0.86 for the zone operators (https://statistics.laerd.com/), confirming a good test trust. In fact as good reliability index of the test, individual item responses for the two samples had not a high variance;
b) preliminary factorial analysis. From the SPSS factorial analysis, we identified the following 3 significant factors: sleep quality, sleep latency and duration of sleep, with an overall explained variance above 70%, that confirms the good internal consistency of the instrument;
c) preliminary analysis of normality in order to use the two-tailed tests of Pearson. The results showed only in the case of need of medicines to sleep, asymmetry and kurtosis that deviate from normal over the recommended range [10] (Table 1 and Fig. 1);
d) Pearson's correlation analysis. The fact that, with the exception of need meds to sleep, all other distributions approach the normal distribution, allows us to use Pearson's index to explore the possible correlation between the areas of: sleep quality; sleep latency; duration of sleep; sleep efficiency; sleep disturbance; day dysfunction due to sleepiness; sleep disturbance; dream activity due to work (Table 2). In addition, we can also correlate demographic variables (education and age with days of injury and disease 2010-13); in fact age and school attendance curves follow a normal trend (Figs 2 and 3).

Table 1: Analysis of normality: asymmetry and kurtosis.

	KURTOSIS	ASYMMETRY
Sleep quality	0.17	0.46
Sleep latency	0.54	-0.83
Duration of sleep	0.59	-0.84
Sleep efficiency	0.69	0.35
Sleep disturbance	0.03	0.65
Need meds to sleep	4.06	17.13
Day disfunction due to sleepiness	0.35	0.69
Sleep disturbance	0.35	0.34
Dream activity due to work	-0.38	0.65

www.witpress.com, ISSN 1743-3509 (on-line)

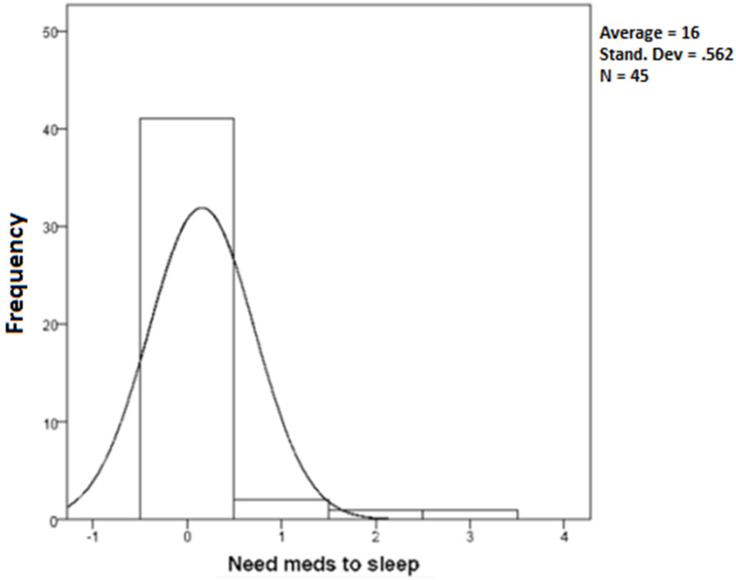


Figure 1: Need of meds to sleep deviation from normal.

Table 2: Pearson's correlation values.

Sleep quality	0.6
Sleep efficiency	0.48
Sleep disturbance	0.41
Dream activity due to work	0.4

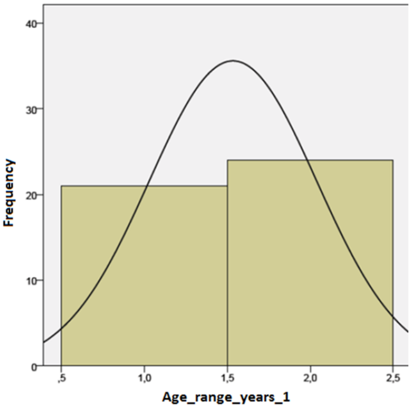


Figure 2: Trend of age curve.

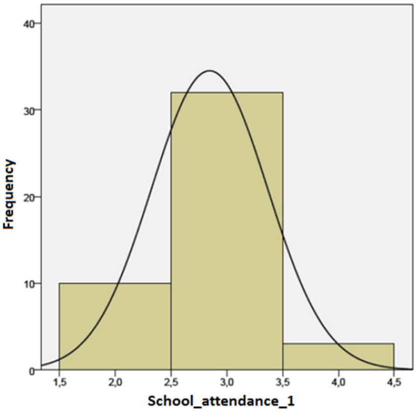


Figure 3: Trend of school attendance.

e) T-test and ANOVA univariate analysis. In order to have a double check of the results, it was performed a comparison of SPSS averages functions (http://www.cs.uu.nl/ /SPSS/spss5.pdf) with the t-Test and the ANOVA univariate analysis, because our models involve a single dependent variable. The analyses of personal data and that of results of PSQI scales were carried out together for the two samples, and from the results, we deduce that they both have not a statistically different behavior.

5 Results and discussion

We recall that the questionnaire administered to the analyzed sample was divided into the following two parts: Part 1: personal data (anonymous); Part 2: modified in 15 items PSQI. We also had general register of data associated to days for injuries and for diseases in the last three years. The samples analyzed, consisted of less than 100 subjects (45 for each group) respectively attendants to operational center and to monitoring and first responders service; the particular criticality of both these tasks lies in the activities carried out as security guards and with high-risk. In addition, the shifts, including night shift, further influence the quality of sleep. With regard to the issues related to fall asleep, generally wake time exceeds 30 minutes in more than 50% of the older subjects.

In our research, the matter of injury has been standardized through specific indicators related to number of occurring occasions. Settlement data, stratified for homogeneous groups consistent with definitions used in sampling risk protocols of work-related stress, were obtained from the company's accident register, the National Institute for Insurance Against Industrial Injuries (INAIL) databank and/or periodic statistics publications related to specific production sectors. The indicators considered in our analysis are:

a) the specific injury rate for homogeneous groups of workers, as obtainable from the company's accident record, stratified by level of consequential (mild, serious or fatal outcome);
b) the industry's injury rate, as determined by the INAIL db or other sources of free access;
c) the average level of damage associated with each category of damage, normalizing the injury in lost work days.

In the analysis, performed with the t-Test and the ANOVA in order to have a double check of results, we basically identified 3 significant factors from the PSQI administration: sleep quality, sleep latency and duration of sleep. This result, with an overall variance explained above 70%, confirms a good internal consistency of the utilized instrument and also demonstrates that the two samples have not a statistically different behavior; in fact for both it is manifest a Pearson correlation of 0.5.

Actually, to the reduction of the Duration of Sleep can contribute even physical problems, drugs and metabolism. In addition, another situation that can aggravate insomnia in adults is the tendency to doze off during the day that increases with age. This trend can be fostered by lack of interest for external stimuli (ipovisus or hearing loss) or physical limitation to movement with confinement of the elderly at home. In particular the latency delay before falling asleep (sleep latency or initial insomnia) represents the most frequently complained about noise from older. Our data also highlight direct correlation between sleep duration and the amount of time to fall asleep. The higher the sleep duration, the greater the time to fall asleep. An important comment deserves the correlation between age and working days lost for injury: the significance is next to the value of verification (0.05). Then the result of Pearson's correlation (0.28) should not be despised. The phenomenon that emerges is that, with increasing age, there is a greater propensity to days lost for injury. The result is consistent with the literature in the field and consistent with the INAIL data 2007-2011. Even though in our samples there are only 4 people over the age of 50 nevertheless they are on average with the INAIL data of correlation, in contrast to what happens for the correlation between old age and illness. Moreover, as there is no correlation between the longest serving (job seniority) and days lost for injury/illness we can assume that the accident data analyzed are the result of objective person's age and wear not work. Another interesting correlation is evident among those who do work-related dreams, all of whom claim to be more subject to problems during the day derived from drowsiness and who must resort to the use of medications for sleeping.

6 Conclusion

The significant association found in our research between the occurrence of the work environment in dreams and the tendency to increasing insomnia (sleep latency), directly correlated with aging, as the accidents at work, but not with the longest company serving or illness, suggests an exciting new symbolic meaning in work environment dream-like representation. In fact, recalling the assumption that the symbol never refers to itself, but redirects to an implicit reference or, if generally shared, to a universal one, we can say that the dream representing our own working environment allows us to unconsciously face the uncertainty of risks associated with aging. Therefore, the universality of this existential experience allows, through the use of a shared symbolism, the Jungian solution of the distressing possible conflict: avoid not to grow old! In conclusion, from the psychodynamic perspective, our study would find a new universal symbol for the analytical processing of dreams at the service of the real Ego for the discovery and the full expression of one's Personal Identity.

References

[1] Cox T. Griffiths A.J. "The assessment of psychosocial hazard at work" Cooper CL (editors) 1995.

[2] Cox T., Griffiths A.J., Barlow C., Randall R., Thomson T & Rial Gonzales E. "Organisational intervention for work stress: a risk management approach" Sudbury HSE Books 2000.

[3] Segura O. "Burnout: concepts and implications affecting public health" Biomedica. 34(4):535-45. Dec 2014.
[4] Tomei G.1., Cinti M.E., Sancini A., Cerratti D., Pimpinella B., Ciarrocca M, Tomei F, Fioravanti M. "Evidence based medicine and mobbing." G Ital Med Lav Ergon. 29(2):149-57, Apr-Jun 2007.
[5] Selye H. "Stress and the general adaptation syndrome" BMJ 4667:1383-1392. 1950.
[6] Winkler A., Rief W. "Effect of Placebo Conditions on Polysomnographic Parameters in Primary Insomnia: A Meta-Analysis". Sleep. 00487-14. Nov 1, 2014.
[7] Borghini F., Garzia F., Borghini A., Borghini G. "Psychology of Safety & Security, Emergency and Risk", WIT Press (in print).
[8] Buysse D.J., Reynolds C.F., Monk T.H., Berman S.R., Kupfer D.J. "The Pittsburgh Sleep Quality Index (PSQI): A new instrument for psychiatric research and practice" Psychiatry Research, 28(2), 193-213, 1989.
[9] Nie N.H. "SPSS Statistical Package for the Social Sciences" Mc Graw Hill NY, 1975.
[10] Hae-Young Kim "Statistical notes for clinical researchers: assessing normal distribution using skewness and kurtosis". Restor Dent Endod.; 38(1): 52-54, Feb 2013.

Section 7
Modelling and experiments

This page intentionally left blank

FDS+Evac models and cryogenic and oxygen deficiency emergency management for underground facilities in Gran Sasso National Laboratories

M. Tobia[1,2], R. Tartaglia[1], R. Perruzza[1] & F. Nusca[2]
[1]*PPS Department, National Institute of Nuclear Physics, Gran Sasso National Laboratory, Italy*
[2]*DIIIE, Department of Industrial and Information Engineering and Economics, University of L'Aquila, Italy*

Abstract

The aim of this work is to refine the emergency and evacuation management by the application of FDS+Evac (by NIST and VTT) models within the Gran Sasso National Laboratories (LNGS); one of the structures owned and managed by the Italian National Institute for Nuclear Physics (INFN). The application of these models to a peculiar site, such as the LNGS one, has the fundamental role to evaluate the correct definition of the emergency procedures proposed and adopted inside the plant. Thus ensuring, by an agent-based dynamic simulation, a preliminary evaluation of the behaviour of users and emergency teams in case of emergency and, specifically, an assessment of the time of intervention and full evacuation from the site. The analysis has been applied to a new experimental installation in one of the main experimental halls of the LNGS. The object of the study has been the simulation of evacuation after a direct nitrogen release in the service building of the Xenon1T experiment, located in Hall B of the underground laboratories. The implemented models have the great potential to take into account not only the characteristics of the surrounding environment, but also the psychological and human aspects induced in people involved in an emergency. The study aims to provide a first step evaluation of the accuracy of the Internal Emergency Plan (PEI) procedures adopted in the LNGS, highlighting the pros, cons, critical aspects, future progresses and the possibility of

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150271

widening the analysis to the entire site in view of continuous improvement in the matter of safety and emergency management.

Keywords: safety, emergency management, FDS+Evac, confined space, ODH, asphyxia, underground laboratory.

1 Gran Sasso National Laboratories: INFN

The Gran Sasso National Laboratories (LNGS) are one of the experimental research centres belonging to the Italian National Institute of Nuclear Physics (INFN). The LNGS facility is made up of two main areas:
- An external operations centre in Assergi, L'Aquila;
- Underground laboratories.

Both of the areas are located in the heart of Gran Sasso and Monti della Laga National Park. The underground laboratories, housing about 20 experiments, are located under a rock layer of about 1,400 m of thickness, acting as a shield against cosmic radiation. The underground cavity is just in the middle of the Gran Sasso highway tunnels (a double-tunnel 10,500 m long gallery). Moreover, LNGS are surrounded by a huge water reservoir. The research areas in which the laboratories operate or plan to operate are:
- the study of rare nuclear phenomena;
- the study of the most penetrating components of cosmic rays;
- neutrino physics;
- dark matter.

LNGS consist of three experimental halls of about 100x20x20 m^3 each: Hall A, Hall B, Hall C. The connection among the halls is achieved by other smaller galleries: car tunnel, truck tunnel, connecting tunnels.

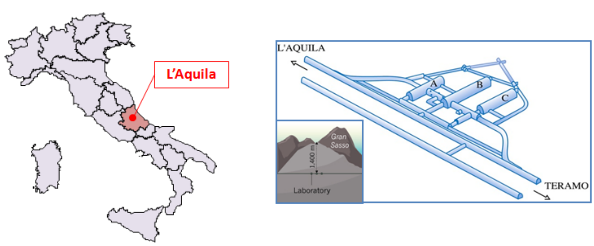


Figure 1: Gran Sasso National Laboratories, underground laboratories.

From the "safety point of view", besides health and safety regulations in the work place, LNGS are subjected to the European Directive Seveso III (2003/105/CE): they are classified as major accident hazard plant because of Experiments using and storing big amounts of substances classified as dangerous for the environment [1]. In compliance with Seveso, LNGS have adopted a Safety Management System (SGS) implemented through 16 procedures and operating instructions. Furthermore, LNGS have a specific Internal Emergency Plan (PEI) and a General Emergency Plan (PEE – including the PEI and the emergency aspects connected with the complex surrounding environment). Moreover, before starting any activity or new project/experiment, LNGS and Experimental Collaborations must realize a Safety Risk Analysis in order to evaluate the likelihood of occurrence of possible events and to guarantee the highest safety standards in a complex system such as the one in which LNGS are involved.

2 Xenon1T experiment

Several extensions of the standard model of particle physics lead to the Weakly Interacting Massive Particles (WIMPs) as candidates for the demonstration of astrophysical dark matter. Xenon1T is an experimental project for the direct search for dark matter designed to look for WIMPs through a detector in the laboratory with unprecedented sensitivity.

The experiment is in phase of completion inside the Underground Laboratories in Hall B, a 100x20x20 m^3 area (fig. 2).

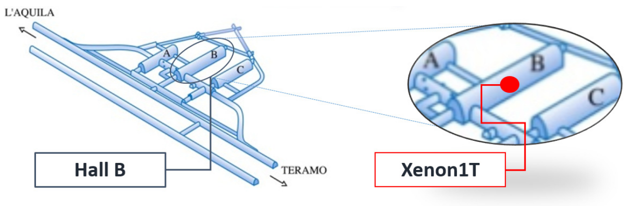


Figure 2: The Hall B and the Xenon1T location.

The infrastructure of Xenon1T is composed of two main elements: the Water Tank providing the needed shielding for Xenon1T's detector and a Service Building containing all the systems and equipment for the experiment running (i.e. the cooling and purification systems; DAQ and electronic controls, the storage tank of xenon gas).

Table 1: Xenon1T's infrastructure and characterisation.

Water tank		Service building	
Description	Vertical cylinder with conic roof (stainless steel AISI304)	Description	3-floor steel structure
Volume	~700 m^3	Volume	~600 m^3
Weight	~33,500 kg	Width	7,000 mm
Diameter	9,600 mm	Length	8,000 mm
Height	11,600 mm	Height	11,000 mm

The Xenon1T's cryogenic infrastructure consists of six interconnected systems:

– Xenon Refrigeration System: used to cool the Xenon1T's detector, liquefy the gas Xenon and keep it at an operating temperature of about 180 K;

– Xenon Storage and Recovery System (ReStox): a double wall vacuum insulation spherical vessel designed to withstand an absolute pressure of 65 bar, allowing conservation of Xenon in the gas phase;

– Xenon Purification System;

– Column for the Removal of Radon (charcoal);
– Column for the Removal of Krypton;
– Monitoring and Control System.

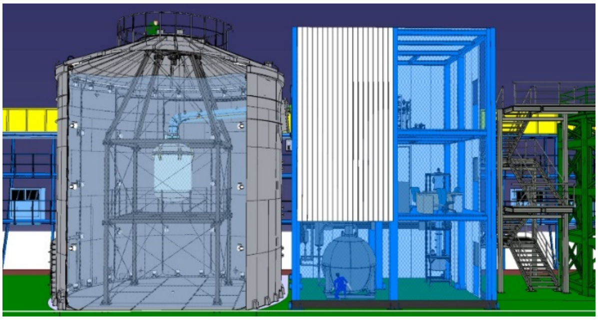


Figure 3: 3D representation of the Xenon1T Experiment in Hall B of the LNGS.

3 Cryogenic and oxygen deficiency hazard (ODH)

The Xenon1T Experiment uses cryogenic fluids for both the scientific (detection of WIMPs) and operating purposes (i.e. refrigeration). In particular, the fluids processed in the Xenon1T apparatus are gaseous and liquid Xenon and nitrogen. The use, storage and processing of cryogenic fluids in a close and confined space, such as the one of the Underground Laboratories, imposes a punctual evaluation of the associated risks and the definition and implementation of preventive and protective measures to guarantee high safety standard for people and equipment.

The elements responsible of the cryogenic fluids' hazards, basically, are their temperature and typology. The hazards of physiological derivation intervene because of the very low temperatures of cryogenic fluids and, in particular, have effects affecting the human beings. Among the main hazards of direct type there are:

• damage to human tissue – hypothermia: very cold temperatures are an obvious danger if the fluid may come into contact with human tissue. Some contacts may lead to an almost instantaneous freezing, and the resulting damage for the skin can be compared to a thermal burn. This damage is called "frostbite" or "cryogenic burn". Although it seems obvious the importance of preventing any contact with both the cryogenic liquid and cold gas, an equal important precaution is to preclude the possibility of contact – even instantaneous – with any cold metal which is at cryogenic temperatures (below -100°C). Moreover, body heat is maintained by metabolism, by the action of muscles and breathing. If the body is not able to generate heat in an amount equal to the one lost, body temperature will decrease continuously, with the result of hypothermia. If the body temperature falls below 35°C, a deterioration of the organic functions at nervous, cardiac and respiratory level may appear. At temperatures below 28°C, ventricular fibrillation appears. In many cases, a person in an environment where there may be hypothermia can hardly be able to escape.

www.witpress.com, ISSN 1743-3509 (on-line)

• hypo-oxygenation: the cryogenic liquid evaporates if it is heated to room temperature. The presence of a relatively small amount of cryogenic liquid can dilute the breathable atmosphere (normally 21% of oxygen concentration in air) in a place near the feed point of the liquid. The situation is made more critical by releases occurring in very small confined spaces. The consequences of an oxygen deficiency appear to be different in relation to the diverse response between a person and another. In any way, it is possible to draw up a list of symptoms and effects generally found in subjects exposed to a given percentage of oxygen concentration in the air (Table 2).

Table 2: Symptoms and effects of oxygen deficiency [2].

% of oxygen in volume	Symptoms and effects
15–19	Possible abnormal coordination; could lead to early symptoms in people with heart, respiratory or circulatory problems.
12–15	Wheeze; accelerated pulse; judgment, coordination and perception altered.
10–12	Breathing difficulty and increased rhythm; blue lips; poor coordination and judgment.
8–10	Nausea; vomiting; livid face; mental confusion; fainting; loss of consciousness.
6–8	4–5 minutes of exposure: recovery only after first aid; 6 minutes of exposure: fatal in 25-50% of cases; 8 minutes of exposure: fatal in 50-100% of cases.
4–6	Coma in 40 seconds; convulsions; respiratory arrest; death.

An oxygen-depleted atmosphere is defined as an “oxygen deficiency atmosphere” when the O_2 concentration in the environment is less than 19.5%. The hypo-oxygenation is a very critical hazard because of its inherent characteristics: it occurs instantly and without warning. The insidious danger is related to the occurrence of anoxia (the decrease or total lack of oxygen at cellular level) characterized by being unnoticed by the body. In these conditions, a person hardly notices the danger and even more hardly moves away from the dangerous area. In fact, cryogenic fluids have the characteristic to be odourless, colourless and tasteless.

Considering the accidental scenario object of this study, it will be easy to understand the criticality of a cryogenic release in the particular conditions in which it occurs. The scenario, in fact, evolves in a building, inside a confined underground environment, with the presence of staff.

4 Human behaviour during evacuation

The evacuation from a building interested by an emergency is a complex process. The presence of a fire or, in this study, of an ODH is a very critical aspect. Moreover, if we consider the evolvement of the emergency in a multi-ethnic and international environment such as the LNGS, the process is clearly more complex. This process starts when people become conscious of the emergency putting in place a series of mental processes and activities before and after the actions that lead them to a safe place. Thus, is possible to define the reference parameters for the evacuation [3]:

www.witpress.com, ISSN 1743-3509 (on-line)

– RSET (Required Safety Egress Time): is the time necessary for a person to reach a safe place, far from the accidental area. In order to define it, is essential to know the personal characteristics of reaction to an emergency;
– ASET (Available Safety Egress Time): is the maximum allowed time by the event (i.e. a fire) guaranteeing the surviving conditions. In order to define it, is essential to know the event's boundary conditions.

A safe and successful evacuation is necessary associated to the following relation comparing the required and available egress times:

$$RSET < ASET \tag{1}$$

It is therefore evident that the difficulty resides in the assessment of the human behaviour. RSET definition is strictly linked to the interaction between people and the environment around them. Related to the people's characteristics and the behaviour in an environment, it is possible to divide the type of response in three groups [3]:
– interaction between physical ability of people and environment;
– interaction between cognitive ability of people and environment;
– interaction between physical and cognitive ability of people and environment.
Focusing on the characteristics of "occupants" (people inside a building) some of the key aspects are the knowledge of the place; the familiarity with emergency procedures; the reaction ability; the reaction speed.

All these elements determine the knowledge of the reaction, interpretation and validation process of clues. Detection systems, alarm systems, direct perception of the products of combustion (i.e. during a fire), communication by other people, stop of services and facilities are some of the possible clues available and that are not essential for the starting of the exodus. The clues validation's process (Table 3) is mainly composed of three phases: reception (feeling physically); recognition (recognizing the clue for what it is); interpretation (giving the real meaning to the clue). These validations vary according to the physical and psychological characteristics of the person perceiving the clues.

Table 3: Clues validation's process.

<table>
<tr><td>Starting or development of the emergency and of the clue</td><td colspan="4">Clues validation's process</td></tr>
<tr><td></td><td>Clues' reception</td><td>Clues' recognizing</td><td>Clues' interpretation</td><td>Reception, recognizing, interpretation…</td></tr>
<tr><td colspan="2"></td><td colspan="3">Decision's period</td></tr>
<tr><td colspan="2"></td><td colspan="2">Pre-movement period</td><td>Decision during the movement</td></tr>
<tr><td colspan="4"></td><td>Movement until the safe place</td></tr>
</table>

The decision process goes through other evaluations made by the person after the perceived clues. We can distinguish:
– finding further information;
– finding other people;
– trying to warn other people;

– trying to “solve the problem”;
– starting the evacuation;
– continuing the own activity.

5 FDS+Evac modelling

The dimensioning and design of escaping routes follows the so-called “traditional model”: a prescriptive approach based on the laws and rules’ respect. Aiming at overcoming this traditional model, following the so-called “performance-based approach” suggested and foreseen by law, a flux/fluid dynamic model has been adopted to solve the problems and peculiar elements of the case study. The basic hypothesis is that all the people present are contemporary warned and start the exodus without delay and not changing their physical conditions during the exodus. The “movement’s time” is determined by the distance to cover and by the speed and is divided in:
- time to free the building;
- time to free the floor;
- time to free the stairs;
- time needed by the person covering the longest path.

Using the method proposed by Nelson and Mowrer, the evacuation time can be defined as the following relation:

$$t = t_1 + t_2 + t_3 \qquad (2)$$

where t_1 is the time needed for the first person to reach the escaping route’s control element; t_2 is the time needed for the group to overcome the escaping route’s control element; t_3 is the time needed for the last person to leave the control element and to reach the safe place (the control element is the element of the escape route which obliges the group to form the longest queue).

In order to obtain reliable results and simulations, the real scenario has been modelled using FDS+Evac: the evacuation module of the Fire Dynamic Simulator (FDS). FDS+Evac allows also simulating only the human egress process without any fire effects. This model treats each evacuee as a separate entity, named “agent”, which has its own personal properties and escaping strategies. The movement of the agents is simulated using two-dimensional planes representing the floors of buildings. The basic algorithm behind the egress movement solves an equation of motion for each agent in a continuous 2D space and time, i.e., FDS+Evac is doing some kind of an artificial molecular dynamics for the agents. The forces acting on the agents consist of both physical forces, such as contact forces and psychological forces exerted by the environment and other agents [4–6]. Finally, the post-processor Smokeview (SMV is a separate visualization program that is used to display the results of an FDS simulation) has been used to display the results of the simulation and to have a clear view of the scenario’s evolution.

6 Emergency scenario

The emergency scenario taken into account occurs in the Service Building of the Xenon1T Experiment. As shown before, this is a three-floor steel structure hosting the following parts:
– ground floor: pumps and compressors room, hosting the Xenon Storage and Recovery System (ReStox) and the base of the distillation column;
– first floor: hosting electronics and the control room;
– second floor: hosting cryogenic equipment.
The emergency evolves in Hall B of the Underground Laboratories (fig. 4). The entire experimental hall, in particular 44 m from the Service Building to the "South side filter" (considered as an "assembly point"), has been modelled.

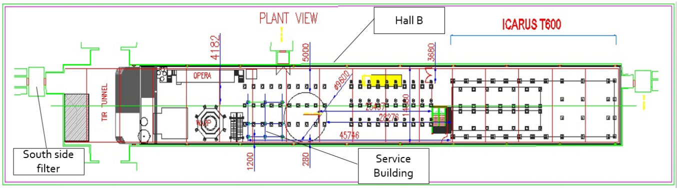


Figure 4: Plant view of Hall B.

6.1 Top event: direct nitrogen release in Hall B

The Safety Risk Analysis (SRA) performed for the experimental apparatus with HazOp, FMEA and FTA methods, highlighted the top event "direct nitrogen release in Hall B". As defined in the SGS of the LNGS, the SRA are elaborated by the Experimental Collaboration, examined and approved by the LNGS. In the Xenon1T case, the event reported is one of the top events highlighted in the SRA. LNGS, and in particular the Prevention and Protection Service (SPP) of the labs, have chosen this event as the one to be deepened according with the high risk of such release in a closed and confined space with people present. The Safety Risk Analysis resulted into a possible release due to hole or leak from valves, pipes or systems devoted to the operating of Xenon1T apparatus.

Considering the event, the following step has been the calculation of the time needed to reach a percentage of oxygen in the air of 18% (Table 2). The relation used, based on an O_2 balance for the confined volume, is the following one [7]:

$$C(t) = 0{,}21e^{-\frac{R}{V}t} \tag{3}$$

where C(t) is the oxygen concentration (C(t) is 0.21 when t is 0); R is the rate of release of nitrogen in the building (set at 0.1 m^3/s); V is the volume of the building (set at 280 m^3 considering the internal encumbrances); t is the time in seconds. Obtaining t from eqn (3):

$$t = ln\left(\frac{C(t)}{0{,}21}\right) * \left(-\frac{V}{R}\right) \tag{4}$$

Thus, the results gained are presented in fig. 5.

www.witpress.com, ISSN 1743-3509 (on-line)

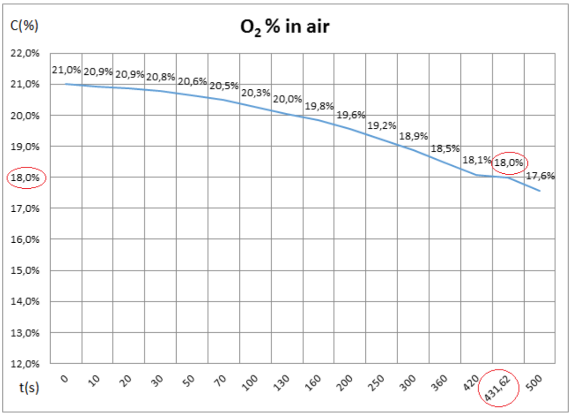


Figure 5: O_2 percentage in air decreasing in time.

Setting C(t) at 0.18, eqn (4) gives a time of 431.62 s that is the maximum time of stay in the building before reaching the critical conditions for people (the ASET parameter).

7 Simulation hypothesis

According to the work organization in the service building, the maximum crowding considered is of 11 people, divided as follows:
- ground floor (0f): n. 2 Italian male technicians;
- first floor (1^{st}f): n. 7 researchers of different nationalities, 3 of them women;
- second floor (2^{nd}f): n. 2 male technicians of different nationalities.

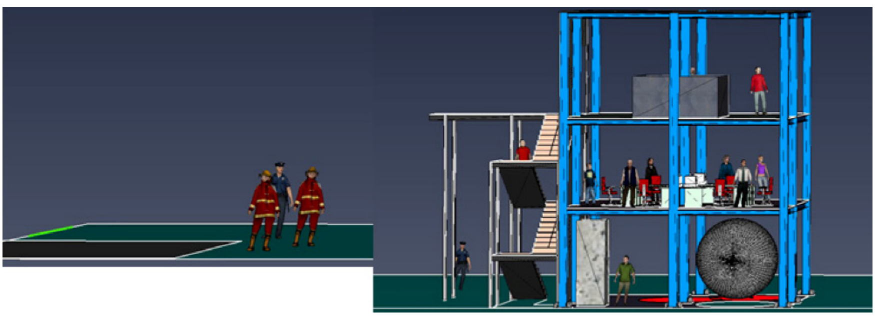
N. 2 security guards and n. 2 firemen specialists (4 of the 6 24h-presence people in the Underground Laboratories as emergency team) ready to operate have been considered [8]. Table 4 refers to the parameters and hypothesis assumed for the agents and the scenario evolution considering the slow factor (a factor taking into account the athleticism of people and how quickly they reach a fatigue which reduces the speed of walking), weight, height, allowed movements.

8 Results

The respect of eqn (1) guarantees a safe and successful evacuation. The case study, and the performed simulation, emphasized the full respect of eqn (1). Specifically, the arrival time of the Guard2 at the 2^{nd} floor of the Service Building, where the Technician4 was continuing his work not participating in the evacuation, has been calculated of 109.3 s. Moreover, the full evacuation of the building and the reaching of the safe place (South side filter) by all the 11+4 people present took 178.53 s. Thus, all the calculated times stand under the 431.62 s. It can be observed that the number of agents reaching the South side filter in safe conditions after only 56.11 s is 11 (10 occupants of the Service Building and 1 security guard closing the queue). After 178.53 s also the two firemen, the security guard and the technician are “safe and sound” (fig. 7).

Table 4: Parameters and hypothesis for the agents and the scenario evolution.

Agent	Gender	Place	Description
Technician 1	M	0f	Italian, 1.80 m, 85 kg, slow factor 0,1, 45 years old
Technician 2	M	0f	Italian, 1.70 m, 80 kg, slow factor 0,1, 40 years old
Researcher 1	F	1^{st}f	Italian, 1.65 m, 50 kg, slow factor 2, 30 years old
Researcher 2	F	1^{st}f	French, 1.60 m, 55 kg, slow factor 2, 35 years old
Researcher 3	F	1^{st}f	American, 1.50 m, 55 kg, slow factor 2, 45 years old
Researcher 4	M	1^{st}f	Italian, 1.70 m, 80 kg, slow factor 0,1, 40 years old
Researcher 5	M	1^{st}f	French, 1.77 m, 76 kg, slow factor 0,1, 55 years old
Researcher 6	M	1^{st}f	Italian, 1.70 m, 80 kg, slow factor 0,1, 40 years old
Researcher 7	M	1^{st}f	English, 1.78 m, 79 kg, slow factor 0,1, 43 years old
Technician 3	M	2^{nd}f	Italian, 1.70 m, 88 kg, slow factor 0,1, 39 years old
Technician 4	M	2^{nd}f	Russian, 1.82 m, 80 kg, slow factor 0,1, 40 years old. Doesn't take part in evacuation because he could not hear (or voluntarily ignored) the alarm
Emergency team			Behaviour
Guard 1	M	Hall B	Closes the queue during evacuation and proceeds with the evacuation of the Service Building towards the South side filter
Fireman 1	M	Hall B	Wears the aqualung in less than 50 s, identifies the failure and fixes it
Fireman 2	M	Hall B	Wears the aqualung in less than 50 s, identifies the failure and fixes it
Guard 2	M	Hall B	Wears the aqualung in 50 s + 20 s more than firemen, inspects the Service Building ensuring the complete evacuation of it



(a) (b)

Figure 6: The simulated environment: (a) south side of Hall B and (b) Service Building.

Fig. 8 highlights the *flow rates* (person/s) overcoming successfully specific "check points", namely the different exit doors, with the following legend:

– green: flux towards South side filter's door ("Door13"); between 80 s and 160 s there is no flux because the emergency team is still in Hall B;

– yellow: flux towards ground floor's door ("Door p0"); after 10 s the occupants in the ground floor are outside, then, the flux after 140 s is related to the firemen going away after solving the nitrogen release;

– blue: flux towards first floor's door ("Door 12"); at 100 s the flux is related to the passing of the security guard checking the floor;

– violet: flux towards second floor's door ("Door p2"); after 120 s the flux is related to the escaping of the security guard and the technician unaware of the alarm.

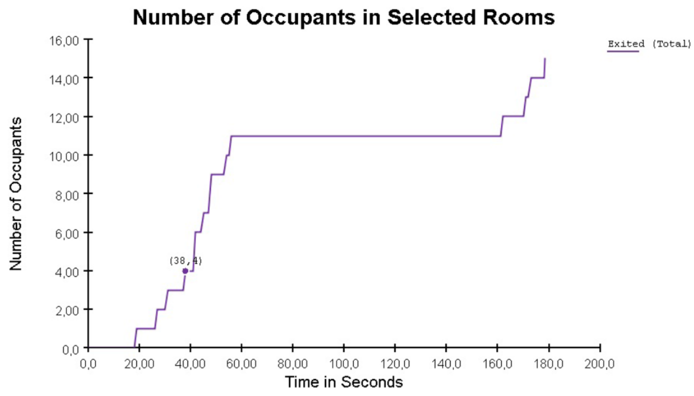


Figure 7: Number of occupants in selected rooms.

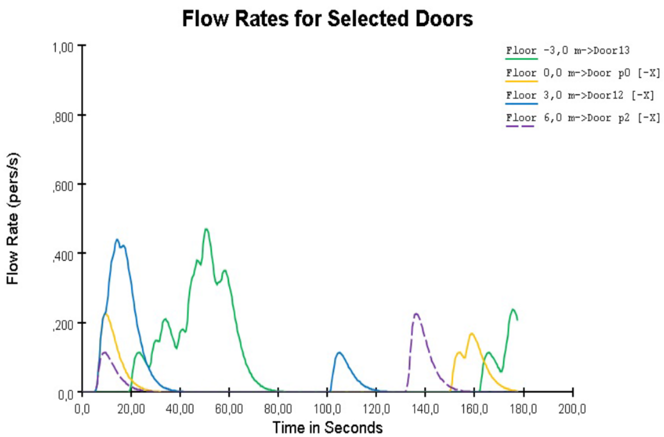


Figure 8: Flow rates for selected doors.

9 Conclusions

The goal of the study has been the critical analysis of a direct nitrogen release in the Service Building, in order to simulate and better study the response of users and LNGS' emergency team. The simulation carried out helped to evaluate the emergency procedures and their adequacy according to a performance-based approach founded on an agent-based model: FDS+Evac. The risk of asphyxia is a very crucial aspect in closed and confined spaces, such as the Underground Laboratories. The study, however, showed that the arrival time of the emergency

www.witpress.com, ISSN 1743-3509 (on-line)

team was adequate and lower than the time needed for an Oxygen Deficiency Hazard (ODH) atmosphere to occur. The results emphasized a right definition of the emergency procedures, integral part of the LNGS' Internal Emergency Plan (PEI).

The use of the presented interactive and dynamic tool testifies the utility of such approach, underlining, however, the need to validate the results with "real" emergency drills (to be performed periodically). Furthermore, the heterogeneous environment, with people coming from different countries and having diverse cultures, emphasize the need of these tests. Thus, aiming at avoiding situation of unheard/ignored alarms (such as the simulated one), it is out of doubt the importance of continuous training of LNGS' users and emergency teams in matter of safety and emergency procedures.

The potential of these tools is much higher if we consider the continuous improving on the modelling and characterization of human behaviour during an emergency from both a physical and psychological point of view.

The results obtained confirm the possibility to widen the analysis to the entire Underground Laboratories area, crosschecking the periodic emergency drills' results with the simulated emergency drills' ones. Finally yet importantly, the outcomes strengthen the opportunity to extend the study and the use of these tools in other INFN structures, in similar Underground Laboratories in the world and industrial plants with comparable risks.

References

[1] LNGS, *Rapporto di sicurezza,* 2011

[2] Arlington, Virginia: Compressed Gas Association, *Oxygen Deficient Atmospheres (less than 19,5%)*, CGA SB-2, 1992

[3] S. Marsella, L. Nassi, *L'ingegneria della sicurezza antincendio e il processo prestazionale*, EPC LIBRI, 2010

[4] NIST, *Fire Dynamics Simulator (Version 5) – User's Guide*, 2010

[5] NIST, *Fire Dynamics Simulator (Version 5) – Technical Reference Guide*, 2010

[6] VTT Technical Research Centre of Finland, *Fire Dynamics Simulator with Evacuation: FDS+Evac Technical Reference and User's Guide*, 2010

[7] FNAL, *FESHM 5064: Oxygen Deficiency Hazards (ODH)*, Fermilab ES&H Manual, 2012

[8] LNGS, *Piano di Emergenza Interno rev. 04,* 2013

Water jet streams modeling for firefighting activities with the aid of CDF

F. A. Ponziani[1,2] & A. Tinaburri[1,2]
[1]*Central Direction for Prevention and Technical Safety, Department of Firefighters, Ministry of the Interior, Italy*
[2]*Department of Industrial Engineering, Rome "Tor Vergata" University, Italy*

Abstract

The aim of this study is to illustrate the advantage of using computational fluid dynamics (CFD) in order to help manage fire-fighting operations on the field.

The jet streams from a water nozzle in an open field are investigated in terms of essential hydraulics characteristics such as overall shape patterns and throw.

The model developed by CFD is also based on the measures taken in an open field test programme for characterizing the nozzle of a robot kit designed for fire-fighting operations in hostile environments. The observations made during the tests are used in two ways: one way is to try to feed information to the CFD model on the hydraulics in the jet issuing from the nozzle, the other way is to compare the overall outcome from the CFD model to the results obtained in the test programme.

The first part of the study describes the features of the nozzle set up (geometry, positioning, pressures), the open field environment of the tests (space, wind), the outcome observed (stream shape, flow rate, throw). The second part of the study describes the CFD model in terms of specific characteristics of the nozzle (emerging shape patterns), of the numerical domain set (global dimensions and wind influence) and in terms of the outcome obtained (stream shape, flow rate, throw). The comparison between the tests results and the numerical results completes the study and forms the basis for a proposed combined use of information gained from real and associated virtual environment, which can be of help in managing fire-fighting activities.
Keywords: water jet, throw, CFD, droplet diameter, particles injection rate.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150281

1 Experimental setup

The experimental set-up was designed to assess the hydraulics and the functional requirements of the fire-fighting module of a robot-kit intended for use in hostile environments. The campaign of tests was carried on in the Hydraulics Laboratory of the Central Direction for Prevention and Technical Safety – ex Centro Studi Esperienze that is Studies and Experiences Centre – of the Italian National Firefighters [1].

The tests were divided in two groups: one to get information about the flow rates and the pressures at the nozzle, one to get information about the throws and the flow patterns of the water jet.

In order to test the flow rates and the pressures at the nozzle, a properly designed circuit was used inside the laboratory and in the open field where both series and parallel assembly of the hose branches carrying water to the end nozzle were investigated. Various configurations were tested, also varying the type of the water pumps, and several devices were used to monitor the dynamics and obtain the information required (Figure 1).

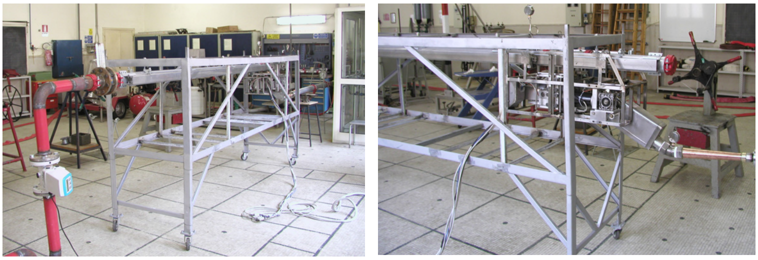


Figure 1: Hydraulic assembly tested in the laboratory.

In order to test the throws and the flow patterns of the water jet, a properly designed configuration was assembled in the open space outside the Lab where different nozzle positions were tested. By varying the hydraulics circuits coming from the Lab, several configuration were tested, and the dynamics and the information required were obtained using several monitoring devices (Figure 2).

Figure 2: Hydraulic assembly in the open field.

The nominal flow rate test was made using a properly set prototype of the robot-kit unit, composed of a horizontal DN 80 pipe, with one plug-in valve, and of the monitor assembly mounted on a hand-movable frame. A local panel was used to control the water flowing in the same way as on board the fire-fighting module, thus simulating the operational conditions of the robot-kit unit. The test assembly reproduces the plug-in condition made with the nozzle in the horizontal plane and full water jet (Figure 3).

The flow rate is measured at a reference pressure of 0.6 MPa (± 0.02 MPa) at the nozzle (position E in Figure 3). The nozzle (position F) inside diameter was measured with a digital calibre Mitutoyo resulting to be 30 mm. The flow rate test was made through several measures always maintaining an open circuit, having water flowing out from the nozzle. Depending on the circuit prepared, two types of pump stations and subsequent feeding tanks were used: one fire engine pump with a 7.5 m^3 tank or one motor pump with a 5 m^3 storage tank, having both the required characteristics to maintain the flow in the conditions fixed for each test performed. In each case, a flow measuring section (position B) was provided between the pump and the nozzle unit, on the feeding branch of water for the outflow. The flow rate measurement was made by means of an electromagnetic device Siemens Sitrans F M MAG 5100 W, class II of Directive 2004/22/CE "MID" with uncertainty < 0.1%, digital display with scale end 100 m^3/h (~ 1667 l/min). All the tests were made at a constant pressure of 0.6 MPa (6 bar) at the reference position foreseen in the test assembly, controlled by means of a manometer (AF Engineering with scale end 16 bar) at the nozzle entrance (position E). For the 30 mm nozzle diameter, the average of the measures done resulted in 1251 l/min at the reference pressure of 0.6 MPa (6 bar).

The effective throw test was made through several measures in the open field, varying the height of the installation so to have the nozzle axis placed at the heights of 2 m, 3 m and 4 m above the ground level according to the system intended use. The test assembly reproduces the plug-in condition in the installed system, with the nozzle in the horizontal plane and full water jet (Figure 4).

All the tests were performed at the same reference pressure of 0.6 MPa (position E in Figure 6) and with the same nozzle configuration (30 mm internal diameter).

The effective throw measurements at the various heights of installation were made through the analysis of the video recordings of the tests, examining the impact area of the water jet on the ground in conjunction with the distance from the outflow nozzle and using a marking mesh. The measurements were done in calm wind conditions (Beaufort scale: grade 0, wind 0 to 0.5 m/s, corresponding to a smoke plume that rises vertically) and the results are reported in Table 1.

Table 1: Effective throw measurements as a function of height.

Installation height *h* (m)	2	3	4
Effective throw $l°$eff (m)	21	24	27

Reference pressure: 0.6 MPa – nozzle ID 30 mm – $\alpha = 0°$ – full water jet.

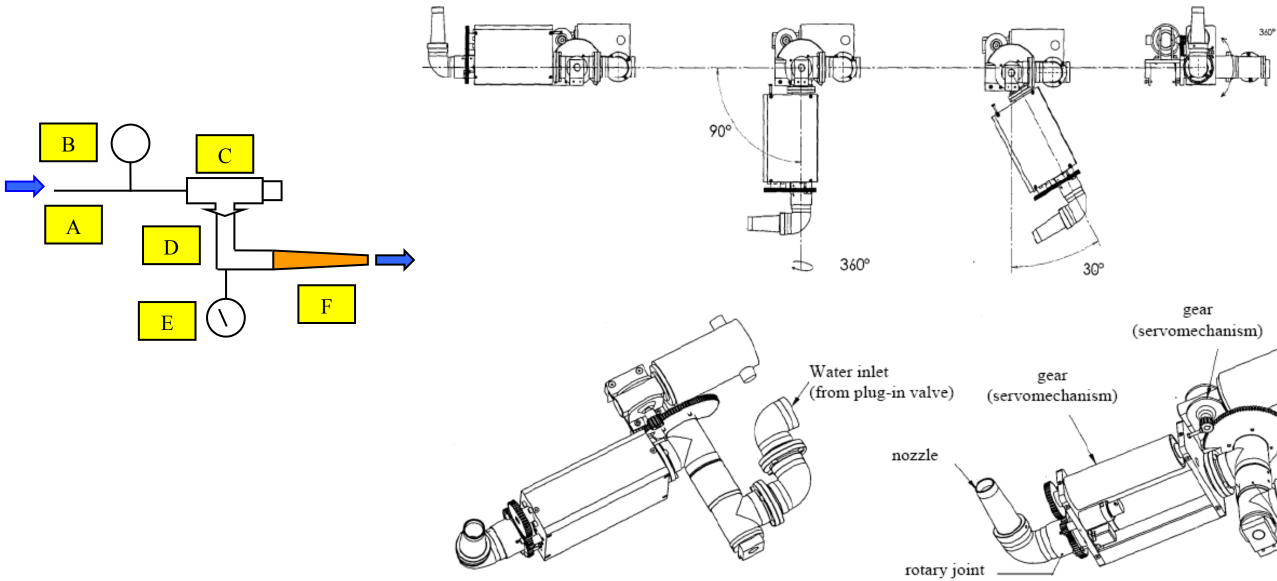


Figure 3: Nominal flow rate test rig with a detail of the monitor assembly. A: feeding water pipe (with one end closed); B: flow rate measuring device; C: plug-in valve; D: monitor assembly connected to the plug-in valve; E: manometer (gauge device); F: nozzle (full water jet).

WIT Transactions on The Built Environment, Vol 151, © 2015 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)

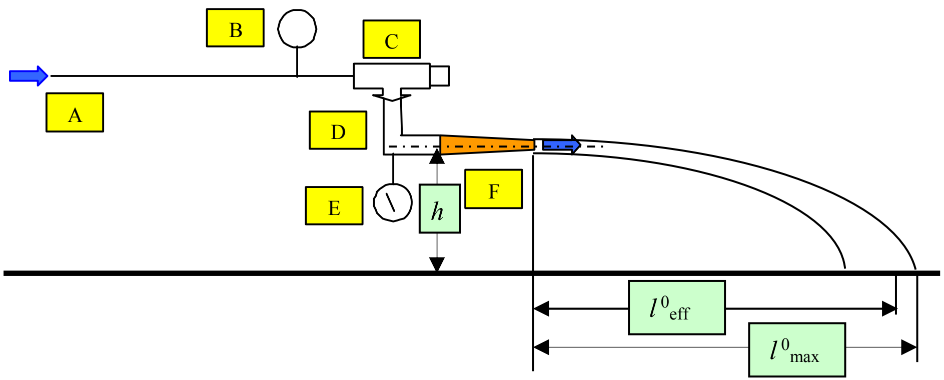


Figure 4: Test assembly for the throw. A: feeding water pipe (with one end closed); B: flow rate measuring device; C: plug-in valve; D: monitor assembly connected to the plug-in valve; E: manometer (gauge device); F: nozzle (full water jet); h: installation height (central axis of the exit nozzle); $l^0{}_{eff}$: effective throw at α = 0° (horizontal installation); $l^0{}_{max}$: maximum throw at α = 0° (horizontal installation); $l^0{}_{eff} = 0{,}90\, l^0{}_{max}$: effective throw is 90 % of max throw.

A slight variation in the angle of inclination (say up to about 5°) might be considered in the CFD simulations of the effective throw to reproduce the limited misalignment produced by the vibrations generated by the water flow under the conditions tested in the open field (Figure 5).

Figure 5: Test assembly in a throw test.

2 Numerical simulation

The numerical simulation consisted in a study of the overall water jet properties issuing from the nozzle of the robot kit unit, using the CFD package Fire Dynamics Simulator [2, 3] and Smokeview [4, 5] version 6. Starting from the data obtained in the open field tests, the numerical model was prepared by defining a proper domain and setting the initial conditions for the nozzle water flow. The computational domain represents part of the open field where the tests were conducted, describing an outdoor domain around the water jet stream of rectangular form with overall dimensions: 8 m width by 40 m length by 8 m height, with one bottom boundary as the ground floor and the remaining other external boundaries open to the atmosphere. Multiple meshes are used, and the variation of the mesh grid from coarser to finer is a significant part of the assessment. Since the CFD study refers to the experimental set-up in the open field with the nozzle set at the height of 4 m above ground level, this same position has been chosen for the nozzle from which a water flow is set to be launched in the numerical simulation. From the hydraulics data obtained in the tests come a flow rate of 1250 l/min at the pressure of 6 bar issuing from a nozzle with a diameter of 30 mm: hence an exit velocity of 29.5 m/s.

Visual observations from the videos and the photographs reveal a conical spray starting with a narrow pattern emerging from the nozzle, whose inclination is slightly above the horizontal. After some checking, the following values are used to initialize the hydrodynamics simulation: 30 m /s of exit velocity for the water jet from the nozzle, spray pattern of 12° issuing from the nozzle, 5° upward of inclination for the nozzle.

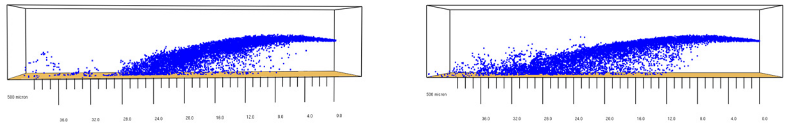
The practical absence of wind during the open field tests programme has some direct consequences for the CFD runs programme:

- there is no need to accurately investigate the wind scheme that might be used in the numerical simulation;
- there may be expected no significant interference on the water jet stream pattern;
- the high momentum of the water jet relative to the surrounding air is strong enough to maintain the original shape for a long time.

One more important parameter is required to initialize the runs: the median volumetric droplet diameter. This parameter is part of a statistical description of the water flow pattern, and helps to distinguish between different possible characteristics and behaviors [6–8]: finer diameters (on the order of magnitude 100 μm) are useful to rapidly absorb a vast amount of heat but may be more easily deviated by the thermal and fluid dynamics currents before they reach the target, coarser diameters (on the order of magnitude 1000 μm) are useful to penetrate at a distance reaching the heated target more efficiently but are less effective in rapidly absorbing heat in that they have a less specific surface to exchange heat with the surroundings. Detailed measurements are required to get the values of the droplet diameters issuing from the various nozzles under the various flow configurations. For the aim of this study, the water streams of interest are those able to flow and penetrate at a distance, so the droplet diameter is in the upper range above mentioned. In the absence of further information about the droplet diameters, a sensitivity analysis is conducted and the outcomes are compared to assess the numerical simulations relative to the experimental tests. Three values of the median volumetric droplet diameter are chosen for the numerical initializations: 500 μm, 1000 μm, 2000 μm. The statistical size droplet distribution and injection are left as the default given by the CFD package (Rosin-Rammler-Lognormal, 5000 particles per second injection).

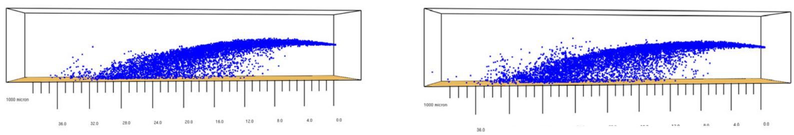
Due to the current limitation in describing the detailed forms of the finer elements of the water jet streams (knowledge of measured data, interpretations of sub-grid scales …) one practical approach in modeling for this study is to extract information about global aspects, such as visual shapes and distances travelled by the water stream, and compare the numerical data with the data obtained in the physical tests. To this end, close attention is required for defining the numerical mesh grid, in that even an overall shape of the water stream can sensibly differ from the one observed in the tests. Starting with the 500 μm droplet runs, a sensitivity study about the mesh grid of the domain revealed how a finer mesh is required to obtain an overall shape of the water streams that better resembles the one observed in the open tests. As a matter of fact, for the configuration investigated, the change from a 40 cm cubic cell to a 20 cm cubic cell has been highly significant (Figure 6).

Studies on finer mesh grids have been done for the 1000 μm and 2000 μm droplet runs, too. The case of the 1000 μm droplets runs, for example, shows an improvement in further refining the mesh, yet in general less marked when the



40 cm cubic cell mesh 20 cm cubic cell mesh

Figure 6: CFD throw and mesh grids for 500 μm droplets.



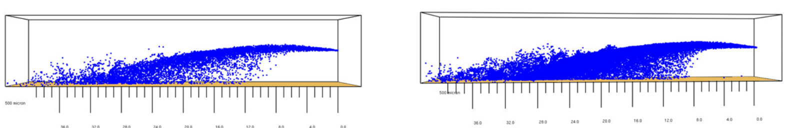
20 cm cubic cell mesh 10 cm cubic cell mesh

Figure 7: CFD throw and mesh grids for 1000 μm droplets.

refinement is from 20 cm to 10 cm compared to the 40 cm to 20 cm change (Figure 7).

Another parameter to be defined in the modeling is the number of particles injected per second by the nozzle: this serves to refine the simulation, but is not directly related to the very number of water droplets issuing from the nozzle in a real water jet stream. In the absence of sophisticated and expensive measurements, if available, a sensitivity analysis of this parameter may help in evaluating the quality of the numerical simulation and the grade of rendering.

The case of 500 μm droplet has been investigated to see the variation in the rendering between 5000 and 20000 particles per second injected from the nozzle. Given the capability of this parameter and the goal of this study, there has not been such a marked improvement as the one obtained refining the mesh grid (Figure 8).



5000 particles per second 20000 particles per second

Figure 8: CFD throw with a fine mesh grid (20 cm cubic cells) for 500 μm water droplets with two differing particles injection rates.

The results show a qualitative agreement with the overall shapes and the pattern observed in the open field tests, with some differences in the throws depending on the droplet dimension chosen for initializing the run (Figures 9 to 11).

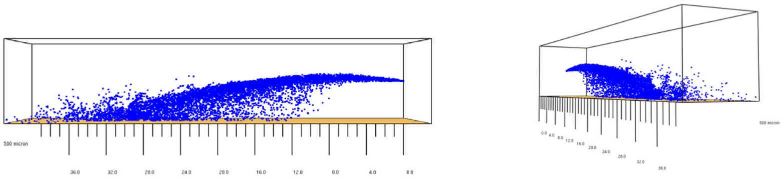


Figure 9: CFD side view and perspective for 500 μm droplets and 20 cm cell size.

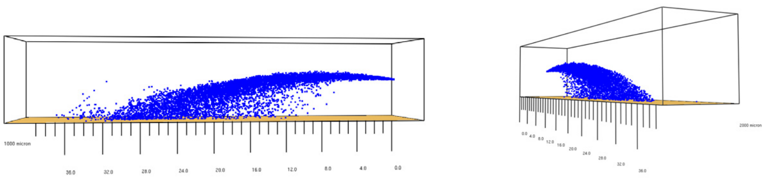


Figure 10: CFD side view and perspective for 1000 μm droplets and 20 cm cell size.

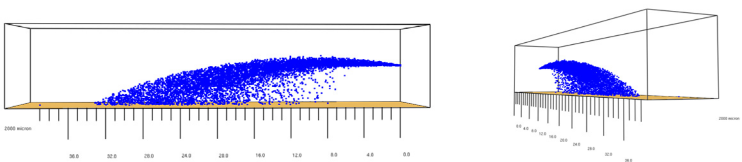
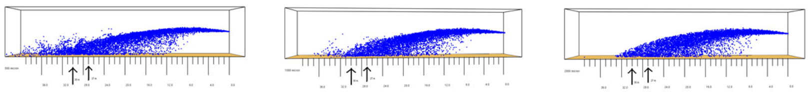


Figure 11: CFD side view and perspective for 2000 μm droplets and 20 cm cell size.

By looking at the global aspects, the elongated form of the stream and the cascading effect to the end pattern appear in the numerical simulations, even if some details cannot be replicated in terms of pulses of water sheets and very fine fringes.

As far as the throw is concerned, the length of about 27 m of the effective throw obtained in the open field tests is reasonably simulated by the numerical runs, where the global impact on the ground is a bit different depending on the droplet dimension. Taking into account the maximum throw of about 30 m, from which the effective throw is defined as its 90 %, it is possible to make further observations (Figure 12).

The global character of the throw is captured in its essential geometry (shape and pattern) and dynamics (distance and impact). Depending on the hydro-dynamical parameters used for initializing the runs, there may be more or less fading in the side ends of the water toward the ground, and some mesh refinement may add further accuracy in the similarities between the CFD models and the data obtained by the open field tests. Anyway, due to the inherent type of modeling available in the CFD for the water stream, there is not an ever increasing improvement in reducing the grid cell independently of the simulation scope, and an engineering judgement is crucial in order to acquire balanced and useful information.



500 µm 1000 µm 2000 µm

Figure 12: CFD comparison about max throw (longer arrow) and effective throw (shorter arrow) at droplets diameter: 500, 1000, 2000 µm, on a suitable same mesh grid: 20 cm cell size.

The case of 500 µm droplet runs with 5000 particles per second injection is shown as an example. By means of the available capabilities of the numerical modeling, comparison of the results show that the runs with a 20 cm cubic cell mesh grid and 500 µm droplets – ceteris paribus – seem to sufficiently resemble the overall hydraulic characteristics experienced in the open field tests, especially in terms of launching shape and throw pattern (Figure 13).

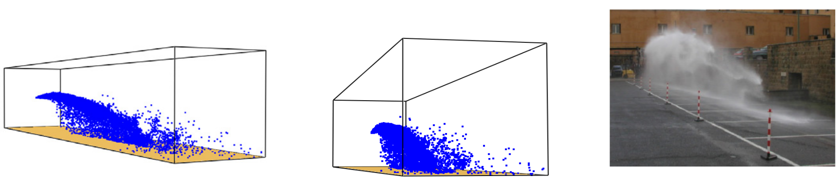


Figure 13: CFD simulation (500 µm droplets diameter, 20 cm grid cell) vs. test.

On the other hand, when dealing with a fire simulation, a mesh refinement is a necessary part of the study that deserves further considerations. In that case, together with the overall characteristics there are also some more detailed features that are of importance, principally regarding the smoke and flame treatment. In order to understand the order of magnitude involved, there are two important parameters that may be invoked that give information about the fire behavior and about the CFD package resolution of the fire plume.

The former is the Zukoski number, *Zu*, defined as a nondimensional combination of fire and ambient characteristics [6]:

$$Zu = Q\,\rho_a^{-1}\,c_p^{-1}\,T_a^{-1}\,g^{-1/2}\,D^{-5/2} \tag{1}$$

where Q is the firepower [MW], ρ_a is the ambient air density [kg m^{-3}], c_p is the air heat capacity at constant pressure [kg kJ^{-1} K^{-1}], T_a is the ambient air absolute temperature [K], g is the acceleration due to gravity [m s^{-2}], D is the fire diameter [m].

The second is the Plume resolution index *PriFDS*, defined as a nondimensional combination of fire, ambient and grid cell characteristics [3]:

$$PriFDS = (Q\, \rho_a^{-1}\, c_p^{-1}\, T_a^{-1}\, g^{-1/2})^{2/5}\, \delta_x^{-1} \tag{2}$$

where in addition δ_x is the grid cell side [m].

Considering a 4 MW fire from a 4 m^2 area in a 10 cm grid cell side domain at the ambient temperature of 15 °C, the two parameters are:

$$Zu = 0.47 \qquad PriFDS = 16.70 \tag{3}$$

showing a suitable accuracy for the fire simulation.

This mesh may now be used to model the adding of the water stream and assess the combined effect of water and fire streams. Showing the example of the 500 μm droplet, with 5000 particles per second injection, the mesh refinement from 20 cm to 10 cm cubic cells brings about an upgrading of the simulation both in terms of dynamical resolution and visual rendering (Figure 14).

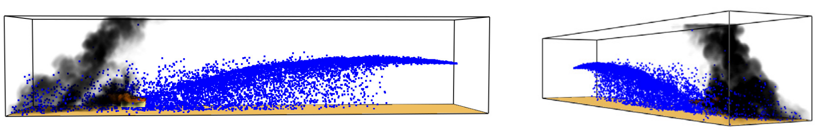


Figure 14: CFD simulation of the interaction of a water jet (500 μm droplets diameter) with a 4 MW fire source, using a 10 cm cubic cell mesh.

The essentials aspects are captured in the overall dynamics: the water stream flows and arrives on the fire target; the flame is shortened and bended; the smoke is pushed and deflected. Some finer details are also captured: the cascading of the water stream toward the fire, the twisting smoke curls rising. As for the smoke plume deflection caused by the water flow interaction with the fire source, further investigation is needed to deepen the understanding of this particular flow field and to assess the real occurrence in a field test.

3 Conclusion

The aim of this study was to illustrate how CFD may be an advantageous tool to help manage fire-fighting matters. As for the CFD water jet stream of this study, several results have been obtained by combining physical and numerical information: proper comparisons are set (influence of water droplets model), some choices appear better than others (suitable mesh grids), relative positions may be assessed (water stream on fire target). By a combined use of information acquired through numerical simulation and physical tests, it is possible to schedule a virtual environment where to compare and assess different strategies.

These strategies may represent, for example, the setting-up of a specific test or the outcome of various operations. Always bearing in mind the limitations of such an approach, principally related to a general lack of precise data to rely upon and to the inherent cut-off of the virtual modeling, the possibility of doing several runs may be nevertheless of practical importance. In fact, the virtual data that are processed may be examined and compared, so that at least some of the characteristic parameters involved may be found out, and various strategies may be examined, compared or discarded.

References

[1] Tinaburri, A. & Ponziani, F.A., CUAP 11.03/06 Fire-fighting robot kit to be used in tunnels, subsurface facilities and restricted spaces, European Organization for Technical Approvals, Bruxelles, 2012.

[2] Fire Dynamics Simulator (Version 6) – Technical Reference Guide; NIST Special Publication 1018, 2014, Online. http://www.nist.gov/el/fire_research/fds_smokeview.cfm.

[3] Fire Dynamics Simulator (Version 6) – User's Guide; NIST Special Publication 1019, 2014, Online. http://www.nist.gov/el/fire_research/fds_smokeview.cfm.

[4] Smokeview (Version 6) – Technical Reference Guide, NIST Special Publication 1017-2, 2014, Online. http://www.nist.gov/el/fire_research/fds_smokeview.cfm.

[5] Smokeview (Version 6) – User's Guide, NIST Special Publication 1017-1, 2014, Online. http://www.nist.gov/el/fire_research/fds_smokeview.cfm.

[6] Di Nenno, P.J., *The SFPE Handbook of Fire Protection Engineering*, NFPA, pp. 4-311, 4-319, 2002.

[7] Fire-fighting flow rate; London Fire Brigade, Grimwood, 2005 www.firetactics.com.

[8] Vaari J., Kling T., Hostikka S., Rinne T. & Ketola J., Simulating the Rescue Service Response in a Railway Tanker Fire, Proc. of the 13th Int. Conf. Interflam, Interscience, pp. 1359-1369, 2013.

Over 20 years of research into cybersecurity and safety engineering: a short bibliography

S. Paul & L. Rioux
Thales Research and Technology, France

Abstract

This paper provides a bibliography of research papers on safety and cybersecurity co-engineering since the early 90s. It only covers papers that address both safety and security architecting and/or engineering specialties explicitly and simultaneously.
Keywords: safety, cybersecurity, engineering.

1 Introduction

Safety and security are two risk-driven activities that are traditionally tackled separately. Since the 9/11 attacks on the Twin Towers and the discovery of the Stuxnet computer worm in June 2010, it is more and more recognised worldwide that both engineering specialties cannot continue to ignore each other.

It is evident that there are major opportunities to share on onomastics, algorithms, processes, (formal) methods and tools, in particular to reach higher levels of safety and security assurance at contained costs. Much work has already been done. This paper provides a snapshot bibliography in safety and cybersecurity co-engineering, going back to the early 90s, even if the majority of the papers are quite recent.

Safety and security are often considered as sub-factors of dependability (Laprie [1]), however the present state of the art covers dependability engineering publications only if both concerns are mentioned explicitly (Rushby [2]).

Our state of the art is organised as follows. A first group (cf. §2) comprehends the papers that state the issues related to engineering safety and cybersecurity separately, and assert that there is room for improvement, but do not explain how. The second group (cf. §3) comprehends the papers that propose to extend

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150291

the scope of safety engineering by adapting cybersecurity-related techniques. The third group (cf. §4) comprehends the papers that propose to improve cybersecurity engineering by adapting safety-related techniques. With respect to the second and third groups our paper complements the recent state of the art by Piètre-Cambacedes and Bouissou [3]. The fourth group (cf. §5) of publications advocates clean slate approaches for safety and cybersecurity co-engineering.

2 Houston, we have a problem!

A number of papers explicitly state the issues related to engineering safety without security, or engineering safety and security separately, and assert that there is room for improvement, but they do not explain how, e.g. Pfitzmann [4], Nordland [5], Gerhold [6], Schwarz [7], Wiander [8]. Many of these papers are domain specific, e.g. ICAO [9], Deleuze *et al.* [10], Bloomfield *et al.* [11], Gebauer [12], 79 FR 60574 [13], or Vogt [14].

Beyond just expressing the issues, some papers also provide high-level recommendations on the manner to address them or on the directions to investigate, but they do not run that road themselves, e.g. Daniel [15], Carter [16], Eames and Moffett [17], Smith *et al.* [18], Dewar [19], Saglietti [20] and Goertzel and Feldman [21].

Running a bit against the current, Hansen [22] recalls that even though safe systems were not designed to be secure, they often offer good properties against attacks, with a tendency to fail-safe.

3 Improving safety engineering with security considerations

Safety engineering traditionally excludes malevolent behaviour. This is usually an implicit assumption, but it is (or was) sometimes explicitly stated. Attacks on safety-critical systems have recently changed the game. The safety engineering community is addressing the issue by elaborating new techniques and standards, e.g. S+IEC 61508 [23], to seamlessly cope with cybersecurity threats that can have an impact, direct or indirect, on safety. It is possible to organise these new techniques in two sets.

The first set consists of established safety-related techniques that are enhanced to also cope with some security issues within a safety engineering process, e.g. Winther *et al.* [24], Winther [25], Yang and Yang [26], Cusimano and Byres [27], Schmittner *et al.* [28, 29], Gorbenko *et al.* [30], Babeshko *et al.* [31], Bezzateev *et al.* [32] and Bieber and Brunel [33].

The second set consists of security-related techniques that are adapted to enhance safety engineering, e.g. Johnson [34], Sindre [35], Stålhane and Sindre [36], Raspotnig ansd Opdahl [37] and McGuire [38].

Security specification is sometimes defined as the specification of what the system should not do, i.e. negative properties, e.g. non-interference in multi-level security. But negative properties are not an exclusivity of security. Such security for safety approaches are proposed by Rushby [39] and Simpson *et al.* [40].

If the major part of the paper contributions relates to adaptations, there are also some novel and/or disruptive approaches, e.g. Sommerville [41], Olive *et al.* [42], Knorreck and Apvrille [43], Pedroza *et al.* [44], Apvrille and Roudier [45] and Brunel *et al.* [46, 47].

Beyond the aforementioned focused techniques, there are various initiatives of the safety community which address the issue in a more comprehensive manner, in particular with respect to standards, e.g. SEISES [48], Bieber *et al.* [49], Paulitsch *et al.* [50], MODSafe [51], Bock *et al.* [52] and Goertzel *et al.* [53]. We can distinguish two categories of initiatives. The first category defines new approaches that include security aspects whist maintaining compliance to existing standards. The second category defines new standards, or new versions of standards, that natively include security aspects.

Initiatives of the first category usually consist in analysing the gaps and overlaps between two (or more) existing standards in order to identify additional activities that need to be performed with respect to one standard used as baseline, in order to achieve dual compliance, e.g., Corneillie *et al.* [54], Alves-Foss *et al.* [55], Taylor *et al.* [56, 57], Novak *et al.* [58], Ridgway [59], Derock *et al.* [60], Blanquart *et al.* [61] and Czerny [62].

Initiatives of the second category are essentially domain-specific, e.g. ED-202 [63], ED-202A [64] as discussed in Casals *et al.* [65], Rowe [66], Joyce and Fabre [67], and EN 20159 [68], or S+IEC 61508 [23] as discussed in McGuire [38] and Schoitsch [69].

4 Improving security engineering with safety techniques

Safety engineering is recognised as a more mature engineering speciality than security engineering. Thus, multiple authors propose to adapt safety engineering techniques to the security domain. Most approaches are technical, but there are a few exceptions, e.g. Brostoff and Sasse [70], Fruth and Nett [71] and Gutgarts and Temin [72].

Papers describing focused technical approaches include Lynch [73], Foster [74], Lano *et al.* [75], Srivatanakul *et al.* [76], Daruwala *et al.* [77], Helmer *et al.* [78], Brooke and Paige [79], Murdoch *et al.* [80], Nicol *et al.* [81] and Rushdi and Ba-Rukab [82, 83].

Beyond specific techniques, some papers have a more comprehensive approach by adapting the overall good practices and lessons learnt of safety engineering to security engineering, e.g. Axelrod [84] and Young and Leveson [85].

5 Towards safety and security co-engineering

Amongst the first communities to address the relations between safety and security was the formal methods community, with the challenge of formalising the concepts, the mechanisms employed to safeguard them, and their interplay, e.g. Rushby [2, 39], Burns *et al.* [86], Stavridou and Dutertre [87], Ramirez *et al.* [88]. This community is still very active, e.g. Boettcher *et al.* [89], EURO-MILS

[90], Müller *et al.* [91], Tverdyshev [92], Fisher [93] and Tiwari *et al.* [94] in the scope of DARPA I2O HACMS [95] and Delange [96]. A comprehensive review of Formal Methods for Safe and Secure Computers Systems is given by Garavel and Graf [97].

Some studies are less formal, but have the similar goals of better understanding the relations between safety and security, e.g. Piètre-Cambacédès and Chaudet [98], and establishing a common information model for safety and security, e.g. Avizienis *et al.* [99], Jonsson [100], Jonsson and Olovsson [101], Stoneburner [102], Firesmith [103, 104], Mattila [105], Burns *et al.* [86] and Piètre-Cambacédès and Chaudet [98]. A compromise between formal and non-formal approaches is proposed by Chapon and Piètre-Cambacédès [106] and Sadvandi *et al.* [107].

Unifying focused engineering techniques used in safety and security is often recommended, e.g. by Lano *et al.* [75], Fovino *et al.* [108], Förster *et al.* [109], Steiner and Liggesmeyer [110], Piètre-Cambacédès and Bouissou [111] and Reichenbach *et al.* [112]. Except for Raspotnig and Opdahl [113], few papers however propose a framework to justify why specific attention is given this or that technique.

Even if a unification or harmonisation of the safety and security engineering approaches is commonly proposed, disruptive focused techniques are also proposed, e.g. Sallhammar *et al.* [114], Aven [115], Kornecki *et al.* [116] and Vouk [117].

Beyond the aforementioned focused techniques, there are various proposals for an overall unification, e.g. the MAFTIA project [118], Hessami [119], SafSec [120], Jackson and Dobbing [121], Ibrahim *et al.* [122], Firesmith [103], Raspotnig and Opdahl [37], Raspotnig *et al.* [123], and Raspotnig [124], Katta *et al.* [125], Pedroza *et al.* [44], Sadvandi *et al.* [107], Aoyama and Koike [126], Axelrod [127–129], Schoitsch [130], Line *et al.* [131], Aven [132, 133], Förster *et al.* [109], Aoyama *et al.* [126], Banerjee *et al.* [134] and the SeSaMo project [135] as discussed in Mazzini *et al.* [136] and Favaro and Stroud [137].

It is difficult to assess which unified approach will emerge as we believe that the ultimate approach to co-engineering has not yet been found, cf. Kriaa *et al.* [138].

Unification initiatives can also be found in standards, e.g. ISO 31000 [139], IEC 31010 [140], ISO/IEC 15026-2 [141] OMG SACM [142]. In domains in which compliance to standards is of utmost importance, generic co-engineering approaches and technical solutions as presented above are rarely helpful, especially when one starts searching for the devil in the details, cf. Åkerberg [143] and Braband [144, 145].

Of course, when both safety and security concerns are addressed for a giving system, striking the proper balance between these two, sometimes contradictory, sets of requirements may be a challenge. Proposals are given by Nielson and Nielson [146] and Labreuche and Lehuédé [147], and further ones should be published in the scope of the MERgE project [148].

6 Future work

The ITEA2 MERgE project was launched at the end of 2012 to address the industrial challenges of efficiently and economically handling multi-concerns, with a particular focus on the co-engineering of the safety and security specialities. The research work presented here represents a snapshot of this collaborative work. A more comprehensive review of the safety and cybersecurity engineering state of the art will be provided soon in Paul *et al.* [149].

Acknowledgements

The research leading to these results has received funding from the European Union ITEA 2 Programme (Call 6) under grant no. 11011 (MERgE). The authors wish to acknowledge F. Vallée and A. Faucogney (ALL4TEC), T. Wiander (STUK) and J. Brunel (ONERA).

References

[1] J.-C. Laprie, Dependability: Basic Concepts and Terminology, vol. 5, Vienna: Springer, 1992, pp. 3–245.
[2] J. Rushby, "Critical properties: survey and taxonomy," Menlo Park, 1994.
[3] L. Piètre-Cambacedes and M. Bouissou, "Cross-fertilizations between safety and security engineering," *Reliability Engineering & System Safety,* vol. 110, pp. 110–126, 2013.
[4] A. Pfitzmann, "Why Safety and Security Should and Will Merge, Volume," in *Computer Safety, Reliability, and Security, Lecture Notes in Computer Science*, vol. 3219, 2004, pp. 1–2.
[5] O. Nordland, "Some Security Aspects in Safety-Related Systems," in *The Relationship between Safety and Security in Software-Based Systems, SafeComp Workshop*, 2008.
[6] L. Gerhold, "The Future of Research on Safety and Security in Germany – Results from an Explorative Delphi Study," in *Security in Futures – Security in Change, Proceedings of the Conference "Security in Futures – Security in Change", 3–4 June 2010, Turku, Finland*, B. Auffermann and J. Kaskinen, Eds., 2011.
[7] R. Schwarz, "My thoughts on safety and security metrics," in *1st IESE Workshop on Safety and Security*, Kaiserslautern, 2014.
[8] T. Wiander, "Positive and Negative Findings of the ISO/IEC 17799 Framework," in *Proceedings of the 18th Australasian Conference on Information Systems (ACIS)*, Toowoomba, 2007.
[9] ICAO, "Study on the Safety and Security Aspects of Economic Liberalization," International Civil Aviation Organization, 2005.
[10] G. Deleuze, E. Chatelet, P. Laclemence, J. Piwowar and B. Affeltranger, "Are safety and security in industrial systems antagonistic or

complementary issues?," in *17th European safety and reliability conference (ESREL)*, Valencia, CRC Press, 2009, pp. 3093–3100.

[11] R. Bloomfield, R. Bloomfield, I. Gashi and R. Stroud, "How secure is ERTMS?," in *Workshop on Dependable and Secure Computing for Large-scale Complex Critical Infrastructures (DESEC4LCCI)*, Herrenkrug, 2012.

[12] C. Gebauer, "Safety & security as drivers for future system development," in *1st Workshop on Safety & Security*, Kaiserslautern, 2014.

[13] 79 FR 60574, "Request for Comment on Automotive Request for Comment on Automotive Security," in *Federal Register Volume 79, Issue 194 (October 7, 2014)*, 194 ed., vol. 79, Office of the Federal Register, National Archives and Records Administration, 2014, pp. 60574–60583.

[14] R. Vogt, "Safety/security conflicts in large system architectures," in *1st Workshop on Safety and Security*, Kaiserslautern, 2014.

[15] H. Daniel, "Security in Safety Systems: the Need to Step beyond Traditional Engineering," in *The Relationship between Safety and Security in Software-Based Systems, SafeComp Workshop*, 2008.

[16] A.-L. Carter, "Safety-Critical versus Security-Critical Software," in *5th IET International Conference on System Safety*, Manchester, 2010.

[17] D. P. Eames and J. Moffett, "The Integration of Safety and Security Requirements," in *SAFECOMP '99 Proceedings of the 18th International Conference on Computer Computer Safety, Reliability and Security*, London, Springer-Verlag, 1999, pp. 468–480.

[18] J. Smith, S. Russell and M. Looi, "Security as a Safety Issue in Rail Communications," in *Proceedings of SCS'03, 8th Australian Workshop on Safety Critical Systems and Software, Canberra, October 9–10, 2003*, vol. 33, I. Australian Computer Society, Ed., ACM, 2003, pp. 79– 88.

[19] R. B. K. Dewar, "Safety and security: two sides of the same coin?," in *The Relationship between Safety and Security in Software-Based Systems, SafeComp Workshop*, 2008.

[20] F. Saglietti, "Common Analysis and Verification Techniques for Safety- and Security- Critical Software Systems," in *The Relationship between Safety & Security in Software-Based Systems, SafeComp Workshop*, 2008.

[21] M. K. Goertzel and L. Feldman, "Software Survivability: Where Safety and Security Converge," in *Proceedings of the AIAA Infotech@Aerospace Conference*, Seattle, 2009.

[22] K. Hansen, "Security attack analysis of safety systems," in *Proceedings of IEEE Conference on Emerging Technologies & Factory Automation (ETFA)*, Mallorca, 2009, pp. 1–4.

[23] S+IEC 61508, "Functional safety of electrical/electronic/programmable electronic safety-related systems," International Electrotechnical Commission, 2010.

[24] R. Winther, O.-A. Johnsen and B. A. Gran, "Security assessments of safety critical systems using HAZOPs," in *SafeComp'01 Proceedings of the 20th International Conference on Computer Safety, Reliability and Security*, Springer-Verlag, Ed., London, 2001, pp. 14–24.

[25] R. Winther, "Qualitative and Quantitative Analysis of Security in Safety and Reliability Critical Systems," in *Probabilistic Safety Assessment and Management*, vol. 6, C. S. .. U. Schmocker and V. N. Dang, Eds., London, Springer, 2004, pp. 2345–2351.

[26] L. Yang and S. H. Yang, "A Framework of Security and Safety Checking for Internet-Based Control Systems," *Int. J. Information and Computer Security,* vol. 1, no. 1/2, pp. 185–200, 2007.

[27] J. Cusimano and E. Byres, "Safety and Security: Two Sides of the Same Coin," April 2010. [Online]. Available: http://www.controlglobal.com/articles/2010/safetysecurity1004.

[28] C. Schmittner, T. Gruber, P. Puschner and E. Schoitsch, "Security Application of Failure Mode and Effect Analysis (FMEA)," in *33rd International Conference on Computer Safety, Reliability and Security (SafeComp)*, Florence, 2014b.

[29] C. Schmittner, Z. Ma and P. Smith, "FMVEA for Safety and Security Analysis," in *1st International Workshop on the Integration of Safety and Security Engineering (ISSE), 33rd International Conference on Computer Safety, Reliability and Security (SafeComp)*, Florence, 2014a.

[30] A. Gorbenko, V. Kharchenko, O. Tarasyuk and A. Furmanov, "F(I)MEA-technique of Web Services Analysis and Dependability Ensuring," in *Rigorous Development of Complex Fault-Tolerant Systems, Lecture Notes in Computer Science*, vol. 4157, M. Butler, C. B. Jones, A. Romanovsky and E. Troubitsyna, Eds., Berlin Heidelberg, Springer, 2006, pp. 153–167.

[31] E. Babeshko, V. Kharchenko and A. Gorbenko, "Applying F(I)MEA-technique for SCADA-Based Industrial Control Systems Dependability Assessment and Ensuring," in *Third International Conference on Dependability of Computer Systems*, Szklarska Poreba, 2008.

[32] S. Bezzateev, N. Voloshina and P. Sankin, "Joint Safety and Security Analysis for Complex Systems," in *13th Conference of Open Innovations Association FRUCT*, Petrozavodsk, Russia, 2013.

[33] P. Bieber and J. Brunel, "From Safety Models to Security Models: Preliminary Lessons Learnt," in *1st International Workshop on the Integration of Safety and Security Engineering (ISSE)*, Florence, 2014.

[34] R. G. Johnson, "Adversarial safety analysis: borrowing the methods of security vulnerability assessments," *Journal of Safety Research,* vol. 35, no. 3, pp. 245–248, 2004.

[35] G. Sindre, "A look at misuse cases for safety concerns," in *Situational Method Engineering: Fundamentals and Experiences*, vol. 244, S. Boston, Ed., IFIP, 2007, pp. 252–266.

[36] T. Stålhane and G. Sindre, "Safety Hazard Identification by Misuse Cases: Experimental Comparison of Text and Diagrams," in *Model Driven Engineering Languages and Systems, Lecture Notes in Computer Science*, vol. 5301, Springer Berlin Heidelberg, 2008, pp. 721–735.

[37] C. Raspotnig and A. L. Opdahl, "Improving security and safety modelling with failure sequence diagrams," in *International Journal of Secure Software Engineering (IJSSE)*, 2012a, pp. 20–36.

[38] N. McGuire, “Utilizing security methods of FLOSS GPOS for safety,” in *Embedded World Exhibition & Conference*, Nürnberg, 2011.
[39] J. Rushby, “Kernels for Safety?,” in *Safe and Secure Computing Systems*, Blackwell Scientific Publications, 1989, pp. 210–220.
[40] A. Simpson, J. Woodcock and J. Davies, “Safety through Security,” in *IWSSD'98 Proceedings of the 9th international workshop on Software specification and design*, I. C. Society, Ed., Washington, 1998, pp. 18–24.
[41] I. Sommerville, “An Integrated Approach to Dependability Requirements Engineering,” in *Current Issues in Safety-Critical Systems*, Springer, Ed., London, 2003, pp. 3–15.
[42] M. L. Olive, R. T. Oishi and S. Arentz, “Commercial Aircraft Information Security — An Overview of ARINC Report 811,” in *25th Digital Avionics Systems Conference (DASC)*, Portland, 2006.
[43] D. Knorreck and L. Apvrille, “TEPE: A SysML Language for Time-Constrained Property Modeling and Formal Verification,” in *Third IEEE International workshop UML and Formal Methods (UML&FM)*, Shanghai, 2010.
[44] G. Pedroza, L. Apvrille and D. Knorreck, “AVATAR: A SysML environment for the formal verification of safety and security properties,” in *11th International Conference on New Technologies of Distributed Systems (NOTERE)*, Paris, 2011.
[45] L. Apvrille and Y. Roudier, “Towards the Model-Driven Engineering of Secure yet Safe Embedded Systems,” in *Proceedings of 1st International Workshop on Graphical Models for Security (GraMSec)*, Grenoble, 2014.
[46] J. Brunel, L. Rioux, S. Paul, A. Faucogney and F. Vallée, “Formal Safety and Security Assessment of an Avionic Architecture with Alloy,” in *3rd International Workshop on Engineering Safety and Security Systems (ESSS)*, vol. 150, Singapore, EPTCS, 2014a, pp. 8–19.
[47] J. Brunel, D. Chemouil, L. Rioux, M. Bakkali and F. Vallée, “A Viewpoint-Based Approach for Formal Safety & Security Assessment of System Architectures,” in *11th Workshop on Model Driven Engineering, Verification and Validation (MoDeVVa)*, Valencia, 2014b.
[48] SEISES, “Cooperative Projects,” FUI, 2008. [Online]. Available: http://www.aerospace-valley.com/les-projets?keywords=seises.
[49] P. Bieber, J.-P. Blanquart, G. Descargues, M. Dulucq, Y. Fourastier, E. Hazane, M. Julien, L. Léonardon and G. Sarouille, “Security and Safety Assurance for Aerospace Embedded Systems,” in *Embedded Real-Time Software and Systems (ERTS)*, Toulouse, 2012.
[50] M. Paulitsch, R. Reiger, L. Strigini et R. E. Bloomfield, “Evidence-Based Security in Aerospace: From Safety to Security and Back Again”, chez *IEEE 23rd International Symposium on Software Reliability Engineering Workshops (ISSREW)*, 2012.
[51] MODSafe, “Modular Urban Transport Safety and Security Analysis,” EU FP7, 01 09 2008. [Online]. Available: http://www.modsafe.eu/.
[52] H.-H. Bock, J. Braband, B. Milius and H. Schäbe, “Towards an IT Security Protection Profile for Safety-Related Communication in Railway

Automation," in *31st International Conference on Computer Safety, Reliability and Security (SafeComp)*, Magdeburg, 2012.

[53] K. M. Goertzel, T. Winograd and B. A. Hamilton, "Safety and Security Considerations for Component-Based Engineering of Software-Intensive Systems," Navy Software Process Improvement Initiative (SPII) and Department of Homeland Security, 2011.

[54] P. Corneillie, S. Moreau, C. Valentin, J. Goodson, A. Hawes, T. Manning, H. Kurth, G. Liebisch, A. Steinacker, Y. Deswarte, M. Kaaniche and P. Benoit, "SQUALE Dependability Assessment Criteria," LAAS-CNRS, 1999.

[55] J. Alves-Foss, B. Rinker and C. Taylor, "Towards Common Criteria Certification for DO-178B Compliant Airborne Software Systems, Comparing Evaluation Assurance Level 5 (EAL5) to DO178," Center for Secure and Dependable Systems, 01 2002. [Online]. Available: http://www2.cs.uidaho.edu/~jimaf/papers/compare02b.pdf.

[56] C. Taylor, J. Alves-Foss and B. Rinker, "Towards Common Criteria Certification for DO-178B: Executive Summary," Center for Secure and Dependable Systems, 03 2002a. [Online]. Available: http://www2.cs.uidaho.edu/~jimaf/papers/compare02a.pdf.

[57] C. Taylor, J. Alves-Foss and B. Rinker, "Merging Safety and Assurance: the Process of Dual Certification of Software," in *Software Technology Conference*, 2002.

[58] T. Novak, A. Treytl and P. Palensky, "Common Approach to Functional Safety and System Security in Building Automation and Control Systems," in *Proceedings of Conference on Emerging Technologies and Factory Automation (ETFA)*, IEEE, 2007, pp. 1141–1148.

[59] J. Ridgway, "Achieving Safety through Security Management," in *The Safety of Systems*, London, Springer, 2007.

[60] A. Derock, P. Hebrard and F. Vallée, "Convergence of the latest standards addressing safety and security for information technology," in *On-line proceedings of Embedded Real Time Software and Systems (ERTS2 2010)*, Toulouse, France, 2010.

[61] J.-P. Blanquart, P. Bieber, G. Descargues, E. Hazane, M. Julien and L. Léonardon, "Similarities and dissimilarities between safety levels and security levels," 03 02 2012. [Online]. Available: http://www.erts2012.org /Default.aspx?Id=1050&Idd=1129.

[62] B. J. Czerny, "System Security and System Safety Engineering: Differences and Similarities and a System Security Engineering Process Based on the ISO 26262 Process Framework," *Journal of Passenger Cars – Electronic and Electrical Systems,* vol. 6, no. 1, 2013.

[63] EUROCAE ED-202, "Airworthiness security process specification," European Organization for Civil Aviation Equipment (EUROCAE), 2010.

[64] EUROCAE ED-202A, "Airworthiness Security Process Specification," European Organization for Civil Aviation Equipment (EUROCAE), 2014.

[65] S. G. Casals, P. Owezarski and G. Descargues, "Risk Assessment for Airworthiness Security," in *Computer Safety, Reliability, and Security, Lecture Notes in Computer Science*, vol. 7612, 2012, pp. 25–36.

[66] J. Rowe, "Software Security & Design Assurance," in *Design & Manufacture Seminar*, 2013.

[67] J. Joyce and L. Fabre, "Integration of security & airworthiness in the context of certification and standardization," in *1st workshop on the Integration of Safety and Security Engineering (ISSE)*, Florence, 2014.

[68] CENELEC EN 20159, "Railway applications – Communication, signalling and processing systems – Safety-related communication in transmission systems," European Committee for Electro-technical Standardization, 2010.

[69] E. Schoitsch, "Safety and security – what about a joint process?," in *1st Workshop on Safety & Security*, Kaiserslautern, 2014.

[70] S. Brostoff and M. A. Sasse, "Safe and sound: a safety-critical approach to security," in *NSPW'01 Proceedings of the 2001 workshop on new security paradigms*, ACM, Ed., New York, NY, 2001, pp. 41–50.

[71] J. Fruth and E. Nett, "Uniform Approach of Risk Communication in Distributed IT Environments Combining Safety and Security Aspects," in *1st International Workshop on the Integration of Safety and Security Engineering (ISSE), 33rd International Conference on Computer Safety, Reliability and Security (SafeComp)*, Florence, 2014.

[72] P. B. Gutgarts and A. Temin, "Security-Critical versus Safety-Critical Software," in *Proceedings of IEEE International Conference on Technologies for Homeland Security (HST)*, 2010.

[73] J. A. Lynch, "Applying Safety Critical Systems Engineering Techniques to Secure Systems," 2002.

[74] N. L. Foster, "The application of software and safety engineering techniques to security protocol development," University of York, 2002.

[75] K. Lano, D. Clark and K. Androutsopoulos, "Safety and Security Analysis of Object-Oriented Models," in *Computerp. Safety, Reliability and Security – Proceedings of 21st International SAFECOMP Conference, Catania, Italy, September 10–13, 2002*, vol. 2434, S. B. Heidelberg, Ed., 2002, pp. 82–93.

[76] T. Srivatanakul, J. A. Clark and F. Polack, "Effective Security Requirements Analysis: HazOp and Use Cases," in *Information Security, Lecture Notes in Computer Science*, vol. 3225, Berlin/Heidelberg, Springer, 2004, pp. 416–427.

[77] B. Daruwala, S. Mandujano, N. K. Mangipudi and H.-c. Wong, "Threat Analysis for Hardware and Software Products Using HazOp," in *International Conference on Computational and Information Science (CIS'09)*, Stevens Point, Wisconsin: World Scientific and Engineering Academy and Society (WSEAS), 2009, pp. 446–453.

[78] G. Helmer, J. Wong, M. Slagell, V. Honavar, L. Miller and R. Lutz, "A Software Fault Tree Approach to Requirements Analysis of an Intrusion

Detection System," *Requirements Engineering,* vol. 7, no. 4, pp. 207–220, 2002.

[79] P. J. Brooke and R. F. Paige, "Fault trees for security system design and analysis," *Computers & Security,* vol. 22, no. 3, pp. 256–264, 2003.

[80] J. Murdoch, J. Allen, F. Anderson, M. Ashford, N. Bartol, M. Campbell, P. Caseley, V. Cocca, E. Fitzsimmons, P. Flora, J. Gaffney, G. Hafen, J. Janigan, J. Jarzombek, C. Jones, M. Kass and G. Larsen, "Security Measurement," Practical Software and Systems Measurement, 2006.

[81] D. M. Nicol, W. H. Sanders and K. S. Trivedi, "Model-based evaluation: from dependability to security," *IEEE Transactions on Dependable and Secure Computing,* vol. 1, no. 1, pp. 48–65, 2004.

[82] A. Rushdi and O. Ba-Rukab, "A doubly-stochastic fault-tree assessment of the probabilities of security breaches in computer systems," in *Proceedings of the 2nd Saudi Science Conference*, vol. 4, 2004, pp. 1–17.

[83] A. Rushdi and O. Ba-Rukab, "Fault-tree modelling of computer system security," *International Journal of Computer Mathematics,* vol. 82, pp. 805–819, 2005.

[84] C. W. Axelrod, "Applying Lessons from Safety-Critical Systems to Security-Critical Software," in *IEEE Systems, Applications and Technology Conference (LISAT)*, Farmingdale, NY, USA, 2011.

[85] W. Young and N. G. Leveson, "Inside Risks: An Integrated Approach to Safety and Security Based on Systems Theory," *Communications of the ACM,* vol. 57, no. 2, pp. 31–35, 2014.

[86] A. Burns, J. McDermid and J. Dobson, "On the meaning of safety and security," in *The Computer Journal – Special issue on safety and security parallel*, 1st ed., vol. 35, Oxford, Oxford University Press, 1992, pp. 3–15.

[87] V. Stavridou and B. Dutertre, "From Security to Safety and Back," in *Computer Security, Dependability and Assurance: From needs to Solutions. Proceedings*, IEEE, Ed., York, 1998, pp. 182–195.

[88] A. G. Ramirez, J. Schmaltz, F. Verbeek, B. Langenstein and H. Blasum, "On Two Models of Noninterference: Rushby and Greve, Wilding, and Vanfleet," in *33rd International International Conference on Computer Safety, Reliability, and Security (SAFECOMP)*, Florence, 2014.

[89] C. Boettcher, R. DeLong, J. Rushby and W. Sifre, "The MILS Component Integration Approach to Secure Information Sharing," in *Proceedings o fthe 27th IEEE/AIAA Digital Avionics Systems Conference (DASC)*, St. Paul, MN, 2008.

[90] EURO-MILS EC FP7 Project, "EURO-MILS," 01 10 2012. [Online]. Available: http://www.euromils.eu/. [Accessed 16 09 2014].

[91] K. Müller, M. Paulitsch, R. Schwarz, S. Tverdyshev and H. Blasum, "MILS-Based Information Flow Control in the Avionic Domain: a Case Study on Compositional Architecture and Verification," in *31st Digital Avionics Systems Conference (DASC)*, Williamsburg, 2012.

[92] S. Tverdyshev, "MILS – Architecture for Safety and Security," in *1st workshop on safety and security*, Kaiserslautern, 2014.

[93] K. Fisher, “High Assurance Cyber Military Systems (HACMS): Making sure you are in control of your vehicle,” 2013.
[94] A. Tiwari, D. Jovanovic, P. Lincoln and D. Sadigh, “Safety Envelope for Security,” in *3rd international conference on High Confidence Networked Systems (HiCoNS)*, Berlin, 2014.
[95] DARPA I2O HACMS, “High-Assurance Cyber Military Systems (HACMS),” DARPA, 06 11 2014. [Online]. Available: http://www.darpa.mil/opencatalog/HACMS.html. [Accessed 21 11 2014].
[96] J. Delange, “Security and dependability integration for the construction of critical middleware (in French),” TELECOM ParisTech, Paris, 2010.
[97] H. Garavel and S. Graf, “Formal Methods for Safe and Secure Computers Systems,” Federal Office for Information Security, 2013.
[98] L. Piètre-Cambacédès and C. Chaudet, “Disentangling the relations between safety and security,” in *AIC'09 Proceedings of the 9th WSEAS international conference on Applied informatics and communications*, Stevens Point, Wisconsin, 2009.
[99] A. Avizienis, J.-C. Laprie, B. Randell and C. Landwehr, “Basic concepts and taxonomy of dependable and secure computing,” in *IEEE Trans. Dependable Secur. Comput.*, 2004, pp. 11–33.
[100] E. Jonsson, “Towards an integrated conceptual model of security and dependability,” in *First International Conference on Availability, Reliability and Security (ARES)*, 2006.
[101] E. Jonsson and T. Olovsson, “On the Integration of Security and Dependability in Computer Systems,” in *International Conference on Reliability, Quality Control and Risk Assessment*, Washington DC, 1992.
[102] G. Stoneburner, “Toward a Unified Security-Safety Model,” vol. 39, IEEE Computer, 2006, pp. 96–97.
[103] D. G. Firesmith, “Tutorial: Engineering safety- and security-related requirements for software-intensive systems,” in *6th International Workshop on Software Engineering for Secure Systems (SESS’10) Workshop at the 32nd ICSE Conference*, Cape Town, South Africa, 2010.
[104] D. G. Firesmith, “Common concepts underlying safety, security, and survivability engineering,” 2003.
[105] M. Mattila, “Different Views on Defining Safety, Security and Social Responsibility,” *Interdisciplinary Studies Journal – Special Issue on Security, Safety and Social Responsibility,* vol. 3, no. 1, pp. 7–20, 2013.
[106] N. Chapon and L. Piètre-Cambacédès, “Vers une ingénierie système intégrant sûreté et sécurité (in French),” in *Génie Logiciel*, 100th ed., 2012, pp. 16–21.
[107] S. Sadvandi, N. Chapon and L. Piètre-Cambacédès, “Safety and Security Interdependencies in Complex Systems and SoS: Challenges and Perspectives,” in *Complex Systems Design and Management (CSDM)*, Springer Berlin Heidelberg, 2012, pp. 229–241.
[108] I. N. Fovino, M. Masera and A. De Cian, “Integrating Cyber Attacks within Fault Trees,” *Reliability Engineering and System Safety,* vol. 94, no. 9, pp. 1394–1402, 2009.

[109] M. Förster, R. Schwarz and M. Steiner, "Integration of modular safety and security models for the analysis of the impact of security on safety," Fraunhofer IESE, 2010.

[110] M. Steiner and P. Liggesmeyer, "Combination of Safety and Security Analysis – Finding Security Problems that Threaten the Safety of a System," in *ERCIM/EWICS Workshop on Dependable Embedded and Cyber-physical Systems (DECS)*, 2013.

[111] L. Piètre-Cambacédès and M. Bouissou, "Modeling safety and security interdependencies with BDMP (Boolean logic Driven Markov Processes)," in *IEEE International Conference Systems Man and Cybernetics (SMC)*, Istanbul, 2010.

[112] F. Reichenbach, J. Endresen, M. M. R. Chowdhury and J. Rossebø, "A pragmatic approach on combined safety and security risk analysis," in *IEEE 23rd International Symposium on Software Reliability Engineering Workshops (ISSREW)*, Dallas, IEEE, 2012, pp. 239–244.

[113] C. Raspotnig and A. L. Opdahl, "Comparing risk identification techniques for safety and security requirements," *Journal of Systems and Software,* vol. 86, no. 4, pp. 1124–1151, 2013a.

[114] K. Sallhammar, B. E. Helvik and S. J. Knapskog, "Towards a Stochastic Model for Integrated Security and Dependability Evaluation," in *1st International Conference on Availability, Reliability and Security*, Washington, 2006.

[115] T. Aven, "Identification of safety and security critical systems and activities," in *Reliability Engineering & System Safety*, 2009, pp. 404–411.

[116] A. J. Kornecki, N. Subramanian and J. Zalewski, "Studying Interrelationships of Safety and Security for Software Assurance in Cyber-Physical Systems: Approach Based on Bayesian Belief Networks," in *Proceedings of the 2013 Federated Conference on Computer Science and Information Systems (FedCSIS)*, Kraków, 2013.

[117] M. A. Vouk, "Differences and Similarities between Software Reliability and Software Security Engineering," in *Software Reliability in 2013: Theory & Practice*, Levallois-Perret, 2013.

[118] MAFTIA, "Malicious-and Accidental-Fault Tolerance for Internet Applications," IST MAFTIA Project n°11583, 01 01 2000. [Online]. Available: http://webhost.laas.fr/TSF/cabernet/maftia/.

[119] A. G. Hessami, "A systems framework for safety and security: The holistic paradigm", chez *Systems Engineering*, 2nd éd., vol. 7, Wiley Periodicals, 2004, pp. 99–112.

[120] Altran Praxis, "SafSec Methodology, Issue 3.1," 2006.

[121] D. Jackson and B. Dobbing, "Changing Regulation in Safety and Security – Implications and Opportunities," in *The Relationship between Safety and Security in Software-Based Systems, SafeComp Workshop*, 2008.

[122] L. Ibrahim, J. Jarzombek, M. Ashford, R. Bate, P. Croll, M. Horn, L. LaBruyere, C. Wells and al., "Safety and Security Extensions for Integrated Capability Maturity Models," 2004.

[123] C. Raspotnig, P. Karpati and V. Katta, "A Combined Process for Elicitation and Analysis of Safety and Security Requirements," in *Enterprise, Business-Process and Information Systems Modeling (EMMSAD), Lecture Notes in Business Information Processing*, vol. 113, Springer Berlin Heidelberg, 2012b, pp. 347–361.
[124] C. Raspotnig, "Requirements for safe and secure information systems," 2014.
[125] V. Katta, C. Raspotnig and T. Stålhane, "Requirements management in a combined process for safety and security assessments," in *8th International Conference on Availability, Reliability and Security (ARES)*, Regensburg, Germany, 2013a.
[126] T. Aoyama, M. Koike, I. Koshijima and Y. Hashimoto, "A unified framework for safety and security assessment in critical infrastructures," in *Safety and security engineering V*, vol. 134, F. Garzia, C. A. Brebbia and M. Guarascio, Eds., WIT Press, 2013.
[127] C. W. Axelrod, Engineering Safe and Secure Software Systems, Artech House Publishers, 2012.
[128] C. W. Axelrod, "Securing Cyber-Physical Software," 18–21 Nov. 2013b. [Online]. Available: http://2013.appsecusa.org/2013/wp-content/uploads/2013/12/APPSEC2013-Presentation-Final.ppt.
[129] C. W. Axelrod, "Managing the risks of cyber-physical systems," in *IEEE Systems, Applications and Technology Conference (LISAT)*, Farmingdale, NY: IEEE, 2013c, pp. 1–6.
[130] E. Schoitsch, "Design for safety and security of complex embedded systems: a unified approach," in *Cyberspace Security and Defense: Research Issues, NATO Science Series II: Mathematics, Physics and Chemistry*, vol. 196, Springer Netherlands, 2005, pp. 161–174.
[131] M. B. Line, O. Nordland, L. Rostad and I. A. Tondel, "Safety vs. Security?," in *International Conference on Probabilistic Safety Assessment and Management (PSAM 8)*, New Orleans, USA, 2006.
[132] T. Aven, "A unified framework for risk and vulnerability analysis covering both safety and security," in *Proceedings of Reliability Engineering & System Safety*, 2007, pp. 745–754.
[133] T. Aven, "A unified framework for risk and vulnerability analysis covering both safety and security," 4th ed., vol. 39, IEEE, 2011, pp. 123–134.
[134] A. Banerjee, K. K. Venkatasubramanian, T. Mukherjee and S. K. S. Gupta, "Ensuring Safety, Security, and Sustainabilityof Mission-Critical Cyber–Physical Systems," *IEEE Proceedings,* vol. 100, no. 1, pp. 283–299, 2012.
[135] SeSaMo, "Security and Safety Modelling," 2012. [Online]. Available: http://sesamo-project.eu/. [Accessed 20 05 2014].
[136] S. Mazzini, S. Mazzini, A. Martelli and L. Baracchi, "Security and Safety Modelling in Embedded Systems," in *Embedded Real Time Software and Systems (ERTS)*, Toulouse, 2014.

[137] J. Favaro and R. Stroud, "ARTEMIS SESAMO Project: Work Achieved and Perspectives," in *1st International Workshop on the Integration of Safety and Security Engineering (ISSE), 33rd International Conference on Computer Safety, Reliability and Security (SafeComp)*, Florence, 2014.
[138] S. Kriaa, C. Raspotnig, M. Bouissou, L. Pietre-Cambacedes, P. Karpati, Y. Halgand and V. Katta, "Comparing two approaches to safety and security modelling: BDMP technique and CHASSIS method," in *OECD Halden Reactor Project, 37th Enlarged Halden Programme Group (EHPG) meeting*, Storefjell, 2013.
[139] ISO 31000, "Risk management – Principles and guidelines," International Organization for Standardization, 2009.
[140] IEC 31010, "Risk management – Risk assessment techniques," International Electrotechnical Commission, 2009.
[141] ISO/IEC 15026-2, "Systems and software engineering – Systems and software assurance – Part 2: Assurance case," International Standards Organization/International Electrotechnical Commission, 2011.
[142] OMG SACM, "Structured Assurance Case Meta-model," 2 2013. [Online]. Available: http://www.omg.org/spec/SACM. [Accessed 23 05 2014].
[143] J. Åkerberg, "On Safe and Secure Communication in Process Automation," Mälardalen University Press Dissertations, Västerås (Sweden), 2011.
[144] J. Braband, "Towards an IT security protection profile for safety-related communication in railway automation," in *Embedded Real-Time Software and Systems (ERTS2)*, Toulouse, 2014a.
[145] J. Braband, "IT security for functional safety in railway automation," in *1st Workshop on Safety and Security*, Kaiserslautern, 2014b.
[146] H. R. Nielson and F. Nielson, "Safety versus Security in the Quality Calculus," in *Theories of Programming and Formal Methods, Lecture Notes in Computer Science*, vol. 8051, Springer, 2013, pp. 285–303.
[147] C. Labreuche and F. Lehuédé, "MYRIAD: a tool suite for MCDA," in *4th Conference of the European Society for Fuzzy Logic and Technology (EUSFLAT)*, Barcelona, 2005.
[148] MERgE, 2012. [Online]. Available: http://www.merge-project.eu/.
[149] S. Paul, L. Rioux, T. Wiander and F. Vallée, "Recommendations for security and safety co-engineering (v2)," ITEA2 MERgE project, 2015.

This page intentionally left blank

An investigation into the smoldering combustion of paper

A. Tinaburri[1,2], F. A. Ponziani[1,2] & V. Ricci[1]
[1]*Central Direction for Prevention and Technical Safety, Department of Firefighters, Ministry of the Interior, Italy*
[2]*Department of Industrial Engineering, Rome "Tor Vergata" University, Italy*

Abstract

Following some fire investigation activities on the smoldering phase of paper items in a stack configuration, a campaign of tests was conducted to examine the particular dynamics of this type of combustion. The smoldering phase of stacks made up by various paper elements was investigated, using heptane poured on the top of the stack as the ignition source. The following parameters were varied: size and grammage of the paper sheets; height of the paper stack. Several thermocouples and a scale were used to log data during each test whose duration was on a typical timescale of a day. Among the outcome, two issues of paramount importance for the smoldering phase under analysis were highlighted: the identification of a constant mass loss rate phase and, provided the ignition source is of sufficient strength, the total involvement of the paper stack if sufficient time is allowed for the smoldering combustion to proceed. A regression model based on the test results was then developed that could take into account the behavior of the smoldering combustion representative of the different paper format under investigation. A metric useful for reconstruction of smoldering of a paper stack is thus derived.
Keywords: smoldering, mass loss, paper stack, combustion, flaming.

1 Introduction

The starting point for this research was an investigation into an arson fire of a number of stacks of paper or binders. Among the several questions raised, one was outstanding and challenging. After a flaming combustion process is

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150301

activated by the pouring of relatively small quantities of an accelerant liquid, will the combustible package be able to self-sustain the combustion process, and if so, in which form (flaming vs. smoldering), to which extent (partial vs. total involvement) and how long?

Recognizing the limitations of the current software in modeling flaming to smoldering transition and the following smoldering combustion (if any), laboratory tests were performed in a confined space to obtain basic data on the critical parameters representing the smoldering behavior of stacks of paper. The ignition source was obtained by pouring a small quantity of liquid accelerant (heptane, 35÷200 ml, typically 70 ml) mainly on top of the stack. This technique is representative of all cases in which the combustion of the stack is initiated by a transient heat flux applied to the top layers.

2 The experimental campaign

Several tests were performed to study the combustion behavior of paper sheets differing for sizes (from 10.5x42 cm to 40x56 cm), grammage (from 40 to 200 g/m^2) of the sheet and initial mass (height) of the stack (from 3836 to 9885 g). For each test performed, the following parameters were recorded: flaming combustion duration and possible transition to smoldering, mass loss rate along all the combustion process, temperature profile in ten points inside the stack. The tests have been performed in a confined space having a total volume ≈766 m^3, large enough to supply the air required by the combustion reactions. Single paper sheets of different grammage and size have been arranged in a stack configuration. The paper stack weight loss as a function of time has been measured with a Sartorius scale, type BP34000-P, connected to a computer station for data logging. Ten thermocouples (type K) have been provided to record the temperature inside the burning material with a data logger (Datataker, model DT 500), with a sampling rate of 30 s. Refer to Figure 1 for the thermocouples location details: the monitoring points were selected in order to minimize the disturbance caused by the initial flaming phase and by the shape changes caused by the combustion reactions (for instance small material collapse during smoldering).

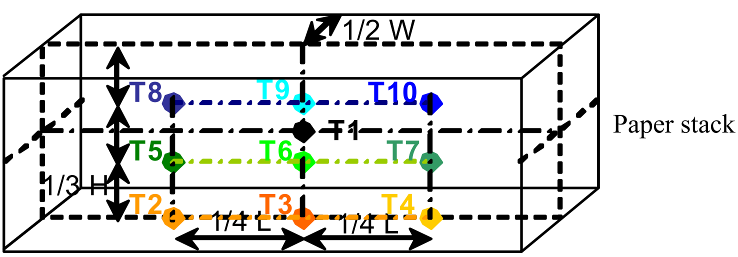


Figure 1: Thermocouples arrangement.

Table 1 shows the summary of the tests performed, where the smoldering mechanism has been activated after the initial flaming phase.

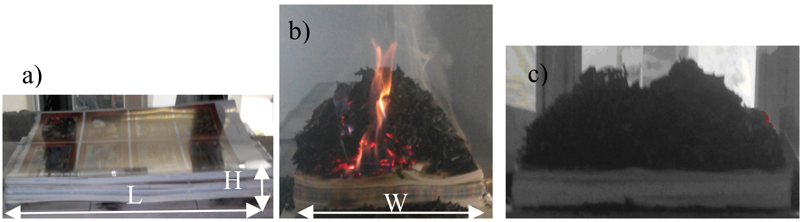
Table 1: Summary of smoldering test results.

Test no.	*Paper sheet type*	Paper initial mass (g)	*Smoldering combustion*			
			1st phase: Linear mass loss		2nd phase: Quadratic mass loss	
			Duration (min)	Mass loss (% initial mass)	Duration (min)	Mass loss (% initial mass)
1	Glossy paper (bindakote) Dimensions (LxW): 50 x 35 cm Paper grammage: 200 g/m^2 Stack height (H): 7 cm	9094	855	68.5	1333	12.5
2	As test n. 1	9105	833	67.5	1326	13.3
3	As test n. 1 with a reduced stack height: 3.5 cm	4313	245	48.8	301	15.8
4	Cardboard Dimensions (LxW): 42 x 10.5 cm Paper grammage: 200 g/m^2 Stack height (H): 10.5 cm	3836	551	67.9	325	5.8
5	A3 paper Dimensions (LxW): 42 x 29.7 cm Paper grammage: 80 g/m^2 Stack height (H): 9.8 cm	9885	Note 1			
6	Newspaper Dimensions (LxW): 35 x 25 cm Paper grammage: 40 g/m^2 Stack height (H): ~ 21 cm	8097	1334	49.7	1490	36.9
7	Newspaper 2 adjacent stacks Dimensions (LxW): (2x22) x 31 cm Paper grammage: 40 g/m^2 Stack height (H): ~ 13.5 cm	8145	2107	53.7	1021	35.9
8	Newspaper Dimensions (LxW): 30 x 20.5 cm Paper grammage: 40 g/m^2 Stack height (H): ~ 16 cm	4460	1232	49.0	1250	34.2
9	Newspaper Dimensions (LxW): 40 x 29 cm Paper grammage: 40 g/m^2 Stack height (H): ~ 13 cm	6906	1222	53.5	1751	30.6

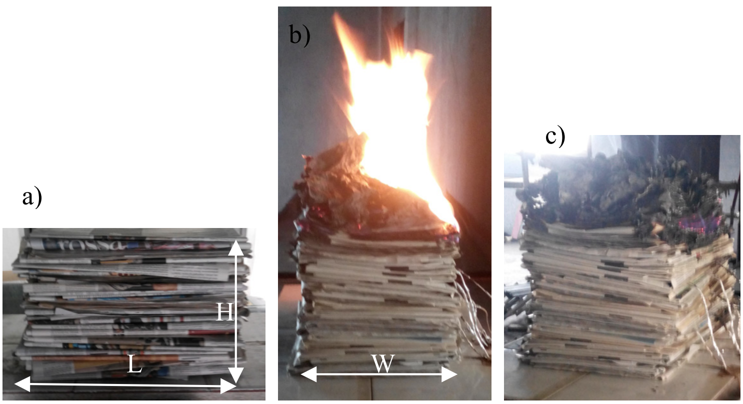
Note 1: Test intentionally interrupted after 47 hours @ 72% paper mass loss.

Even if it is not dealt with in this paper, it may be useful to report that the initial flaming phase had a duration in the order of 15 minutes and an overall mass loss in the range of 1÷5% referred to the initial paper mass. The accelerant quantity was selected to be the minimum required to initiate a smoldering phenomenon, if any, for each paper type and format. The fuel package shape changes assuming a complex 3D pattern, with an increase of the sample apparent height caused by the top stack sheets that are bended and turned by the flame attack leaving a typical black colored residue (Figure 2).

Test n. 1: Glossy paper (bindakote)
Size (LxW): 50x35 cm, paper grammage: 200 g/m^2, stack height (H): 7 cm



Test n. 6: Newspaper
Size (LxW): 35x25 cm, paper grammage: 40 g/m^2, stack height (H): ~ 21 cm



Test n. 9: Newspaper
Size (LxW): 40x29 cm, paper grammage: 40 g/m^2, stack height (H): ~ 13 cm

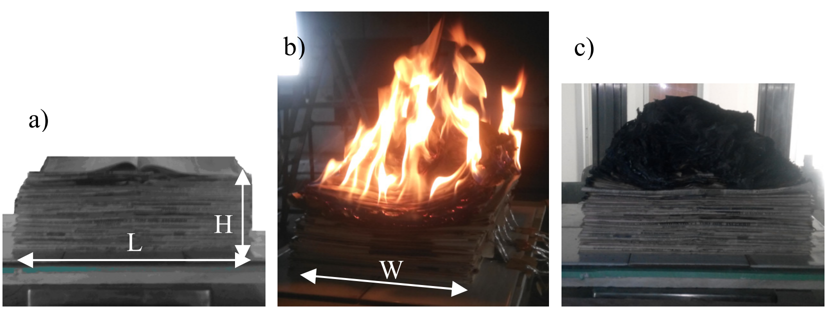


Figure 2: Material morphology during flaming phase till smoldering starts a) prior to ignition; b) during the flaming phase; c) flame out, the start of smoldering.

After this initial stage, smoldering may or may not proceed depending on the fuel package configuration. It has been observed on that respect that the A3 format or the cardboard strips are more prone to sustain the combustion reactions till complete consumption, leaving mainly white unburned residue (ash) under the external black appearance left by the flaming phase (Figure 3).

Test n. 1: Glossy paper (bindakote)
Initial size (LxWxH): 50 x 35x7 cm, paper grammage: 200 g/m^2
a) External (front view); b) Internal

Test n. 4: Cardboard
Initial size (LxWxH): 42 x 10.5x10.5 cm, paper grammage: 200 g/m^2
a) External (front view); b) Internal

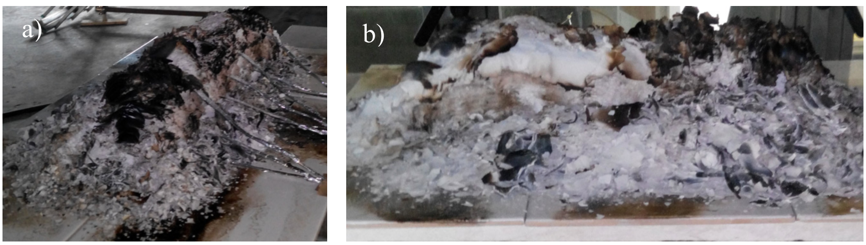


Figure 3: Final material morphology.

Newspapers activate a slower smoldering process influenced by the folding, that introduce anisotropy in the fuel package response to the flame attack. For the largest size (Test n. 9), it was necessary to repeat the test several times increasing the accelerant amount to the maximum ever used (200 ml), partially (25%) poured also in the first two top leaves, in order to observe the smoldering process to proceed to complete paper consumption. The following Figures 4 and 5 report the measured sample mass and temperature profiles (refer to Figure 1) for six of the tests performed. In order to facilitate the comparison, results are ordered in group of three on the basis of the sample initial mass and in each graph same time/temperature/mass scale is selected. These experiments demonstrated that the process is characterized by a first phase of constant rate of mass loss (linear decay of the sample mass) followed by a progressive decline of the rate of mass loss which is nearly linear (quadratic decay of the sample mass). Unburned residue (ash) is about 16% of the initial mass. The overall duration and mass loss during each of this two phases is summarized in Table 1 for all the tests.

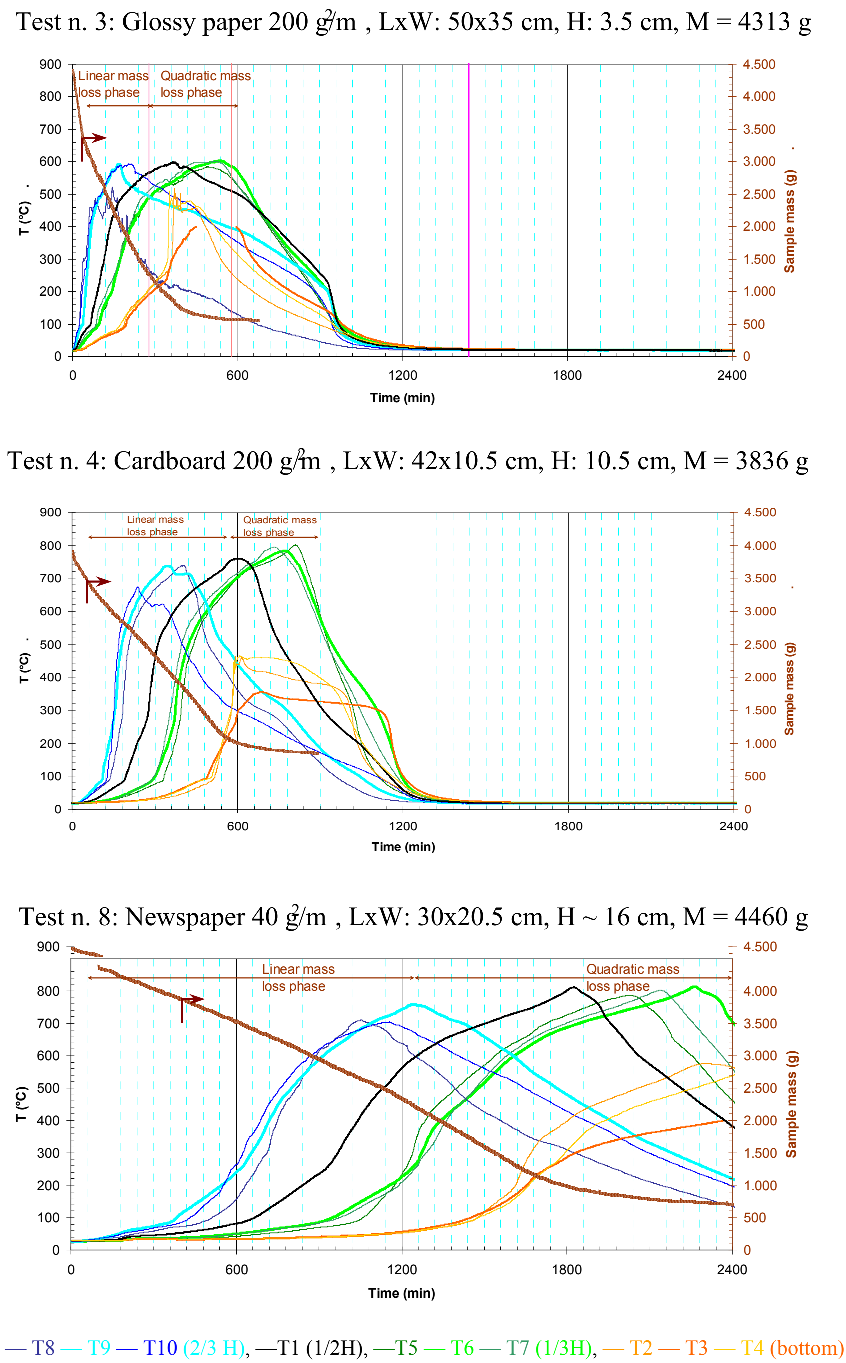
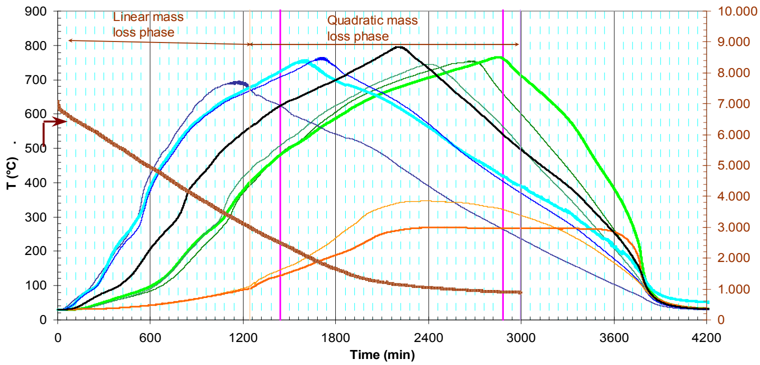
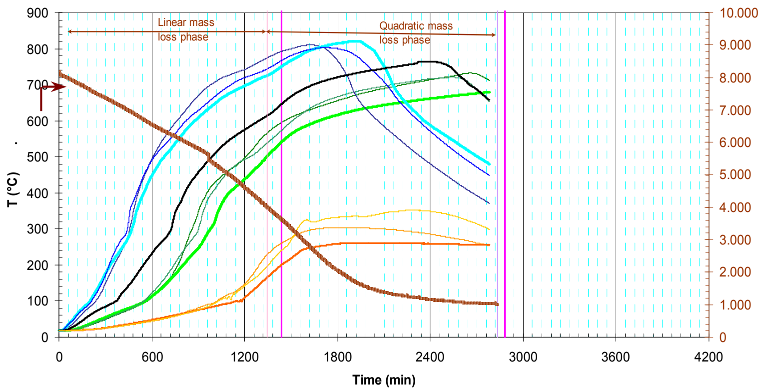


Figure 4: Sample mass and thermocouples profiles.

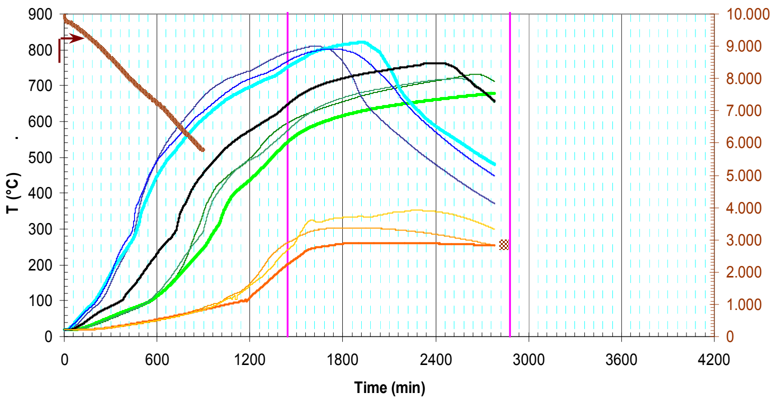
Test n. 9: Newspaper 40 g/m^2, LxW: 40x29 cm, H ~ 13 cm, M = 6906 g



Test n. 6: Newspaper 40 g/m^2, LxW: 35x25 cm, H ~ 21 cm, M = 8097 g



Test n. 5: A3 sheets 80 g/m^2, LxW: 42x29.7 cm, H: 9.8 cm, M = 9885 g



— T8 — T9 — T10 (2/3 H), —T1 (1/2H), —T5 — T6 — T7 (1/3H), — T2 — T3 — T4 (bottom)

Figure 5: Sample mass and thermocouples profiles.

The temperature profiles within each sample reproduce the typical dynamics of the smoldering: a phase of penetration of the thermal wave with a temperature increase, resulting in the activation of the glowing combustion within the stack, followed by a cooling phase. Each group of three thermocouples located in the same horizontal plane shows a similar trend: at any given time in the growing phase the two external thermocouples record higher temperature than the central thermocouple, the reverse occurring in the decaying phase. The maximum temperatures recorded are in the order of 600−800°C, as reported in the literature [1]. The peak temperature at the base level (TCs 2,3,4) is always well below the above mentioned maximum value, the spread being the lowest for the sample having the minimum initial height (Run n.3). These results confirmed a trend also observed in a previous campaign focused on the A4 format [2]. To link the measured physical data to the extent of the reaction volume inside the stack, Test n. 5 was interrupted after ~47 h from the ignition, to unveil the interior appearance of the sample. As shown in Figure 6, after removing the surrounding external ash, it is possible to isolate a glowing core and to determine its dimensions and shape. The last two photos in the sequence show the detail of the core structure: several single sheet parts all involved in glowing reactions.

Figure 6: Test n. 5: Smoldering zone after 47 h from the ignition. (A3 sheets 80 g/m^2, LxWxH: 42x29.7x9.8 cm, M = 9885 g.)

3 Analysis of the smoldering phenomenon of paper stack

The smoldering combustion is a chemical reaction in heterogeneous phase, its study requiring knowledge of the phenomena of heat and mass transport in both the gas and solid phase. To initiate the reactions mechanisms, external energy is required to heat the solid fuel. The resulting increase in temperature of the solid phase starts, above a temperature characteristic of the material, the thermal degradation reactions until the balance between net heat generated by the oxidation reactions is sufficiently high to compensate the heat required for the propagation of the front of reaction to layers of adjacent material still “virgin” and the heat losses towards the outside. Factors such as ignition source geometry, fuel geometry, and the strong influence of buoyant flow on oxygen supply usually interact to assure that a smoldering reaction zone has significant gradients of temperature and species in two or three dimensions. In examining self-sustained smolder propagation and its response to oxygen supply conditions, dimensionality is important. For the configuration examined, when the top layer is ignited, the fuel package soon evolves into a new complex shape. Thermal diffusion and smoldering reactions cause a curvature of each individual paper element thus determining a change in shape and porosity of the fuel package that can enhance air penetration. On that respect, folding in newspapers introduces a further factor to consider: the presence of one or more spines obstacles air diffusion inside the stack, introduce an anisotropy also depending on their relative orientation. The result is a reaction zone that propagates downward from the top of the stack to the bottom. The air inflow is arriving mainly from the stack lateral sides (in a cross-flow pattern) under natural convection conditions, favored also by the curvature of the fuel element borders, while the hot gases produced move upward. At any given depth in the stack, the reaction front proceeds mainly from the external to the internal core. The result is a reaction volume that moves downward from the top of the layer to the bottom, involving multiple sheets in a reaction zone that is several centimeters thick. As the fuel package under analysis is highly permeable to air and of relatively small size, oxygen surrounds the fuel particles as they are heated by the advancing reaction zone: as a consequence the curvature of the surface delimitating this volume is relatively small compared to its dimensions.

Table 2 shows the summary of the least squares regression of the sample mass data. Discarding the initial flaming phase, smoldering data were fitted starting from a reference time of 60 minutes. The best fit is obtained by a linear function in time, followed by a 2^{nd} order polynomial modeling the decaying phase; the correlation coefficients show the degree of accuracy of the regression along the whole time line. The onset of a linear mass loss phase indicates that the self-sustained smoldering volume is in steady-state condition. The constancy of the mass loss rate implies that a constant reaction volume is established in the stack and travels downward at a constant velocity, and across it occurs the transition from unburned fuel to ash. A very simplified representation of the phenomenon is possible by a global energy balance around this smoldering

Table 2: Smoldering data analysis.

Test no.	Paper sheet type	Paper initial mass (g)	Smoldering combustion							
			1st phase: Linear curve $M(t) = Mo - k_{lin}\,t$ $60 < t < t_{1,lin}$ (min)			2nd phase: Quadratic curve $M(t) = k_{quad,2}\,t^2 + k_{quad,1}\,t + k_{quad}$ $t_{1,lin} < t < t_{2,quad}$ (min)				
			$t_{1,lin}$ (min)	Constant mass loss rate k_{lin} (g/min)	r^2	$t_{2,quad}$ (min)	$k_{quad,2}$ (g/min^2)	$k_{quad,1}$ (g/min)	k_{quad} (g)	r^2
1	Glossy paper LxW: 50 x 35 cm Gram.: 200 g/m^2 H: 7 cm	9094	870	7.0223	0.997	2204	0.0009	-3.4614	4528.2	0.992
2	As test n. 1	9105	845	6.7579	0.997	2170	0.0009	-3.3625	4386.3	0.950
3	As test n. 1 but H= 3.5 cm	4313	245	8.6308	0.997	578	0.0109	-11.436	3279.2	0.994
4	Cardboard LxW: 42x10.5 cm Gram.: 200 g/m^2 H: 10.5 cm	3836	564	4.6467	0.999	889	0.0019	-3.3707	2347.7	0.994
5	A3 paper LxW: 42x29.7 cm Gram.: 80 g/m^2 H: 9.8 cm	9885		4.7166	0.999	Test intentionally interrupted after 47 hours				
6	Newspaper LxW: 35x25 cm Gram.: 40 g/m^2 H: ~ 21 cm	8097	1344	2.9864	0.99	2834	0.0021	-10.81	14684	0.991
7	Newspaper 2 adjacent stacks LxW: (2x22)x31 cm Gram.: 40 g/m^2 H: ~ 13.5 cm	8145	2122	2.0275	0.996	3142	0.0041	-24.68	37767	0.988
8	Newspaper LxW: 30x20.5 cm Gram.: 40 g/m^2 H: ~ 16 cm	4460	1245	1.8385	0.998	2495	0.0015	-6.6503	8254	0.994
9	Newspaper LxW: 40x29 cm Gram.: 40 g/m^2 H: ~ 13 cm	6906	1242	3.1246	0.999	2993	0.0010	-5.3562	8111	0.994

volume [3]. The velocity of propagation is determined by the balance between the heat released in the volume by the smoldering reactions and the energy required to heat the "virgin" solid fuel and the air at the higher temperature of the front of smoldering, taking into account heat losses to the environment. The quadratic mass loss phase corresponds to the transition that occurs when the smoldering front approaches the bottom of the stack: the fuel depletion causes a linear shrinkage in time of the reaction volume, which is still several centimeters thick as shown in Figure 6.

A *nominal* downward smoldering velocity u_{sml} can be determined by the relation:

$$u_{sml} = \frac{(\Delta m / \Delta t)}{\rho_s (1-\phi) A_c} = \frac{(\Delta m / \Delta t)}{(M/H)} \tag{1}$$

where M, H and A_c are, respectively, the sample initial mass and height and cross section, ρ_s. is the density of the paper, ϕ is the porosity of the fuel package and ($\Delta m/\Delta t$) is the mass loss rate. For the linear phase:

$$u_{sml,lin} = \frac{k_{lin}}{(M/H)} \tag{2}$$

Table 3 reports for the various fuel packages tested the values of $u_{sml,lin}$ and the stack apparent density, M/V, where V is the stack volume. This ratio, linked to the porosity ϕ of the stack, is a characteristic of the paper type and it is linked not only to the properties of the single paper element but also to the collective behavior in piling (especially for foldable elements like newspaper sheets).

Concerning the data regarding the transient temperature profiles at different heights along the stack, it is interesting to observe a general trend: the thermal wave is always delayed in respect to the smoldering front as measured by the mass loss data. For instance, at a given position along the stack, the peak temperature is always achieved in a later time to that corresponding to the mass loss pertaining to that position. Hence it appears that the temperature peak in a specific location is registered when the smoldering front has already passed. As expected, this time delay increases as long as the smoldering proceeds downward along the stack, being maximum toward the bottom. The magnitude of this time delay varies with the fuel package, assuming the minimum value for the paper format having the highest smoldering velocity, ranging from ≈ 1 h for cardboard to ≈ 10 h for newspapers. Due to the complexity of the phenomenon, a detailed description of the transport mechanisms coupled with the reaction kinetics would be necessary to describe the thermal response of this configuration. In that respect, experimental studies like the once presented here, are a useful tool to get a comprehension of the physical aspects governing the smoldering (for instance the change in morphology) and get practical information on the time and temperature characteristics.

Focusing on the linear phase, an attempt to identify the relationship linking the measured k_{lin} and $u_{sml,lin}$ to the physical variables governing the phenomenon has been attempted using multiple regression techniques. The data were subject to a linear multiple regression analysis using the least squares approach to identify the key variables and quantify the strength of their relationship with k_{lin} and $u_{sml,lin}$. The explanatory variables investigated covered both the single paper element (length L, width W, grammage, aspect ratios like W/L) and the stack configuration (height H, perimeter p, cross section A_c, lateral area A_L, volume V, mass M, porosity ϕ, aspect ratios like p/A_C or A_L/A_C).

The analysis allowed us to identify the grammage and cross section for k_{lin} and grammage and ratio p/A_C for $u_{sml,lin}$ as the simpler and more efficient subset

Table 3: Nominal downward smoldering velocity during the linear phase.

Test no.	Paper sheet type	Paper initial mass M (g)	Stack apparent density M/V (g/cm^3)	Constant mass loss rate k_{lin} (g/min)	Nominal smoldering velocity $u_{sml, lin}$ (cm/min)
1	Glossy paper LxW: 50 x 35 cm Gram.: 200 g/m^2 H: 7 cm	9094	0.742	7.0223	$5.41\ 10^{-3}$
2	As test n. 1	9105	0.743	6.7579	$5.20\ 10^{-3}$
3	As test n. 1 but H= 3.5 cm	4313	0.725	8.6308	$6.80\ 10^{-3}$
4	Cardboard LxW: 42x10.5 cm Gram.: 200 g/m^2 H: 10.5 cm	3836	0.828	4.6467	$1.27\ 10^{-2}$
5	A3 paper LxW: 42x29.7 cm Gram.: 80 g/m^2 H: 9.8 cm	9885	0.809	4.7166	$4.68\ 10^{-3}$
6	Newspaper LxW: 35x25 cm Gram.: 40 g/m^2 H: ~ 21 cm	8097	0.441	2.9864	$7.75\ 10^{-3}$
7	Newspaper 2 adjacent stacks LxW: (2x22)x31 cm Gram.: 40 g/m^2 H: ~ 13.5 cm	8145	0.442	2.0275	$6.60\ 10^{-3}$
8	Newspaper LxW: 30x20.5 cm Gram.: 40 g/m^2 H: ~ 16 cm	4460	0.453	1.8385	$5.88\ 10^{-3}$
9	Newspaper LxW: 40x29 cm Gram.: 40 g/m^2 H: ~ 13 cm	6906	0.458	3.1246	$6.72\ 10^{-3}$

of explanatory variables. The results are reported in Tables 4 and 5. These variables allow easy predictions of the smoldering behavior of similar paper types. For instance the predicted value of k_{lin} for a stack of A4 papers (grammage: 80 g/m^2, A_c: 623.7 cm^2) is 2.84 g/min while the measured value is 3.66 g/min [2].

4 Conclusion

The smoldering behavior of paper stacks ignited on top has been investigated. In the tests performed, smoldering after flaming has resulted to be a stable process that proceed with continuity, provided the ignition source is of sufficient strength. In all configurations tested, it has been observed a first phase of constant mass loss rate, followed by a decaying phase. A linear regression model has been derived that allowed to select grammage and paper size as the key variables. Further research is planned to cover other paper types and sizes and to establish an advanced model that could explain the results obtained.

Table 4: Multiple linear regression of the constant mass loss rate k_{lin}.

	$k_{lin\ (g/min)} = \beta_{Gr}$ Grammage $_{(g/m2)} + \beta_{Ac} A_{c\ (cm2)}$					
	β_{Gr}			β_{Ac}		
	Coefficient	Standard error	*t* Stat	Coefficient	Standard error	*t* Stat
All data (9 tests): glossy paper, cardboard, A3	0.017967	0.00313	5.739	0.002246	0.000349	6.444
Regression statistics	Multiple R	R^2	Adjusted R^2	Standard error		
	0.995	0.989	0.845	0.607		
Analysis of variance	Sum of Squares	Mean Square error	F	Significance F		
Regression Residual Total	236.9 2.6 239.5	118.5 0.4	321	*p*-value= 7.92E-07		

Table 5: Multiple linear regression of the smoldering velocity $u_{sml,lin}$.

	$u_{sml,lin\ (cm/min)} = \beta'_{Gr}$ Grammage $_{(g/m2)} + \beta'_{p/Ac}\ p/A_{c\ (1/cm)}$					
	β'_{Gr}			$\beta'_{p/Ac}$		
	Coefficient	Standard error	*t* Stat	Coefficient	Standard error	*t* Stat
All data (9 tests): glossy paper, cardboard, A3	7.804E-06	3.56E-06	2.19	4.441E-02	3.48E-03	12.77
Regression statistics	Multiple R	R^2	Adjusted R^2	Standard error		
	0.994	0.987	0.843	0.001		
Analysis of variance	Sum of Squares	Mean Square error	F	Significance F		
Regression Residual Total	4.63E-04 6.00E-06 4.69E-04	2.32E-04 8.58E-07	270	*p*-value= 1.32E-06		

References

[1] Ohlemiller, T. J., Smoldering Combustion (Section 2, Chapter 9). *The SFPE Handbook of Fire Protection Engineering*, NFPA, pp. 200-210, 1981.

[2] Tinaburri, A. & F.A. Ponziani, Investigation on the flaming to smoldering transition in an arson fire, *Proc. of the Int. Conf. on Fire and Materials*, Interscience, pp. 743-757, 2013.

[3] Rein, G., Smouldering Combustion Phenomena in Science and Technology, International Review of Chemical Engineering, Vol. 1, pp. 3-18, 2009.

This page intentionally left blank

Reliability analysis of road safety barriers

J. Markova[1], M. Kalinsky[2], P. Marek[2] & O. Janda[3]
[1]Czech Technical University in Prague, Klokner Institute, Czech Republic
[2]TÜV SÜD Czech Ltd., Czech Republic
[3]ALGON a.s., Czech Republic

Abstract

The design and verification of the new types of road safety barriers suffers from several deficiencies including a lack of prescriptive models for impact forces caused by various types of road vehicles. For specification of the load-bearing members of barriers, alternative procedures including dynamic, non-linear and probabilistic analyses may be applied. Detailed analysis is based on crash test simulations using models of vehicles based on the finite element method.
Keywords: road barrier, impact forces, crash test, crash simulation, models of vehicles, reliability.

1 Introduction

Road safety barriers provide protection for traffic on roads, as well as for their immediate surroundings. Various aspects have to be considered when selecting the appropriate types of safety barrier, including road categories, surface characteristics, road surroundings, the permitted speed for vehicles, types of danger spots in road surroundings, and traffic intensity including expected future trends. For the selection of appropriate safety measures, the retention level for road barriers has to be determined, taking into account the dangerous sections of the road and the need for the protection of road surroundings.

The safety barriers are designed for the relevant retaining levels, and verified within a crash test. Presently, it is not allowed to substitute experimental tests with theoretical analyses only. However, analyses are mostly accepted for barrier modifications. Therefore, the aim of the current research is to contribute to the development of a methodology for the possible improvements of vehicle crash tests into traffic barriers by computer simulation, together with the application of the methods of the theory of structural reliability.

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150311

For structural design and theoretical verification of road safety barriers, the basic requirements given in EN 1317 and in Eurocodes should be applied. Additional guidance for the application of probabilistic methods and dynamics is provided in Annexes B and C of EN 1991-1-7 [1].

Presently, the working draft of the Technical report [2] of CEN/TC 226 gives basic guidance for the verification of road safety barriers based on crash test simulations. The general guidance on how to specify models of vehicles is included. However, the standardised models of vehicles which could be applied for theoretical simulations have not yet been recommended.

For the approval of a new type of road safety barrier, the crash test, at present, is the only one recognized. The results of theoretical simulations may be compared with crash tests, which may be used for test validation with respect to the modification of barriers (improvement of details, changes in material and restraining level). However, the modifications of specific barriers cannot significantly differ from the experimentally tested original barrier.

For the designing of barriers, various supplementary national codes and technical requirements should also be applied in various countries, including the Technical Requirements TP 114 [3] in the Czech Republic. Two types of road barrier are given within the scope of this document: "approved" road barriers, for which rules of EN 1317 shall be applied (barriers are considered as construction products), and "other" road bridge barriers, which include barriers designed according to project specifications that are not repeated in individual bridges. They represent the original road restraining system.

For these "other" barrier designs, five categories of impact forces are given in TP 114 [3] in a range from 100 kN to 600 kN. The requirements on impact forces for verification of "other" safety barriers are based on EN 1991-2 [5]. However, it appears that the recommended impact forces for the design of road safety barriers are rather low and should be further verified.

The aim of the research is to prepare and verify the methodology which facilitates the design and production of the innovative traffic barrier prototype possible. The first phase of the research was focused on the analysis of the critical points of existing types of road barriers. Non-linear dynamic software PAM-CRASH, suitable for the computation of large plastic deformations step-by step beyond the yield strength of the material, is used for all crash simulations in the research project.

2 Development of models

2.1 Impact characteristics of vehicles

The position of the main deformation members in passenger cars and buses is a structural property which has a decisive effect on the correct distribution of the deformation energy within a frontal collision.

Within the analysis of the random effects of impact forces on road barriers, a database of the location of the vehicle deformation members and position of the main safety features has been developed. Currently, the database covers about

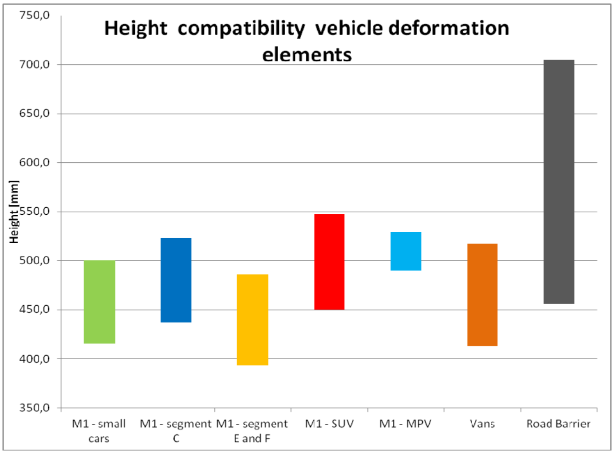


Figure 1: Different height of deformation members on several classes of cars.

70% of all types of registered cars in the Czech Republic. Results of measurements of the height of vehicle deformation elements are shown in fig. 1.

EN 1317-2 [4] defines the basic parameters of cars to be used in real crash tests, such as dimensions, weight and centre of gravity position. However, the results of the real test may vary according to the vehicle type. The type of passenger vehicle has quite a significant effect on the simulation results. If each testing institution uses different vehicles then the compatibility of the crash test results cannot be fully guaranteed. This may be even more significant when older vehicles are applied because their structure might be considerably damaged by corrosion or improper repair.

2.2 Model of passenger car

The model of the car used for tests TB11, TB 21 and TB 22 is based on the model of Skoda Fabia. The model of the passenger car is also equipped with two dummies Hybrid HIII 50%, as well as other safety features such as safety belts, belt pretensioners etc., allowing to assume the biomechanical load of the occupants within the crash test. However, these basic variables are not required to be considered by EN 1317.

2.3 Model of bus

For test TB51, the basic model of a bus is developed (see fig. 2). It is a typical representative of the intercity bus (category MII) with a length of 12 m.

EN 1317 defines the basic parameters of the vehicle to be used in real crash tests, such as dimensions, weight and centre of gravity position. According to the available information, the testing institution in the Czech Republic uses an older type of Karosa bus for the standard crash test.

The preliminary model of the vehicle was unable to ensure the numerical stability of the simulation. That is why the vehicle model had to be supplemented by outer bodywork surfaces to avoid the capture and contact errors between the vehicle and the road barrier.

Figure 2: The model of the bus used for TB51 tests.

2.4 Model validation of passenger car

The developed model of a passenger car was validated with real crash tests in accordance with regulation ECE R 94 (frontal impact) and the Euro NCAP methodologies for Frontal, Side and Pole tests. Deformation of the body and acceleration were in good agreement.

Fig. 3 indicates a real frontal crash test, in accordance with Euro NCAP methodology and developed simulation with an improved passenger car model performed under the same conditions (speed 64 km/h, 40% offset, weight, etc.).

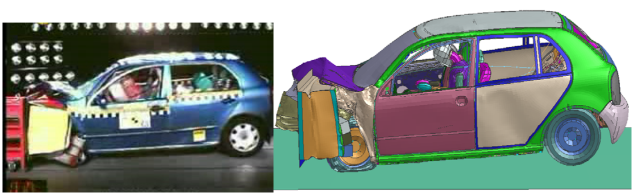


Figure 3: Euro NCAP Frontal test and simulation comparison.

2.5 Model validation of bus

The model of bus used in crash analysis was also verified with regard to the passive safety tests. The original model of the bus was used for a homologation rollover test in accordance to Regulation ECE R66.02. The material used in bus structure is verified by the standard tensile tests to determine the basic mechanical properties.

3 Crash simulation and conditions

3.1 Simulation set up

In all the simulations, the height of the curb rails is assumed to be 150 mm, which is in accord with CSN 73 6201 [6], where the recommended standardised range is given as 120 to 200 mm. It should be noted that in other countries the ranges of curb height are usually from 0 to 70 mm.

Preliminary simulations are used to evaluate the limiting conditions (see fig. 4). The following restrictive conditions are detected:

- A rigid post connection in the bridge deck is assumed.
- The effect of cracks, mechanical defects in materials and corrosion are not taken into account.
- In some simulations it is necessary to have information on a rupture model.

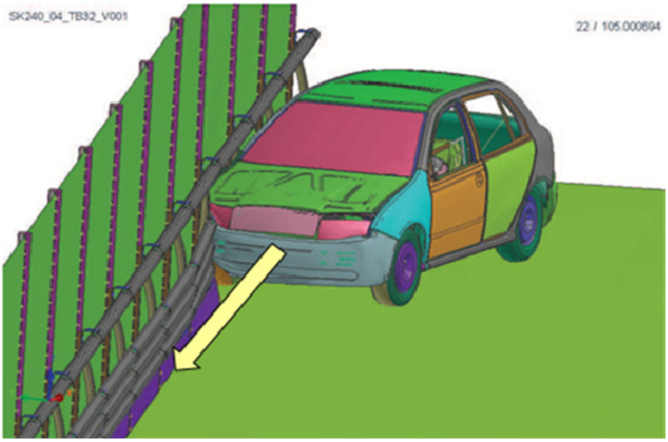


Figure 4: Configuration of test for different heights of the curb.

The dominant impact effect on the road barrier is for configuration without curb. Thus, this case is considered in simulations.

3.2 Analysis of friction

Friction between the tyre and road affects the results of simulations and leads to modification of the contact force between the car and the barrier. An increase in friction leads to a shifting of the secondary impact, while the primary impact remains almost unchanged as illustrated in fig. 5. In the study case the time shift is about 30 ms.

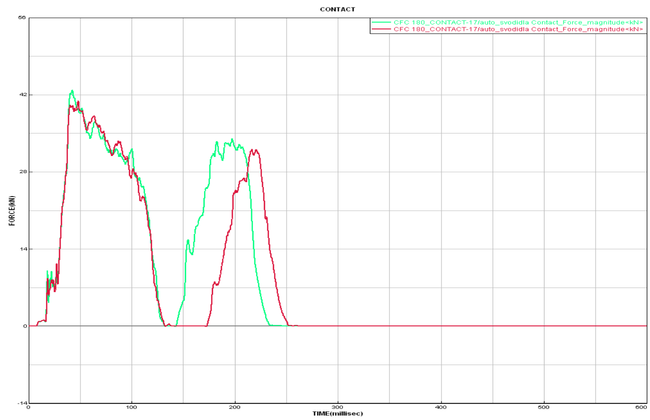


Figure 5: Impact force in time for vehicles with low (green) and high (red) friction coefficient.

The total energy of the secondary impact is significantly lower when a higher level of friction is considered in the simulation. The reason may be found in the dissipation of kinetic energy between the wheel and road. This effect should be taken into account.

3.3 Definition of contact task in simulation

One of the major issues of the simulation is to properly define the contact task. This problem is evident for crash simulations with buses. The steel profile of a car structure in contact with a barrier leads to the capturing of some elements. This causes an extreme and unrealistic extension of these elements and therefore an absolute impairment of the results. Therefore, the bus should be complemented by external body panels to minimize the risk of capturing the structure. Although these panels have a minimal effect on the body stiffness it is necessary to include them in the model of bus.

3.4 Validation of material characteristics

Validation of material properties consists in the simulation of the actual test and tunes the material parameters to achieve the same response. Samples usually have a length of 1200 mm, and the distance of rotational support is 1000 mm. A drop test is carried out for the speed corresponding to the strain rate of the element or its part. The material characteristics are used in simulations. The general response of the model is much more precise and therefore, the model is predictable.

4 Selected results of analysis

4.1 Conclusion from simulations

The simulation of impact tests is a complex problem depending on many input parameters. Modeling the impact test using nonlinear dynamic simulations has limiting conditions. The first simulations indicated several fundamental problems that had to be taken into account.

- The size of the curb rail and road barrier offset affects the test results. Currently there is no given a harmonized height of the curb rail for a physical test in the EU. It is therefore necessary to prepare computational simulation within the parameters of the testing institution.
- Contact tasks are crucial parameters for tuning the simulation. Within simulations of higher speed (especially TB 32), the problem with the stability of the numerical calculations and capturing elements was observed leading to the complete impairment of results. The problem is also magnified by the requirement for a lengthy time simulation (more than 600 ms). Therefore, it is necessary to avoid the accumulation of numerical errors by use of high precision solutions.
- The friction coefficient between the wheel and road affects the results. Therefore, it is better to use different friction coefficients in the radial and axial directions of the tyre to ensure more realistic behaviour.
- Vehicle models should be validated to ensure a real deformation of the structure. This demand is not so strict when modeling the impacts with larger vehicles (buses, trucks).
- The material characteristics should be validated through the real experiments.

Therefore, some parts of simulations had to be improved, e.g. by using a simple steering mechanism on the front axle. The trajectory of the vehicle could be more accurately evaluated after the test.

4.2 Contact forces between car and barrier

Specification of maximal force between the car and road barrier is illustrated in fig. 6. The forces may be compared with the theoretical design forces introduced standards, e.g. in prescriptive documents [3, 5].

The comparison of maximum contact forces specified by simulation and theoretical design forces given in some prescriptive documents leads to the following conclusions.

- Simulations always indicate higher peak values of the contact force. With increasing intensity of the impact (tests TB 11, 31, 32, 51, 61 and 71) the difference increases up to 100%. For tests with lower impact intensity, the forces are nearly comparable (tests TB 21 and 22). The height of the curb has also to be considered in simulations having a considerable effect on the extent of contact.

www.witpress.com, ISSN 1743-3509 (on-line)

– The time course of the contact force gives a complex view on the total impact. Secondary impacts can also be defined including their intensity and contact duration. This is important for comparison and development of individual variants of the road barrier structure and its members.

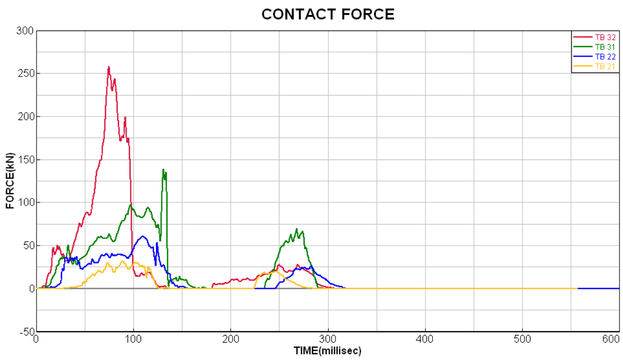


Figure 6: Contact force in time.

4.3 Analyses in RFEM software

Selected analyses of load effects of a car on road safety barriers were also developed in the RFEM software programme, which is focused on solving structural problems in civil engineering. The dynamic analysis is based on the application of a force impulse on a structural model. The software makes it possible to import a force impulse record based on a real crash test (or theoretical car crash simulation), and to use it for the loading of selected members of the model.

The RFEM software is also suitable for various sensitivity analyses of input parameters on the basis of a quasi-statistic approach. The main prerequisite for effective application of RFEM is the calibration of the boundary conditions focused on achievement of comparable results with the software PAM Crash or real tests, if they are available. Analysis of deformations of the road safety barrier is illustrated in fig. 7.

Validation analysis was carried out on the safety barrier for the test condition TB11. As the barrier had relatively small weight (mass) compared to vehicle weight, the quasi-static analyses were carried out. RFEM does not offer non-linear material model in dynamic modules, but for static tasks, the non-linear material model is available. The vehicle model before crash is defined by kinetic energy, which is then absorbed by vehicle bearing frame and safety barrier. It was calculated in PAM Crash, that energy absorbed by the safety barrier creates about 80% of kinetic energy for test condition TB11.

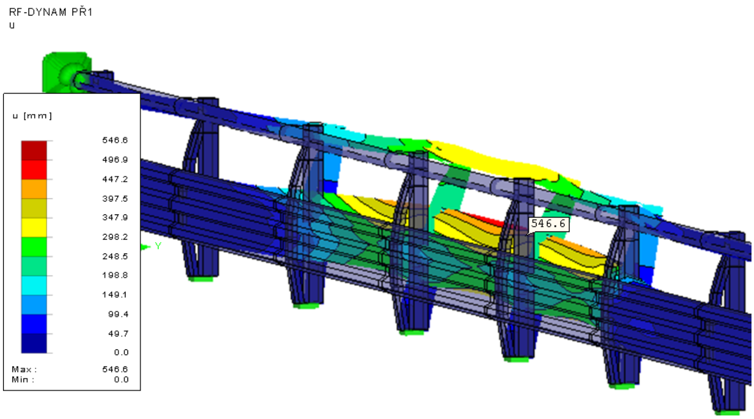


Figure 7: Deformations of a road safety barrier in time.

The deformation of barrier depending on kinetic energy and crash angle based on several analyses is illustrated for the vehicle weight of 1300 kg. The calculation of safety barrier is stable (converges) in RFEM up to deformation of approximately 0.6 m. Therefore, the graph in fig. 8 is limited by this value. In reality such result indicates that behind this deformation the safety barrier does not damp impact and tensile forces are activated.

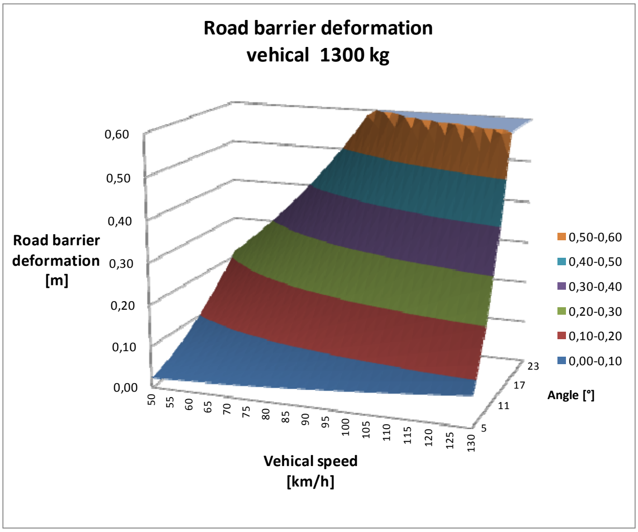


Figure 8: Road barrier deformations versus vehicle speed and angle of impact for a passenger car weight of 1300 kg.

www.witpress.com, ISSN 1743-3509 (on-line)

5 Probabilistic assessment of impact forces

Probabilistic methods of reliability theory are applied for the verification of impact forces for "other" (individually designed) safety barriers, which are recommended in the Czech prescriptive document TP 114 [3], and also in EN 1991-2 [5] for the verification of barrier anchorage to bridge deck or bridge cantilever.

The probability of a structural member being impacted by a heavy car leaving its traffic lane may be assumed to be 0.01 per year. The target failure probability for a structure, given a truck approaching in its direction, is $10^{-4}/10^{-2} = 0.01$. The design impact force may be assessed on the basis of the following condition of EN 1991-1-7 [1] given as

$$P_{\mathrm{f}} = n\, T\, \lambda\, \Delta x\, \mathrm{P}[\sqrt{km(v^2 - 2\,a\,s)}\} > F_{\mathrm{d}}] = 0{,}01 \tag{1}$$

where n is the number of vehicles per time unit, T is the period of time under consideration, λ is the probability of a vehicle leaving the road per unit length and Δx is the part of the road from where the collision may be expected.

The probabilistic models of basic variables are based on the Probabilistic Model Code of JCSS [7], and on previous analyses made in the Klokner Institute CTU (see Markova [9] and Jung and Markova [10]).

Fig. 9 indicates the range within which should be selected, for the design of "other" barriers, the impact forces F_{d} based on the target value of reliability index β_{t} about 2.3 (corresponding to the target probability 0.01).

The recommendations of the prescriptive document TP 114 [3], and also of EN 1991-2 [5] concerning the values of design impact forces which should be applied for "other" road bridge barriers, are shown to be significantly lacking, and need further consideration.

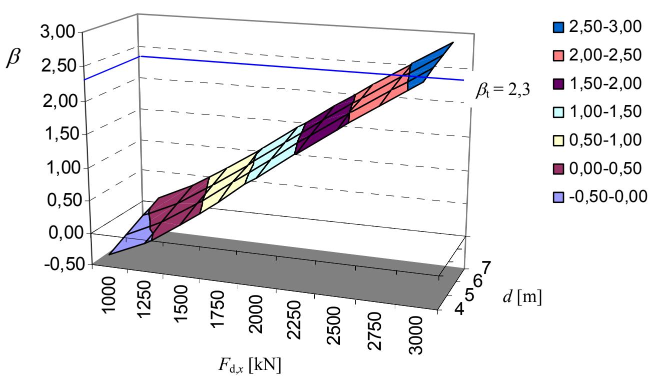


Figure 9: Design impact force $F_{\mathrm{d,x}}$ versus distance d of a heavy truck from centreline of a road for the target reliability index β_{t} for roadways.

6 Conclusions

The crash test simulation is a complex problem depending on many input parameters of random character, and with complex boundary conditions. Modelling the crash test using nonlinear dynamic simulations has limiting conditions. Several problems need to be taken into account including

- contact tasks being crucial parameters for the stability of numerical calculations and simulations,
- different friction coefficients in the radial and axial directions of tyres,
- required height of the size of curb rail which considerably affects the test results and which is presently non harmonized,
- vehicle models should be validated to ensure a real deformation of the structure,
- computational simulation should also take into account the real crash testing conditions of the authorized body.

Further improvements concerning some parts of the simulations of crash tests are foreseen to be made. The material characteristics and geometry of individual members of the road barrier should be well defined and optimized in simulations. Finally, the developed steel safety bridge barrier for the retention class H2 is going to be tested in a real crash test. The results of theoretical simulations will be compared with results of crash test making it possible to specify some foreseen modifications of the road barrier.

Acknowledgement

This study has been conducted within the framework of research project TA02030150 Application of Reliability Methods in Research and Verification of Innovative Road Safety Barriers.

References

[1] EN 1991-1-7, Eurocode 1 – Actions on structures: Part 1–7: General actions – Accidental actions, 2006
[2] Technical Report, Road restraint systems – Guidelines for computational mechanics of crash testing against vehicle restraint system, CEN/TC 226
[3] TP 114, Safety barriers on roads. Actions, specification of road barrier retention level and designing of “other” barriers on roads (in Czech). Technical requirements. Ministry of Transport, 2010
[4] EN 1317-2 Road restraint systems – Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets. CEN/TC 226, 2010
[5] EN 1991-2, Eurocode 1 Actions on structures: Part 2 - Traffic loads on bridges. 2003
[6] CSN 73 6201, Design of bridge assets (in Czech) ÚNMZ, 2008
[7] Probabilistic Model Code. 2012. JCSS. http://www.jcss.ethz.ch

[8] ISO DP 10252, Accidental actions due to human activities, ISO, 1994
[9] Markova, J., Calibration of Safety Elements in Accidental Design Situation. In: Esrel 2006. pp. 1515-1518. Estoril, 2006
[10] Jung, K. & Markova, J., Risk Assessment of Safety Barriers on Roads in the Czech Republic. In: Esrel 2007. Stavanger, pp. 2615-2618, 2007

Section 8
Systems safety

This page intentionally left blank

On the meaning of security for safety (S4S)

S. Paul
Thales Research and Technology, France

Abstract

Safety engineering traditionally leaves out malevolent behaviour. Recent attacks in safety-critical domains, e.g. 9/11, Stuxnet, have definitely changed the game. The academic safety engineering community is addressing the issue through a significant amount of publications and workshops. The industrial safety standardisation communities are addressing the issue by revisiting safety standards or elaborating new cybersecurity standards to seamlessly cope with IT security threats that can have an impact, direct or indirect, on safety. Regulation is also increasing. However, because the *security for safety* approach is not a simple juxtaposition of safety and cybersecurity processes and techniques, and despite all this hustle and bustle by academic and industrial communities, it is still very difficult to precisely define what is meant by *security for safety*. In this paper we analyse this would-be seamless integration of security engineering activities into the safety engineering world, and we discuss the areas in which a lot of fuzziness still remains.
Keywords: safety, cybersecurity, engineering.

1 Introduction

Safety engineering traditionally left out malevolent behaviour. Typically, the 1998 obsolete version of the Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems standard [1], clause 1.2.j stated that "this standard […] does not cover the precautions that may be necessary to prevent unauthorized persons damaging, and/or otherwise adversely affecting, the functional safety of E/E/PE safety-related systems." Recent attacks in safety-critical domains, e.g. 9/11 [2], Stuxnet [3], have changed the game. Typically, the 2010 version of the aforementioned standard [4] reads, in clause 1.2.l: "…requires malevolent and unauthorized actions to be considered during hazard and risk analysis and provides informative guidance on the

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150321

security required for the achievement of functional safety". And indeed, since a couple of decades, multiple safety communities are actively addressing the safety and security co-engineering issue, considering that safety-critical systems may not be as safe as they claim, if they are not also secure.

The academic community has been publishing an impressive amount of papers on the subject of safety and security co-engineering since the early 90's [5], organising their conferences and workshops, discussing commonalities and differences, and showing that there is a significant overlap between both specialties [6]. States are financing large research and development projects on the topic, both in Europe [7–9], and across the Atlantic [10]. The industrial standardisation community is actively revisiting standards (e.g. ED-202 [11], S+IEC 61508 [4], IEC 62645 [12]) to better cope with IT security threats that can have an impact, direct or indirect, on safety-critical systems and/or infrastructures. Industries, large or small, have also invested and are starting to propose services [13, 14] and products [15, 16] on the market to make business out of this growing public concern.

Despite all this hustle and bustle, it is very difficult to precisely define what is meant by *security for safety*, beyond simply stating that safety must be ensured even in case (or in some cases) of malevolent behaviour.

The fuzziness exists at different levels. First, at process level: should safety and security processes be kept apart, simply harmonised or radically fused? The answer to this first question may help answer the following one at standardisation level: should the traditional and generic security standards (e.g. ISO/IEC 27001 [17], Common Criteria [18]) be used to ensure the security of safety-critical systems, or should domain-specific security standards be developed? Standardisation obviously brings to mind regulation, or rather the lack of regulation concerning the security of safety-critical systems and/or infrastructures. Finally, at a finer grain level, questions arise with respect to the (dependability) criteria to consider in *security for safety* studies, the need for security levels, and the use of qualitative versus quantitative approaches, the definition of metrics, etc.

This paper discusses some of these topics, with the aim of clarifying what can be expected under the terms *security for safety*.

2 Security-informed safety, or safety-informed security?

A good example of the fuzziness around *security for safety* is the question whether this approach leads to *security-informed safety* or on the contrary to *safety-informed security*.

Security-informed safety implies that the original safety processes and/or techniques are modified to cope with security concerns. Typical examples of this are, at process level, the obsolete ED-202 standard in which the security activities are embedded inside the safety process [19], or at technical level, an extended safety-case, as proposed in the SeSaMo project [20]. In this approach, safety experts are required to be sufficiently competent in cybersecurity to run their modified safety process and/or use their extended safety techniques to cover relevant security concerns. Of course, security experts may be involved in the process, but then, it is them who must make the effort of understanding the safety-related jargon, techniques and processes. The work is highly collaborative, and both specialties must learn how to work together.

By contrast, *safety-informed security* implies that the security process is defined independently from the safety process, but that it is run using inputs coming from the safety process, limiting its scope of application to a frontier defined by safety experts. A typical example of this, at process level, is the new ED-202A standard [11], in which both safety and security processes interact as peers with the mainstream system engineering process [21]. At technical level, a typical example would be an attack tree analysis which would use for attack tree roots (a.k.a. attacker top-level goals or feared events) all the hazards resulting from the Functional Hazard Analysis (FHA) performed by safety experts, and nothing more. In this approach, safety experts are simply required to provide defined sets of data to security experts and the security experts can then work, more or less independently, according to their usual practices, in terms of standards, methods and tools. The negative side-effect of this approach are the possible resulting conflicts between the safety and security objectives; the difficulty is then not so much solving those conflicts, because the *safety-first* principle usually applies, but rather in identifying and consistently managing those conflicts, to avoid doing and undoing.

Based on the evolution of the ED-202 standard [11, 19], the aeronautical safety community seems to have opted for a *safety-informed security* approach, although, considering the discussions within the EUROCAE and RTCA standardisation groups, all individuals of that community do not seem to adhere. The executive summary of ED-202 even states that: “As an alternative, when considered practical, compliance may be accomplished through a blended process – documented by the applicant – that would integrate safety and security […]”. Thus, it is difficult to state if this experience will set a trend in other domains, as the question seems to be as much political, as practical.

Our prognostic is that the safety communities will thrive to maintain their current safety organizational approaches as stable as possible, because safety standards, often used as acceptable means of compliance to regulation, have proven efficiency records, and are extremely difficult to change, technically and politically, especially considering the rate of occurrence of new types of cyber-attacks. Some minor updates to the safety standards may however be necessary to ensure interaction points, reduce overlaps and provide guidance for conflict management between the safety and security specialties. For example, in the space domain, section §5.3 of ECSS-Q-ST-40C [22] reads: “The implementation of safety requirements shall not be compromised by other requirements. NOTE *For example: security requirements*”.

3 Towards domain-specific security standards?

The compartmentalised safety standardisation communities have created nearly as many safety standards as business domains. If, as discussed above, the trend of *security for safety* is towards *safety-informed security*, then the traditional and generic security standards (e.g. ISO/IEC 27000 series [17, 23–25], Common Criteria [18, 26–28], NIST SP 800 series [29–31], NIST Cybersecurity Framework [32]) should have home court advantage to be selected to ensure the security of safety-critical systems. Initial publications do not confirm this hypothesis.

Indeed, the Nuclear Power Plants – Instrumentation and control systems – Requirements for security programmes for computer-based systems [12] has been developed using the ISO/IEC 27000 series, IAEA and country specific guidance as sources of information, but in §1.1, this standard states that "Standards such as ISO/IEC 27001 and ISO/IEC 27002 are not directly applicable to the cyber-protection of nuclear I&C CB&HPD systems. This is mainly due to the specificities of these systems, including the regulatory and safety requirements inherent to nuclear facilities." The standard proceeds with a list of particular differentiators that justify a targeted security standard, all of which more or less related to the potential for much greater impact of a cyber-attack than that occurring at other industrial facilities.

Likewise, the aforementioned ED-202A aeronautical security standard [11] goes down the same pathway, with no qualms: it references the ISO/IEC 27k series as well as the NIST SP 800 framework, but fails to justify why the generic standards are not suited for securing aeronautical safety-critical systems.

In the automotive domain, the 10 parts Road Vehicles – Functional Safety Standard [33, 34] does not yet include security considerations. However, this point is becoming a hot topic, and the need for a new standard is frequently mentioned, e.g. in Czerny [35] and Gebauer [36].

Slightly more cross-domain, the new Industrial Communication Networks – Network and System Security series (IEC 62443) is a set of eleven documents currently elaborated by the International Society for Automation. The individual parts of the standard are at different stages of development, some being published [37–40], while others are still drafts. There currently is a German initiative to apply the IEC 62443 series to railway.

From the above, it can be seen that the safety standardisation communities seem keen to repeat their multiplication of domain-specific standards. One may ask if that will set the trend for the other domains. However, the key question remains why the traditional and generic security standards did not (yet) make it? Is the reason that the term *security* does not have quite the same meaning when used standalone, or when used in the *security for safety* expression? Or is it simply a question of appropriation of the security specialty by the safety community?

4 About regulation

A reason behind the fuzziness surrounding the elaboration of *security for safety* standards might be the lack of clear international regulation.

For example, in the aeronautical domain, aircraft type certification currently acts in the absence of comprehensive rules and guidance for how cyber-security affects safety. The FAA and EASA use ad-hoc processes, typically in the form of Special Conditions to address specific security concerns for specific aircraft models, e.g. for the Boeing 787-8 [41, 42].

In Europe, in contrast with safety, security is a National sovereignty prerogative. Therefore, to our knowledge, there is no relevant transnational regulation. This makes life difficult for international standardisation bodies. It is interesting to see however that a number of industrial standards (as discussed above) are emerging, either in advance to the regulation, or in compliance to National regulations only, e.g. YVL A.12 [43] in the nuclear domain.

In the US, President Obama has very recently established that it is the Policy of the United States to enhance the security and resilience of the Nation's critical infrastructure and to maintain a cyber-environment that encourages efficiency, innovation, and economic prosperity while promoting safety, security, business confidentiality, privacy, and civil liberties [44]. This Executive Order is at the origin of the creation of the NIST Cybersecurity Framework [32], with significant impacts on the overall security engineering domain, e.g. in the aerospace domain [45].

In a context of cyber-warfare [46, 47], chance is that regulation will increase in the coming years, clearing up the overall picture with the emergence of acceptable means of compliance. For example, in the medical domain, since it was shown that some medical devices, e.g. pacemakers and insulin pumps, can be remotely controlled, engendering concern about privacy and security issues [48], the Food and Drug Administration (FDA) released over 20 regulations [49] aiming to improve the security of data in medical devices. But until this regulatory work is generalized in all safety-critical domains, some confusion is to be expected.

5 Security criteria to be considered in Security for Safety

In section §3 above, we asked ourselves if the term *security* had the same meaning when used standalone, or when used in the *security for safety* expression. Classically, information security is defined as a composite of Confidentiality, Integrity and Availability (CIA), whereby Confidentiality is the absence of unauthorized disclosure of information, Integrity is the absence of unauthorised IT system state alteration, and Availability the readiness for correct IT system service for authorized users.

Safety being usually understood as the absence of catastrophic consequences on the user(s) and the environment, the question here is whether the three CIA criteria make sense in a *security for safety* approach. The question is particularly pregnant for the Confidentiality criterion, the compromising of which usually has only indirect consequences on safety. Another pregnant question is whether denial-of-service attacks are in the scope.

In the railway domain, EN 20159 [50] includes provisions for intentional attacks by means of messages to safety-related applications, but it does not cover general IT security issues and in particular it does not cover IT security issues

www.witpress.com, ISSN 1743-3509 (on-line)

concerning the confidentiality of safety-related information, and the overloading of the transmission system.

By contrast, the obsolete ED-202 [51] defined airworthiness security as "the protection of the airworthiness of an aircraft from the information security threat: an adverse effect on safety due to human action (intentional or unintentional) using access, use, disclosure, denial, disruption, modification, or destruction of data and/or data interfaces. This includes the consequences of malware and forged data and access by other systems to aircraft systems". Here, access, use and disclosure clearly relate to the Confidentiality criterion; denial, disruption and destruction clearly relate to the Availability criterion, and modification to the Integrity criterion. ED-202 excluded a number of areas from its scope, and in particular security sensitive handling of security assessment results, national rules on confidentiality, privacy or key escrow regulations. Nevertheless, this ambitious challenge seems to have been dramatically reduced in the new edition, ED-202A [11], in which airworthiness security is now defined as: "the protection of the airworthiness of an aircraft from intentional unauthenticated electronic interaction: harm due to human action (intentional or unintentional) using access, use, disclosure, disruption, modification, or destruction of data [etc., as above]". It is to be noted that the term *denial* has disappeared from the definition, and the information threat limited to intentional unauthenticated interaction.

The above tends to show that indeed the term Security is not well defined in the Security for Safety context. This may explain why the industrial safety communities are chary about recommending generic security standards, which would possibly engage them beyond what they can reasonably achieve.

6 Conclusion

Safety and security co-engineering seems to be primarily a concern of the safety engineering communities. Indeed, the increasing number of cyber-attacks in the world tends to show that safety-critical systems, and in particular cyber-physical systems, which are particularly exposed by nature, may not be as safe as they claim, if they are not also secure. The multiplication of security-related workshops in conjunction to safety-related conferences, and the multiplication of safety standards updates that include security concerns, both provide significant testimonies of this growing interest for safety and security co-engineering by the safety community. There is no similar booing within the security community with respect to safety engineering.

Nevertheless, despite all the papers and standards published by the different academic and industrial safety engineering communities, we have shown that it is still very difficult to precisely define what is meant by *security for safety*.

In terms of overall engineering process definition, certain options, such as *security-informed safety* may have tremendous impacts on the competencies required by safety experts, whereas other options, such as *safety-informed security* may require specific trade-off support. The different safety communities do not seem very clear on the directions to take, even if the aeronautical community has recently opted for a *safety-informed security* approach.

In terms of standards, we have shown that the safety standardisation communities seem keen to create their own domain-specific security standards, rather than use the traditional and generic security standards. This may be because the meaning of *security* is not very clear when used in conjunction to safety engineering, in particular with respect to the *confidentiality* criteria and *denial of service* attacks.

In terms of regulation, we have shown that the current standardisation effort is made difficult by the absence of international regulatory bodies, and thereof, the multiplication of National regulations. Chance is that this situation will evolve towards more regulation, and thus clarify the picture.

7 Future work

The ITEA2 MERgE project was launched at the end of 2012 to address the industrial challenges of efficiently and economically handling multi-concerns, with a particular focus on the co-engineering of the safety and security engineering specialities. This paper represents a snapshot of the collaborative work realised as part of the MERgE project. Beyond the big picture given herein, work is ongoing on more focused technical questions. In this context, recommendations for security and safety co-engineering are under preparation [52].

Acknowledgements

The research leading to these results has received funding from the European Union ITEA 2 Programme (Call 6) under grant no. 11011 (MERgE).

The author wishes to acknowledge Frédérique Vallée and Anthony Faucogney (ALL4TEC), Timo Wiander (STUK), Julien Brunel (ONERA), and Laurent Rioux (TRT).

References

[1] IEC 61508-1, "Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements," International Electrotechnical Commission, 1998.

[2] Wikipedia 9/11, "September 11 attacks," Wikipedia, the free encyclopedia, 21 12 2014. [Online]. Available: http://en.wikipedia.org/wiki/September_ 11_attacks. [Accessed 22 12 2014].

[3] N. Fallière, "Stuxnet Introduces the First Known Rootkit for Industrial Control Systems," Symantec, 06 08 2010. [Online]. Available: http://www.symantec.com/connect/blogs/stuxnet-introduces-first-known-rootkit-scada-devices. [Accessed 12 05 2014].

[4] S + IEC 61508, "Functional safety of electrical/electronic/programmable electronic safety-related systems," International Electrotechnical Commission, 2010.

[5] S. Paul, "Over 20 Years of Research in Safety and Cybersecurity Co-Engineering: a Bibliography," submitted at the *6th International Conference on Safety and Security Engineering* (*SAFE*), Opatija, 2015.

[6] L. Piètre-Cambacedes and M. Bouissou, "Cross-fertilizations between safety and security engineering," *Reliability Engineering & System Safety,* vol. 110, p. 110–126, 2013.

[7] SeSaMo, "Security and Safety Modelling," 2012. [Online]. Available: http://sesamo-project.eu/. [Accessed 20 05 2014].

[8] MERgE, 2012. [Online]. Available: http://www.merge-project.eu/. [Accessed 27 11 2014].

[9] ARTEMIS EMC2, 2014. [Online]. Available: http://www.artemis-emc2.eu/. [Accessed 30 09 2014].

[10] DARPA I2O HACMS, "High-Assurance Cyber Military Systems (HACMS)," DARPA, 06 11 2014. [Online]. Available: http://www.darpa.mil/opencatalog/HACMS.html. [Accessed 21 11 2014].

[11] EUROCAE ED-202A, "Airworthiness Security Process Specification," European Organization for Civil Aviation Equipment (EUROCAE), 2014.

[12] IEC 62645, "Nuclear power plants – Instrumentation and control systems – Requirements for security programmes for computer-based systems," International Electrotechnical Commission, 2014.

[13] A. G. Hessami, "Surety: Atkins Integrated Safety, Security and Environmental Assurance, Product Sheet," [Online]. Available: http://www.atkinsglobal.com/. [Accessed 2014].

[14] SafeRiver, "Safe River, Safety & Security Forge," Safe River, 2014. [Online]. Available: http://www.saferiver.fr/?setlang=en. [Accessed 22 12 2014].

[15] Sysgo, "PikeOS Hypervisor," 2014. [Online]. Available: http://www.sysgo.com/products/pikeos-rtos-and-virtualization-concept/. [Accessed 16 12 2014].

[16] Green Hills Software, "Integrity Real-Time Operating System," 2014. [Online]. Available: http://www.ghs.com/products/rtos/integrity.html. [Accessed 16 12 2014].

[17] ISO/IEC 27001, "Information technology – Security techniques – Information security management systems – Requirements," International Standards Organization/International Electrotechnical Commission, 2013.

[18] ISO/IEC 15408-1, "Information technology – Security techniques – Evaluation criteria for IT security – Part 1: Introduction and general model," International Standards Organization/International Electrotechnical Commission, 2009.

[19] EASA, "Regulations," European Aviation Safety Agency , 2014. [Online]. Available: http://easa.europa.eu/regulations. [Accessed 27 09 2014].

[20] J. Favaro and R. Stroud, "ARTEMIS SESAMO Project: Work Achieved and Perspectives," in *1st International Workshop on the Integration of Safety and Security Engineering (ISSE), 33rd International Conference on Computer Safety, Reliability and Security (SafeComp)*, Florence, 2014.

[21] J. Joyce and L. Fabre, "Integration of security & airworthiness in the context of certification and standardization," in *1st workshop on the Integration of Safety and Security Engineering (ISSE)*, Florence, 2014.

[22] ECSS-Q-ST-40C, "Space product assurance – Safety," European Cooperation on Space Standardization (ECSS), Noordwijk, 2009.

[23] ISO/IEC 27000, "Information technology – Security techniques – Information security management systems – Overview and vocabulary," International Standards Organization/International Electrotechnical Commission, 2014.

[24] ISO/IEC 27002, "Information technology – Security techniques – Code of practice for information security controls," International Standards Organization/International Electrotechnical Commission, 2013.

[25] ISO/IEC 27005, "Information technology – Security techniques – Information security risk management," International Standards Organization/International Electrotechnical Commission, 2011.

[26] ISO/IEC 15408-2, "Information technology – Security techniques – Evaluation criteria for IT security – Part 2: Security functional components," International Standards Organization/International Electrotechnical Commission, 2008.

[27] ISO/IEC 15408-3, "Information technology – Security techniques – Evaluation criteria for IT security – Part 3: Security assurance components," International Standards Organization/International Electrotechnical Commission, 2008.

[28] ISO/IEC 18045, "nformation technology – Security techniques – Methodology for IT security evaluation," International Standards Organization/International Electrotechnical Commission (ISO/IEC), 2008.

[29] NIST SP 800-30, "Risk Management Guide for Information Technology Systems, Special Publication 800-30," National Institute of Standards and Technology, Gaithersburg, 2002.

[30] NIST SP 800-53, "Security and Privacy Controls for Federal Information Systems Federal Information Systems, Special Publication 800-53, Revision 4," National Institute of Standards and Technology, Gaithersburg, 2013.

[31] NIST SP 800-82, "Guide to Industrial Control Systems (ICS) Security, Special Publication 800-82, Revision 1," National Institute of Standards and Technology, Gaithersburg, 2013.

[32] NIST Cybersecurity Framework, "Framework for Improving Critical Infrastructure Cybersecurity," National Institute of Standards and Technology, 2014.

[33] ISO 26262-1, "Road vehicles – Functional safety – Part 1: Vocabulary," International Organization for Standardization, 2011.

[34] ISO 26262-10, "Road vehicles – Functional safety – Part 10: Guideline on ISO 26262," International Organization for Standardization, 2012.

[35] B. J. Czerny, "System Security and System Safety Engineering: Differences and Similarities and a System Security Engineering Process

Based on the ISO 26262 Process Framework," *Journal of Passenger Cars – Electronic and Electrical Systems,* vol. 6, no. 1, 2013.

[36] C. Gebauer, "Safety and security as drivers for future system development," in *1st Workshop on Safety and Security*, Kaiserslautern, 2014.

[37] IEC/TS 62443-1-1, "Industrial communication networks – Network and system security – Part 1-1: Terminology, concepts and models," International Electrotechnical Commission, 2009.

[38] IEC 62443-2-1, "Industrial communication networks – Network and system security – Part 2-1: Establishing an industrial automation and control system security program," International Electrotechnical Commission, 2010.

[39] IEC/TR 62443-3-1, "Industrial communication networks – Network and system security – Part 3-1: Security technologies for industrial automation and control systems," International Electrotechnical Commission, 2009.

[40] IEC 62443-3-3, "Industrial communication networks – Network and system security – Part 3-3: System security requirements and security levels," International Electrotechnical Commission, 2013.

[41] 25-356-SC, "Special Conditions: Boeing Model 787-8 Airplane; Systems and Data Networks Security-Isolation or Protection From Unauthorized Passenger Domain Systems Access," Federal Aviation Administration, 01 02 2008. [Online]. Available: https://federalregister.gov/a/E7-25467. [Accessed 12 11 2014].

[42] 25-357-SC, "Special Conditions: Boeing Model 787-8 Airplane; Systems and Data Networks Security-Protection of Airplane Systems and Data Networks from Unauthorized External Access," Federal Aviation Administration, 28 12 2007. [Online]. Available: https://federalregister.gov/a/E7-25075. [Accessed 10 10 2014].

[43] STUK Guide YVL A.12, "Information security management of a nuclear facility," Radiation and Nuclear Safety Authority (STUK), 22 11 2013. [Online]. Available: http://www.finlex.fi/data/normit/41822-YVL_A.12e.pdf. [Accessed 23 12 2014].

[44] B. Obama, *Improving Critical Infrastructure Cybersecurity,* Washington: The White House, Office of the Press Secretary, 2013.

[45] Boeing Cybersecurity Framework, "Developing a Framework to Improve Critical Infrastructure Cybersecurity," Boeing, 2013.

[46] E. Bumiller and T. Shanker, "Panetta Warns of Dire Threat of Cyberattack on U.S.," The New York Times, 11 10 2012. [Online]. Available: http://www.nytimes.com/2012/10/12/world/panetta-warns-of-dire-threat-of-cyberattack.html?pagewanted=all&_r=0. [Accessed 23 12 2014].

[47] K. Calamur, "Lengthy, Widespread Internet Outage Reported In North Korea," NPR, 22 12 2014. [Online]. Available: http://www.npr.org/blogs/thetwo-way/2014/12/22/372531702/widespread-internet-outage-reported-in-north-korea. [Accessed 23 12 2014].

[48] Wikipedia Medical Device, “Medical device,” 01 09 2014. [Online]. Available: http://en.wikipedia.org/wiki/Medical_device#cite_note-4. [Accessed 06 10 2014].
[49] FR-78-151-47712, “Federal Register/Vol. 78, No. 151, p 47712,” 06 08 2013. [Online]. Available: http://www.gpo.gov/fdsys/pkg/FR-2013-08-06/pdf/2013-19020.pdf. [Accessed 06 10 2014].
[50] CENELEC EN 20159, “Railway applications – Communication, signalling and processing systems – Safety-related communication in transmission systems,” European Committee for Electro-technical Standardization, 2010.
[51] EUROCAE ED-202, “Airworthiness security process specification,” European Organization for Civil Aviation Equipment (EUROCAE), 2010.
[52] S. Paul, L. Rioux, T. Wiander and F. Vallée, “Recommendations for security and safety co-engineering (release n°2),” ITEA2 MERgE project, 2015.
[53] IEC 61508-7, “Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 7: Overview of techniques and measures,” International Electrotechnical Commission, 2000.

This page intentionally left blank

Smart safety management with ARIADNE SMS: Save Money. Prevent.

W. D. Käppler
Fraunhofer FKIE Research Institute for Communication, Information Processing and Ergonomics, Wachtberg, Germany

Abstract

This paper presents the practical result of many years of research into human error and failure in the form of accident and incident risk analyses and prevention: ARIADNE, the integrated safety management system. This is based on the three-level model of accident causation, seeing human errors as accident causes and the product of a network of influences which already embody the risks of error-relevant conditions as accident causes. In ARIADNE, the accident event is structurally classified using 2,000 keys. Risk management assigns probabilities and accident as well as measure costs to errors and causes of error, and suggests preventative measures on a cost-risk basis. Risk changes are predicted with the aim of improving safety, saving resources and cutting costs. Benefits are described and the selected results of 10,000 accident analyses are presented.
Keywords: action, accident analysis, cognition, cost model, descriptor, endangerment error causes, data mining, human error, injury to persons, investigation cost, judgement, keytable, material damage, measures, perception, prevention, probability, quality assurance, risk management, safety management, safety culture, scaling, semantic net, taxonomy, three-level-model of accidents, what-if-risk simulation.

1 Introduction and problem statement

Safety, for example at work or in traffic, is a central issue for society. Nonetheless, even work is a cause of accidents and damage. On economic grounds and for reasons of liability, as well as from a humanistic point of view, this is no longer acceptable; after all, according to the Brockhaus encyclopedia

WIT Transactions on The Built Environment, Vol 151,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SAFE150331

[1] an accident is an unintentional, suddenly occurring event due to external influences such as a knock, fall, etc., causing material damage or damage to life or limb. Accidents, according to Brockhaus, mainly occur in traffic and at work, as well as during leisure activities and in the home.

Brockhaus does not explain why accidents occur in the first place, or why risks exist. A glance at the statistics shows that errant behavior is the cause of 90 percent of all accidents. In final reports, it is then said that the cause of the accident was human error. Public opinion is satisfied: "So nothing could be done about it …"

Experts are aware that, in the case of highly developed technology, this cannot be the last word, but is merely an admission of abject failure by those in charge. For example, in road traffic, the central focus is on clarifying issues of liability: Whose fault is the accident? Who has to pay for the damage? To answer these questions, errant behavior, e.g. in the form of alcohol consumption or speeding, is tracked down and punished. However, the processes and factors which lead to errant behavior or speeding in the first place remain almost unnoticed.

Safety can hardly be effectively improved in this manner, which is where the concept of human error comes in. Reason [2] and Senders and Moray [3] ask why even experienced operators overlook important information, make bad decisions and react inappropriately. They concentrate their search on errors, and, moreover, see them as the product of a wide-reaching network of influences, made up of different risk conditions.

Thus, this concept applies not only to failure from a legal point of view, but also to concrete actions or decisions in a current situation and, moreover, to discovering related causes of error and boundary conditions. According to this, errors are a natural byproduct of human behavior and occur in a concrete, situational context. This dependence on context is the basis for modern safety management.

This is illustrated by a simple example in Figure 1. Fast driving, in the upper picture, leads to the destination quickly and without an accident, if the boundary conditions are taken into account. In the worst case, greater risks occur due to excessive speeds. However, tracing this back as the cause of the accident in Figure 1, below, hides the causes of the accident.

Figure 1: Accident (Käppler *et al.* [4]).

In fact, when considered more closely, the error of Running off the Road leads to the accident; excessive speeds and the trees along the avenue worsen the consequences. The question now is therefore: Why was this error made? This simple example only allows speculative answers: Perhaps fatigue or inattentiveness led to errors of perception, and lack of time to speeding.

In the example, fatigue, inattentiveness or speed need to be checked and monitored. However, modern safety management goes far beyond this: It involves the development, implementation and checking of specific measures for prevention. In the example, these are crash barriers, sleep warning devices, or even the removal of the trees or the reduction of time pressure.

2 Idea and technological implementation

With this in mind, the three-level model of accident causation in Figure 2 was developed by Käppler [5, 6]. According to Frieling and Sonntag [7], in the usual environment of technological, organizational and personal conditions of work organization, for example, there are ample combinations of accident causes. In certain conditions these result in concrete errors, which, in turn, can cause accidents.

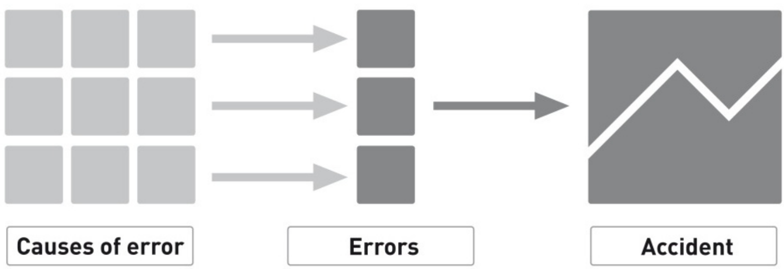


Figure 2: Three-level model of accident causation (Käppler [6]).

With this idea in mind, an empirical investigation was carried out into more than 2,000 accidents during different working activities, including aviation and road traffic. A taxonomy of errors and causes was developed based on Chappelow [8]. Originally, it was divided into errors and technological defects. This duality was discarded, however, as careful analysis showed that defects could also be traced back to errors, e.g. during procurement, construction or manufacturing. That taxonomy describes roughly 150 causes of error in the eight main categories in Figure 3.

- *Work organization* causes of error are faults in the targeted ordering, regulation and incorporation of tasks and activities into social structures, e.g. in the case of rules, regulations or working materials
- *Communication* causes of error are faults in verbal and non-verbal processes of information transfer

- *Personnel and qualification* causes of error are faults in staff selection, allocation and qualification with regard to the knowledge and skills enabling them to carry out the activity
- *Quality management* causes of error are faults in regularly testing the quality and nature of results, e.g. in the case of standards, instructions and manuals
- *Attitude* causes of error are constraints on workers' ability to judge subjects and objects consistently in a certain manner, caused by preferences or predispositions, e.g. due to a need for recognition
- *Physiology* causes of error are constraints on workers caused by life processes such as growth or illness
- *Behavior* causes of error are observable flaws in workers' actions and decisions. This includes processes of experience which workers are aware of to a greater or lesser degree
- *Environmental* conditions causes of error are characteristics of the environment which can be described using physical data and which increase risks.

Figure 3: Categories of error causes (Käppler [6]).

Figure 4 shows the classification of the 35 types of error observed into three categories:

- Errors of perception are a lack of ability to derive from sensory information a comprehensive, sufficient representation of characteristics of the physical and social environment
- *Errors of cognition* are when plans are formulated based on the correct perception of relevant information, but do not stand up to the requirements of the task and situation
- Errors of action are when a correct plan of action is carried out wrongly; i.e. when sequences of actions are mixed up or the worker falls into similar, habitual routines.

Figure 4: Categories of error (Käppler [6]).

Error identification is often based on indications and it is sometimes unclear whether an error actually set off the accident; for example, a failure to act may merely increase risks or consequent damage. Thus, the likelihood of errors occurring and the effect they have differs. This likelihood can be estimated following the error identification. For scaling, an interval scale was developed with five equal intervals, following Rohrmann [9] and Käppler [10] (see Figure 5).

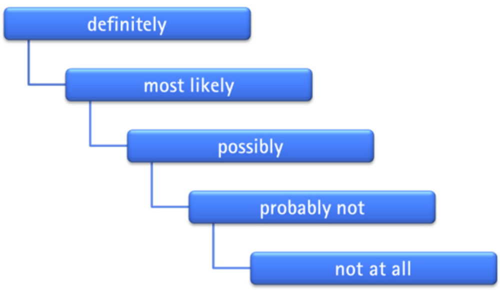


Figure 5: Scaling of errors regarding occurrence and initiation.

If, for example, errors which trigger accidents are more highly rated than those which "only" aggravate the consequences, the scale produces "chains of errors". The identified causes of the accident are also rated in the same way as the errors and developed into chains.

In safety management, knowledge of the errors and their causes, with the scale and chains of effect, allows risk management to be carried out. Risk management is understood as a form of safety culture which sees risks as a lack of information on target achievement, and which aims to reduce these risks. It takes place in these phases:

- Risk identification
- Risk analysis and simulation
- Risk policy.

In Phase 1, using complex mathematical models, the risks of error and causes of error are identified using probabilities and loss expenses.

www.witpress.com, ISSN 1743-3509 (on-line)

In Phase 2, the risk simulation follows, to look into the cause and effect relationship in the case in hand. Using "what-if" simulation, the occurrence and effect of individual causes and errors are manipulated and hypotheses formulated on whether accidents and damage will fail to occur after possible preventive measures are carried out. Simulations of different prevention scenarios show changes in the risks and expenses, and predict potential savings and safety benefits (see Figure 6).

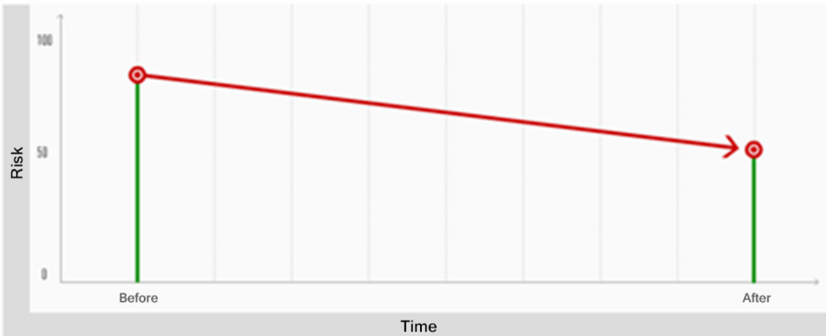


Figure 6: Risk before and after the introduction of preventive measures (Käppler *et al.* [4, 11]).

Finally, in Phase 3, decisions about risk policy measures are made and implemented to avoid, reduce and distribute risks, build up a reserve to cover risks, prevent losses or pass on costs. One part of the risk policy is quality assurance, a running check on the measure's costs and benefits. This overall concept is today summed up with the term safety management. It is a practical expression of the predominating safety culture according to INSAG [12] and Hudson [13] distinguishes between five levels of increasingly mature safety culture (see Figure 7).

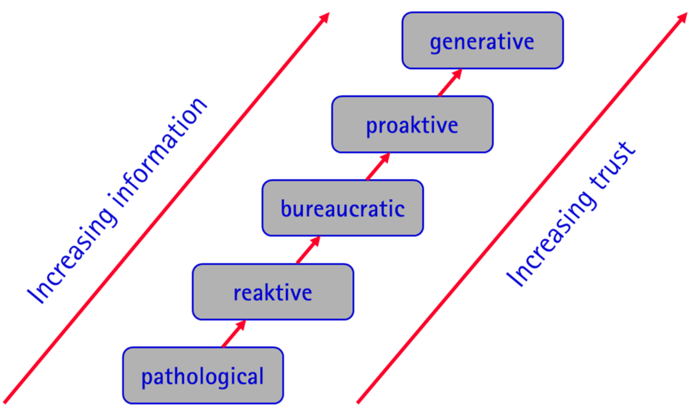


Figure 7: Safety Culture Maturity Model (Käppler *et al.* [4, 11]).

- *Pathological:* Based on the idea, today seen as pathological, that reasonable people do not make any mistakes, along the lines of Palmstrom: "... since, he argues reasonably, that cannot be what must not be" (Morgenstern [14])
- *Reactive:* Recognizes that safety is a problem and acts after incidents occur
- *Bureaucratic:* Characterized by hierarchical communication and the bureaucratic administration of large quantities of data. Typical conclusion: "So nothing could be done about it."
- *Proactive:* Characterized by democratic communication and involves the workers' level. Preventive measures are implemented due to risk or hazard analyses, without damage having occurred
- *Generative:* Sees safety as an indispensable part of business, e.g. alongside the maximization of profits, and depends upon the active participation of all staff at all levels of organization: strategy, management and work (see Figure 8), (INSAG [12]).

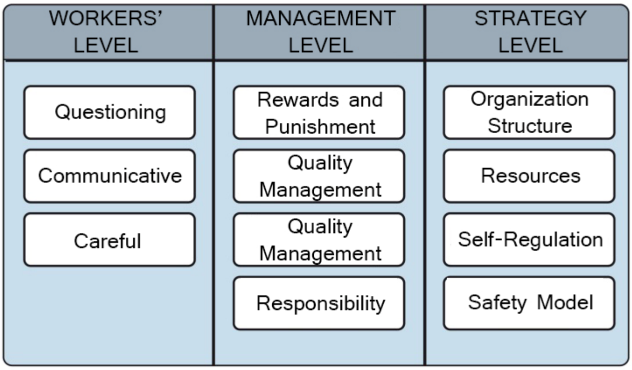


Figure 8: Safety culture and organization (Käppler *et al*. [4, 11]).

Modern safety management is proactive and promotes a generative safety culture. At the level of the workers, careful questions are asked; at the managerial level, decisions are made in democratic processes; as well as quality management and monitoring, incentives are used to encourage people to report their own errors. On the level of strategy, models are created as targets, for example as regards saving resources.

Safety management sees preventive measures as barriers formed by technology, people or organization to prevent accidents or reduce their results, despite errors occurring. Reason [2] modeled the remaining risks as holes in a Swiss cheese; Figure 9 shows a preventive situation which is "full of holes".

Safety management combines individual measures such that at least one barrier shown in the figure prevents the accident; for example, training measures can reduce the consequences of accidents caused by operating errors.

www.witpress.com, ISSN 1743-3509 (on-line)

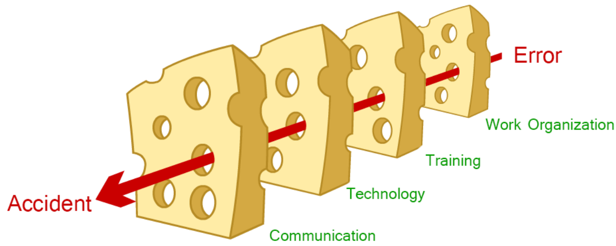


Figure 9: Preventive measures as barriers (Käppler *et al.* [4, 11]).

2.1 ARIADNE safety management system

The ideas outlined above have been joined together to form an integrated safety management system (SMS) for hazards and accidents at work, and put into practice as the ARIADNE web application (see Figure 10). Worldwide access via an internet browser permits:

- Multiple, parallel use by any number of people
- Detailed documentation of how the accident occurred, its consequences and costs
- Analysis of errors and causes
- Risk management and quality assurance.

Figure 10: The ARIADNE web application (Käppler *et al.* [4, 11]).

2.2 Detailed documentation

First, accident and hazard data are collected in the database or offline, using a notebook at the scene of the accident; later, they are aligned with the database. Along with the multi-user capability, this ensures flexibility and currency. Up to 2,000 individual items of data are thus documented in the online database (see the example in Figure 11). The individual values are mainly captured by the selection of key values, so as to create a structured database with comparable data. This is made possible by wide-reaching reporting and statistics tools which are available online.

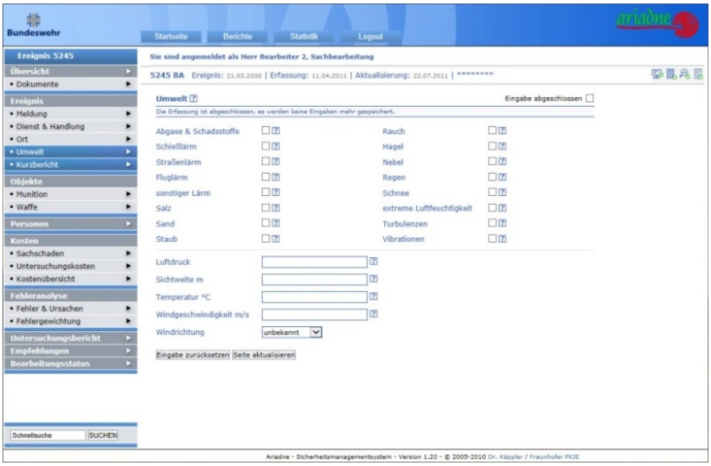


Figure 11: Webpage for capturing the environmental data application in German (Käppler *et al.* [4, 11]).

2.3 Accident consequences and costs

The documentation also includes the consequences and costs of an accident. These are captured in 30 cost accounts as injury to persons, material damage and costs of the investigation (see Figure 12).

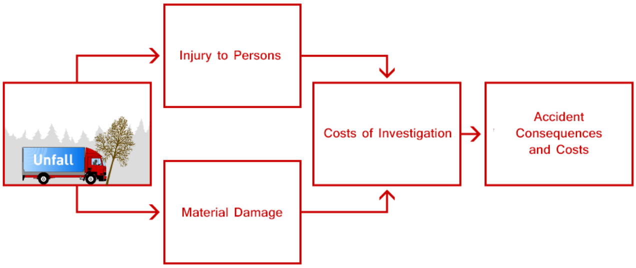


Figure 12: Cost-recording structure application (Käppler *et al.* [4, 11]).

2.4 Analysis of errors and causes

Next, the analysis of errors and causes in Figure 13 is carried out. First, all errors are identified which have caused damage or hazards.

They are weighted and attributed to people. In the same way, causes of error are then identified, weighted and attributed to errors.

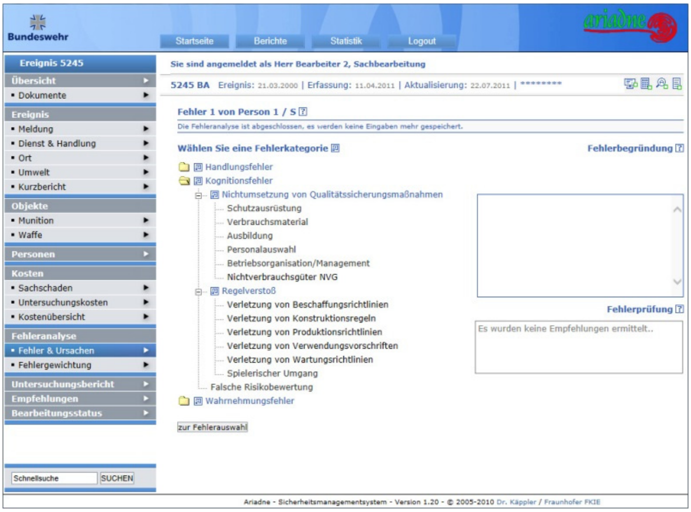


Figure 13: Webpage for error identification in German (Käppler *et al.* [4, 11]).

2.5 Risk management

This extensive management system results in risks, costs and measures. Risk identification shows how likely causes of error are to result in errors, and errors to result in accidents, and proportionally allocates costs to the errors and the causes of error which gave rise to them (see Figure 14).

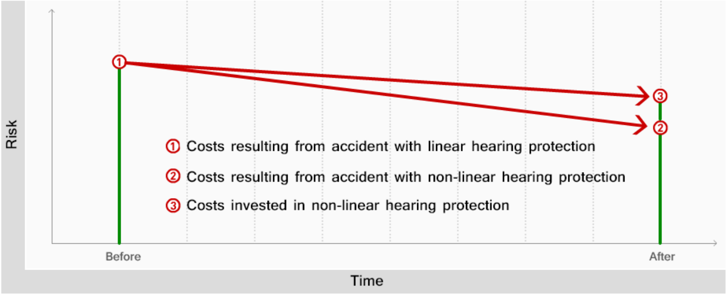


Figure 14: Costs of an accident and preventive measure (Käppler *et al.* [4, 11]).

"What-If" risk simulation predicts changes in these risks and costs after corresponding preventive measures are introduced. Preventive measures also cost money. These costs are determined and cut back the expected savings, see Figure 14. Detailed descriptions of the mathematical models and processes can be found in Käppler *et al.* [4], Käppler [5] and Käppler and Dalinger [15].

2.6 Quality assurance

Preventive measures are documented. The processes and schedules are checked in the SMS quality management, see example in Figure 15. After the start-up period and when a measure has been implemented for the set time, the SMS suggests quality checks and repeating the “before and after” risk analysis, to validate the preventive measure.

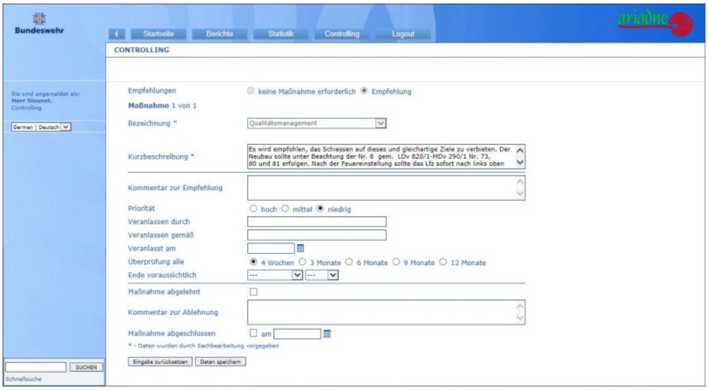


Figure 15: Webpage for quality assurance in German (Käppler *et al*. [4, 11]).

2.7 SMS access and security

The database contains personal data and other information. These are protected against manipulation, unauthorized access and theft using a wide-reaching security concept. Furthermore the SMS manages different access rights for the following groups of users:

- *Administration* governs the rules and rights of usage, including the key tables, with access to the whole system.
- *Analysis* has access to all the data material, checks it and carries out evaluations and risk analyses. It runs the development and quality assurance of the application.
- *Processing* enters data, analyzes the errors and causes of error and suggests preventive measures
- *Quality management* implements and checks preventive measures
- *Guest* has read-only access to statistics, analyses and reports
- *Audition* supervises access and security of the site and data.

3 Results

ARIADNE provides information on results online using descriptive statistics, in the form of graphs and tables, mainly using pie charts and histograms. The following figures show examples of the results of accident and hazard analyses in the past when handling weapons and munitions in the German armed forces. In these examples it must be noted that data from all incident classes were analyzed together to demonstrate ARIADNE's potential. This is only the first step in developing accurate preventive measures and the basis for identifying trends and weak spots in accident incidents as a whole. Next, the data from the identified problem areas are filtered in detail and evaluated to develop targeted measures. This is shown in detail in Käppler [16] and Käppler *et al*. [4] also addressing road accidents with motor bikes.

All the following images are downloads from the web application and a data sample recorded in recent years. Altogether, 3,010 incidents were caused by 6,222 errors and 12,419 causes of error. On average, that made two errors and four causes per case in this sample (see Figure 16).

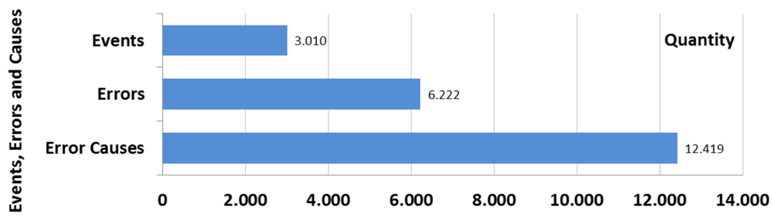


Figure 16: Accidents, errors and causes (Käppler *et al*. [4]).

3.1 Documentation

Figure 17 shows that in the reporting timeframe, more than €26 million cost in total was caused; on average just under €9,000 per incident. The lion's share of the costs resulting from the accident goes to injury to persons; only 20 percent are material damage. Investigation costs seem negligible, as according to the information only external costs are calculated, and not, for example, the personnel costs for those processing the case.

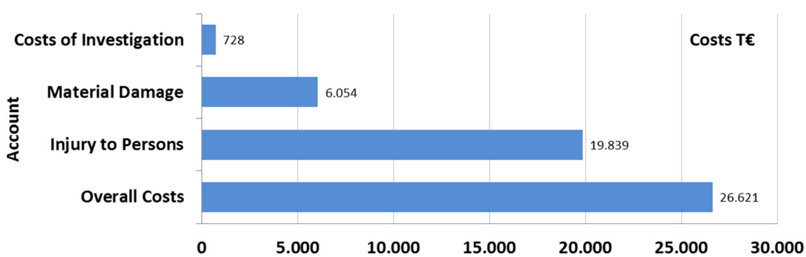


Figure 17: Overview of the costs resulting from accidents (Käppler *et al*. [4]).

Figure 18 shows that just below 10 percent of accidents produced almost 90 percent of all costs resulting from accidents.

Altogether, 5,926 people were involved, of whom only 146 were female (see Figure 19), that means just 2 percent.

According to Figure 20, 12 soldiers were killed and 50 percent of those involved were injured; 36 percent slightly and 3 percent seriously. In 11 percent

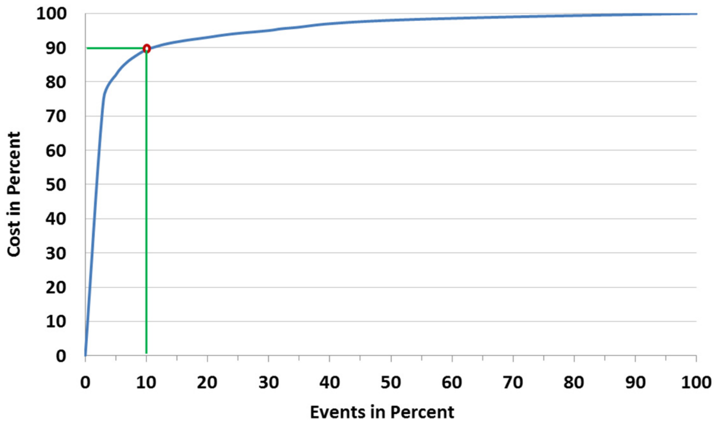


Figure 18: Costs resulting from accidents by number of accidents, in percent (Käppler *et al*. [4]).

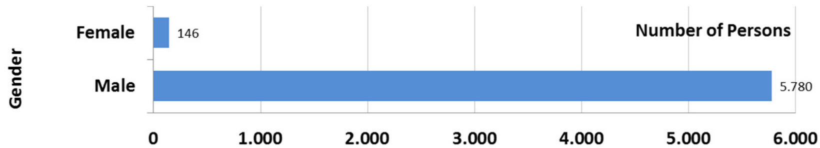


Figure 19: People involved in accidents, by gender (Käppler *et al*. [4]).

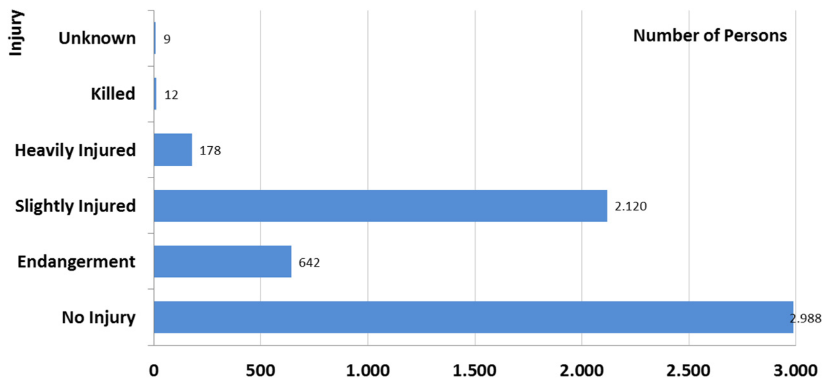


Figure 20: Degree of injury and mortalities (Käppler *et al*. [4]).

www.witpress.com, ISSN 1743-3509 (on-line)

of cases, people were merely at risk. The proportion of injuries of unknown seriousness relates to technical weapons and munitions complaints where no injuries to people were documented.

Figure 21 shows that accidents were more likely to occur on Tuesdays, Wednesdays and Thursdays, with a peak on Wednesdays. This is typical for accidents at work.

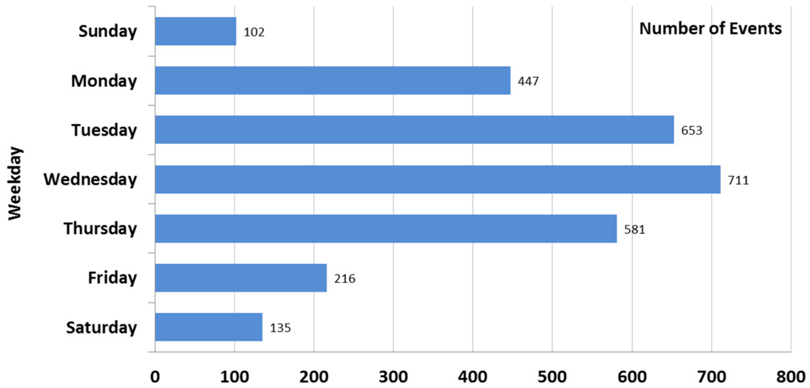


Figure 21: Distribution of accidents across days of the week (Käppler *et al.* [4]).

3.2 Analysis of errors and causes

Sixty percent of the errors causing the event were errors of cognition and 31 percent errors of action. A mere 9 percent of the incidents were traced back to errors of perception (see Figure 22).

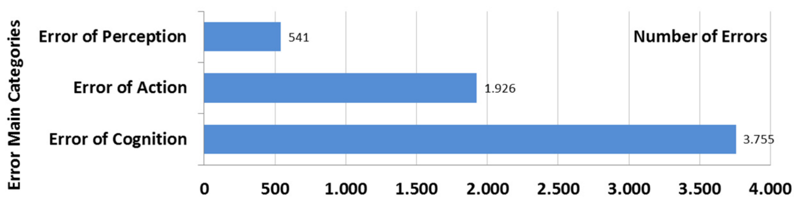


Figure 22: Overview of error main categories (Käppler *et al.* [4]).

Figure 23 shows details: the most common errors were incorrect operation and actions, followed by the violation of usage regulations, as well as errors in organization and management, incorrect risk evaluation, erroneous use of materials and failure to implement quality assurance measures.

The overview of causes of error in Figure 24 provides further indication of trends and weak spots. The areas of behavior (42 percent), quality management

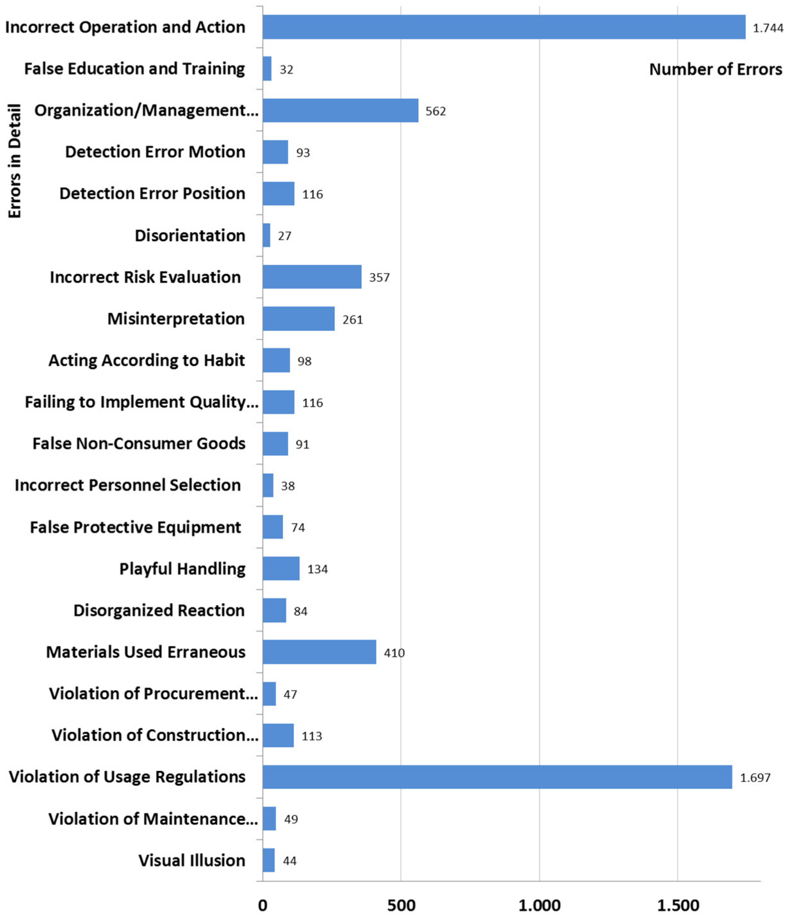


Figure 23: Errors in detail (Käppler *et al*. [4]).

(22 percent) and personnel and qualification (13 percent) were named the most often. Causes of error in the areas of work organization and attitude were only named in 7 and 10 percent of cases, respectively. Named in between 1 and 2 percent of cases, problems with environmental conditions, communication or physiology played only a minor role as causes of error.

3.3 Risk management

However, frequencies do not reveal anything about risks and costs, which are typically discussed in great detail in bureaucratic safety strategies. Formulating preventive measures based on statistical frequencies may be rash and result in ineffective measures, as the past has shown. One aim of a proactive safety

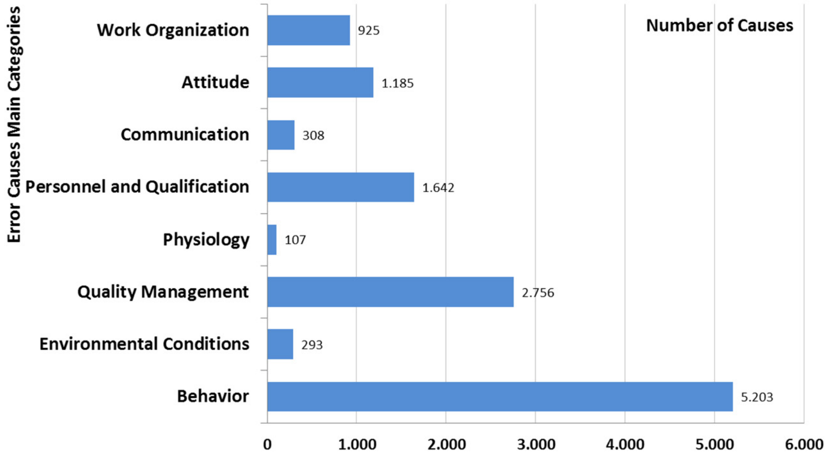


Figure 24: Overview of error causes main categories (Käppler *et al.* [4]).

strategy, on the other hand, is to gain information on risks and costs so as to allow successful risk management which can be verified by quality control.

Figure 25 shows cost risks of the observed errors of violation of usage regulations, incorrect risk evaluation, playful handling, failing to implement quality assurance measures and incorrect operation and actions. These errors account for almost all cost risks; Nota Bene that simple addition results in more than 100 percent since more than one errors occurred per event. Here, the circle of conventional accident analysis and modern safety management is completed. Indeed, in the case of weapon and munitions handling, errant behavior is also the cause of 90 percent of all accidents. Improvements can certainly be made in this respect by stricter controls on adherence to rules and prohibitions. "Prevention" based on law enforcement and the fear of possible consequences is, however, of little long-term success, as unsuccessful efforts in the past have shown.

This is where a proactive, or even a generic, safety culture comes in. It even specifically avoids the enforcement of rules, to motivate workers to cooperate openly in central error documentation and analysis of causes of error, for example. It goes further, applying their efforts to the causes of these errors. Preventive measures are not developed until insights have been gained.

Figure 26 shows a corresponding overview of cost risks for the eight categories of causes of error in thousands of euro. Behavioral failures are not as expensive as might be expected: They were a factor in 42 percent of incidents, but caused only 34 percent of resulting costs. Similar picture with personnel and qualification failures: Only 9 percent of cost risks were caused, although they occurred in 13 percent of cases. In contrast, attitude failures were only involved in 10 percent, but caused more than double, i.e., 21 percent of total costs. Investment and costs for work organization failures were driving cost risks, too, a factor in 7 percent of the cases but causing 11 percent of cost risks. Quality management failures showed a different result: A factor in 22 percent of incidents, they also caused 19 percent of costs.

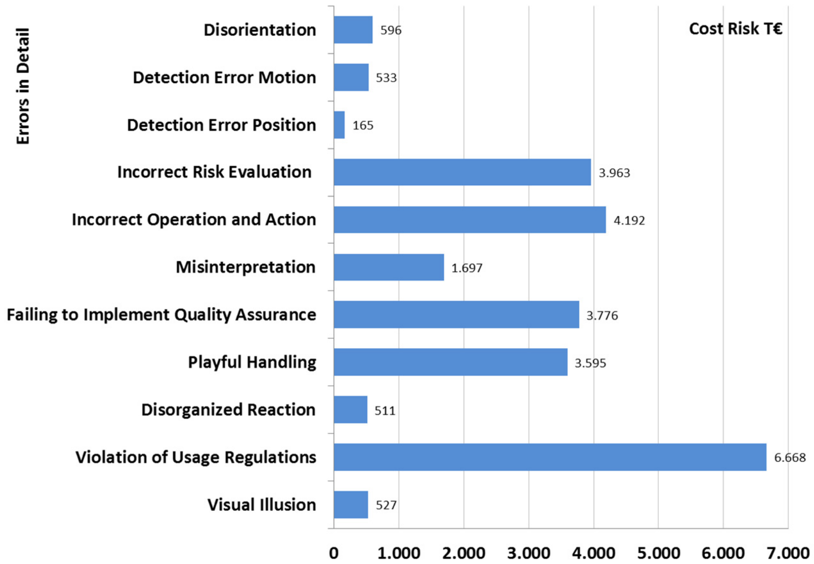


Figure 25: Cost risk of errors in detail in €K (Käppler *et al*. [4]).

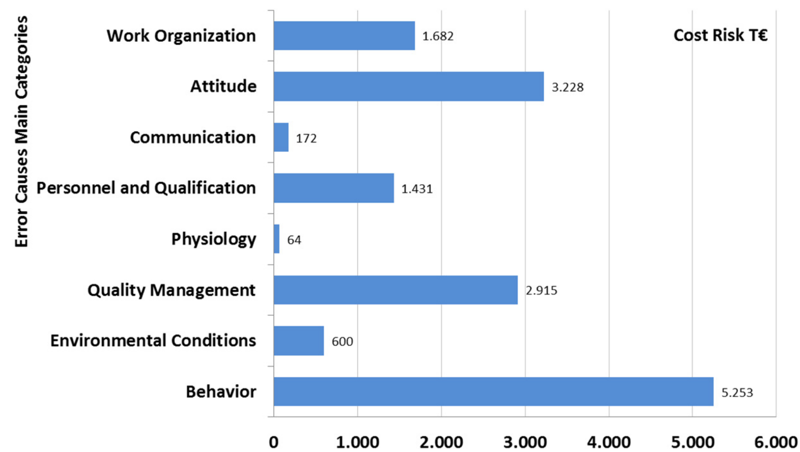


Figure 26: Overview of cost risk of error causes main categories in €K (Käppler *et al*. [4]).

This comparison shows one significant advantage of risk and cost analyses and allows important decisions to be made: Personnel and qualification failures may have been the second most frequent cause of error, but risk analysis attributes a relatively low cost risk to them. In terms of prevention, this is initially of secondary importance. On the other hand, the results of the statistical analysis for communication failures are confirmed, as are the commonly quoted physiology and environmental conditions: Their cost risks are all below 1 percent and for now only come in third place altogether for preventive measures. Based on this strategic decision, detailed information is now required in order to derive concrete preventive measures.

Figure 27 shows the causes of error with the highest direct expenses; costs below €100K are not listed, to give a clearer overview.

Forty-four percent of cost risks are incurred by just three causes: Lack of conscientiousness (attitude), deficient supervision and control (quality management) and knowledge deficiencies (behavior). Failures in equipment, practical training, workload and inattentiveness involve markedly lower cost risks; from a preventive point of view they are initially of secondary importance. Preventive measures related to other causes of error come in third place.

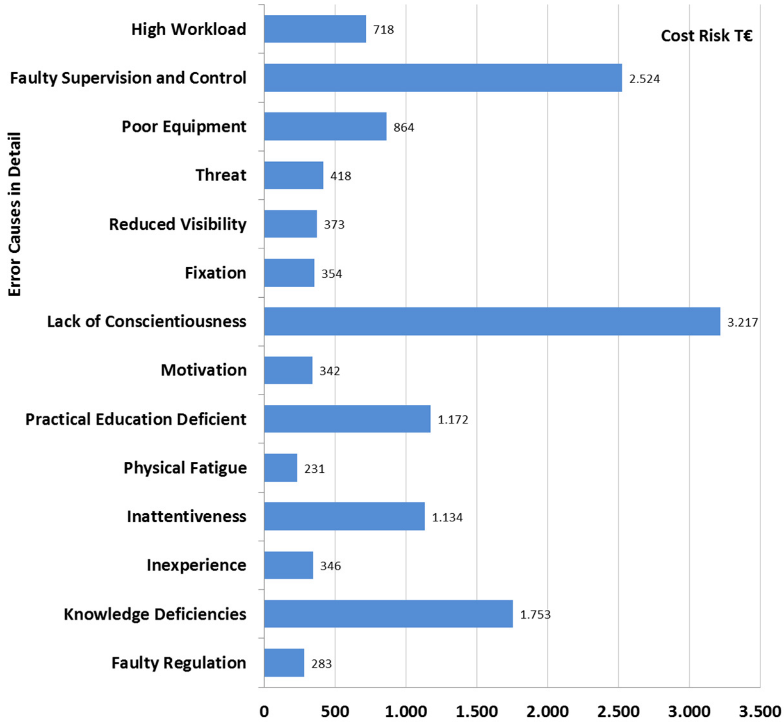


Figure 27: Direct cost risk of error causes in detail in €K (Käppler *et al*. [4]).

Based on this information, risk management suggests preventive measures, starting with conscientiousness, supervision and control, as well as knowledge gaps. Thus, all that remains is to investigate in detail which knowledge gaps there are, which separate failures in training, procedure or the manuals have caused errors, and which measures can be used to reduce the number of accidents occurring or lessen their results. That task does not fall to this report, but to the hands of experts. Here, there can only be speculation on whether, for example, selection processes can already diagnose lack of conscientiousness up front. The same is true of optimization measures for supervision and control.

Interestingly, above all, the trends observed put safety culture at the management level of the German armed forces to the test, as they concern quality assurance, supervision and testing, and responsibility. Altogether, the analysis shows potential savings of more than €10 million a year just for these three areas.

3.4 Quality assurance

Of course, there are also technological failures, as the following example shows: Favored by knowledge gaps (workers' level) and lacking supervision (management level), when dealing with weapons and munitions, acoustic traumas are a frequent injury which can lead to hardness of hearing or even deafness. The hearing protection used today is linear and cuts out all external sounds equally across the whole range of frequencies, including communication, radios or sounds people make themselves. For some exercises, it needs to be removed, even when there is a danger of shots breaking: quite clearly poor equipment.

An analysis of the 2002 data showed that only one in ten acoustic traumas are reported and that in 2002, including this hidden figure, there must have been 2,000 traumas, of which about half were put down to linear hearing protection. In 2002 alone, the costs for sickness and absence were around € 2.8 million.

Non-linear earplugs could be a remedy. The plastic devices defend against thuds and bangs, yet, according to Randow [17] allow the soldiers to perceive their environment at normal sound levels without restriction. Implementing this preventive measure for all soldiers requires a one-off cost of € 2.5 million in total. This can be expected to pay for itself within a year, even without taking into account damage payments, rehabilitation costs or pensions. Consequently, implementation was initiated. Non-linear earplugs are currently in a trial phase.

One last comment on this as regards quality assurance and Swiss cheese, and once again, the circle is completed: As part of the trial, earplugs were originally purchased in the sizes small and large; after removal from the outer packaging, they cannot be told apart from the earplug itself. The soldiers were also rarely aware that different sizes existed at all. Unsurprisingly, acoustic traumas occurred increasingly due to unsuitable or lost earplugs. In the meantime this was remedied by using one flexible standard size for all.

4 Summary and outlook

ARIADNE is an integrated safety management system which promotes a proactive safety culture. On a cost-risk basis, it formulates effective preventive measures to improve safety, performance and reliability. It aims to reduce costs while simultaneously improving the protection of lives, health and resources. ARIADNE offers the following advantages:

- The database's *central archive* makes all the information, data, documents, reports and analyses available online all over the world, at any time. When there is no internet connection, all documents and data are imported and exported at a later time.
- The safety management system sets *standards* for data acquisition, investigation, analysis, risk management, prevention and quality assurance of accidents and hazards, with an extensive workflow and intuitive user guidance
- Intricate *cost models* calculate actual costs resulting from accidents and attribute them in detail to errors and causes
- *Risk management* creates effective hazard and trend analyses and predicts the risks and costs of all errors and causes
- *Risk simulation* leads to well-founded decisions about effective preventive measures
- *Quality management* ensures that the effectiveness of the preventive measures is documented and checked.

ARIADNE is currently deployed by the German armed forces in the field of weapons and munitions and adapted to German Air Force incidents. The results show, for example, that 10 percent of accidents cause 90 percent of the resulting costs. Causes of error from the "behavior" category accrue the highest costs.

ARIADNE is based on Internet technology, is used as an Internet or intranet application and operated using an Internet browser. It does not require the installation of software or clients. This total lack of proprietary platforms and formats offers considerable financial advantages. ARIADNE is available in German and English as a complete safety management system or service, and can be applied to a wide range of working activities. More information is provided on www.ariadne-sms.com.

References

[1] Bibliographisches Institut & F. A. Brockhaus AG, 2007.

[2] Reason J. *Human Error.* Cambridge, Mass: University Press, 1990.

[3] Senders J. & Moray N. (1991) *Human Error*. Hillsdale, NJ: Erlbaum, 1991.

[4] Käppler W.D., Pressler R., Siebel M. & Specht D. *Smart Safety Management mit ARIADNE SMS.* Berlin Heidelberg: Springer Vieweg, 2014.

[5] Käppler W.D. *Menschliche Fehler als Unfallursachen: Untersuchungen und Ergebnisse mit ARIADNE*. In Grandt, M (Ed) *Verlässlichkeit der Mensch-Maschine-Interaktion*. Bonn: Deutsche Gesellschaft für Luft- und Raumfahrt eV, Report 04-03, pp. 197–212, 2004.

[6] Käppler W.D. *Smart Driver Training Simulation. Save Money. Prevent.* Berlin Heidelberg: Springer, 2008.

[7] Frieling E. & Sonntag K. *Lehrbuch Arbeitspsychologie.* Bern: Huber, 1999.

[8] Chappelow J.W. *Causal Factors in Military Aircraft Accidents: Study Outline.* Farnborough: DERA/CHS/MID/TR980168, 1998.
[9] Rohrmann B. *Empirische Studien zur Entwicklung von Antwortskalen für die sozialwissenschaftliche Forschung*. Z.f. Sozialpsychologie 9, pp. 222–245, 1978.
[10] Käppler W.D. *Beitrag zur Vorhersage von Einschätzungen des Fahrverhaltens*. Düsseldorf: VDI Fortschrittsberichte 12/198, 1993.
[11] Käppler W.D., Pressler R. & Specht D. *Sicherheitsmanagement mit ARIADNE*. In *Ergonomie und Mensch-Maschine-Systeme* (pp. 437–462, Eds Schmidt, Schlick, Grosche) Heidelberg, Berlin, New York: Springer Vieweg, 2008.
[12] INSAG *Safety Culture.* Vienna: IAEA Safety Series 75-INSAG-4, 1991.
[13] Hudson P. Applying the Lessons of High Risk Industries to Health Care. Qual. Saf. Health Care 12, pp. 7–12, 2003.
[14] Morgenstern C. *Die unmögliche Tatsache*. In Gesammelte Werke. Munich: Piper, 1910, edn. 2004.
[15] Käppler W.D. & Dalinger E *Derivation of Safety Measures through Human Error Risk Analyses*. In C.A. Brebbia *et al.* (Eds.) *Safety and Security Engineering*. Southampton, Boston: Witpress, pp. 253–263, 2005.
[16] Käppler W.D. *Sicherheit im Motorradhandel.* Bonn: BG Handel und Warendistribution FB 1, 2008.
[17] v. Randow G. *Stöpsel und Kanonen*. Frankfurter Allgemeine Sonntagszeitung 10, p. 59, 2003.

This page intentionally left blank

Author index

Flood Early Warning Systems

Knowledge and tools for their critical assessment

***D. MOLINARI, S. MENONI, F. BALLIO**, Politecnico di Milano, Italy*

This book presents the results of an ambitious research activity designed to understand why Early Warning Systems (EWSs) fail. However, from the beginning, the objective of the research proved to be challenging for two reasons. First, as yet there is not a shared understanding of what an EWS is among either research or practitioner communities. Second, as a consequence, it is equally unclear when an EWS can be considered successful or not. Because of this, the research needed first to define EWS and identify its components, functions, peculiarities, and weak points. Only at that point was a first attempt to evaluate EWSs performance possible.

Flood Early Warning Systems Performance is organised according to the conceptual steps required by the research. In part I the "open questions" about the definition and the role of EWSs are handled, the aim being the identification of how to evaluate EWSs effectiveness/performance. Part II focuses on the real aim of the research, providing concepts and tools to assess EWSs performance; suggested tools are also implemented in a case study to describe how they can be applied in practice. The sections are independent of each other to allow readers to focus only on the content they are most interested in.

The book is designed for a wide audience. The book can serve as a sort of manual for EWSs designers, managers, and users, but also has appeal for general readers with an interest in the subject. While the focus of the book is flood risk in mountain regions, most of the results can be applied to other hazards as well.

Traditionally early warning systems (EWSs) have been identified with monitoring and forecasting systems and their assessment has therefore focused only on the accuracy of predictions. The authors propose a shift in thinking towards the more comprehensive concept of total warning systems, where monitoring and forecasting systems are coupled with risk assessment, emergency management and communication aspects. In line with this, a new approach to assess EWSs is proposed that is based on system's capacity of reducing expected damages, with the hope that improved EWSs will result.

ISBN: 978-1-84564-688-2 eISBN: 978-1-84564-689-9
Published 2013 / 196pp / £84.00

This page intentionally left blank