Using the decision ladder to reach a better design

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Abstract. As with all safely critical interfaces, it's imperative that medical devices communicate the right information, to the right people, at the right time, in the right place, and in an optimal format. This paper describes an approach for eliciting information requirements based on Rasmussen's decision ladder. A hypothetical example of radiography equipment is used to illustrate the process; however, the approach is also considered to be applicable to a wide range of domains. The approach is based on a semi-structured interview and creates an explicit link between the data collection activity and the final design interface.

Keywords. Medical devices; healthcare; systems; sociotechnical

1. Introduction

The link between the quality of a user interface and system performance is now almost universally accepted. For very simple interactions, such as an alarm clock app for a mobile phone, developing an interface may be an intuitive and straight forward process. The adoption of style guide and consideration of a set of heuristics (e.g. Nielsen & Molich, 1990) may be enough to ensure a useable design. However, the challenge is proportional to the complexity of the product or service being designed. The consequence of system failure is also an important consideration in the approach adopted, while the failure of an alarm clock may result in missed appointments or even flights, it is unlikely to cause a fatality. Conversely, in safety critical environments the cost of failure may be much higher.

The Therac-25 radiation machine is a frequently cited case (see Leveson & Turner, 1993) of where interface failure is reported to have tragically contributed to multiple fatalities. Six incidents were reported between 1985 and 1987 where patients were given significant overdoses of radiation. The Therac 25 machine had two modes of operation, direct electron-beam therapy (E) and Megavolt X-ray beam therapy (X). When operating in the direct electron therapy mode (E), the machine delivers shallow lower power beams. Conversely in X-ray mode (X), a deeper focused beam is delivered which is flattened with an attenuating filter which is positioned in the path of the beam.

One case occurred in Tyler, Texas, in 1986 after two years of use and nearly 500 treatments. The operator was performing a routine electron treatment. As per usual, the patient was set up, face down, on the table and the operator left the room. At the control terminal the operator manually entered the treatment details. In the course of this the operator mistyped an (X) in place of an (E). On checking, she noticed the error and overwrote it. An unfamiliar error was presented on the screen "Malfunction 54" however, no information was provided on the details of this error. The operator manual supplied with the machine did not explain or address the malfunction codes, nor did it give any indication that these malfunctions could place a patient at risk. System errors were a relatively common occurrence, and routinely accepted, the operator typed (P) for proceed.

At a much later date, it became apparent that the interface had not recognised the change in beam type (X to E) as a piece of legacy code ignored changes made within eight seconds of the initial entry. Not only was the wrong treatment delivered, but a dose designed to penetrate the thick attenuating filter was delivered, without the filter in place. As a result, the patient received a massive overdose (16,000 rads instead of 180 rads). Previous versions of the machine had a mechanical interlock in place to prevent this situation; however, this was not present in the Therac 25.

As with most complex systems, it is difficult, and more importantly, inappropriate to seek a single root cause for this failure; however, the user interface played a critical role. The product lacked the required interlocks and the interface lacked the feedback to communicate the situation and its criticality.

2. Approach

Most interface designs start by establishing the information requirements. More often than not, these information requirements are communicated as a text-based document. The resultant document typically forms the bridge between systems architects, or engineers, and the interface designers. Perhaps, unsurprisingly, the quality of these information requirements has a direct relationship on the quality of the resultant interface and the performance of the systems in which they are used. Thus, in order to ensure the safety, efficacy, efficiency, usability and resilience of products and services, it is important that the process for developing information requirements is fit for purpose.

Thus, ostensibly at least, the foundation for a well designed interface design lies in establishing: (1) What information is required? (2) When it needs to be displayed? (3) Where it should be displayed? (4) Whom it should be displayed to? And (5) How – in what format?

Decision making is at the heart of all control tasks. There have been many attempts to model the decision making activity. Most involve some form of observation of information, orientation to the current situation, a choice as to which action to adopt, and finally an action. The decision-ladder (Rasmussen, 1974) is the tool most commonly used within Cognitive Work Analysis to describe decision-making activity. Unlike some of its counterparts, its focus is on the entire decision-making activity, rather than the moment of selection between options. It is not specific to any single actor; rather it represents the decision-making process of the combined work system. In many cases, the decision making process may be collaborative, distributed between a range of human and technical decision-makers. Novice users (to the situation) are expected to follow the decision-ladder in a linear fashion. The left side of the decision-ladder represents the observation of the current system state, whereas, the right side of the decision-ladder represents the planning and execution of tasks and procedures to achieve a target system state.

2.1 Data collection

The approach starts with a list of the information requirements that could be needed by the system. This list is then coded to provide additional detail and constraints, such as when, where, to whom and how information should be displayed. The approach for eliciting the systemic information requirements is based on a series of semi-structured interviews with system experts and/or stakeholders. These interviews are structured around a template with a decision ladder at its centre. The process involves capturing the questions that decision makers pose themselves and the system at each stage of the decision making process. A separate model should be created for each of the key situations. These are typically identified through a contextual activity template or a hierarchical task analysis (HTA). A case study based on a generalised description of a radiography machine is used to illustrate the process. The task is divided in to subtasks via an HTA. Task step 5, Deliver radiation, will be explored in greater detail as detailed in Figure 1 and Table 1. This process would be repeated for each of the task steps.

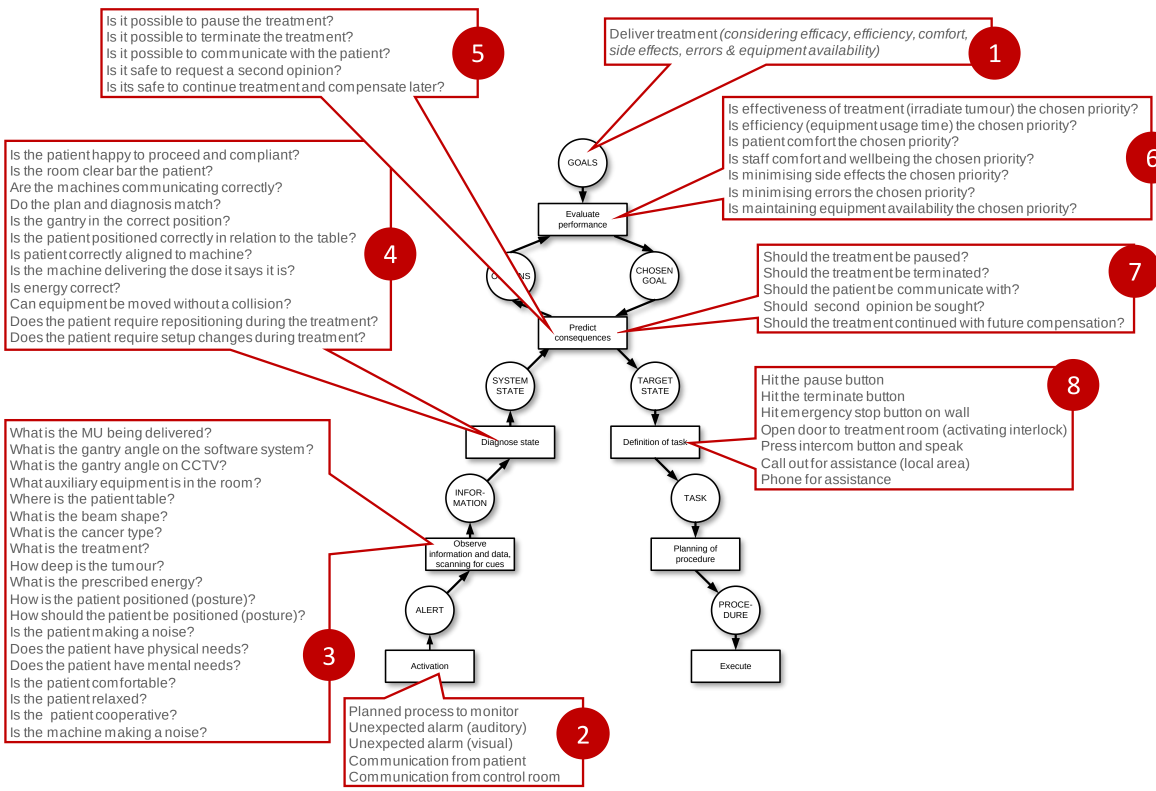

Figure 1 – Decision ladder

Table 1 – Interview process

Stage 0 – Define task steps Prior to starting the interviews, the activity should be decomposed into separate parts. The optimal method of decomposition will vary depending on the system. Activities that can easily be delineated into a series of notably different task steps are best deconstructed using a task analysis technique such as HTA. Activities that are defined by more environmental conditions, such as location, are better deconstructed in a Contextual Activity Template. A separate decision ladder should be produced for each task step or situation.
Stage 1 – Determining the goal The first stage of the interview process for each model is to structure the goal of the system. The expert should be asked to provide a high order goal, along with a number of constraints affecting it. The expert should be reassured that the constraints could possibly be in conflict. The information works well placed in the format “To (insert goal) considering (insert constraints)”. For the case study, the goal at this stage of the process is simply to ‘deliver the treatment’, the caveat is that it must also consider the system values of efficacy, efficiency, comfort, side effects, error and equipment availability.

Stage 2 – Alert The expert should be asked to begin the walk-though at the chronological start of the process. Alerts capture the events that first draw them to the need to make a decision. During the delivery process alerts to a system state change include monitoring the process, alarms (visual and auditory), communications from the patient and communications from other members of staff in the control room.
Stage 3 – Information The expert is asked to list the information elements they would use to gain an understanding of the situation. The information elements are the nuggets of information that can be brought together to understand the state of the system. In this case they include information about the physical equipment (e.g. the gantry angle, the equipment in the room, the position of the table) along with information from the HMI (e.g. the dose being delivered, the beam shape), information from patient records (e.g. treatment type and location), information from the patient (e.g. are they comfortable, relaxed).
Stage 4 – System state The system states represent a perceived understanding of the work system based upon the interpretation of a number of information elements. The key distinction between an information element and a system state is that system states are formed of more than one quantifiably different element of information. In short, information elements are processed and fused to form system states. Questions such as 'is the patient positioned correctly?' can be assessed by considering the treatment type and the current position of the patient.
Stage 5 – Options The options within the ladder can be described as the opportunities for changing the system state in an attempt to satisfy the overall goal. The points are structured as questions in the form; "is it possible to (…)?" The number and type of options available will be informed by the system state. It is anticipated that in certain situations there may only be one option available. At a high level, during treatment there are five main options available to the operator: to pause the treatment, terminate the treatment, communicate with the patient, request a second opinion, and continue treatment and compensate later.
Stage 6 – Chosen goal The chosen goal, at any one time, is determined by selecting which of the constraints receives the highest priority. This does not have to be an absolute choice per se, rather, one takes a higher priority than the other does in the given situation. In the case of the Therac-25, the operator had to decide which aspect of the goal to focus on based on the information presented. The system values of efficacy, efficiency, comfort, side effects, and error and equipment availability were in this case in conflict. Most notably, the efficiency and equipment availability were in conflict with safety and side effects.
Stage 7 – Target state The target states mirror the option available; once a particular option is selected, it becomes the target state. The options are rephrased in the form "Should (option) take place?"
Stage 8 – Task The listed tasks relate to the tasks required for achieving the target state while maintaining the overall goal (e.g. hit the pause button, press intercom button and speak).
Stage 9 – Procedure The procedure lists questions that will inform the choice of task procedure.
Stage 10 – Analysing the models Once a decision ladder has been created for each task or scenario, the variability between the models can be compared. At this stage, it is useful to give each element in the model a unique identifier. For example Alerts (AL001), Information elements (IE001), System states (SS001), Options (OP001), Goals (GL001), Target states (TS001), Tasks (TA001) and Procedures (PR001). Where appropriate, similar elements can often be combined and reworded to reduce the total number of elements.

2.2 Analysing the models

The structured interviews provide a list of information elements answering the question of 'what' information may be required. Further analysis is required to establish when information should be displayed, where, to whom and how. This analysis can be conducted by coding the list of elements extracted from the interviews. Table 2 provides guidance for each of these questions.

Table 2 – Analysis guidance

When should information be displayed? The level of consistency between the decision ladder models can be a very useful cue to design. Information elements can often be divided into two groups (1) persistent and (2) context specific. As the name suggests, persistent information elements should be presented regardless of the situation or task, while context-specific information elements should only be displayed during the tasks or situations where they are relevant. For interfaces that predominately contain persistent data, an argument could be made for showing all information elements as this reduces the complexity of a moded display A matrix can be created listing each of the alerts, information element, system states, option, goals, target states, tasks and procedures. This can be coded to show which elements are present in which situations or tasks. An example of this is provided in Table 3. The matrix can be coded to show when the elements are typically needed (dark grey cell) and when they may be needed (light grey cell). As illustrated in Table 3, some of the information elements may be required all of the time, such as the name of the patient, whereas other elements are only required in specific situations (e.g. the dose being delivered during stage 5).
Where should information be displayed? The where question can be addressed in two ways, firstly a decision needs to be made on where information should be displayed in the environment. This may mean different sites (e.g. maybe in different countries), different rooms within a site (e.g. control room, plant room, treatment room), or different locations within a room (e.g. wall mounted display, equipment display, indicator lamp, hard-copy manual, whiteboard, poster). The second way of addressing the question is to consider the arrangement within each of these locations (e.g. the location on the poster, or the screen). There are a number of applicable approaches for grouping information elements. The output of the analysis approach provides a useful means of structuring the interface. By explicitly mapping which information elements relate to which systems states. By adding a column to the matrix for each location the information elements can be coded to indicate the relationship.
Whom should information be displayed to? In a similar way, different actors in the system may need different access to information. Actors may include: Digital agents, Operators, Supervisors, Administrators, Maintenance staff, etc. The matrix of information elements and system states can also be coded to indicate which actors the information should be displayed to. This can help to inform and document decisions relating to whether separate system views are required and whether actor types can be combined to reduce the number of views required.
How should the information be displayed The decision as to how information should be displayed will be informed by a consideration of the factors above. Once the information elements for each situation, location, and actor have been defined, the decision on representation needs to also consider the appropriateness of the representation.

Table 3 – Example elements coded by task step (dark grey cells indicate typically needed, light grey cells indicate may be needed)

ID	Description	1. Patient check in	2. Machine prep	3. Patient set up	4. Machine set up	5. Deliver radiation	6. Unload patient	7. Clean machine
AL01	Patient appears agitated							
AL02	Unexpected alarm (auditory)							
AL03	Communication from patient							
IE01	What is the name of the patient							
IE02	What is the weight of the patient							
IE03	Does the patient have physical needs							
IE04	What is the MU being delivered							
IE05	What is the cancer type							
IE06	Does the patient have multiple appointments							
SS01	Is the patient happy to proceed							

3. Discussion and Conclusion

For complex systems, a structured approach is needed to ensure, firstly that all the required information elements are considered, and secondly that they are included in the optimal way to ensure an appropriate balance of system values (e.g. safety, efficacy, efficiency, usability and resilience). The approach described in this paper has proved to be effective in a wide range of situations. It has been applied to the design of unmanned aerial vehicle (Elix & Naikar, 2008; Jenkins, 2012), a military command and control system (Jenkins et al, 2010), a policing command and control system (Jenkins et al 2011a), a tank training simulator (Jenkins et al, 2011b), an automotive interface (McIlroy &Stanton, 2015), and a number of medical devices.

It provides welcome structure to the process of eliciting and structuring information requirements that focus on end users and stakeholders. One of the clear strengths of the approach is that it provides a very explicit link between the data collection, the analysis and the design.

Informed decision making is fundamental to safe and effective system control. There is a long established connection between the quality of decision making and the information available to decision makers. This does not necessarily mean presenting more information; on the contrary, too much information can be as detrimental as too little. Rather, to optimise system performance (e.g. safety, efficacy, efficiency, resilience) effective decision making must be supported by the right information, at the right time, in the right place, to the right actors, in a format that can be readily understood.

It is certainly not claimed that the structured approach described in this paper would prevent all cases of error in isolation; however, as part of a suite of error prevention measures, it is contended that it would lead to the development of safer more considered systems. Furthermore, due to the focus on user information requirements, it is contended that it results in more useable interfaces that will have a positive impact on multiple system performance metrics (e.g. efficacy, efficiency resilience).

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