Deciding to design better user interfaces

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ABSTRACT
This paper describes an approach developed to establish information requirements for human machine interfaces within complex systems. The approach, rooted in decision making, is not limited to the design of digital interfaces; instead, it encourages the consideration of information that is distributed across the physical, digital and social environment. The technique has been successfully applied to the design of radiotherapy equipment, which is used here as a case study. The process starts with a semi-structured interview, around Rasmussen's decision ladder, designed to elicit the information that could be used at each stage of the treatment process (rather than is used, or should be used). The identified information elements are then coded to indicate when the information may be needed, where the information is required, and who may need it. The resultant model has been designed to create an explicit link between analysis and the design of physical and digital artefacts.

KEYWORDS
Practical application; decision making; interface design; medical; radiotherapy

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 a 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, such as radiotherapy treatment, the cost of failure may be much higher.

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 with and impact 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 it should be delivered?

This paper aims to illustrate how a highly structured approach to analysis, based on the consideration of decision making, can inform the design of commercial products.

Decision making as a starting point

Decision making is at the heart of all control tasks. There have been many attempts to model decision making activity. Most rational models 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; see Figure 1) 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 has been adopted here as it is capable of representing more linear 'rational' or knowledge-based decision making activity, as well as more naturalistic rule and skill-based decision making activity. For more rational, or knowledge-based, decision making, where decision makers are responding to unfamiliar situations, a more linear path through the decision-ladder is expected. Following activation, users are expected to observe available information, determine a system state, consider options, and relate this to a chosen goal. The context specific interpretation of the goal is then used to determine a target state, task and procedure. Thus, 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.
The key utility of the decision making model; however, is its ability to also represent more naturalistic decision making activity. 'Recognition-primed decision making' can be represented with 'shortcut' links between nodes (most notably between the two legs; see Figure 1). Another key distinction from other decision making models is that the decision ladder does not have to be limited to a single decision making entity. The decision ladder model can also be used to represent collaborative decision making, distributed between a range of human and technical decision-makers. The concept of the approach described in this paper is to create a structure for capturing the information requirements that could be required and to code them based on when, where they could be needed as well as to whom and in what format.

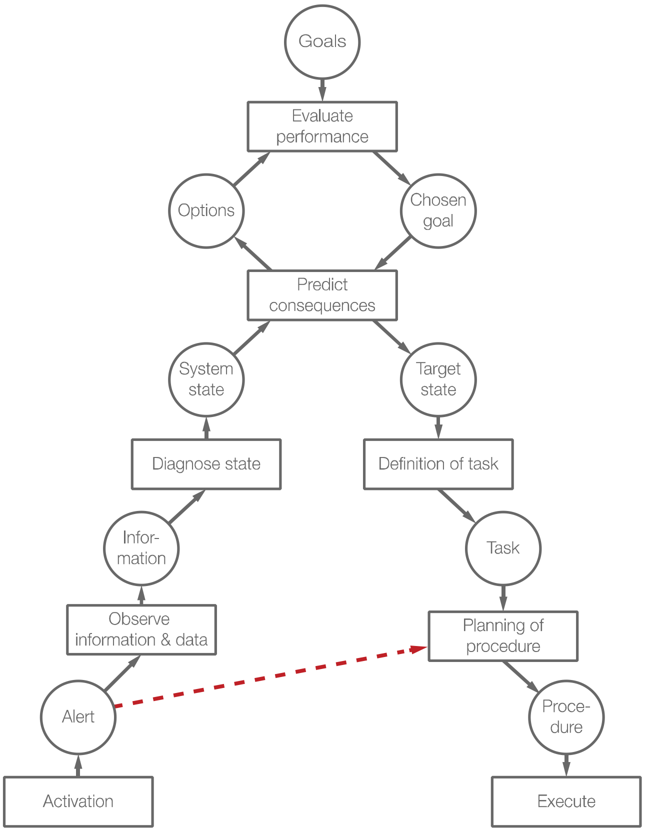

Figure 1. Decision ladder template

Radiotherapy as a case study

External radiotherapy involves targeting specific parts of the body with radiation delivered by high energy x-rays. External radiotherapy is most commonly used to treat cancerous tumours and is typically delivered by a large medical device called a linear accelerator (LINAC). LINACs have been optimised to focus the radiation on the identified volume (normally containing the tumour), while minimising the exposure to surrounding health tissue. LINACs use microwave technology to generate a beam of radiation which is shaped to fit the patient's tumour. This beam is then rotated around the patient allowing the radiation to be delivered from different angles (reducing the damage to surrounding tissue). Each patient has a unique treatment plan that involves specific beam intensities and shapes and, as well as angles of delivery. Due to the size and complexity of the LINAC, the machine tends to be in a fixed location. The patient is aligned to the machine on a movable table. Traditionally, this alignment is done to reference marks drawn onto their body (referred to as tattoos), more recently LINACs are equipped with imaging technologies that allow the position of the tumour (or given volume) to be verified.
DCA supported Elekta in designing and developing a next generation suite of radiotherapy equipment at an early stage of the design process. While conceptual, these 'visions for the future' were grounded through collaborative technical review and based on an extensive body of evidence collected from visits to seven treatment sites worldwide (including sites in Belgium, Brazil, Canada, USA; see Figure 2), over 90 hours of observations (approximately 360 treatment sessions), and over 50 in-depth interviews with health care professionals, thought-leaders, and system stakeholders.
A detailed audit and understanding of the information required to support treatment delivery was fundamental to these concepts. The overarching philosophy was to provide the right information, at the right time, in the right place, to the right people in the right format. This involved splitting information into three categories.

1. Typically required (at given time, location, for given user)
2. Could be required (at given time, location, for given user)
3. Not required (at given time, location, for given user)

Figure 2. Observation of radiotherapy treatment

APPROACH

Interface designers require an understanding of what information is needed in different contexts. . Where the requirements for information are difficult to predict one simplistic approach is to provide all of the information all of the time, or allow users to navigate to the information they require as they need it, which may indeed be the best option for design. However, where the information requirements change predictably based on situation it may be advantageous to change the way information is presented.

The approach involves establishing a long list of all of the information requirements that could be needed by the system, which is 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 constructed around a template with a decision ladder at its centre for each key situation. The process involves capturing the questions that decision makers pose themselves and the system at each stage of the decision making process. An example of one of these decision ladder models is shown in Figure 3.

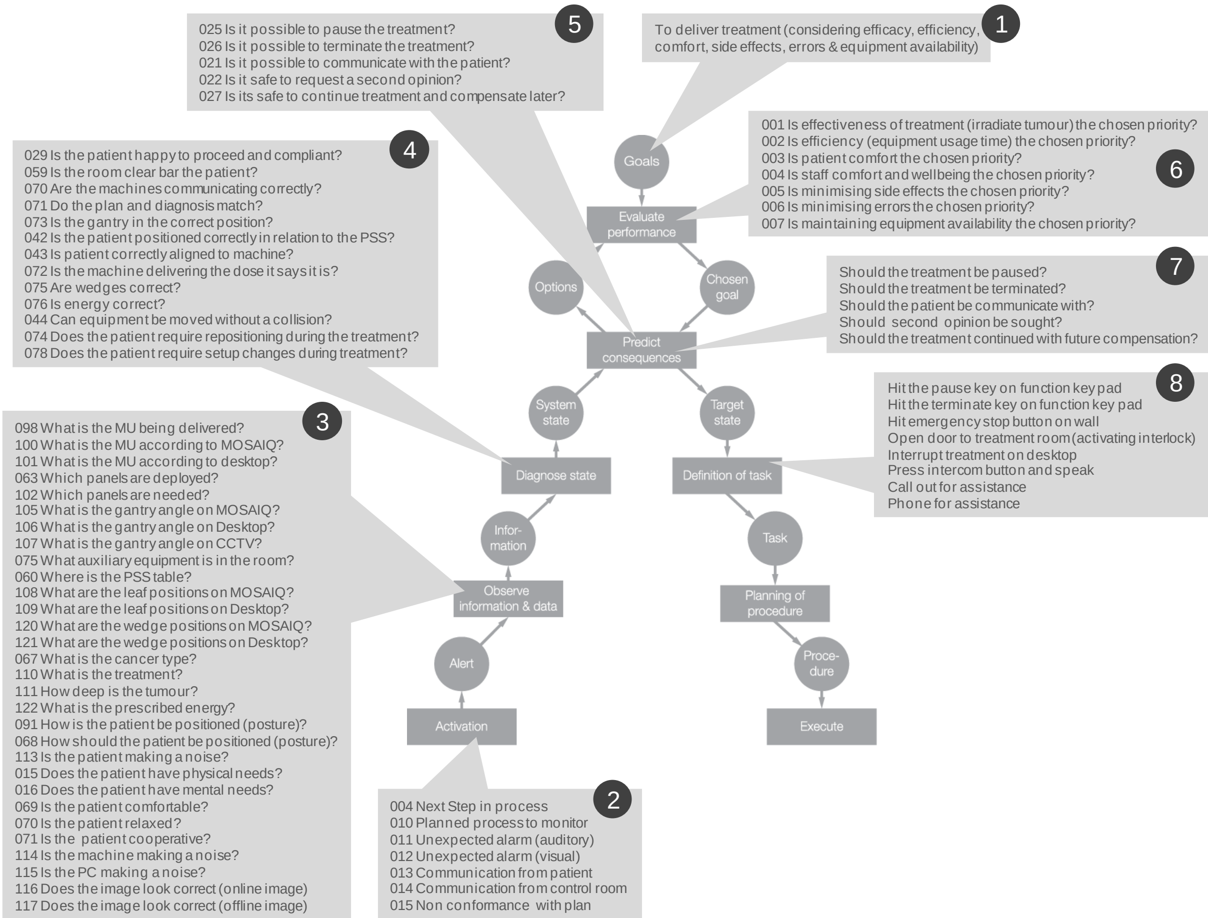

Figure 3. Model for 'beam on' (large numbers relate to task phase in Table 2)

Dividing up the activity

A separate decision ladder model should be created for each of the key situations. These situations are typically identified through a contextual activity template (another tool from CWA) or a hierarchical task analysis (HTA) model. For the case of radiotherapy, the treatment process can be broken down into ten discrete phases (see Table 1) each requiring different decisions and thus different information elements. Task phase 8, (Beam on; illustrated in Figure 3), will be explored in greater detail in this paper to illustrate the process. The same process was applied to each of the ten phases.

Table 1. Task phases

Task phases	Description
1 Patient registration	Identify the patient and relate them to the treatment database
2 Manage patient	Explain the treatment process
3 Machine preparation	Set up the machine to receive the patient, add set up aids
4 Patient loading	Sit the patient on PSS and lay them down
5 Patient set-up	Configure fixation / immobilisation devices, position the patient
6 Image	Image the patient (if required)
7 Prepare for beam delivery	Adjust the position of the patient, retract panels (if required)
8 Beam on	Treat patient
9 Unload patient	Remove fixation / immobilisation devices, help patient up
10 Clean up	Wipe down machine, reset ready for next patient

A semi structured interview is the basis of building each of the models. The broad structure for the semi-structured interviews with radiotherapists is presented in Table 2. The output of the interview is presented in Figure 3.

Table 2. Interview process

Step 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 phase 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.
Step 2 – Alert The expert should be asked to begin the walk-through 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), and communications from the patient and communications from other members of staff in the control room.
Step 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).
Step 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.
Step 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 options 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, or continue treatment and compensate later.
Step 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. The system values of efficacy, efficiency, comfort, side effects, and error and equipment availability are likely to be in conflict.
Step 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?"
Step 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).
Step 9 – Procedure The procedure lists questions that will inform the choice of task procedure.
Step 10 – Validate model Once a first pass of the decision ladder has been completed, the expert is then asked to repeat the process adding additional or alternate elements. The interviewer can support this by posing the question what if (information element) were unavailable, are there any other cues that you could use? Another useful technique is to cross-check the information elements against the system states to see if system states can be informed by new information elements, or if information elements could inform new system states.

ANALYSIS

What information could be needed?

The analysis approach starts with a combined list of the information requirements that could be needed by the system. This list is aggregated from each of the decision ladder models (in this case the ten task phases). These are listed in a spreadsheet allowing coding to provide additional detail and constraints, such as when, where, to whom and how information should be displayed. 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.

When could the information be required?

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 nearly 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 phase 8).

Table 3. Example elements coded by task phases (dark grey cells indicate typically needed, light grey cells indicate may be needed) – this is a cut down list of elements for illustrative purposes

ID	Description	1. Patient registration	2. Machine prep	3. Machine preparation	4. Patient loading	5. Patient setup	6. Image	7. Prepare for beam delivery	8. Beam on (Deliver radiation)	9. Unload patient	10. Clean up
AL005	Patient appears agitated										
AL011	Unexpected alarm (auditory)										
AL013	Communication from patient										
IE001	What is the name of the patient										
IE008	What is the weight of the patient										
IE015	Does the patient have physical needs										
IE098	What is the MU being delivered										
IE067	What is the cancer type										
IE025	Does the patient have multiple appointments										

Where could the information be required?

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. An example of this is presented in Table 4.

Table 4. Example elements coded by location (dark grey cells indicate typically needed, light grey cells indicate may be needed)

		Environment			Feedback		Documentation				Comms	
ID	Description	Reception area	Treatment room	Patient appearance	Equipment feedback	Imaging outputs	Patient documentation	Treatment description	Workflow description	Schedule description	Staff communication	Patient communication
AL005	Patient appears agitated	▒	▒	■								■
AL011	Unexpected alarm (auditory)		▒		■							
AL013	Communication from patient				▒							■
IE001	What is the name of the patient			▒			▒			■	▒	▒
IE008	What is the weight of the patient			▒			■				▒	▒
IE015	Does the patient have physical needs			▒			■				▒	▒
IE098	What is the MU being delivered				■							
IE067	What is the cancer type						■	■				
IE025	Does the patient have multiple appointments						■				▒	▒

To whom should the information be displayed?

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. An example of the coding for the radiography system is presented in Table 5.

Table 5. Example elements coded by role (dark grey cells indicate typically needed, light grey cells indicate may be needed)

ID	Description	Greet and manage patients (typically receptionist)	Treatment delivery staff (radio-therapists / technicians)	Oncologists	Treatment planning (Physicist / Dosimetrist)	Equipment maintenance	Porters
AL005	Patient appears agitated	■	■	▒			▒
AL011	Unexpected alarm (auditory)		■		▒	▒	
AL013	Communication from patient	▒	■				▒
IE001	What is the name of the patient	■	■	■	■		▒
IE008	What is the weight of the patient	■	■	■	■		▒
IE015	Does the patient have physical needs	■	■	■	■		■
IE098	What is the MU being delivered		■	■	■		
IE067	What is the cancer type		■	■	■		
IE025	Does the patient have multiple appointments	■	▒				■

How

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 6. Example elements indicating potential formats

ID	Description	Format
AL005	Patient appears agitated	High quality image and videos of patient
AL011	Unexpected alarm (auditory)	Unique sounding alarm louder than background
AL013	Communication from patient	High quality audio
IE001	What is the name of the patient	Text
IE008	What is the weight of the patient	Numerical with units
IE015	Does the patient have physical needs	Numerical with units
IE098	What is the MU being delivered	Text field
IE067	What is the cancer type	Numerical with units
IE025	Does the patient have multiple appointments	Text field / map of body
AL005	Patient appears agitated	Schedule
AL011	Unexpected alarm (auditory)	High quality image of patient

TRANSITION TO DESIGN

As stated in the introduction, the objective of this approach is to create a far more explicit link between analysis and design. The first stage of the design process is to convert the information, represented in the matrix, into a graphical representation that can be passed to interface designers. Figure 4 shows an example of the information requirements for the control room displays during the ‘manage patient’ phase. A full list of information elements is presented and these are coded to show which are needed, which may be needed and which are not needed. It is proposed that these graphics provide a much more usable representation than the solely textual descriptions that they are intended to replace. It is also proposed that they replace some of the subjective ‘black art’ of the interpretation of these documents.

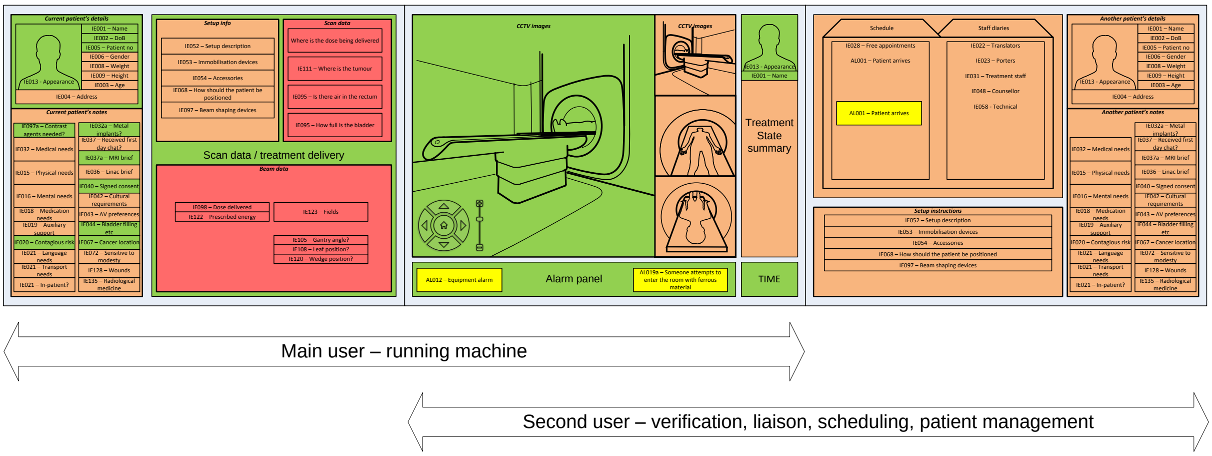

Figure 4. Example of control room display information requirements for the manage patients phase (Green – Typically required at the current phase; Amber – Could be required at the current phase; Red – Not required at then current phase; Yellow – Alerts to be displayed as required).

Similarly, Figure 5 shows a representation for the information that may be required within the treatment room during the patient loading phase of the treatment process. Here a distinction is made between which information elements are presented on/by the patient themselves, those in the general physical environment, those on some form of graphical display and those that are auditory alerts.

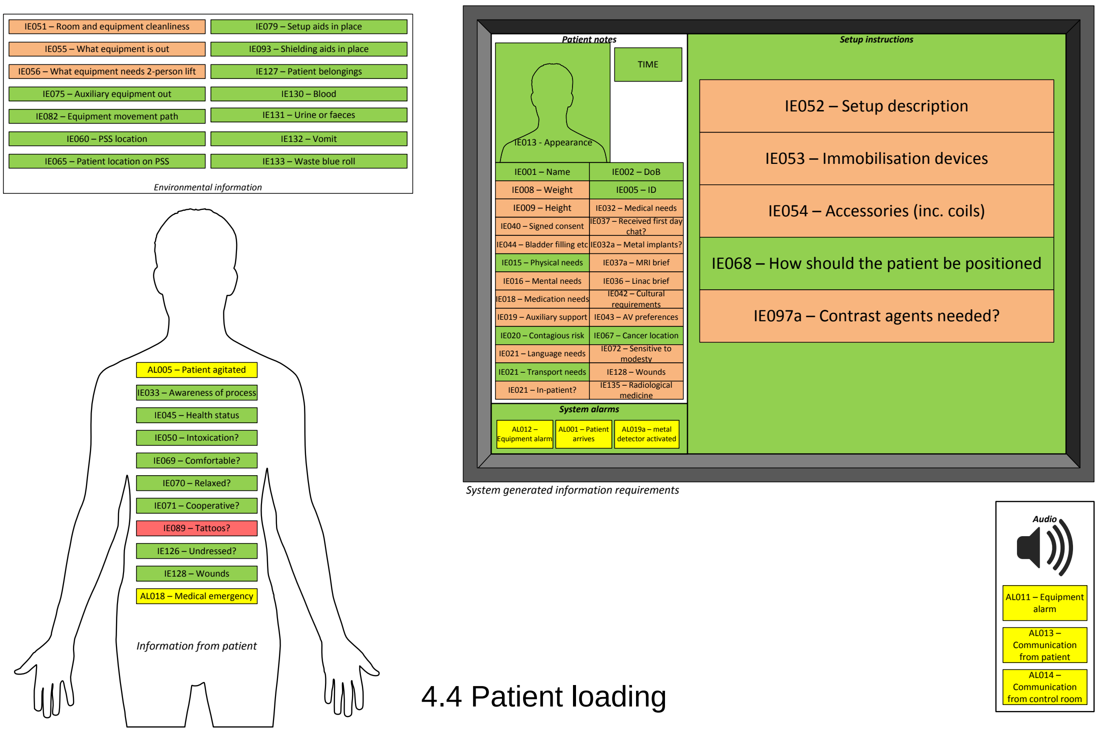

Figure 5. Example of treatment room information requirements for patient loading phase (Green – Typically required at the current phase; Amber – Could be required at the current phase; Red – Not required at then current phase; Yellow – Alerts to be displayed as required).

DISCUSSION AND CONCLUSIONS

The case study described in this paper formed the first step of the information requirements capture and of the interface design process. This activity described in this paper was completed in 2012. Since then, the development of the product has continued and is approaching clinical trials. The approach described here for identifying information requirements was repeated at a later date to validate the findings. A variety of other user interface design approaches have also been adopted to fit the fidelity of the concepts as they move through paper prototypes, to digital wireframes and eventually to fully coded interfaces.

For complex systems, it is highly advantageous to consider system information requirements at an early stage of the project. 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). Most critically the output of this analysis needs to be presented in a format that can be shared and be well understood across the design team.

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 of early interface concepts.

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).

REFERENCES

Elix, B., & Naikar, N. (2008). Designing safe and effective future systems: A new approach for modelling decisions in future systems with Cognitive Work Analysis. Proceedings of the 8th International Symposium of the Australian Aviation Psychology Association.

Jenkins, D. P. (2012). Using Cognitive Work Analysis to describe the role of UAVs in Military Operations. Theoretical Issues in Ergonomics Science. 13(3)335-357

Jenkins, D. P., Salmon, P. M. Stanton, N. A. Walker, G. H. and Rafferty. L. (2011a). “What Could They Have Been Thinking? How Sociotechnical System Design Influences Cognition: A Case Study of the Stockwell Shooting.” Ergonomics 54 (2): 103–119.

Jenkins, D. P., Stanton, N. A., Salmon, P. M. & Walker, G. (2011b). A formative approach to developing synthetic environment fidelity requirements for decision-making training. Applied Ergonomics. 42 (5) 757-769

Jenkins, D. P., Stanton, N. A. Salmon, P. M. Walker, G. H. and Rafferty. L. (2010). “Using the Decision Ladder to Add a Formative Element to naturalistic Decision-Making Research.” International Journal of Human-Computer Interaction 26 (2–3): 132–146.

McIlroy, R.C., Stanton, N.A. (2015) A decision ladder analysis of eco-driving: the first step towards fuel-efficient driving behaviour, Ergonomics,

Nielsen, J., and Molich, R. (1990). Heuristic evaluation of user interfaces, Proc. ACM CHI'90 Conf. (Seattle, WA, 1-5 April), 249-256