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Risk Management Persuasive Technologies: The case of a Technologically Advanced, High-Risk Chemical Plant

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ABSTRACT

Our study focuses on applications of persuasive technologies (Fogg, 2002) as a means to manage risks in technologically advanced industrial sites. An analysis of the production processes of a chemical plant allowed us to identify two risk scenarios where human factors are particularly relevant: in chemicals identification and in the use of personal protective equipment. Possible solutions based on persuasive technologies and aimed at minimizing the occurrence of human errors were prototyped. Qualitative evaluation of the proposed solutions, which involved 7 potential users, both operators and safety engineers (the population consisting of 29 people), allowed us to have a first confirmation of their acceptability and persuasion effectiveness.

Keywords: *Persuasive technologies, risk management, automation, chemical plant, tunneling, reduction, simulation, cause-and-effect relationship, chemicals, personal protective equipment (PPE).*

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1. Introduction

The occurrence of accidents and incidents represents an intrinsic feature of any industrial activity. As far as technologically advanced industrial sites (like nuclear or chemical plants) are concerned, it has been pointed out that crises are often attributed to human error at present (Catino, 2002; Reason, 1990).

The extensive use of automation has led to considerable changes in the role of human operators, who tend to act mainly as supervisors of procedures carried out by

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machines, rarely performing physical tasks (Cacciabue, 2004). Thanks to automation, modern plants are certainly easier to operate; nevertheless, critical misunderstandings can occur between human and system, because of an inappropriate level of situation awareness or because of unsuitable behaviors induced by automation itself (Bainbridge, 1987). Moreover, the increasing reliability of hardware, which has minimized mechanical faults, emphasizes the contribution of human factors to accident genesis (Cacciabue, 2000; Cacciabue 2004).

In such scenarios, risk management necessarily implies that human fallibility is carefully dealt with in order to avoid negative effects on health, safety and environment. In particular, human behavior should be somehow modeled so that it is as safe as possible and potentially dangerous faults are prevented.

Since operators in highly automated industrial plants mainly interact with machines, it has been hypothesized that persuasive technologies can positively contribute to accident management, promoting correct behavior. According to Fogg, persuasive technologies can be defined as any type of computing system, device, or application that was designed to change users' attitudes or behaviors in a predetermined way (Fogg, 2002).

In particular, the introduction of microsuasion elements[1] in technologies ordinarily used to carry out industrial processes could stimulate operators to follow safe procedures and rules, thus minimizing the occurrence of errors and inappropriate behaviors.

At the same time, it has been assumed that technologies with an overall intent to persuade, such as simulators, could be expressly designed in order to improve operators' awareness of risks. These technologies could be effectively utilized in education and training courses.

2. Project Overview

This paper describes a study conducted in 2006 and aimed at testing our hypothesis, according to which persuasive technologies can contribute to make operators' behaviors' safer, thus proving effective in risk management.

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[1] As defined in (Fogg, 2002), *microsuasion* elements are small persuasive elements incorporated in a technology which has an overall goal other than persuasion, in order to increase its effectiveness.

Our study focused on a highly automated chemical plant in the Piedmont region (Italy), which belongs to a well-known international group. It produces polyurethane systems containing MDI (*Methylene diphenyl diisocyanate*) and makes use of several chemical substances that can have damaging effects both on the environment and on human health, in case an accident occurs.

The project consisted of three phases: (1) *preliminary analysis*, aimed at identifying concrete risk scenarios where persuasive technologies may be applied; (2) *prototyping* of human-machine interfaces based on persuasive technologies; (3) *qualitative evaluation* of the proposed solutions.

3. Preliminary Analysis

The main goal of preliminary analysis was to understand whether there existed concrete scenarios where persuasive technologies may be applied in order to improve risk management. Therefore, we tried both to gain an overall understanding of production processes management and to identify specific risk scenarios. At the same time, risk management solutions already adopted in the plant were taken into consideration and compared with persuasive technologies potentialities.

3.1. Production Processes Management

Valuable information was obtained both by simply observing the operators at work, and by conducting a few semi-structured interviews with some of them. Most tasks are carried out automatically by a Production Processes Management System (PPMS), while operators have to check the list of simple actions (called “steps”) that are going to be performed in order to obtain a certain material and to start the procedure. After that, operators mainly act as supervisors and are sometimes asked to give their explicit consent for some steps to be performed. Nevertheless, some chemicals require manual loading. In order to accomplish this task, operators have to leave the control room, go and find the needed material in a warehouse, type the chemical identifying-code in a computer linked up to the reactor in use and (if the code is correct) manually load the reactor itself.

3.2. Risk Scenarios

Risk scenarios were identified both by interviewing the operators and by analyzing the incident register of the plant.

Whereas operators are forced to follow a standard, step-by-step procedure when they act as supervisors, manual operations like chemicals loading are affected by individual variability and thus appear more error-prone. Two main risk scenarios were recognized:

- *Chemicals Identification*

  Chemicals can be distinguished by an identifying code, which is written on two different labels[2] on the container and which has to be typed in before loading. Unfortunately, when the code is automatically checked by a computer, there is no way to discover whether: (1) the code has actually been read on the container; (2) both labels have been read. Operators admit rarely reading labels, as these are written in small, scarcely visible fonts. Moreover, skilled operators know most codes by heart, so that label-reading seems a waste of time.

  One of the most relevant incidents which actually took place in the plant was caused by loading a wrong chemical. The involved operators did not read the two labels on the container and missed noticing that they displayed different codes, because of a labeling error. As they typed in the required code by heart, the computer did not detect anything wrong and allowed to load a wrong chemical.

- *Use of Personal Protective Equipment (PPE)*

  Operators should wear PPE at work. However, protective long-sleeved shirts are not well accepted since temperatures are very high in the plant, especially in summer. Moreover, operators think it is very unlikely that they can come into contact with dangerous chemicals, because only a few steps are performed manually. Skilled operators also feel quite confident in themselves, so they prefer wearing comfortable T-shirts.

  Nevertheless, 11 out of 32 registered incidents involved contact with dangerous substances.

[2] One of the labels is stuck by the producer, the other one by an internal chemical laboratory.

3.3. Alternative Approaches to Risk Management

Since the international group to which this chemical plant belongs strongly emphasizes safety in its policies, several risk management techniques are already adopted, which can be considered typical of technologically advanced industrial sites.

On the one hand, an integrated system of sensors and alarms is used to monitor critical data and to alert the people in charge, in case unexpected or abnormal events occur.

On the other hand, reliable hardware is adopted, which can also perform automatic controls and prevent some potentially dangerous actions from being executed. Safety rules that define standard, correct procedures and regulate the use of PPE are established in order to model the operators' behavior. Safety rules and related issues are usually addressed in training courses for newly-employees and further discussed during periodic meetings with safety engineers. Traditional media such as posters are also used to provide safety-related information.

Useful though they are, these solutions do not appear sufficient to effectively manage human fallibility, as demonstrated by the accidents that still characterize manual steps, where the trade-off between safety and other relevant factors may negatively influence the performance of the operators.

As stated by (Reason, 1990), safety norms considered trivial (since risk is perceived as remote) are likely to be routinely violated. Unfortunately, formative meetings where operators are passively taught correct behaviors are not so effective as firsthand, interactive experiences (Fogg, 2002). Moreover, some of the operators we interviewed considered the information provided as biased, reflecting the safety engineers' point of view, as opposed to their own. Finally, posters and other traditional media lack interactivity (Fogg, 2002) and cannot guarantee that they are actually accessed.

Persuasive technologies have several advantages over the described risk management approaches (Fogg, 2002). By integrating persuasive elements into the technologies already in use, contextual help can be provided at the right time and place; moreover, technologies can be designed in order to be persistent and ubiquitous, so safety-related information is not limited to specific occasions, such as training courses. In comparison with human persuaders, technologies can not only store and access huge volumes of data, but also convey them using many modalities, in appealing and meaningful ways. Finally, persuasive technologies that provide simulations offer firsthand, interactive experiences and are more likely to be perceived as "objective" and "unbiased".

4. Prototyping

An analysis of the two described risk scenarios was conducted in order to identify which changes in the operators' behaviors and attitudes should be obtained, with the aim of improving safety and preventing incidents. In order to define an appropriate persuasion strategy, both the kind of tasks performed by human operators and the role played by technologies were taken into consideration. According to Fogg, in fact, computing technologies can play three basic roles –tool, medium and social actor[3]-, depending on which they can take advantage of different persuasion techniques (Fogg, 2002).

Prototypes consisted of a series of slides, which simulated a UI and suggested how users would interact with the system, thanks to some simple animations.

4.1. Prototype 1: Chemicals Identification

In order to avoid errors when operators manually load chemical substances, it should be guaranteed that:

- Identifying-codes are read on the labels, instead of being typed in by heart;
- Both labels are read;
- Reading and typing errors do not occur (although these errors are unlikely to cause an incident, they slow down production processes, since the computer will detect a wrong code and not allow loading until the correct one is provided).

We suggested that "traditional" labels should be replaced with bar codes and read automatically with a bar code reader activated by operators. Feedback for the interaction should be provided through a small display, the user interface of which was prototyped, simulating different cases (correct codes, wrong codes, internal and producer codes do not match, same label read twice). Once both labels have been automatically read, the computer checks the codes. It is important to notice that internal and external codes must be distinguishable[4], so that the computer can detect whether the same label has been read twice and not allow loading.

The proposed solution implements both tunneling and reduction strategies, which are suitable for a work tool (as defined in Fogg, 2002). Tunneling consists in guiding users

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[3] Computing technologies mainly act as tools if they are conceived to increase users' capabilities; whereas media are intended to provide experiences by conveying symbolic and sensory information. Computing technologies are perceived as social actors if they are able to create social relationships with their users (Fogg, 2002).

[4] For example, we hypothesized using a prefix before the proper bar code on the internal label.

through a certain process or experience step by step; moreover, each step cannot be afforded before the previous one has been completed, thus creating a series of interlocks. Reduction technique implies that complex activities are simplified and reduced to a few simple steps, thus increasing their benefit/cost ratio.

As far as tunneling is concerned, the prototyped solution actually implies that operators are led through a standard procedure step-by-step: in fact, they are asked to read the first bar code, then the second one, then the computer automatically checks them. Moreover, the following step (actually loading the reactor) is only allowed if the previous procedure was completed properly – namely, if both labels were read and if the codes are correct.

The operators' task is also easier than before, as they only have to perform an automatic reading, using the bar code reader, instead of trying to read a scarcely visible code and typing it in manually (reduction).

We hypothesized the proposed solution should be persuasive (namely, it should help to obtain the desired changes, which we stated at the beginning of the paragraph) because:

- The operators' task is easier and quicker to perform;
- Reading and typing errors are avoided, so that the procedure is more efficient;
- Operators are compelled to follow a safe, standard procedure which guarantees that: (1) codes are read on the labels and not typed in by heart; (2) both labels are read.

4.2. Prototype 2: Use of Personal Protective Equipment

Since they are not fully aware of the risks they are taking, operators are not willing to wear uncomfortable protective long-sleeved shirts. In order to minimize incidents due to contact with dangerous substances, operators should be stimulated to change their attitude and wear their PPE, as stated by safety rules. Consequently, our goals are:

- Producing evidence in support of safety rules;
- Showing available information in an understandable and meaningful way;
- Enabling operators to observe the link between cause (wearing/not wearing their PPE) and effect (the risks they are taking);
- Stimulating a positive attitude toward safety rules;
- Preventing violations.

We suggested that interactive media technologies should be used to simulate cause-and-effect relationships, so that operators can better understand the risks they are taking and the likely consequences of their choices (whether to wear their PPM or not). Such technologies could be used in education and training courses, thus complementing the traditional top-down, “passive” learning.

Our prototype exemplifies the user interface of software that simulates the consequences of operators’ behavior, based on an assessment of risk level in the different departments. Risk level was simply calculated as a ratio between incidents due to contact with dangerous substances and incidents of any kind, using the data provided by the chemical plant itself.

First, the user is asked to choose a department (a simulation is also available for the plant as a whole) and is told how many incidents have occurred there up to now. The operator is then asked to choose whether to wear a protective shirt or not. Finally, a simulation is run which shows the effects of his or her choice.

The proposed solution clearly aims at changing the operators’ attitudes and behaviors by exploiting the so-called Principle of Cause and Effect (as stated in Fogg, 2002): in fact, operators are allowed to safely experiment with different kinds of behaviors and to immediately observe their consequences. This solution is expected to prove persuasive because:

- It provides data in a simple and understandable way; moreover, these data could be completely new to some operators;
- It shows the cause-and-effect relationship between the operators’ behaviour and the risks they are likely to take;
- It allows the operators to have a firsthand, although simulated, experience;
- It offers an “objective” assessment of risk level;

Simulations are based on data about real incidents, which occurred in the plant and are thus personally relevant to operators.

5. Qualitative Evaluation

The prototypes were then examined by help of some potential users, in order to evaluate persuasion effectiveness and acceptability of the proposed solutions. We also welcomed any suggestions about user needs and comments about the persuasion goals we set.

Each session involved only one user at a time and began with a short introduction to the evaluation task. In order to guarantee uniform conditions, all instructions were provided by reading predefined scripts.

In particular, users were told they should interact with the prototypes and carefully observe the provided feedback; although they would be explicitly asked for comments later, they were encouraged to think aloud during the interaction. Users were also assured that neither their performance nor their opinions were going to be assessed and that data would be treated anonymously. Therefore, they were encouraged to express their evaluations freely.

Each session consisted of two main phases that lasted about ten minutes in all and were replicated for both prototypes.

During the first phase, users were asked to try to interact with the prototype after a brief description which also stated the persuasion goals of the prototype itself. As far as the first prototype is concerned, users were asked to simulate a manual loading operation –small boxes were provided to simulate a bar code reader and chemicals containers. The slides which simulated the interface of the display were showed by one of the authors according to users' actions. The second prototype was meant to be freely explored; however, users were asked to run at least two simulations. All comments expressed during this phase were recorded.

During the second phase, a semi-structured interview was conducted in order to better investigate users' opinions. More specifically, questions aimed at assessing the overall acceptability of the proposed solution, the relevance of the defined persuasion goals and the perceived effectiveness of the prototyped solution in achieving these goals (for example, users had to evaluate if prototype 1 was likely to minimize chemicals identification mistakes). Comments about potential pitfalls and critical scenarios were also welcome. Moreover, users may be asked to further elaborate on particularly interesting comments expressed during the previous phase.

Evaluation sessions involved a non-probabilistic sample of seven users, six skilled operators and one safety engineer (the population consisting of 29 people). Comments and suggestions were also provided via email by another safety engineer.

A qualitative content-analysis was then performed in order to distinguish between positive, negative, mixed and neutral evaluations. Specific expressions used to describe both users' reactions and the prototypes were identified, as well as any mention of perceived advantages and disadvantages.

5.1. Prototype 1: Evaluation

Comments about this prototype are very positive.

Users think that the proposed solution would make manual loading operations both quicker and safer. In fact, even if accurate code-checking is likely to take some time, automatic label-reading is fast and easy to perform (operators do not need to try to read scarcely visible labels); moreover, reading and typing errors are avoided, thus speeding up the operation. As far as safety is concerned, users agree that the proposed solution should be effective, because it guarantees that codes on the chemicals containers are checked. Consequently, errors in substances identification should be minimized.

This solution was well-accepted as it “empowers” users: in fact, it allows the operators to perform their tasks more easily and quickly; moreover, it does not require any additional effort. Persuasion goals were also approved, since they perfectly match users’ ones; furthermore, operators considered chemicals identification errors very relevant and they were looking forward to implementing a working solution.

5.2. Prototype 2: Evaluation

Users’ reaction to Prototype 2 is mixed. It is very interesting to note that both users’ role and personal beliefs about the particular safety rule that was considered (wearing protective long-sleeved shirts) seemed to influence the prototype evaluation.

In fact, we noticed that both safety engineers were quite enthusiastic about the proposed solution and thought that it could actually change operators’ attitudes, persuading them to wear their PPE. One of the interviewed engineers stated that such a simulation could prove very useful during training courses for newly-employed operators.

Most operators, on the contrary, had expressed a negative opinion about wearing protective shirts (before trying the prototype) and subsequently declared themselves to be very skeptical about the persuasive effectiveness of the proposed solution. In fact, these operators were very skilled and thought they already had an appropriate perception of risks (even if they admitted that the simulation provided data in a simple and meaningful way), so that they could make informed choices. Nevertheless, most of them were surprised by the data, and they all tried to run more than the two simulations we requested as a minimum. Moreover, some operators said they were “curious” and “very interested” in running the simulations, which were usually chosen based on personal criteria, rather than on mere chance. On the whole, even if the expressed opinions were quite skeptical, the operators were very motivated and showed a positive attitude. Simple though they were, the provided simulations proved quite engaging.

Only one of the interviewed operators thought that wearing protective shirts was useful (before trying the prototype): he also expressed a very positive opinion about persuasion effectiveness of the proposed solution, stating that such a simulation could actually change the other operators' negative attitudes towards wearing their PPE.

6. Conclusion

Our study aimed at providing some insights into possible applications of persuasive technologies in the risk management domain.

The comments and suggestions we collected offer a first, qualitative evaluation of persuasive technologies acceptability and potential effectiveness. However, further experimental studies are needed in order to better understand in which ways –and to what degree- persuasive technologies can contribute to risk prevention and management in technologically advanced industrial sites. In particular, future studies are planned with the aim of addressing the following points:

- Users' opinions should be measured quantitatively, for example using 7-step ladders, in order to allow more accurate comparisons and statistical analysis;
- Larger, probabilistic samples should be defined as a prerequisite for significant findings;
- Actual persuasion effectiveness should be measured, instead of perceived persuasion effectiveness: for example, it is planned to measure and compare the operators' attitudes towards the use of PPE between two different groups, only one of which has interacted with the prototype. A more accurate assessment of risk level is expected among the operators who tried the simulator; a slightly more positive attitude towards the use of PPE is also quite likely. Experimental studies might also be planned aimed at observing behavioral changes – in this case, more sophisticated prototypes will be needed, in particular as far as chemicals identification is concerned.
- As far as prototype 2 is concerned, different modalities to convey data should be compared. Moreover, even if the simulation itself is engaging, it is important to define and test ways to guarantee that: (1) operators are

stimulated to try the simulation, in spite of their initial skepticism; (2) the simulation is still perceived as "objective" and "unbiased", even if it is used during training courses.

Looking forward to future research in this area, it may be useful to emphasize some of the conclusions our present study allowed us to draw. We pointed out that:

- Persuasive technologies (used as tools) are likely to be effective if they do not overload their users with additional tasks; on the contrary, they should "empower" users and help them to achieve their goals simply and quickly;
- Persuasive technologies are more likely to be accepted if they serve their users' goals, rather than any external goal; similarly, persuasive technologies can be welcome if they apply to a domain which is relevant to the user;
- Persuasive devices may be refused if they apply to domains about which users feel confident and skilled. In this case, persuasive devices may be perceived as a sort of "threat" to users' freedom and expertise;
- Persuasive technologies such as simulations are generally quite appealing, so that even skeptical users are motivated to try them. Motivation, curiosity and openness are all prerequisites to the success of persuasion (Fogg, 2002; Petty & Cacioppo, 1981).

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