

ERGONOMIC DESIGN APPLIED IN A SUGAR MILL INTERFACE

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Abstract— In tasks requiring human supervision in an industrial control room there are applied generic disciplines like automatic control and engineering systems. From the point of view of the human computer interaction applied to these disciplines it is necessary to add usability engineering and cognitive ergonomics. This integrated framework is an example of human-centred design on automation systems. The main goal of this work is the application of a cognitive ergonomic guideline for supervisory control in order to improve the efficiency of a sugar mill interface design.

Keywords— display design, supervisory control, sugar mill, industrial automation.

I. INTRODUCTION

In recent years, control systems and the role of control room human operators have changed dramatically (Samad and Weyrauch, 2000). Human operator activity has evolved from manually performing the process to control system supervision (Sheridan, 1992). Today, the human operator requires an in-depth knowledge of the process that he/she is overseeing and the ability to make effective decisions within demanding constraints.

The increased complexity of industrial process control calls for a new methodological approach (for research and design purposes), which reproduces the essential components of current control systems, the environment, the task at hand and human operator activity.

The complexity of industrial process supervision makes it necessary to supplement the Automatic Control approach and the Industrial Automation approach with a cross-disciplinary cooperation in order to integrate knowledge and methods from other fields, especially Cognitive Ergonomics, and Human-Computer Interaction (Cañas, 2004; Granollers *et al.*, 2005; Holstom, 2000; Nimmo, 2004; Raskin, 2000). Our view is that complete control systems engineering must encompass all these approaches.

Ergonomics is concerned with the adaptation of technology to suit human operator need and ability in order to achieve effectiveness, efficiency and user/worker satisfaction and comfort (Karwowski, 2005).

Supervisory control is the set of activities and techniques developed over a set of controllers (programmable logic controllers and industrial regulators) which ensures the fulfilling of control goals (Saez *et al.*, 2005).

One of the main goals is to prevent possible plant malfunctions that can lead to economic loss and/or result in damage. For this reason, other fields of knowledge concerned with manufacturing systems performance – such as maintenance and industrial security – are complementary to the study of supervision systems.

It is necessary to develop techniques to aid the human operator in supervisory control tasks because they reduce the effort he must make. One of the good ways to enhance human operator knowledge is to train them using simulation techniques (PSI, 2008; Costa *et al.*, 2003). Two types of simulators in the industrial domain exist: the simulators for the design of the installations and the process training simulators (RSI, 2008). In the process industry, for example the sugar mill, a typical process training simulator is the Full Scale Simulator (CTA, 2006). This simulator is associated with a replica of the control room with a realistic appearance and functions.

With the use of a training simulator it is possible to develop a training program and a usability study of the human supervisory control task out of the control room, for example in a usability laboratory or in an automatic control laboratory (Shneiderman, 1998).

In this paper a methodology for the creation of an ergonomic guideline for supervisory control interface design is proposed. In section two we present briefly the previous research on human interface design guidelines. A checklist of indicators of the guideline called ‘ergonomic guideline for supervisory control interface design’ (GEDIS *Guía ergonómica para el diseño de interfaz de supervisión* in Spanish version) is described in section three. In section four, transition from the GEDIS model to the sugar mill interface in the control room is evaluated. Finally, we finish with conclusions and future research lines.

II. PREVIOUS RESEARCH

A simulation can be used in the oil & gas, processing, manufacturing, agricultural, and transportation sectors.

One of the modes of the simulation is the use of virtual reality. In this case, with a virtual scenario, the operator is inside a control room that closely emulates a standard environment. This system may be used to inject faults, or to emulate operating sequences. The trainee responses may be fully monitored from a separate room, and certified competence assessment may be given (TSC, 2008).

In order to improve the efficiency of the human supervision in the control room it is necessary to create training scenarios for studying process situations. These training scenarios include:

- normal operation
- troubleshooting in daily operation
- abnormal situations and emergencies
- start-up and normal shutdown procedures
- control and strategy
- safety

These training scenarios are necessary in order to capture the knowledge of experienced operators and pass this on to beginner operators. The experienced operators need artificial aid, a decision support system that must provide the operator with information in real time to enable good decision making under time stress. The benefits are:

- increased information access
- increased decision efficiency and effectiveness

Human error, particularly due to the erosion of expertise, has largely contributed to production losses (Reason, 2000). Appropriate human factors – or ergonomics - considerations have been given to the design, commissioning, and operation of control rooms under both normal and abnormal plant operating conditions to reduce the frequency of human error due to control room deficiencies. Factors to be taken into account:

- control room layout
- maintenance
- thermal and visual environment
- human-machine interface

In this section we will briefly review the research on human interface design guidelines studies related to control and human supervision tasks.

A. ISO 11064

The ISO 11064-7-2006 is a part of ISO 11064 that establishes ergonomic principles for the evaluation of control centers (ISO, 2004). It gives requirements, recommendations and guidelines on evaluation of the different elements of the control center, i.e. control suite, control room, workstations, displays and controls, and work environment.

There is a relationship with other standards like ISO 13407 human centered design processes and ISO 9242 ergonomic visual display design.

B. Human Factors Design Standards (HFDS)

The Human Factors Design Standard (HFDS) is an exhaustive compilation of human factors practices and principles integral to the procurement, design, development, and testing of Federal Aviation Administration (FAA) systems, facilities, and equipment of the United States (FAA, 1996). For example, Chapter 9 is about the human-computer interface and a set of general principles of screen design.

C. Human Interface Design Review Guidelines (Nureg 0700)

The U.S. Nuclear Regulatory Commission (NRC) staff review the human factors engineering (HFE) aspects of nuclear power plants in accordance with the Standard Review Plan (NUREG-0800). Detailed design review procedures are provided in the HFE Program Review Model (NUREG-0711) (NRC, 2002).

As part of the review process, the interfaces between plant personnel and the plant's systems and components are evaluated for conformance with HFE guidelines. The document, Human-System Interface Design Review Guidelines (NUREG-0700, Revision 2), provides the guidelines necessary to perform this evaluation.

The review guidelines address the physical and functional characteristics of human-system interfaces (HSI). The NRC staff can use the NUREG-0700 guidelines to evaluate a specific design.

D. I-002 Safety and Automation Systems NORSOK

The I-002 SAS is an example of NORSOK standards from the Norwegian petroleum industry (Norsok, 2006). This standard covers functional and technical requirements and establishes a basis for engineering related to Safety and Automation System Design.

This standard shall be used together with I-001 "Field Instrumentation", I-005 "System Control Diagrams", Z-010 "Electrical, Instrumentation & telecommunication Installation" and S-001 "Technical Safety". The SAS Life Cycle Cost should be used as a criterion for the evaluation of the system. This includes engineering, commissioning, documentation, spare parts, and production loss during system repair and modifications/maintenance in the operational phase.

E. Man Systems Integration Standard (NASA-STD-3000)

This document provides specific user information to ensure proper integration of the man-system interface requirements with those of other aerospace disciplines (NASA, 1995). These man-system interface requirements apply to launch, entry, on-orbit, and extraterrestrial space environments.

This document is intended for use by design engineers, systems engineers, maintainability engineers, operations analysts, human factors specialists, and others engaged in the definition and development of manned space programs. Concise design considerations, design requirements and design examples are provided.

One of the most important details in the interface design is the design of alarm systems. Alarm systems are important because they are systems that provide stimulus – visual or audible warning – to make the operator aware of an operational problem. They should direct the operator's attention to an abnormal situation so that s/he can take preventive actions (Noyes and Bransby, 2001).

A systematic method to understanding the abnormal situations in the human supervisory task in industrial control room is required. The Abnormal Situation Management (ASM) Consortium is a long-running and active Honeywell-led research and development consortium of 15 companies and universities concerned about

the negative effects of industrial plant incidents. It identifies problems facing plant operations during abnormal conditions, and develops solutions. Abnormal situations are managed by prevention, early detection, and mitigation, in order to reduce unplanned outages and process variability that reduce profits and increase the risk to plant employees and local communities (ASM, 2008).

And a systematic method to display design is required in order to identify the important interface elements and enhance task efficiency and safety by reducing human errors (Attwood *et al.*, 2006; Han *et al.*, 2007; Bastien and Scapin, 1995).

III. GEDIS GUIDELINE

The GEDIS guide is a method that seeks to cover all the aspects of the interface design (Ponsa and Díaz, 2007a). From the initial point of view of strategies for effective human-computer interaction applied to supervision tasks in an industrial control room, the GEDIS guide offers design recommendations at the time of creating the interface. It offers recommendations for improvement of interfaces created. The GEDIS guide is composed of two parts: a description of ten indicators and measure of the ten indicators. The indicators have been defined from extracted concepts of other generic human factors guidelines and from aspects of human interface design in human-computer interaction. The method to continue the use of the GEDIS guide is: analyze the indicator, measure the indicator, obtain the global evaluation index and finally offer recommendations for improvement. For the correct use of the GEDIS guide the collaboration between human factor technicians is necessary since in some cases the expert’s opinion is needed to analyze the indicator.

A. List of indicators

The GEDIS guide consists of 10 indicators that seek to cover all the aspects of the interface design in the supervisory control domain. The indicators are: architecture, distribution, navigation, color, text font, status of the devices, process values, graphs and tables, data-entry commands, and finally alarms (see Table 1 and Table 2). For example, the relationship between architecture and navigation indicators is illustrated in Fig. 1. The physical plant can be separate in area, subarea, and equipment (local process control). In the same way, the interface presents four navigation levels. The distribution indicator of Fig. 2 shows a possible layout to locate all the objects inside the screen.

B. Evaluation

The evaluation expressed in quantitative numeric form or in qualitative format seeks to promote the user’s reflection that feeds the GEDIS guide by means of a questionnaire. This way it collects the user experience in a written form. Each one of the indicators of the Table 1 and Table 2 can substructure in several subindicators. For example, the indicator Color can be detailed in: absence of non appropriate combinations (5), number of colors (5), blink absence (no alarm situation) (5), contrast screen versus graphical objects (3), relationship

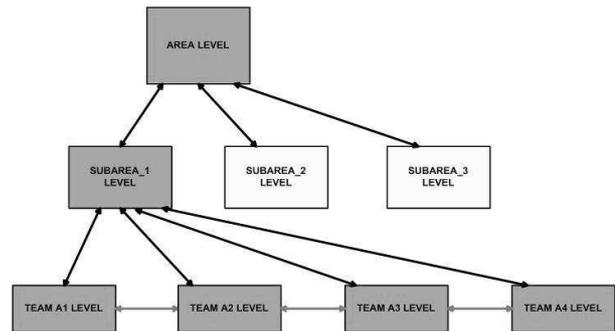


Fig.1 A typical cyclic network menu in supervisory control interface associated to architecture indicator

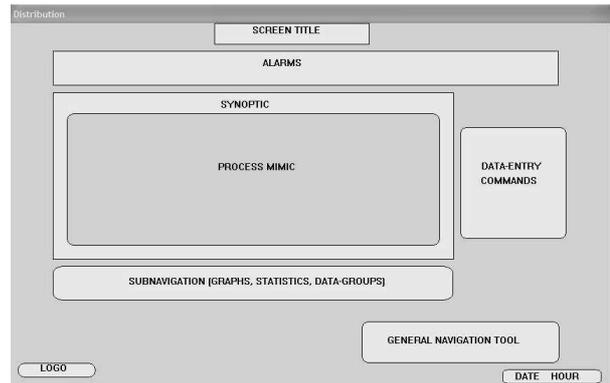


Fig.2 An example of object’s location inside a screen for the distribution indicator.

with text (3). For each subindicator it is recommended they be punctuated numerically in a scale from 1 to 5. In this example the number of subindicators of the indicator Color is J = 5 (see Eq. 1). The equation necessary to calculate the numeric value of each indicator is the Eq. 1.

$$Indicator = \frac{\sum_{j=1}^J w_j Subind_j}{\sum_{j=1}^J w_j} \tag{1}$$

Subind= subindicator and w = weight.

The mean value that is obtained by the Eq. 1 with these numeric values is 4.2 . If it is rounded, the value is 4. Finally, the indicator Color it is assigned the value 4 in this example, considering that each one of the subindicators has the same weight (w1 = w2... =wJ = 1). Each one of the indicators in Table 1 is measured in a scale from 1 to 5. The human expert operator can assess and determine the improvement to be made. The values of the indicators can be put together so that the GEDIS guide offers the global evaluation of the interface and it can be compared with other interfaces. The equation necessary to calculate the GEDIS guide global evaluation index is the Eq. 2.

$$Global_evaluation = \frac{\sum_{i=1}^{10} p_i ind_i}{\sum_{i=1}^{10} p_i} \tag{2}$$

ind = indicator and p = weight.

In a first approach for the procurement of this global evaluation index it has been considered the mean value among indicators expressed in the Eq. 2. That is to say, each indicator is assigned an identical weight ($p_1 = p_2 \dots = p_{10} = 1$) although this will allow it in future studies to value the importance of some indicators above others. The global evaluation is expressed in a scale from 1 to 5.

Assisting the complexity of the systems of industrial supervision and the fact that an ineffective interface design can cause human error, the global evaluation of a supervision interface should be located in an initial value of 3-4 and with the aid of the GEDIS guide it is possible to propose measures of improvement to come closer to the value of 5.

IV. SUGAR MILL INTERFACE IMPROVEMENT

The GEDIS guide has been applied to a real environment: the supervisory control interface of the Sugar Technology Center (Ponsa and Díaz, 2007b). This case is an example of Spanish industrial application.

The Sugar Technology Center (CTA *Centro Tecnología Azucarera* in Spanish version) uses the simulation for the training of control room personnel (CTA, 2006).

Sugar production is a complex process. A typical sugar mill is divided into these parts: diffusion, evaporation, purification, sugar room, boilers, dryer and liquor storage.

It includes several production sections and many production units are involved, both for continuous and batch operation (Merino *et al.*, 2003). Hundreds of process variables must be monitored and controlled, so a Distributed Control System DCS must be used and a set of model predictive controllers must be used.

The tasks of the human operators in this control room are: detection of anomalies in the production process and process operation. In some cases the human operator does not know enough about the process he is supervising. A way to prevent these problems: the Sugar Technology Center uses expert systems for failure detection and diagnostics and predictive control algorithms.

The Sugar Technology Center has been developed as a training simulator for modeling and simulating the production process and the human operators' supervisory tasks.

The simulator developed in the CTA is an example of a full scale simulator, a type of simulator that reproduces the whole operating environment (Merino *et al.*, 2007).

This simulator emulates the control room of a sugar mill. A series of object oriented modeling library tools are used to create each part of the sugar mill.

In this practical case the designer has generated a group of screens and provided us with a sample.

The GEDIS guide has been applied to posteriori in an external way and without the designer's collaboration.

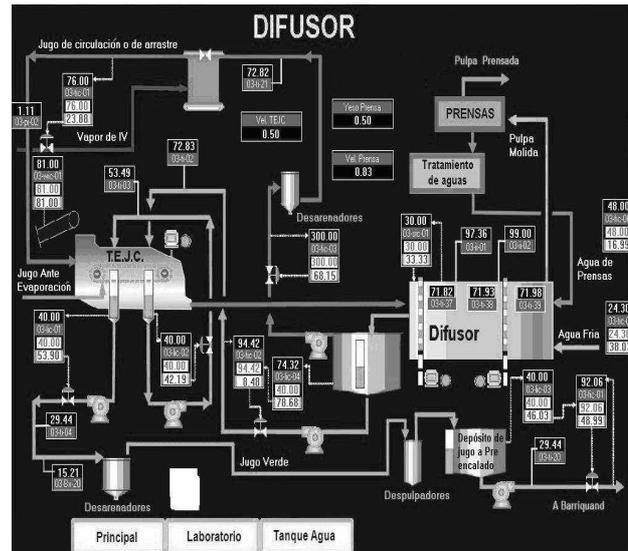


Fig.3 An example of improved CTA interface: diffusion equipment. With the aid of the GEDIS guide it is possible to improve some indicators like Distribution and Use of Colour of the original interface.

In a generic way by means of the use of the GEDIS guide a group of anomalies has been detected, they have intended solutions, has been quantified each one of the indicators numerically and the global evaluation of the guide has been obtained for the studied interface. All the information has been sent to the CTA partners so that they can value the possibility of re-design of some parts of the interface with suitable improvements.

Concerning the first three evaluated indicators, an architecture composed of 3 layers is observed clearly, so that in the supervision interface the navigation prevails in a not very deep width, an aspect that is typical in the context of industrial interface design. As for the ways of navigation among screens corrections have been carried out because in the step from a screen to the following one the navigation submenus change position and format, disorienting the user.

Regarding the use of color, it is necessary the relationship with the status of the devices, for example in the case of the distributed valves, is very important so that they can be distinguished with clarity and differentiate the states "open/close". In some screens an excessive use of red and green colors is detected in the outlying part. The GEDIS guide recommends the use of red be associated with the alarm indicator.

Regarding the graphics of tendencies and tables, although a clear graphic representation has been observed of each one of the variables and the control action, a grouping of variables contained in only one historical trend is necessary that allows the operative to evaluate the future tendency of these variables and to make some decision (changing the set point, and changing the controller's parameters). Regarding the alarm indicator it is necessary to create a faceplate screen with information about the abnormal situation, the alarm grouping by equipments and a priority index to risk assessment.

Table 1: GEDIS guide indicators (part one)

Indicator name and Subindicator name	Numeric/qualitative range and CTA numeric value
Architecture	3,3
Map existence	[YES, NO] [5,0] 0
Number of levels le	[le<4, le>4] [5,0] 5
Division: plant, area, sub-area, equipment	[a, m. na] [5,3,0] 5
Distribution	3
Model comparison	[a, m. na] [5,3,0] 3
Flow process	[clear, medium, no clear] [5,3,0] 3
Density	[a, m. na] [5,3,0] 3
Navigation	3
Relationship with architecture	[a, m. na] [5,3,0] 3
Navig. between screens	[a, m. na] [5,3,0] 3
Color	2,8
Absence of non appropriate combinations	[YES, NO] [5,0] 3
Color number c	[4<c<7, c>7] [5,0] 5
Blink absence (no alarm situation)	[YES, NO] [5,0] 5
Contrast screen versus graphical objects	[a, m. na] [5,3,0] 3
Relationship with text	[a, m. na] [5,3,0] 3
Text font	4,5
Font number f	[f<4, f>4] 5
Absence of small font (smaller 8)	[YES, NO] [5,0] 5
Absence of non appropriate combinations	[YES, NO] [5,0] 5
Abbreviation use	[a, m. na] [5,3,0] 3

Table 2: GEDIS guide indicators (part two)

Indicator name and Subindicator name	Numeric/qualitative range and CTA numeric value
Status of the devices	4
Uniform icons and symbols	[a, m. na] [5,3,0] 3
Status equipment representativeness	[YES, NO] [5,0] 5
Process values	3
Visibility	[a, m. na] [5,3,0] 3
Location	[a, m. na] [5,3,0] 3
Graphs and tables	4,5
Format	[a, m. na] [5,3,0] 5
Visibility	[a, m. na] [5,3,0] 5
Location	[a, m. na] [5,3,0] 5
Grouping	[a, m. na] [5,3,0] 3
Data-entry commands	3
Visibility	[a, m. na] [5,3,0] 3
Usability	[a, m. na] [5,3,0] 3
Feedback	[a, m. na] [5,3,0] 3
Alarms	3,8
Visibility of alarm window	[a, m. na] [5,3,0] 3
Location	[a, m. na] [5,3,0] 3
Situation awareness	[YES, NO] [5,0] 5
Alarms grouping	[a, m. na] [5,3,0] 5
Information to the operator	[a, m. na] [5,3,0] 3

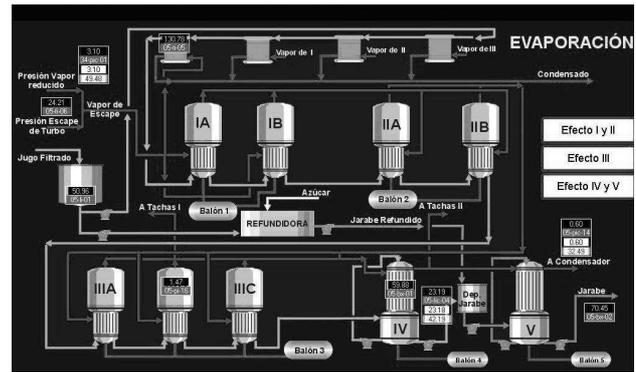


Fig.4 Original Evaporation screen

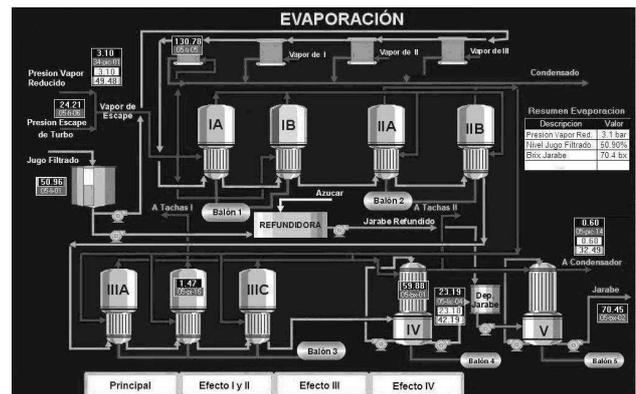


Fig.5 Revisited Evaporation screen

The global evaluation that the GEDIS guide makes of the supervisory control interface of the CTA simulator is located in 3,2. By means of the mentioned corrections, the index can arrive without problems between 4 and 5, that is to say the maximum values of the numeric scale.

With the GEDIS guide it is possible too to indicate to the CTA simulator designer a set of important recommendations about graphical screen improvement. For example, the Evaporation screen can improve with a set of changes in color and text font indicators.

Figure 4 shows the original Evaporation screen and Fig. 5 shows the revisited Evaporation screen. From the point of view of the distribution indicator, Fig. 5 improves the object's distribution inside the screen. In Fig. 4 it is not possible to see the navigation switch to return to the Principal screen.

From one screen to another the switches are located in different places. In these improvements, the navigation menu is located at the bottom of all screens. From the point of view of the Status of the Devices indicator, in Fig. 4 the equipment IB and the filling of the 'Jugo Filtrado' Tank status is not clear. In Fig. 5 the representation of the status of the devices is clearer.

In order to give information to the operator, the revisited Evaporation screen shows a summary ('Resumen Evaporacion' in Spanish) with the most important variables of the Evaporation part.

V. CONCLUSIONS

In tasks where human supervision in the industrial control room is necessary, it is normal that an external de-

signer - by means of the commercial programs Supervisory Control and Data Acquisition SCADA - takes charge of designing the supervision interfaces according to the knowledge of the physical plant and the group of physical-chemical processes contributed by the process engineers. Although standards exist regarding security in the human machine systems that have an impact in aspects related to physical ergonomics and interface design by means of rules of style, the absence of the design of interactive systems focused on the user where the engineering usability and the cognitive ergonomics can contribute significant improvements is remarkable.

The GEDIS guide is an approach that tries to fill a methodological gap that joins the efforts of the engineering systems and the ergonomics for the improvement of the effectiveness of the human-machine system in the industrial control room.

The application of the GEDIS guide to the study of cases contributes among other details a measure in the form of indicators of aspects about interface design, the recommendation of changes for the improvement of the interface, and a global evaluation index that allows quantifying the current state of the interface regarding the future state after applying the correct measures.

The studied case explained in this paper shows a Spanish industrial application. With the GEDIS guide approach it's possible to spot different anomalies and to propose improvements to the interface design.

Another current study with the GEDIS guide is the analysis of a natural gas interface (Ferrándiz and Ponsa, 2005). Enagas is Spain's top natural gas transportation, regasification and storage company (ENAGAS, 2006; Ramirez *et al.*, 2007). There is a regasification plant in Barcelona (Spain). The first author of this paper is working with a human operator of the control room with the aim to apply cognitive ergonomics to the interface improvement. The gas interfaces is complex because there are many equipments, many control loops and many event alarms. In order to improve the efficiency of the human supervision in the control room, it is necessary to apply usability engineering, for example, to measure the mental workload of the operators, improve the display design, and apply usability techniques like the cognitive walkthrough.

In these moments the 4all-L@b Usability Laboratory of the Technical University of Catalonia is analyzing the GEDIS guide to simplify the number of indicators of the guide, to improve the evaluation method, and to promote the use of the guide inside the cycle of life of software engineering, in this case in the early phases of the supervisory control interface design.

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REFERENCES

- ASM, *Abnormal Situation Management*, Honeywell. In URL: <http://www.asmconsortium.com/> (2008)
- Attwood, D., P. Baybutt, C. Devlin, W. Fluharty, H. Hughes, D. Isaacson, P. Joyner, E. Lee, D. Lorenzo, L. Morrison and B. Ormsby, *Human factors methods for improving performance in the process industries*, American Institute of Chemical Engineers, Wiley (2006).
- Bastien, C. and D. Scapin, "Evaluating a user interface with ergonomic criteria," *International Journal of Human-Computer Interaction*, **7**, 105-121 (1995).
- Cañas, J.J., *Personas y máquinas*, Editorial Pirámide, Colección Psicología (2004).
- Costa, E.F., R.C. Vieira, A.R. Secchi and E.C. Biscaia Jr., "Dynamic simulation of high-index models of batch distillation processes," *Latin American Applied Research*, **33**, 155-160 (2003).
- CTA, Centro de Tecnología Azucarera, *Simulador de sala de control de fábricas azucareras*, In URL: http://www.cta.uva.es/CTANEW/espanol/proyectos/Simuladores/Frame_Simuladores.htm (2006).
- ENAGAS, *Annual Report*, In URL: http://www.enagas.es/cs/Satellite?cid=1142417698085&language=en&pagename=ENAGAS%2FPage%2FENAG_listadoComboAnio (2006)
- Ferrándiz, M and P. Ponsa, "Ergonomic design of an industrial control room". Technical University of Catalonia Report. In URL: <https://upcommons.upc.edu/pfc/bitstream/2099.1/3954/1/40473-1.pdf> (2005)
- FAA, Federal Aviation Administration, *Human factors design guide for acquisition of commercial-off-the-shelf subsystems, non-developmental items, and developmental systems (DOT/FAA/CT-96/01)*, Atlantic City International Airport, DOT/FAA Technical Center (1996).
- Granollers, T., J. Lorés and J.J. Cañas, *Diseño de sistemas interactivos centrados en el usuario*. Editorial UOC, Colección Informática, 43 (2005).
- Han, S.H., H. Yang and D.G. Im, "Designing a human-computer interface for a process control room: a case study of a steel manufacturing company," *International Journal of Industrial Ergonomics*, **37**, 383-393 (2007).
- Holstom, C., *Human factors and control centre issues. What lessons we have learned*, Institute for Energy Technology, OECD Halden Reactor Project (2000).
- ISO, International Organization for Standardization, *Ergonomic design of control centres*, parts I, II, III, IV". In URL: <http://www.iso.org> (2004).
- Karwowski, W., "Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems," *Ergonomics*, **48**, 436-463 (2005).
- Merino, A., S. Pelayo, A. Rueda, R. Alves, A. García, F. Acebes, C. De Prada, G. Gutiérrez and M. García,

- “Un simulador de alcance total para la formación de los operarios de sala de control de factorías azucareras,” *XXIV Jornadas de Automática*, León, In URL: <http://www.cea-ifac.es/actividades/jornadas/XXIV/documentos/si/200.pdf> (2003).
- Merino, A., S. Pelayo, A. Rueda, R. Alves, F. Acebes, C. De Prada, G. Gutiérrez and M. García, “Full scope Simulator in EcosimPro for training of sugar mill control room operators,” *Internal documentation of EcosimPro*, In URL: http://www.ecosimpro.com/documentation_articles_process.html (2007).
- NASA, *Man system integration standards*, NASA-STD-3000. In URL: <http://msis.jsc.nasa.gov/> (1995).
- Nimmo, I., “Designing control rooms for humans,” *Control Magazine*, 47-53 (2004).
- NRC, U.S. Nuclear Regulatory Commission, *NUREG-0700, Human-system interface design review guidelines*, Office of Nuclear Regulatory Research, Washington DC 20555-0001. In URL: <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0700/nureg700.pdf> (2002).
- Norsok, *Standard I-002 Safety automation system*, Norwegian Technology Centre Oscarsgt. 20, Postbox 7072 Majorstua N-0306 Oslo, In URL: <http://www.olf.no> y <http://trends.risoe.dk/detail-organisation.php?id=52#corpus> (2006).
- Noyes, J. and M. Bransby, *People in control: human factors in control room design*, IEE Control Engineering Series, United Kingdom, **60** (2001).
- Ponsa, P. and M. Díaz, “Creation of an ergonomic guideline for supervisory control interface design,” *LNCS*, **4562**, 137-146 (2007a).
- Ponsa, P. and M. Díaz, “An application of an ergonomic guideline for sugar mill control room interface design,” *17 th International Conference on Factory Automation and Intelligent Manufacturing*, Philadelphia, USA (2007b).
- PSI, *Oil and gas pipeline systems*, In URL: <http://www.pipesys.com/linecards/oil.pdf> (2008).
- Ramirez, J.J., J.D. Martínez and S.L. Petro, “Basic design of a fluidized bed gasifier for rice husk on a pilot scale,” *Latin American Applied Research*, **37**, 299-306 (2007).
- Raskin, J., *The human interface: new directions for designing interactive systems*, Addison-Wesley (2000).
- Reason, J., *Human errors: models and management*, In URL: <http://www.bmj.com/cgi/content/full/320/7237/768>, (2000)
- RSI, *Operator training simulators*, In URL: http://www.simulationrsi.net/RSI-products_services-ots.htm (2008)
- Saez, D., A. Ordys and M.J. Grimble, “Design of a supervisory predictive controller and its application to thermal power plants”. *International Journal of Optimal Control Applications and Methods*, **26**, 169-198 (2005).
- Samad, T. and J. Weyrauch, *Automation, control and complexity*, John Wiley and Sons (2000).
- Schneiderman, B., *Designing the user interface. Strategies for effective human-computer interaction*, Addison-Wesley, third edition (1998).
- Sheridan, T.B., *Telerobotics, automation and human supervisory control*, M.I.T. Press (1992).
- TSC, Simulation, *Virtual reality control room*, In URL: <http://www.tscsimulation.co.uk/controlroom.html> (2008).

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