Critical Factors Influencing Intra-operative Surgical Decision-making

Ashis Jalote-Parmar
Faculty of Industrial Design and Engineering
Technical University of Delft
Landbergstraat 15, 2628 CE Delft, The Netherlands
ashisjalote@yahoo.com

Petra Badke-Schaub
Faculty of Industrial Design and Engineering
Technical University of Delft
Landbergstraat 15, 2628 CE Delft, The Netherlands

***Abstract*— The development of intra-operative surgical decision support systems requires a thorough understanding of the factors influencing the decision-making of surgeons in the surgical workspace. These factors are a construct of the surgical workspace which generate situation awareness and hence provide real-time information to guide intra-operative decision-making The knowledge of these factors is especially required to provide real-time image guidance or procedural support to the surgeons' via surgical information systems to assist the minimally invasive techniques. Related research has focused on investigating the types of decision-making strategies that surgeons may use such as intuitive (recognition-primed), rule based, option comparison and creative. The researches have not investigated the factors influencing the intra-operative surgical decision-making. Addressing this gap the presented research focuses on the following two questions: First: which critical factors influence the intra-operative surgical decision-making, and second: are there differences in importance of these factors for different minimally invasive techniques? In order to answer these questions two studies have been conducted with surgeons related to three different minimally invasive techniques. The first study included three focus group sessions with 20 surgeons. The second study confirms the findings of the first study by conducting real-time observations (n=15) in the surgical workspace. The findings reveal that three factors are of major importance: task visualization, communication and mental model. These factors are elaborated by illustrating their influence on decision-making during the minimally invasive techniques. On the basis of these result basic guidelines for the development of expert decision-support system have been derived.**

***Keywords*—Surgical information system , decision making, medical informatics,Minimally invasive surgeries, image guidance,**

I. Introduction

Empirical studies reveal that requirements of intra-operative decision support systems stem mainly from the lack of adequate procedural and visualization aids (image guidance) for the surgeon while conducting minimally invasive techniques [1]. An analysis these systems reveal that these systems are developed mainly based on previous design and on the availability of latest technological trends [2] rather than on knowledge of information requirements supporting decision-making [3, 4]. As a result, the surgeons are subjected to unstructured or missing information which may cause surgical error hence affecting patient safety [5, 6].

Similar to other complex workspaces such as aviation [7] the development of surgical expert systems is critically dependent on the knowledge of how experts make decisions in conditions of high uncertainty, time pressure and zero tolerance for errors [4, 8]. Theoretical concepts which provide an explanation on how experts make decisions in complex workspaces can be derived from naturalistic decision-making [9] and complex problem solving theories [10, 11]. These theoretical concepts evolved from empirical research of human behavior in situations which can be described as complex, dynamic, uncertain, and with high personal stakes involved.

Contrary to classical decision making theories both approaches emphasize the need to analyse the cognitive processes of the decision maker instead of focusing on an input-output model. The result of these analyses are models describing what decision makers actually do, why they seek what kind of information and how they derive decision making rules and strategies. Since more than 15 years the Naturalistic Decision Making (NDM) approach has especially focused on the question what expert decision makers actually do while working in their 'natural' environments, and how they solve problems they encounter.

The empirical findings of a variety of studies are condensed in the Recognition-Primed Decision Making Model (RPD-Model) which distinguishes three ways of how experts make decisions. The first way is a pattern-matching process where the expert identifies and immediately categorizes the situation and reaction according to a typical situation stored in his/her memory. The second mode occurs in case the situation is unclear; then the expert has to develop a mental model based on his/her experience. The third mode, the expert simulates and anticipates mentally a course of actions and its consequences, can be observed in unknown surprising situations [9]. The perception of the environmental factors and how these determine the decision-making process are described by Endsley's concept of situation awareness [8].

This brief outline of the framework of NDM might underscore why an application of naturalistic decision-making theory has been deemed relevant in investigating decision making processes of experts in the medical field [12].

1-4244-2384-2/08/$20.00 © 2008 IEEE

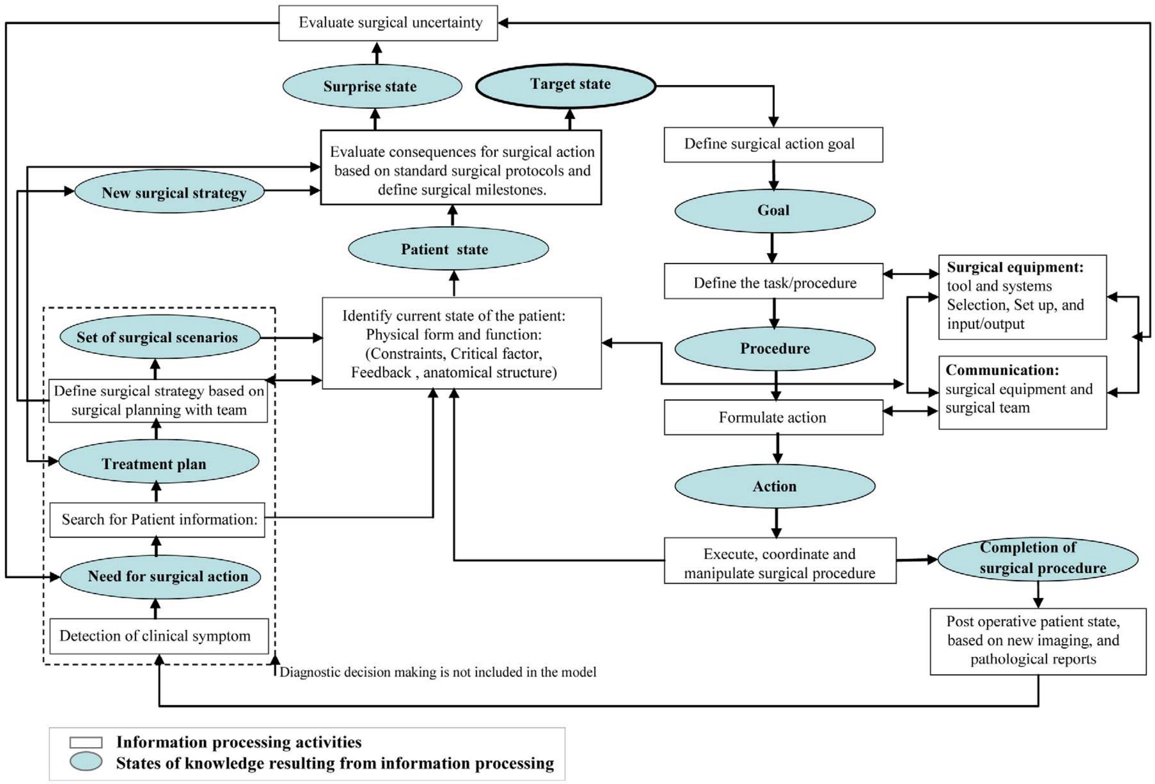

Figure 1. *Problem solving process model, illustrating the boundaries of the workspace determines decision-making [14]*

Till recently, the studies specifically investigating factors influencing intra-operative surgical decision-making have still received scant attention. One such recent research study [13] has focused on identifying the types of intra-operative surgical decision that surgeons may use such as intuitive (recognition-primed), rule based, option comparison and creative. This knowledge intends to assist in enhancing cognitive training for clinicians [13]. Despite these valuable efforts there are questions still to be answered, namely which factors influence intra-operative surgical decision-making and do and if so, how do they differ in the context of minimally invasive techniques. This knowledge is essential to understand the dynamic information needs in the different surgical specialisations for developing expert systems. Addressing this need, the research reported here, investigates the following two issues: First, the analysis of critical factors influencing the intra-operative surgical decision-making process, and second, the importance of these factors for three different minimally invasive surgeries, endoscope liver surgery, cardiac surgery and radiofrequency coagulation.

It is acknowledged that there will be significant role of diagnostic decision-making, or the involvement of other team members for a surgical decision, but team decision-making and diagnostic decision-making is beyond the scope of this paper.

II. THE SURGICAL PROBLEM SOLVING PROCESS

To develop expert systems that provide appropriate decision-making support for the surgeon at the right time in an adequate way it is required to ensure that the content and presentation of the information is coordinated with the surgeon's information processing activities. Therefore the investigation of the information processing requires an understanding of the problem solving process, where the decision is considered as the final part of a problem solving process leading to an action [10]. As a starting point, we developed a surgical problem solving process model [14] (see figure 1). This model is based on concepts of information processing and problem solving theories in complex workspaces [10, 11, 15, 16].

The model depicts the sequence of activities and gained knowledge during the three surgical phases: before surgery (preoperative), during surgery (intra-operative) and after surgery (post operative); furthermore, the task boundaries which determine the surgeon's decision-making, are illustrated. This model has also been used to analyse the empirical observations in the surgical workspace in study 2, what will be explained in the following section.

III. Empirical Investigation

To investigate the critical factors influencing surgical decision-making, we conducted two studies. In study 1 we assessed the influencing factors by the method of focus groups which involved surgeons in a reflective exercise. In study 2 we conducted an observational study in the surgical workspace to analyse the decision making of expert surgeons in the real setting.

A. Study 1: Focus groups

Three focus group sessions [17] were conducted with altogether 20 surgeons (n=20) associated to three different national hospitals, in Netherlands, Norway and Slovenia. Each session consisted of six to seven expert surgeons specialised in different minimally invasive surgical techniques: Endoscopic liver surgery, cardiac surgery and radiofrequency ablation. A designer (human computer interaction specialist) in partnership with a surgeon moderated the focus group sessions. The surgeons were asked to conduct the following three tasks:

- The participants were asked to reflect on a recent critical problem-solving situation, which arose during a surgery, and how they solved it.
- The participants were then asked to draw a flow chart of the problem-solving situation.
- In a last step the participants were required to present their flow chart to the other participants. We applied the recall technique [18] to extract factors of decision-making.

All sessions were recorded and transcribed. The transcripts were analyzed to identify the key statements reflecting the critical decision-making events and the factors influencing them. As an example the following statement is considered: "Especially in a cirrhotic liver you can't be sure of location the tumor …" Here the surgeon expresses uncertainty in the surgical task which is caused by missing knowledge of the location of the tumor. This description indicates the problems caused by missing task visulisation as the critical factor influencing the surgical decion making.

All statements which described aspects of decision making were identified. These statements were then semantically clustered by applying the affinity diagram technique [19]. The following three crtitical factors turned out to be the most important due to the number of frequencies: Task visulisation, communication and accuracy of the mental model. Next, the frequencies of each critical factor was analysed in relation to each miminally invasive technique (see table 1). These factors will be explained in detail in the result section.

B. Study 2: Observations of the surgical problem solving

To confirm the relevance of the critical factors in the real work environment we conducted 15 observations (n=3x5) in total by using the contextual enquiry technique [19] for the three minimally invasive techniques: Endoscopic liver surgery, cardiac surgery and radiofrequency ablation. Contextual enquiry technique involves observing and making the surgeons think aloud during the surgery. As the surgical workspace consists of several parallel workflows, i.e. the workflow of the anesthesiologist, patient, nurse [14]. To identify the key decision making events in the surgeon's workflow the problem solving model (figure 1) was used as a framework to mark the key decision making events of the surgical workflow in the surgical workspace. During the surgical observations the decision making factors were identified and the frequency of occurrence was marked against the information processing activities and states in the model. The frequency of the identified key factors semantically clustered can be seen in table 2.

TABLE I. Frequency results from 3 focus groups

Surgical Specialization	Critical factors influencing decision making		
	Task Visualization	*Communication*	*Mental models*
Radiofrequency	**46**	08	07
Endo.Cardiac	23	**38**	16
Endo.Liver	26	19	**30**

TABLE II. Frequency results from observations

Surgical Specialization	Critical factors influencing decision making		
	Task Visualization	*Communication*	*Mental models*
Radiofrequency	**38**	02	10
Endo.Cardiac	31	**36**	11
Endo.Liver	26	22	**24**

IV. Results

Both studies reveal that the surgical decision-making is primarily influenced by the following three critical factors: task visualization, communication and accuracy of the mental model. The surgical decision-making is influenced by the accuracy of visualization of the patient's anatomy, timely communication between the surgical systems and teams and by the accurate internal representation of the patient anatomy. These factors are found critical in the surgical problem solving process in relation to achieving the surgical goals and complying with the patient treatment strategy. The studies reveal further that the importance of the three influencing factors varies between the surgical specializations. In the following sections, we will explain the three factors and their importance in the three minimally invasive surgeries. Furthermore, we will exemplify these factors in surgical decision-making by a description of cases in three different minimally invasive surgeries. Based on these findings guidelines are proposed to develop intra-operative expert systems.

A. Explanation of the influencing factors

1) Task visualization: Task visualization can be understood as context based critical information required by the surgeons to make decisions in the three task states: the patient state (the world to be acted upon), target state (desired state for the patient) and surprise state (uncertain state) which arises due to new or a lack of information about the patient's anatomy. Task-based visualization involves providing the surgeons with real time organ positions, anatomical details, haptics feedback to assist in dynamic decision-making. Real-time task visualization provides diagnostic cues for the next surgical action.

2) Communication: Communication in the surgical work space refers to the exchange of patient related information that takes place between the main surgeon, the systems and the surgical team. Decision-making is critically reliant on timely communication of patient related information from the team member [20] as well as the system.

3) Mental model: Mental model refers to the internal representation of the patient data, acquired by the surgeon at the time of treatment planning and is continuously updated during the surgery. This internal representation is a construct of both of patient anatomy and surgical course of action to be followed during the surgery. The surgeons need to build accurate mental models to develop anticipations especially in case of uncertainty [21]. Mental models have also been considered critical for understanding the cognitive processes carried out by experts [8, 22, 23, 24].

B. Importance of factors in different surgical specialisations

A comparison of the frequency of the factors in the two studies illustrates that although all factors are important, different surgical specializations (see Figure 2). Referring to a case of Radio frequency ablation, task visualization emerges as a dominant critical factor in decision-making as compared to the other two factors. This is due to the fact that the surgical decision-making is critically dependant on the adequate task visualization of the patient anatomy, rather than primarily on timely communication between teams and systems. Similarly, communication emerges as a dominant factor in endoscopic cardiac surgery and liver surgery respectively.

C. Examples of surgical decsion-making

Three surgical cases have been selected from the focus groups sessions to explain the importance of the factors in surgical decision-making. Each case illustrates the particular factor with the highest frequency for the respective surgical specialization. Based on these cases we propose basic guidelines for the development of future expert decision-making systems to support minimally invasive surgeries.

1) Task visualization in radiofrequency ablation

"The image quality of the Ultrasound (US) was poor, the transducer was large and therefore I couldn't easily reach beyond the surface of the liver. … Finally I saw a tumor in the US. Was this the same tumor I intended to ablate I wasn't sure…I had to decide for this I needed more input. I palpated and tried to compare what I see in the US. It was "the" tumor, but the next issue was how do I get the needle in place? It was so difficult to put the needle into place, how to decide which trajectory is optimal? Meanwhile I turned back to see the US, the tumor was gone…….and I felt I saw another larger tumor? Or was it a cyst? …….we feel lost sometimes…"

As illustrated in the above case, during a minimally invasive procedure called radio frequency ablation, the liver tumour is ablated by placing a radio frequency needle through the skin. Performing the surgical task due to insufficient visualization of the patient anatomy, often leads to grey (uncertain) areas in the surgical decision-making which effect the surgical accuracy [2]. The surgeon has to analyze the

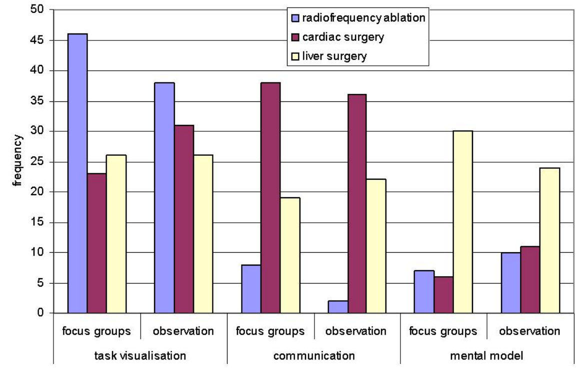

Figure 2 Frequency of the influencing factors in different surgical specializations in two studies.

patient state by identifying the tumour in the preoperative Magnetic Resonance Imaging (MRI) scan. The surgeon then conducts an intra-operative Ultrasound (US) to identify the tumour in the patient liver before placing the needle in the centre of the tumour. The decision-making here is a synchronous process involving small steps including real time imaging inputs from intra-operative US, haptic feedback from the patient's body and the comparison from the planned scenarios with preoperative MRI scan.

In the present analysis we are primarily concerned with identifying the difficulties in task based decision-making. For example consider the following three sentences illustrating three states:

Patient state: "Was this the same tumour I intended to ablate I wasn't sure…I had to decide for this I needed more input". "It was so difficult to put the needle into place.

Target state: but the next issue was how do I get the needle in place? ..how to decide which trajectory is optimal?"

Surprise state: "….and I felt I saw another larger tumour?"

The surgeons require adequate task visualization support in analyzing the patient state, reaching the target state and overcoming the surprise state. For each state, the surgical decision-making oscillates between the problem solving processes in the three surgical phases: preoperative, intra-operative, and postoperative. The problem of identification the correct tumour and placement of the needle in the centre of the tumour while navigating through several organs is interrelated. Here the surgical actions that result from one decision-making influence the problem that follows. Actions are not just results of a decision, but they also provide a diagnostic cue about the next surgical action. If the surgeon does not identify the correct tumour in the intra-operative ultrasound or the needle doesn't hit the tumour in the centre then the cancerous tumour is left unabated. This affects the overall treatment strategy of the patient. Depending on the real-time inputs from the patient body the surgeon may need to revise his/her understanding of the situation, their evidence collection and evaluation of his/her response strategy when new events are detected.

Guidelines and proposals:

In order to improve the overall efficiency of decision-making support, the interconnectivity of task visualization in the three task states should also be taken into consideration. The surgical systems recently being developed to support radio frequency ablation [25] are only focusing on providing visualization aid for one particular surgical task. The solution though effective for isolated tasks does not often complement the over all decision making flow for the complete surgical procedure.

2) Communication in endoscopic cardic surgery

"….I had difficulty to stabilize the balloon position after inflating it. I was so busy doing the tasks that at that moment I missed the pressure drop, my decision to proceed further in the tasks, relied on this very critical information to be given to me by the anaesthesiologist … thankfully the expert surgeon warned me…..I wish the system would communicate to me…"

The above case illustrates the difficulties in decision-making which arise due to a lack of timely communication during the endoscopic mitral valve repair. In order to repair or replace the mitral valve, an end aortic balloon filled with air has to be placed via a catheter inside the heart to block the blood flow. The positioning of the balloon in the right position is highly critical. If the balloon moves from the position, the back flow of the blood can lead to brain damage. Currently, the only way to know if the position of the balloon is stable and in the right position is by checking the pressures (right left radial, aortic root, cardioplegia). Any change in pressures should be immediately reported to the surgeon by the anesthesiologist. As observed, the surgeons, who were learning this new technique, were so involved in the surgical procedure that they missed the communication with the anesthesiologist. In this case the senior cardiac surgeon was acting as a mentor and managed the communication between the surgeons, the system and the team.

In the present study we are primarily concerned with analyzing the difficulties in task based decision-making. For example consider the following sentences:

Patient state: "….I had difficulty to stabilize the balloon position after inflating it".

Target state: "..my decision to proceed further in the task, relies on this very critical information to be given to me by the anaesthesiologist".

Surprise state: "..I was so busy doing the tasks that at that moment I missed the pressure drop.."

To proceed efficiently with the mitral valve repair, the main surgeon relies on timely communication between the surgical team and the systems. A lack of timely communication between the surgeon and systems and between the surgeon and the team is responsible for errors in decision-making and affects the accuracy of the surgical tasks [8]. While conducting minimally invasive mitral valve surgery; the main surgeon is the master commander not only of the surgical procedure but also of the communication between the team and systems at strategic moments.

Guideline and proposals:

Decision making in cardiac surgery is highly dependant on adequate system and team communication. We propose that an expert decision making system should assist the surgeon and the team in following the standard protocol by giving procedural reminders at strategic moments. At the same time, the system can assist in critical decision-making tasks by giving alerts and reminders of the rising and falling pressures. Currently, the machines in the operation theatre do not communicate with each other. We suggest that an expert system may also communicate at strategic moments with all other machines in the operating theatre.

3) Mental models in endoscopic liver surgery

"….Preoperative imaging showed that the patient had Haemangioma. And we planned to have a local resection there and since it was quite a superficial lesion. After analyzing the CT scan I visualized the 3D model of the liver in my head, and simulated the surgery of all the critical anatomical structures I would have to face during the surgery. But during the resection we identified two new tumours with the intra-operative ultrasound…I matched the position of the new tumour to the model I had visualized in my head."

In the case of endoscopic liver resection, the surgeons create a three dimensional model of the liver anatomy and tumour location based on the two dimensional information provided to them through Computerise Tomography (CT) scans or MRI scans. Liver is an opaque organ and due to absence in any real-time imaging modality to present the internal anatomy, the surgeons have to rely on generating an accurate mental model of the liver while conducting the surgery. The surgeons simulate the entire surgical procedure in their mind and are aware of the critical elements during the surgery. In the moment of uncertainty, for example while cutting the liver parenchyma the surgeons rely on the mental model of the liver in order not to damage critical vessels. For example consider the following sentence:

Patient state: "..Preoperative imaging showed that the patient had Haemangioma. After analyzing the CT scan I visualized the 3D model of the liver in my head, and simulated the surgery of all the critical anatomical structures I would have to face during the surgery…"

Target state: "..And we planned to have a local resection there and since it was quite a superficial lesion…."

Surprise state: "..During the resection we identified two new tumours with the intra-operative ultrasound… I matched the position of the new tumour to the model I had visualized in my head…"

With the invention of minimally invasive surgeries, the surgeons rely on the video image of the internal anatomy showing anatomical structures from unusual angles which never have been seen in the anatomy textbooks. Consequently, the surgical tasks require the surgeon to develop an accurate mental model to be able to plan, navigate and reason. Surgeons rely on developing mental models of the patient anatomy to support both spatial cognition and the problem solving process during the surgery [24]. The mental model includes elements of the planning phase but also real-time inputs while conducting the surgery. These models are used for decision-making in times of uncertainty and to visualize the future outcomes [8]

Guidelines and proposals

We emphasize the role of accurate surgical mental models in guiding the development of intra-operative imaging systems. We propose that the real-time visualization of the human organ via an imaging system, which is closer to the surgeon's mental model, is very critical for real-time tasks. Current efforts in three-dimensional visualizations are still focusing on providing photo realistic details of the organs. Our findings indicate that the surgeon's mental model of the organ is abstract, thus photorealism might obstruct the surgical decision-making and lead to information overload. The knowledge of the difference in composition of the mental models in the three surgical phases of the surgery can assist in generating dynamic and intuitive real-time visualization aids.

V. Conclusions

The development of intra-operative decision support systems for surgeons, which provide imaging and procedural support to guide minimally invasive surgeries, is a challenging task. The development of surgical expert systems is critically dependent on the knowledge of what factors influence decisions in conditions of high uncertainty, time pressure and zero tolerance for errors.

This paper investigated the critical factors influencing the intra-operative surgical decision-making and their importance in different surgical specializations. The empirical investigation included two studies for three different minimally invasive surgeries, which include endoscope liver surgery, cardiac surgery and radiofrequency coagulation.

Empirical investigations with surgeons in the surgical workspace revealed two main findings:

- First: three situation factors have been identified as critical towards effective surgical decision-making: tasks visualization, communication and accuracy of the mental model. These factors are important as they guide the surgeons' representation of the situation and hence provide real-time information to guide intra-operative decision-making.
- Second, findings reveal that the importance of these factors differ for different surgical specializations. Hence, the information needs supporting decision-making for different surgical specialization may require different system level developmental attention.

Naturalistic decision-making research in the field of intra-operative surgical workspace is still at a preliminary stage [13] and requires much more empirical investigations. We hope that this study contributes to the knowledge base towards developing efficient surgeon-centred intra-operative decision making systems. The findings provide a better understanding of the decision-making factors affecting the holistic surgical problem solving process. The technologists and designers involved in developing such systems may stand to benefit from these findings.

Acknowledgment

This research is a part of 6th Marie Curie Framework. We would like to thank the surgeons and surgical staff belonging to the hospitals in Slovenia, Norway and The Netherlands.

References

[1] Stone, R. and R. McCloy, Ergonomics in medicine and surgery. British Medical Journal, 2004. 328: p. 1115-1118.

[2] Jalote-Parmar, A., et al., Surgical Workflow Analysis: Identifying User Requirements for Surgical Information Systems, in Diversity in Ergonomics, R. Pikaar, K. Ernst, and K. Settels, Editors. 2007, Elsevier: Oxford. p. 229-241.

[3] Patel, V., L, J. Arocha, F, and D. Kaufman, R, A primer on aspects of cognition for medical informatics. Journal of American Medical Informatics Association, 2001. 8 p. 324-343.

[4] Kushniruk, A.W., Analysis of Complex Decision-Making Processes in Health Care: Cognitive Approaches to Health Informatics. Journal of Biomedical Informatics, 2001. 34: p. 365-376.

[5] Bogner, S.M., Human error in medicine, ed. S.M. Bogner. 1994, New Jersey: Lawrence Erlbaum Associates.

[6] Reason, J., Human error: models and management. British Medical Journal, 2000. 320: p. 768-770.

[7] van Paassen, R., Mulder, M.M. and van Dam, S.J., Cognitive work analysis for vehicle locomotion-aircraft short-term trajectory planning. 2004, Delft Universitity of Technology, Faculty of Aerospace Engineering.

[8] Endsley, M.R., The role of situation awareness in naturalistic decision making, In Naturalistic decision making, Zsambok, C.E. and G. Klein, Editors. 1997, LEA: Mahwah, NJ. p. 269-283

[9] Klein, G.A., A recognition primed decision (RPD) model of rapid decision making. In Klein, G. Orasanu, J. Calderwood, R. and Zsambok, C. (Eds.), Decision Making in Action: Models and Methods, 1993: Norwood, NJ: Ablex.

[10] Dörner, D., ed. The Logic of Failure: Why things go wrong and what we can do to make them right. 1996, Metropolitan Books (Henry Holt): New York.

[11] Simon, H., Science of the Artificial. 1969, Cambridge: MIT Press.

[12] Gaba, D., Dynamic decision making in anaesthesia: Cognitive models and training approaches. in Advanced models of cognition for medical training and practices. 1992. Berlin: Springer:Verlag.

[13] Flin, R. and G. Youngson, How do surgeons make intra-operative decisions? Quality and Safety in Health Care, 2007. 16: p. 235-239.

[14] Jalote-Parmar, A. and P. Badke-Schaub, Workflow Integration Matrix: A framework to support the development of surgical information systems. Design Studies, 2008, (in press).

[15] Badke-Schaub, P. and C. Buerschaper, Creativity and Complex Problem Solving in the Social Context, in Decision Making: Social and Creative Dimensions, C.M. Allwood and M. Selart, Editors. 2001, Kluwer: Dordrecht p. 177-196.

[16] Rasmussen, J., Information Processing and Human-Machine Interaction. North-Holland series in system science and engineering ed. P. Andrew. 1986, New York: Elsevier.

[17] Stewart, D.W. and P.N. Shamdasani, Focus groups: Theory and Practice. 1990, London: Sage
Publications.

[18] Kushiruk, A.W., V.L. Patel, and D.M.Fleiszer. Complex decision making in providing surgical intensive care. In Nineteenth Annual Symposium on Computer Application in Medical Care. 1995.

[19] Beyer, H. and K. Holtzblatt, Contextual Design. 1998: Morgan Kaufmann Publishers.

[20] Oeasanau, J. and E. Salas, Team decision making in complex environments, in Decision making in Action: Models and Methods, J. Oeasanau, Editor. 1993. p. 327-45.

[21] Jalote-Parmar, A., et al., Bridging the Gap: A User centered Design approach towards developing technological tolutions, in Minimally Invasive Therapies & Novel Embedded Technology Systems, ARISER summer school book, S. Casciaro and A. Distante, Editors. 2006, Lupiensis Biomedical Publications, National Research Council: Italy. p. 100-108.

[22] Wood, R.E., Task Complexity: Definition of the Construct. Organizational behavior and human decision processes, 1986. 37: p. 60-82.

[23] Woods D. Coping with Complexity: The psychology of human behaviour in complex systems. In: Goostein LP, Andersen HB, Olsen SE, editors. Tasks, Errors and Mental Models; 1988. p. 128-48.

[24] Edwards, J.C., M. Sardoski, and T. Burdenski, Reported used of mental imagery in the practice of physicians. imagination cognition and personality, 2005. 24(1): p. 41 - 49

[25] Villard, C., et al. RF-Sim: A Treatment Planning Tool for Radiofrequency Ablation of Hepatic Tumors. In Proceedings of the Seventh International Conference on Information Visualization (IV'03). 2003: IEEE Computer Society.