INTERACTION DESIGN AND REDUNDANCY STRATEGY IN CRITICAL SYSTEMS

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Abstract: Hardware and software systems have grown to support the work on critical areas that used to be managed mostly by human beings. Concepts and challenges regarding critical systems have long been discussed by several authors, although communication-based aspects have not been explicitly considered. In this paper, we propose a procedure for designing interaction in critical systems under the communication perspective; the procedure results in a user interface wireframe as outcome. Semiotics is used as theoretical and methodological background in the proposed design procedure. The Scientific Satellite Payload Operation Support System (SAPOP) is used to illustrate the potentiality this perspective brings to safety-critical systems.

1 INTRODUCTION

A growing demand on hardware and software systems is also expanding into critical areas that used to be managed mostly by human beings. The concept of a critical system has been discussed by several authors encompassing from conceptual to technical issues. The safety-critical category of system is defined as a system whose failure would provoke catastrophic or unacceptable consequences for human life (Paulson, 1997).

Literature on critical systems has long shown dramatic cases of human-system failures that resulted in people's deaths. Therac-25 is a typical case: an X-ray used to obtain bone images (through x-ray emission) or to treat tumours (through radiation emission). The message “Malfunction 54” had no meanings for operators, who just ignored it (Mackie and Sommerville, 2000), although, for the software developer, the message intended to inform that the radiation dosage was above normal values. Due to this human-computer communication problem reflected in the user interface (UI), the consequence of this episode was disastrous leading to several deaths because of the extreme radiation injected to patients. More dramatically, as the effect of over dosage was not instantaneous, it took several years for the problem to be identified.

In aviation systems, many incidents (unexpected events that may or may not lead to accidents that may lead to deaths) have reasons originated from failures occurring during user-system interaction. Harrison shows some statistics: from 34 total incidents (1979-1992); 4% of the deaths were due to physical causes; 3% of the deaths were due to software error; 92% of the deaths were due to problems related to human-computer interaction (Harrison, 2004). Moreover, according to ATC (Air Traffic Control), 90% of the air traffic incidents were due to faults attributed to pilots or controllers. Nowadays, the flight decks (or cockpits) have multifunction computer displays where huge amounts of information are presented (Carver and Turoff, 2007). This new concept of modern cockpit, named “glass cockpit”, provides rich amount of information presented as graphical elements through diagrams and symbolic information. In parallel with this evolution, sophisticated automation systems may produce conflicting data from different sources forcing decisions about which information to act upon. The pilot needs to navigate through layers and layers of information becoming more a system engineer than a pilot.

The ReSIST project (ReSIST, 2008) created a new field of study, Resilience Systems, which includes safety-critical systems. Several gaps and challenges regarding resilience-building technology are discussed in terms of architecture, algorithms, socio-technical factors, verification and evaluation

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aspects. The resilience needs encompass several aspects including the usability of systems, particularly the ubiquitous ones. Helping users interaction with ubiquitous systems aims at understanding the potential effects of their actions as well as preventing them from taking actions with unwanted and difficult to anticipate system-level effects. Usability is considered one of the most important aspects to consider in critical systems; gaps and challenges are still being identified in the ReSIST project.

The study of signs and rules operating upon them and upon their use, form the core of the human communication study. As there is no communication without a system of signs, Semiotics, as a discipline concerned with the analysis of signs or the study of the functioning of sign systems, may offer an appropriate foundation for this study. Organizational Semiotics (OS) is one of the branches of Semiotics particularly related to business and organizations (Liu, 2000). The study in OS is based on the fundamental observation that all organized behaviour is made effective through the communication and interpretation of signs by people, individually or in groups. The aim of OS studies is to find new and insightful ways of analyzing, describing and explaining the structure and behaviour of organizations, including their inner workings, and the interactions with the environment and with one another.

The goal of this work is to bring communication to the discussion of safety-critical systems by proposing an interaction design procedure in these systems based on a semiotic-informed theoretical and methodological background. This procedure allows to obtain a UI structure (wireframe) using semiotic artefacts. The proposed approach is presented with a case study on the Scientific Satellite Payload Support System (SAPOP), a system to help research investigators, sub-system operator and operation coordinator to program the satellite for executing experiments during the flight using Web services (Francisco and Sagukawa, 2006).

The paper is organized in the following way: the next section presents the theoretical and technical background of this work. The third section presents the proposed design procedure with some semiotic artefacts considered as income and a UI wireframe as outcome. Section four presents the SAPOP case study with this proposed interaction design. Section five has the analysis of the produced UI wireframe. This work finishes with the conclusion section summarizing the contribution and pointing out to new challenges.

2 THEORETICAL BACKGROUND

Semiotics is a discipline concerned with the use of signs, their function in communicating meanings and intentions, and their social consequences.

Organizational Semiotics (OS), one of the branches of Semiotics, understands that any organized behaviour is governed by a system of social norms which are communicated through signs. OS methods and artefacts provide a better understanding of the interested parties of a focal problem, their requirements, as well as the restrictions not only regarding the information system, but the software system as well (Bonacin et. al., 2006). Methods for Eliciting, Analyzing and Specifying Users’ Requirements (MEASUR), which resulted from Stamper’s research work in the late 70´s (Stamper, 1993), constitute a set of methods to deal with all aspects of information system design. The Semiotic Ladder (SL) is an artefact primarily used to clarify some important Information System notions such as information, meaning and communication (Cordeiro and Filipe, 2004). Stamper extended the traditional semiotic divisions of syntactics, semantics and pragmatics by adding three other layers: social world, physical world and empirics as depicted in Figure 1, which, all together, form the SL.

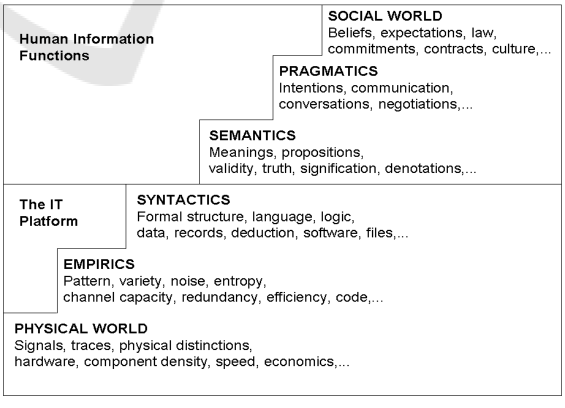
Human Information Functions
SOCIAL WORLD
Beliefs, expectations, law, commitments, contracts, culture,...
PRAGMATICS
Intentions, communication, conversations, negotiations,...
SEMANTICS
Meanings, propositions, validity, truth, signification, denotations,...
The IT Platform
SYNTACTICS
Formal structure, language, logic, data, records, deduction, software, files,...
EMPIRICS
Pattern, variety, noise, entropy, channel capacity, redundancy, efficiency, code,...
PHYSICAL WORLD
Signals, traces, physical distinctions, hardware, component density, speed, economics,...

Figure 1: Semiotic Ladder (Stamper, 1973).

A communication is considered successful if all these six levels of the SL are successfully accomplished. The communication in the upper levels depends on the result of the communication on the lower levels. These levels provide different views for analysis of different aspects of signs. The Physical World deals with the physical aspects of signs (Stamper, 1973). In telecommunication, for example, there are some physical signs such as those transported by cable or radio waves. The Empirics deals with the statistical properties of signs such as channel capacity, patterns, efficiency. In the Syntactic level, the signs and their relations to other signs form a structure, language, data and records. The Semantics deals with signs and their relations to meanings that users perceive. In the Pragmatic level, the signs and their intention and effect on users are identified. Finally, in the Social World, the signs and their relation to social implications are considered. Therefore, the SL links technology, human factors and social issues.

The Fractal Model of Communication (FMC) (Salles et al., 2001; Salles, 2000) is used to capture the structure of the communication involved in the application domain. FMC stresses the fact that, in order to design the primary message (the system's interface), other fractionated messages must be carefully designed and appropriate channels must be chosen to convey them. The FMC models agents in communication through channels. Figure 2 represents this concept of communication in which, in one level, agents B and C communicate through channel A. In another level, A assumes the role of an agent in communication with C through channel AC.

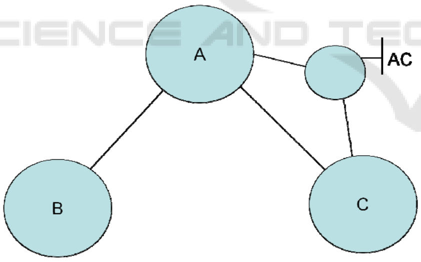

Figure 2: The Fractal Model of Communication (Salles, 2000).

The FMC is appropriate for representing the communication structure in critical systems as it makes explicit information about the agents (physical and human) and all the media used in their communication. It allows capturing potential communication failures and to provide redundancy that would be extremely useful for designing the interaction in critical systems. While the FMC provides a structure for analysing agents in communication, the SL allows a deeper analysis into the channels they use to communicate.

3 COMMUNICATION-BASED INTERACTION DESIGN

The use of Semiotics (Liu, 2000) to focus on the communicational aspects involved in the requirements elicitation for critical systems is discussed in Guimarães et. al. (2007). In a critical system design, the FMC with SL artefacts were proposed in previous work for modelling communication in critical systems (Guimarães and Baranauskas, 2009; Guimarães et. al., 2008). This work extends this modelling focusing exclusively on the interaction design.

The first step is obtaining the FMC model in the interaction design context through a filtering procedure. Initially, the model has user(s) and agent(s) which can also be interaction channels. Interaction agents or interaction channels consist on agents or channels which interact directly with the user (direct connection to user). All agents and channels which don't have direct connection with any user (called non-interactive agents and channels) are just removed and, consequently, all connections are propagated to an interaction channel or agent. Figure 3 illustrates this filtering procedure with the connection propagation where the grey representations are interaction channels and the white ones are non-interactive agents and channels which are removed and the connections are transported to a nearest interaction channel.

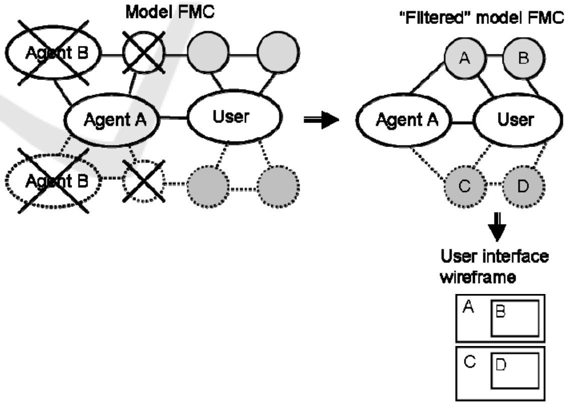

Figure 3: Designing User Interface Wireframe.

The next step is the definition of the UI structure. As Figure 3 depicts, channels may use other channels for communicating with user, if a channel A uses channel B, then B is an interaction object inside A. For example, the channel A could be a window that uses a channel B that could be a button. In the UI wireframe, the user will have a window with a button as internal interaction object.

By the SL definition, as the communication on the upper layers depend on the lower layers, having a physical fault means that all layers above this level will fail and consequently, the overall communication will fail. In critical systems, the mechanism for handling this failure may use a barrier approach that can be defined for the lower layers. Barrier consists on any mechanism that reacts handling the fault if a hazard is detected. This approach can be applied to represent the diverse physical and organisational decisions that are taken to prevent a target from being affected by a potential hazard (Basnyat et. al., 2007).

The characteristics of each interaction channel are specified in the SL which consists of six communication levels with respective hazards as follows in Table 1.

Table 1: Semiotic Ladder.

Layer	Description
Physical world	Information about the positioning, size, colours, label and description of the object interaction appearance. For example, the button OK is placed at (12, 56), size = 10 x 5 pixels.
Physical world hazard	Hazard regarding physical world such as invalid positioning, size, label of interaction object. For example, these problems may happen when the resolution display is changed or when the screen is resized.
Empirics	Information about limitations on the channel capacity or information flow (e.g. transmission rate decreasing, noise rate increasing). For example, the button OK can't handle the double click.
Empirical hazard	Hazards which may handle due to these limitations and problems. For example, what to do, if a button is double clicked.
Syntactic	Information about the sequence of interaction is needed for an interaction object. It consists on interaction behaviour of the interaction channel with the definition about the actions and reactions. For example, when the object is drop-down list, it should appear to user that at first, a button should be clicked and after an option can be listed and then an option can be selected.
Syntactic hazard	Information about the structure of the interaction object and its behaviour. For example, how to inform to user that the drop-down list is empty dispensing with the button click.
Semantics	Information regarding the meaning of an interaction channel for the user. For example, the button should appear clickable.
Semantic hazard	Problems related to meanings or misinterpretation of information, interaction channel or error messages. For example, the user can't recognize that an object is clickable.
Pragmatics	Information about the intention behind the presence of an interaction channel. For example, the button OK is placed at the dialog Confirm Remove File for obtaining the user confirmation before removing the requested file.
Pragmatic hazard	Problems related to intentions of the interaction object. For example, usability problem when the user does not understand the intention behind a specific icon.
Social world	Information about the user expectations, contract, beliefs, and culture related to interaction channels. For example, the expectation of the UI designer must correspond to the user expectation following a specific "contract" (e. g. conventions, culture).
Social world hazard	Problems related to social and cultural issues, beliefs, expectations, contracts, commitments. For example, if the UI behaves differently from what the user was expecting, what it should be done according to the contract.

These SL layers are useful for specifying the communication of each interaction channel and also how to handle communication faults in the six communicational contexts.

4 A CASE STUDY IN SPACE SYSTEM

This section presents the interaction design regarding communication for the Scientific Satellite Payload Operation Support System (SAPOP), developed by National Space Research Institute (INPE) (Francisco and Sagukawa, 2006).

4.1 SAPOP Overview

Each satellite has specific missions (e.g., atmospheric phenomena analysis) and contains a payload which consists on a set of instruments with specific sensors. Each instrument collects and processes specific data from sensors and sends them to the satellite on-board computer. This computer, by its turn, sends data to the ground system through telemetry; these data are useful for investigators (researchers who have the direct access to this payload information) for a specific research purpose.

During the satellite - ground system communication, some satellites receive sequences of telecommands (TCs) and send sequences of telemetry in over-the-air transmission as Figure 4 depicts. The telemetry has information about the internal satellite system (internal temperature, internal components status, battery power and so on) and payload data (information collected by the payload system which has specific purpose sensors for scientific studies).

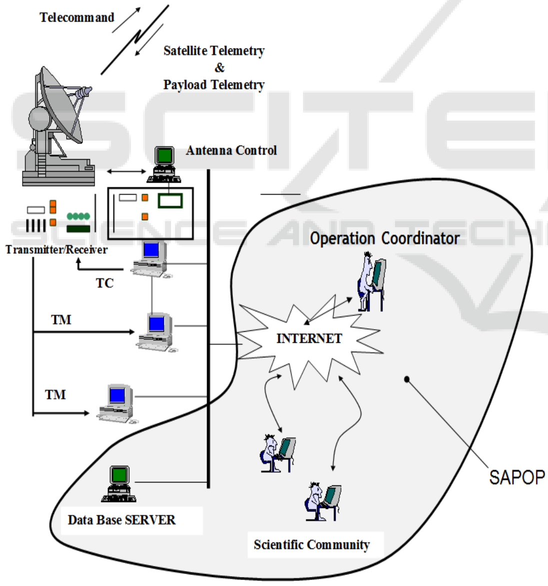

Figure 4: SAPOP system (Francisco and Sagukawa, 2006).

The Payload team (or investigator) uses SAPOP for defining TCs of the payload system and the sub-system operators, uses SAPOP for defining TCs of internal satellite sub-system.. Figure 4 illustrates SAPOP with the TCs as income, which are defined by investigators (represented as Scientific Community) and sub-system operators through Internet network. The Operation Coordinator (OC) is the user who authorizes or not the transmitting of TCs sequences to the satellite through the flight plan that is stored in a data base server.

The safety-critical aspect of the SAPOP is the sequence of the TCs that may lead to total or partial loss of mission (Francisco and Sagukawa, 2006). As SAPOP is an interactive system, the human error (e.g. Operation Coordinator mistake) may lead to total loss of the mission with high cost for the project. This critical aspect will be analysed under the communication perspective focusing on the interaction between the Operation Coordinator (OC) and SAPOP.

SAPOP is an already existent and functional system; its UI was already developed. In this work, the existent UI will be analyzed under the communication perspective for identifying communication problems using one of the strategies known in critical system design: redundancy.

4.2 Designing UI Wireframe

After executing the refining procedure resulting in a detailed FMC model, the designer not only defines agents and channels but also all new redundant channels specifying how the communication is accomplished in SL six communication levels (Guimarães and Baranauskas, 2009). The UI designer executes the filtering procedure to focus on the interaction channels only, the resulting FMC model (Figure 5 depicts only a part of this model) will be useful for defining the UI wireframe. All channels related to the Flight Plan Generation Window agent are considered interaction objects and are located inside the Flight Plan Generation Window. The Passage Selection channel is an interaction object inside the Table View interaction object. The specification of interaction objects is defined at SL for these channels. Therefore, the outcome of this procedure is the wireframe as Figure 6 illustrates.

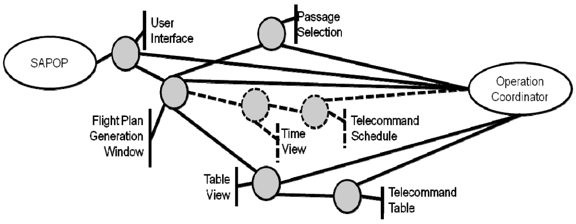

Figure 5: Fractal Model of Communication in Interaction Design Domain.

Table View consists on visualising the TCs in a table which is presented in the UI wireframe of SAPOP original version. The proposed wireframe provides also a Time View and tabs (as Figure 5 depicts) allowing changing the Table View to Time View, which represents another channel for the same information. If the user doesn't feel safe editing TCs in the Table View, the redundant channel Time View becomes active replacing the first channel.

In the SL, there is information about how to detect a hazard and also how to handle it in all six levels. As the SL applies to a specific channel, a hazard can be detected by a more generic channel. For example, if the user makes a mistake inverting the interaction order pressing button Up before selecting a checkbox in the Telecommands table, the SL for this button and for this checkbox don't have the information about how to detect this interaction error because each interaction object can just handle events in its region; events of other interaction objects can't be handled by this button. This interaction error is only detectable by the channel Flight Plan Generation Window because the scope of this channel, encompasses these two interaction objects (button Up and checkbox), allowing to detect this interaction error in the syntactic level.

Figure 6 depicts the window Flight Plan Generation with two views that the OC can switch by clicking on tabs Table View and Time View. To edit TCs in Table view, OC has a table with the TCs list, the start time, the experiment name and the user identification who added the TC. OC can use a checkbox for selecting a TC and can just change the order of selected TCs in the table (by clicking on the buttons Up and Down) or remove selected TCs (by clicking on button Remove).

In the Time View, which is a new view provided by the proposed SAPOP UI, OC has the chronology of TCs (a sequence of time is represented) with start time and end time. The TCs are placed according to the time that corresponds to Start Time column in Table View. OC can change the order and remove hazardous TC selecting a line and after it, clicking a buttons Up, Down or Remove.

When OC finishes the work, to submit the edited TC sequence, OC clicks on button OK or cancels it by clicking on the Cancel button.

After developing the FMC model and the SL artefacts, the UI designer should analyse all interaction channels verifying all SL layers. . The result is a verification whether a specific SL layer may fail. For example, if the user can´t understand the meaning of the Table View in the window Flight Plan Generation, it means that the Semantic layer of channel Telecommand Table failed. According to the SL definition, all upper levels are compromised by that failure.

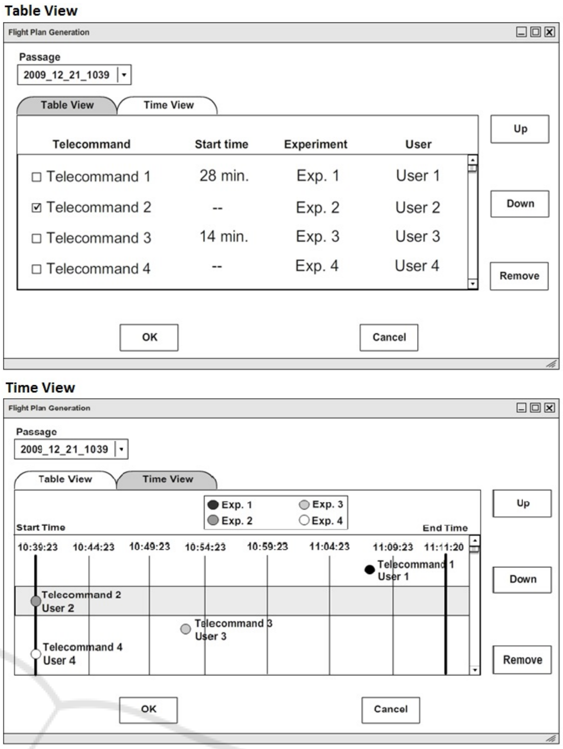

Table View

Flight Plan Generation

Passage: 2009_12_21_1039

Telecommand	Start time	Experiment	User
□ Telecommand 1	28 min.	Exp. 1	User 1
☑ Telecommand 2	--	Exp. 2	User 2
□ Telecommand 3	14 min.	Exp. 3	User 3
□ Telecommand 4	--	Exp. 4	User 4

Time View

Flight Plan Generation

Passage: 2009_12_21_1039

Figure 6: Wireframe for the Flight Plan Generation window.

In the FMC model as Figure 5 depicts, the channel Telecommand Table considered as failed means all paths which passes through this channel are obstructed. Due to the redundancy strategy, there is another path through channel Time View. Therefore, in the case of Semantic layer failure of channel Table View, the Time View can be used.

SL artefacts are useful for determining if more redundancy is needed, verifying for all SL artefacts of all interaction channels whether they cover all possible user profiles defined for SAPOP. Although this analysis is time consuming for UI designers, it provides a complete analysis for the UI wireframes covering from technical contexts (physical world, empirical and syntactics) to human information contexts (semantics, pragmatics and social world). This broad view is necessary mainly for critical systems that need to be meticulously analysed.

5 EVALUATING SAFETY WITH THE PROPOSED WIREFRAME

Focusing on the scenario when OC is editing TC in the window illustrated by Figure 6, the proposed SAPOP UI has two representations (Time and Table views), with tabs for switching these views while the original UI has only the table view. This difference can be analysed based on concepts of the FMC model and the SL artefact. If the Table View fails by any reason related to the communication aspect (any SL layer, e.g. semantically, user cannot understand the meaning of information), the original UI doesn't provide any alternative solution for users because there is no other path to communicate from SAPOP to user. The proposed UI provides another path of communication for users through the channel Time View as Figure 5 depicts. In the concepts of the SL, the difference in the channels *Table View* and *Time View* are located at Semantic and Social layers because the signs were changed. The choice of other type of view provided by the redundant strategy is related to the user safety in choosing the communication channel involving the SL six levels. Moreover, this strategy doesn't impact users who prefer the table view (or any interaction objects of the original version) because it remains present on the proposed SAPOP UI. The redundancy allows the minimum impact for expert users (users who are already adapted to table view) or users with table familiarity and extends UI to a new category of users. The redundancy is not limited to the two options; it can be extended to include more users with different abilities.

The communication perspective with the redundancy strategy contributes for inclusive design underlying the FMC model. The UI designer can define safety strategies for the channels which involve critical information. The SL helps to define how this critical information is communicated to the users providing better situational awareness and either avoiding hazardous consequences.

The drawback of this communication perspective is the growing of the FMC model, which may be huge and complex because of the high complexity of the communicational structure. Developing all the artefacts is considered hard work because the number of agents and channels may be very extensive and, consequently, developing all SLs is also expensive. Visualization tools may allow the presentation of the model with a configurable filter to allow visualizing each fractal dimension separately, zooming in and out to show only the agents and channels needed for a specific consideration.

6 CONCLUSIONS

Communication is a fundamental factor to be addressed in critical systems. Semiotics provides a good foundation for analysis and design regarding communication. This paper proposed a procedure for focusing on interaction design based on artefacts of Organisational Semiotics combined with the Fractal Model of Communication (FMC). The case study involved the space system SAPOP, which provides support for scientific satellite payload operation. If it fails, satellite missions can be lost leading to high financial loss. This work presented a communication-based solution for interaction design, which uses redundancy as strategy to cope with the critical aspects of interaction with this system.

The FMC represents agents and channels of communication with unlimited fractal dimensions. In this way, the communication model can be presented in several granularity levels, including detailed information for each channel, with the six layers of communication analysis of the Semiotic Ladder (SL). The FMC and the SL provide support for designing the structure of communication containing information regarding the physical world, the empiric, syntactic, semantic, pragmatic and social aspects with potential hazards and correspondent actions. The procedure reaches the goal leading the FMC to the interaction design and to the identification of UI design problems of the SAPOP system. Due to communication perspective, the challenge for applying the redundancy strategy for interaction design was accomplished. Nevertheless, it may grow in complexity presenting many agents and channels making the reading difficult and demanding knowledge in several domain contexts.

The communication perspective may provide contributions to usability itself, because it is not only related to "easy to use", but also to "easy to communicate" providing users with better situational awareness and, consequently, diminishing the hazard possibilities related to “human (interaction) error”.

As further work, the UI proposed as a wireframe needs to be evaluated qualitative and quantitatively using other methodologies including those specialized in the critical system field.

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