Improving Situation Awareness in Anaesthesiology

Constanze Pott
University of Groningen
Dept. of Computing Science
Blauwborgje 3
9747 AC Groningen
C.M.Pott@rug.nl

Addie Johnson
University of Groningen
Dept. of Experimental and Work Psychology
Grote Kruisstraat 2/1
9712 TS Groningen
A.Johnson@rug.nl

Fokie Cnossen
University of Groningen
Dept. of Artificial Intelligence
Grote Kruisstraat 2/1
9712 TS Groningen
F.Cnossen@ai.rug.nl

ABSTRACT
Anaesthesiology is practiced within a complex sociotechnical system that can reach an infinite number of states. Therefore, traditional methods of requirements engineering are not suited to model the tasks and support requirements of the anaesthetist. We introduce an approach for developing decision support systems in anaesthesiology based on a model of situation awareness and its determinants during surgery. This model is combined with a cognitive process model of anaesthetists’ decision making to identify situations where decision support is most useful. We demonstrate that these situations can be identified on the basis of measurable patient state variables and introduce a preliminary knowledge-based system for decision support.

Keywords
Decision Support System, Anaesthesiology, System Engineering, Situation Awareness, Cognitive Modelling

INTRODUCTION
Anaesthetists work within a complex sociotechnical system. The problem space is large and the number of relevant factors that anaesthetists (and system designers) need to take into account is enormous. The presence of highly coupled (i.e. interconnected and interacting) subsystems in the operating theatre (OT) makes it difficult to predict all effects of actions or events, or to trace all of the implications of a disturbance caused by a patient problem. Patient and/or medical equipment problems may occur frequently and can evolve rapidly, making the OT a dynamic task environment. Moreover, the patient alone is intrinsically complex. An effectively infinite number of patient states are possible, making it impossible to anticipate all possible patient states and situations. These factors provide a challenge to makers of decision support systems for anaesthesiology contexts.

Our goal has been to develop a decision support system (DSS) that improves the working conditions of anaesthetists as well as patient safety during anaesthesia. The aim of DSSs in general is to support humans in the performance of tasks that involve decision making and the choice of appropriate actions (Sage, 1991). Ideally, DSSs should enhance human abilities such as creativity and overcome human limitations such as low vigilance or limited cognitive capacities.

It is our objective to develop a DSS that enhances the situation awareness (SA) of anaesthetists and that is based on our conclusions about the cognitive processes of anaesthetists. The proverbial “hours of boredom, moments of terror” well characterises the work of an anaesthetist. Despite high percentages of (boring) routine activities, the “moments of terror” determine the success and safety of the anaesthetist’s work. Accordingly, in our approach to develop a DSS we focus on two especially critical states of the anaesthetist: low vigilance during routine situations and high workload situations during critical conditions of the patient. However, under any circumstances the SA of anaesthetists is crucial, i.e., their internal conceptualization of the current situation and where it is headed (Endsley, 1988). Maintaining SA is the precondition for making good decisions. It is therefore our goal to develop a DSS in anaesthesiology to improve the SA of anaesthetists to facilitate and improve their decision making.

REQUIREMENTS ENGINEERING FOR DECISION SUPPORT SYSTEMS IN ANAESTHESIOLOGY
In traditional requirements engineering approaches, developed and tested in the domain of process control, the goal is to develop a complete description of the future product, including the functionality and behaviour of the product (Robertson & Robertson, 1999). For every event that might occur, a strategy must be determined of how to react to this event. This normative approach of finding an optimal solution for a problem as defined by the system designers works efficiently in many contexts. However, the precondition for this normative approach is that the problem space is finite dimensional and determinable (Vicente, 1999). Given the dynamic, highly cross-coupled nature of the anaesthetist’s task, any DSS developed according to more traditional approaches will only be able to approximate optimal reactions to an infinite set of events. By modelling the user (the anaesthetists) instead of the problem space, the complexity of the context can be reduced to a manageable amount of relevant information. Even for unfamiliar events like a strangely behaving patient, human experts can generally formulate an adequate reaction strategy (Klein, 1993), if
they are supplied with appropriate information. By developing a model of the SA of the users and the determinants of their SA together with a model of decision making in anaesthesiology, we can identify appropriate information to improve SA and thus aid anaesthetists in applying practical strategies.

**Approach**

We used the results from naturalistic, observational research in the OT, expert interviews, and group discussions to develop a questionnaire to gain detailed information about the decision making processes of anaesthetists. The results of our survey were used to identify the determinants of SA of anaesthetists, information they use, and the problems they face. The questionnaire was distributed among anaesthetists by e-mail and we received 245 completed questionnaires from 29 different countries. Some results of the questionnaire will be used to support our findings. Based on the results of the survey, we developed a prototype of a DSS that will be introduced in this paper.

**State-of-the-art of Patient Monitoring**

Traditionally, approaches to patient monitoring during surgery have been concerned with the acquisition and presentation of primary physiological data obtained from a variety of sensors. More than 50 different variables indicating the state of the patient may be measured by monitoring devices. Patient variables are measured by a large number of poorly integrated measurement modules connected by a chaotic web of tubes and wires in the OT. Furthermore, several other important variables, such as skin colour or sweating, are observed directly by the anaesthetist. In addition to direct measurement, alarms may be set to indicate out-of-range values or dangerous situations.

**Development of Decision Support Systems for Anaesthetists**

It is a difficult task to design DSSs for complex sociotechnical contexts where highly trained experts are involved in decision making. It is the goal of this project to follow a “formative approach” (Vicente, 1999). In contrast to a “normative approach”, where a prescription of “how a system should behave” is generated, in a “formative approach” requirements are defined that must be satisfied so that the system behaves in a new, desired way. In our project this is done by generating tailored information supply that supports anaesthetists as flexible, adaptive problem solvers. Thus, presenting information that supports anaesthetists to deal with decisions that cannot be anticipated by system designers is a primary concern in our project.

Our research focuses on all tasks of the anaesthetist between the induction (intubation) and wake-up (extubation) of the patient in the OT. The tasks between induction and wake-up are called perioperative tasks. In analogy to aviation, perioperative tasks can be compared with the flight, excluding take-off (cf. intubation) and landing (cf. extubation). During perioperative tasks, the patient is unconscious, ventilated, and without conscious pain. Cognitive tasks of the anaesthetist are dominant in perioperative tasks, whereas during induction and wake-up the physical skills of the anaesthetist are central. Situations during induction and wake-up are mostly familiar and the work can be completed at a high pace, making the need for decision support to improve SA low.

Previous analyses of the work of the anaesthetist have classified anaesthesiologists’ tasks. For example, Weinger et al. (1997) distinguished between procedure, observation, adjustment and conversation, while Gaba and Lee (1990) distinguished between attending, conversing, performing manual tasks, monitoring, doing nothing, and recording. These classifications are, however, impractical for identifying the decision making situations that might require support generated by a computer system. These earlier classifications are based on observable physical tasks of the anaesthetists and do not distinguish between different cognitive tasks or different cognitive workloads. Our approach is based on the assumption that anaesthetists, as experts in general, are capable of handling most decision making situations in the OT. However, we assume that in situations with a very low vigilance and/or very high workload of the anaesthetist, DSSs could be helpful. In fact, anaesthetists who returned our questionnaire indicated that life threatening situations are not always recognized in time (mean $3.0 \pm 1.4$, where 1 was “never” and 7 was “always”). Furthermore, our respondents indicated that they sometimes miss important information if the actual workload is very high (mean $4.0 \pm 1.5$, where 1 was “very seldom” and 7 “very often”).

Respondents to our questionnaire indicated that the state of the patient contributes significantly to their workload (mean $6.0 \pm 1.2$, where 1 was “hardly ever” and 7 “very much”). Thus, rather than basing the evaluation of workload on observable activities of the anaesthetist, we base it on the state of the patient. This classification has two major advantages: (1) no observation and classification of the anaesthetists’ actions in the OT has to take place, and (2) the workload of the anaesthetist can largely be determined automatically by the patient data available from monitoring devices. We introduce a new classification of perioperative tasks depending on the state of the patient: maintenance tasks and repair tasks. In general, two different states of the patient can be distinguished: stable and unstable. If the state of the patient is stable, i.e. inside the range of normal patient’s body functions, the task of the anaesthetist can be described as a maintenance task. If the patient is unstable, so-called repair tasks will have to be carried out. We assume that anaesthetists’ workload during maintenance tasks is low to moderate, whereas during repair tasks the workload might be very high.

During periods with a stable patient (maintenance tasks), other tasks of the anaesthetist like planning or communication tasks that are not directly related to the patient under anaesthesia might take place.
Maintenance Tasks
To maintain the unconscious, painless, and paralysed state of the patient over time, the level of medication in the patient has to be adequate. As every human body reacts slightly differently to the medication, the required amount of medicine differs between patients. Therefore, the depth of the anaesthesia and the vital parameters of the patient have to be monitored accurately and the medication has to be adjusted accordingly. During maintenance tasks, most actions can be anticipated by the anaesthetist, e.g., pain medication is metabolized and has to be re-injected after a certain time. The workload during maintenance tasks is low to moderate as there are not many simultaneous tasks or overly demanding tasks. The most prominent problem for the anaesthetist is to stay vigilant in these routine situations. She or he has to observe the patient’s data carefully in order to detect any possible changes of the state of the patient. As in aviation, excessively low workload is expected to contribute to mishaps (Kantowitz & Casper, 1988) as vigilance might decrease and changes may not be detected in time. Stable situations of the patient may change unexpectedly and unpredictably into unstable situations in which observed or measured variables are outside their normal range.

Planning Tasks
Anaesthetists are usually responsible for the rescheduling of operations. During maintenance tasks, anaesthetists therefore often carry out planning tasks that are not related to the current patient or surgery. After every operation they may have to reschedule the available resources (e.g. OTs, surgeons, assistants), as the expected duration of surgery and anaesthesia can only be estimated. Furthermore, emergency cases cannot be planned ahead and have to be treated immediately, requiring an immediate allocation of available resources. These planning tasks require communication with other staff members as well as the analysis of written information and may lower the attention of the anaesthetist to his or her patient. However, in critical, unstable situations, planning tasks have no priority and can be postponed until the patient has returned to a stable state. Therefore, planning tasks are not likely to increase the workload of the anaesthetist in critical situations, but may influence the detection of unexpected changes in the state of the patient.

Repair Tasks
Repair tasks are triggered by unexpected changes in the state of the patient from a stable state to an unstable state. Repair tasks of the anaesthetist can be defined as the tasks that bring back the state of the patient from unstable to stable and include diagnosing and therapy. Extensive decision making may be required during these tasks. During maintenance tasks and planning tasks, no extensive decision making processes take place. For this reason, we decided to focus on the development of DSSs for anaesthetists during repair tasks. According to the diagnostic-therapeutic cycle (van Bemmel, 1997) human activities in health care can be divided in three consecutive stages: (1) observation, (2) diagnosis, and (3) therapy. The therapeutic state is therefore dependent on the outcome of the preceding state, the diagnosis. Consequently, we focus on decision support for diagnosing the patient problem. The results of our survey support our approach of developing decision support for diagnosing. According to the results of our questionnaire, anaesthetists would appreciate a monitor to display automatically generated diagnostic hypotheses (mean 4.4 ± 1.8, where 1 was “definitely not” and 7 was “definitely yes”) and would appreciate support in hypothesis testing (mean 4.9 ± 1.6, where 1 was “definitely not” and 7 was “definitely yes”).

Situation Awareness in Anaesthesiology
A precondition for making good decisions is to assess SA (Endsley, 1988). Following the proposition of Endsley (1995), we distinguish between the ‘state’ of SA and the ‘processes’ of situation assessment. In order to design a DSS to improve and facilitate the decision making processes of anaesthetists, we decided to develop a DSS to primarily improve the SA of anaesthetists. Therefore, we identified determinants of SA in anaesthesiology. SA in general is a framework describing the “big picture” of a situation. It consists of three different stages: perception, comprehension, and projection.

Perception of the Elements in the Environment
The perception of the status, attributes, and dynamics of relevant elements in the environment is the first stage in assessing SA. Apart from recognizing relevant elements, irrelevant elements have to be filtered out. During repair tasks, the state of the patient has to be observed and real-time patient data should be in the centre of interest. The data can be divided in observed data (e.g. skin colour, sweating) and measured data that is displayed by the monitoring system (e.g. heart rate, blood pressure). However, there are more than 50 different patient variables that might be measured. Sometimes physical actions are required to get information, e.g. listening to the lungs of the patient with a stethoscope. These actions raise the workload of the anaesthetist and lower his or her capacity to perceive other relevant data.

It may be difficult to notice the transition in the state of the patient from stable to unstable. During periods of low workload, the alertness of the anaesthetist might be low and small changes in the patient variable values might not be detected. Accordingly, questionnaire respondents indicated that automatic detection of slow changes in the patients’ physiological state (trend) is important (mean 5.6 ± 1.4, where 1 was “not important at all” and 7 was “very important”). If the patient has a life-threatening problem and this problem is not recognized in time, this delay of detection contributes significantly to the severity of the situation, according to the participants of our survey (mean 6.1 ± 1.1, where 1 was “not at all” and 7 was “very much”).
Comprehension of the Current Situation

At the second stage, comprehension of the current situation, the data from the first stage is put together to form a holistic picture of the environment, including a comprehension of the significance of this data. The directly available data is often insufficient for a complete understanding of the situation or for choosing effective actions. More information is actively searched to draw conclusions about the situation. This could either be by combining and analysing available data or by actively generating new data, e.g. by using or checking more measurement devices. In our questionnaire, our respondents indicated that comparisons with other variables are made to diagnose the patient problem when a variable has an undesired value (mean 5.8 ± 1.2, where 1 was “very seldom” and 7 was “very often”).

During repair tasks, the comprehension of the current situation includes the decision whether the perceived patient variable values are acceptable. If the variable values are acceptable for the particular patient, most times no further action is required. If the values are not acceptable, the future change of variable values must be projected to estimate the future state of the patient.

Projection of Future States

The highest stage of SA is the projection of future states of the elements, at least in the very near future. These predictions enable the complex process of decision making. In the projection of future states, the direction and nature of changes in variable values must be simulated to generate hypotheses about the future state of the patient and to decide about diagnosis and therapies and actions to be taken accordingly. Actions usually have consequences for the state of the patient, and a change in the state of the patient requires situation assessment of the anaesthetist on the perception level.

Determinants of Situation Awareness

The factors that influence the process of situation assessment are summarized in Figure 1. Note that although the different factors may also influence each other, only their influence on SA is described. Not all determinants equally influence all facets of SA. The implications for the design of our DSS are listed at the end of each subsection.

Figure 1: Situation awareness and its determinants

Patient Record

The patient record contains general information about the pre-operative state of the patient that could be of relevance for anaesthesia: e.g. information about allergies or other medical problems, lab results, pre-medication, and general physical condition. The patient’s state before the start of surgery influences perception, comprehension, and projection of the situation. Usually, the pre-operative state of the patient is checked by an anaesthetist or paramedic before surgery and stored in the patient record. Obviously, in case of unknown patients, e.g. from a traffic accident, no such information is available.

If the anaesthetist is aware of patient problems (or aware that no information about the patient is available), his or her alertness might be higher than with a regular patient as the anaesthetist might anticipate further problems. Thus, patient problems influence the perception of data, as more different variables will be checked more frequently. For comprehension the situation, the medical history and the state of the patient are important. For example, in the case of an athletic patient a very low heart rate may be accepted that for other patients will be treated immediately with medication. The pre-operative state of the patient also affects projection. If the patient, even before surgery, has been in a bad state of health, e.g. because of an underlying disease, the prognosis of his or her future medical state will be depending on this pre-operative information. An underlying disease, e.g. heart problems, will strongly influence the projection of the state of the patient.

Thus, we will integrate preoperative patient data in our DSS. Importantly, our respondents indicated that they would highly appreciate equipment presenting information based on the preoperative patient data (mean 6.1 ± 1.3, where 1 was “definitely not” and 7 was “definitely yes”).
Previous Actions
Actions of the anaesthetist and the surgeon influence the state of the patient. Medication usually has effects on the patient; a non-response, however, would be noteworthy. Accordingly, the anaesthetist has to consider previous actions from actors in the OT. For example, a surgeon cutting a patient causes (unconscious) pain in the patient and pain increases the blood pressure. The increase of blood pressure is perceived by the anaesthetist, but is an expected event. Only if the blood pressure does not rise, will the attention of the anaesthetist be required. Regarding comprehension, the knowledge about the previous action of the surgeon explains the phenomenon of the rising blood pressure completely. The projection therefore is that the blood pressure will return back to a normal value.

All actions relevant to determining the state of the patient must be traced by a DSS to support the assessment of SA. Tracing of most relevant actions already takes place during surgery. However, until now this information about actions of crew members in the OT is not integrated in any patient monitoring system. For example, the surgeon cutting the patient is the official start point of the operation and has to be recorded. Furthermore, all medication given to the patient is recorded. Therefore, no additional information input of the anaesthetists into the DSS is required to trace relevant actions of actors in the OT.

Knowledge Stored in Long-Term Memory
By knowledge stored in long-term memory, we understand all information that the anaesthetist has stored in his or her memory. The more experience anaesthetists have, the more information is stored in their memory. This influences the perception and sampling of data, as with growing experience algorithms may be developed for checking variable values. Some variables might be stored in the memory of anaesthetists as chunks of variables, bundled according to a subsystem within the patient (e.g. respiratory system, cardiovascular system, depth of anaesthesia) or according to a particular diagnosis (e.g. low anaesthesia level). Therefore, the perception of information might follow algorithms of only selecting data relevant for certain diagnoses. The comprehension of the relevant data is facilitated when the data can be compared with knowledge of familiar diagnoses. The more information anaesthetists have stored in their long-term memory, the more possible diagnoses they are familiar with, and the easier they can interpret the available data. Projection is also facilitated by having greater experience. Information of former patients is stored in anaesthetists’ long-term memory and can be compared with the patient to make assumptions about his or her future state.

The DSS we are developing includes a knowledgebase where all common complications during anaesthesia (Aitkenhead et al., 2001) are stored. Various reasonable diagnoses are listed on the display sorted according to their occurrence and probability. Anaesthetists can compare their own mental database with the stored information in order to verify potential hypotheses.

Personal Strategies
People may apply different strategies to solve the same problem, which may all have a positive outcome. Different persons may use different strategies, or one person may change the strategy used, e.g. because of an increasing workload. When a DSS only supports one best strategy, this system will not be accepted by expert users using other strategies. Strategies for perception could e.g. be a personal order in checking different variables displayed by the monitoring systems. According to the results of our questionnaire, 50% of our respondents indicated that they had a usual order for checking variables displayed on a monitor in a standard situation (i.e. stable patient). However, almost all anaesthetists indicated different orders of checking variables. One order of variables was listed four times, two other orders appeared three times and the rest were listed only once. Strategies for comprehension are e.g. the selection of other variables to verify or rule out diagnoses. Observing other variables usually helps to diagnose the problem of the patient. These include strategies like investigating the most probable diagnosis or the most dangerous diagnosis. Strategies for projection can be distinguished by a more optimistic approach or a more pessimistic approach. According to the results of our group discussions, more optimistic anaesthetists assume that everything will turn out fine whereas pessimistic anaesthetists constantly worry about what might also happen to the patient. This might influence their cognitive workload, as a continuous process of projection might lead to high cognitive workload.

Every strategy anaesthetists want to use should be supported by the DSS we develop. The DSS will offer additional information and will not replace the information the anaesthetists are normally using. The information we offer is on higher level of interpretation. In comparison to the monitoring devices which display e.g. the heart rate, our system lists the five most likely diagnoses (e.g. in case of an unusual value of the heart rate the diagnosis “heart failure” will be displayed if the blood pressure is also low). The SA of the anaesthetist will be improved as his or her attention will be directed to the displayed (raw) patient data that is relevant for the various probable diagnoses.

Working Memory Capacities
Available working memory capacities influence anaesthetists’ SA. Heavy workload e.g. might influence the availability of their working memory capacities. During heavy workload situations, e.g. if the workload is increased by additional tasks (e.g. planning tasks) or data, the anaesthetists’ perception of information might be impaired. No working memory capacity may be available for other tasks that need visual or acoustic perception, if the anaesthetist is completely occupied with his or her primary physical task (e.g. administering
a blood transfusion). Working memory capacities are also crucial for the comprehension of situations and for the projection of the future states of the patient, as a large amount of data has to be processed simultaneously.

As our DSS presents information in the form of reasonable diagnoses and their probabilities and improbabilities, we assume that the perception, comprehension and projection of the patient’s state will be facilitated even in periods with low working memory capacities.

**Developing a Decision Support System**

To determine situations where decision support is useful to improve SA, we modelled the decision making tasks of anaesthetists in a process model. This cognitive model integrates the main findings of Recognition-Primed Decision Making (RPD; Klein, 1993) and the framework of SA into one model. From RPD, the distinction between familiar situations and non-familiar situations is adopted. The model (see Figure 2) is written as a flow chart and should be read from top to bottom.

![Figure 2: An integrative process model of perioperative repair tasks of anaesthetist.](image)

It contains processes (squares) and decision points (diamonds) and arrows indicating a causal relationship.

**An Integrative Model of Perioperative Repair Tasks**

Repair tasks are triggered only by unexpected changes of the patient’s variable values, i.e., the patient’s state changes unexpectedly from stable to unstable. This is where the cognitive process model (see Figure 2) starts.

The first decision point of the cognitive process model is the detection by the anaesthetist of changes of the patient variable values. If the changes are not noticed, no therapy is given and the patient’s variable values may continue to deteriorate.

**Situation Assessment**

If the change is noticed by the anaesthetist, the next process of ‘situation assessment’ in the model of the variable values takes place. First, the change of variable values has to be validated. Some changes result from measurement faults and are not related to the state of the patient. If the values result from a change in the state of the patient, the anaesthetist compares the variable values with the general state of the patient. If the variable values are acceptable for the individual patient, the task of the anaesthetist returns to maintenance tasks. If values are not acceptable, the anaesthetist starts the process of ‘situation assessment’ by searching for further information to identify the state of patient and by this assesses SA.

**Familiarity**

Following ‘situation assessment’, the next point of decision of the anaesthetist is whether the state of the patient seems familiar to him or her. By comparing the real-time patient data with his or her own mental database she or he has to decide whether this specific configuration is familiar. Expert knowledge in long-term memory can be represented as a set of production rules which specify what action is to be performed if a specific situation arises (Patel & Groen, 1992). Thus, if a problem is familiar to the anaesthetist, a set of rules can be applied that leads to a solution from the facts observed. Using these methods, the anaesthetist will opt for the typical therapy for this specific diagnosis. After administrating this typical therapy, she or he will observe the changes in the variable values, to decide whether the trend of the values is as expected. If the trend is as expected, the task of the anaesthetist will return to maintenance tasks, possibly with higher alertness. If the trend is not as expected, the assumption of familiarity was probably incorrect, and the anaesthetist will return to ‘situation assessment’. The cognitive workload in familiar situations is quite low, as strategies or at least heuristics are available to solve the patients’ problems. Difficulties arise if familiar situations are not recognized as familiar situations or if unfamiliar situations are by mistake seen as familiar situations. Furthermore, a confirmation bias (Oswald, 2004) may occur in which decision makers are completely convinced of their hypotheses and refuse to evaluate alternatives, even when they are more likely.

**Urgency**

If the state of the patient is not familiar to the anaesthetist, she or he decides how urgent the problem of the patient is, e.g. how life threatening. In most repair states, multiple problem chains occur simultaneously, either by one initiating single event or by the coexistence of multiple medical problems in the patient (Gaba, 1992). These problem chains make the detection of the underlying problem difficult, because different interacting processes have to be sorted out. Time for finding a proper diagnosing lacks in urgent situations, as the state of the patient is critical. Therefore, in practice, anaesthetists in these situations usually simply treat the symptom, following the heuristic decision rule ‘treat first what kills first’. This was also shown in our survey: the respondents of our questionnaire indicated that if they did not have enough time for finding a diag-
nosis they adopted a strategy of symptom treatment (mean 5.9 ± 1.1, where 1 was “definitely not” and 7 was “definitely yes”). After this symptom treatment, as in familiar situations, the trend of the variables is observed and then the anaesthetist returns, following the outcomes of the therapy, either to the maintenance context or to ‘situation assessment’.

**Diagnosing**

If the situation is unfamiliar but not urgent (i.e. not acutely life-threatening), the anaesthetist is confronted with an unfamiliar state of the patient. At this point, cognitive resources of the anaesthetist are available to diagnose the state of the patient. This may lead to a high cognitive workload of the anaesthetist, as a high amount of information has to be processed simultaneously. An example could be a patient with a previously undiagnosed heart disease and who is actually a patient for a cardiologist. Nevertheless, symptoms such as an increase in heart frequency could also be attributed to a complication in anaesthesia.

When a diagnosis has been made, therapy can be given. After this ‘diagnosis-based therapy’, the patient’s variable values are observed. If the value (or trend) is acceptable, the anaesthetist goes back to the maintenance task. Otherwise she or he continues the ‘situation assessment’.

**Improving Situation Awareness**

According to our cognitive process model, we divide the repair tasks of anaesthetists in three different contexts: familiar, urgent and diagnosing, each of which has different requirements for decision support to improve SA.

Decision making in **familiar contexts** in general induces only low cognitive workload of the anaesthetist and anaesthetists as experts might perform well without any decision support. However, also in familiar situations errors in decision making can occur. In low vigilance and/or high workload situations (cf. section ‘working memory capacities’), the anaesthetist might not pay (enough) attention to the state of the patient. If the state of the patient changes from stable to unstable, the DSS should detect this change and inform the anaesthetist. Additionally, familiar situations might not be identified as familiar, e.g. because of deficient knowledge of the anaesthetist (cf. section ‘knowledge stored in long-term memory’). Also, unfamiliar situations of the patient might be interpreted as being familiar by the anaesthetist resulting in wrong therapy. Furthermore, erroneous beliefs like the ‘garden path fallacy’ (also called cognitive tunneling) should be prevented, in which decision makers focus on only one diagnosis and refuse to evaluate alternative diagnoses (Klein, 1993).

Based on a textbook (Aitkenhead, 2001), expert interviews, and previous work of le Feber and Ballast (le Feber & Ballast, 2004), we developed and implemented production rules for detection and presentation of familiar situations in anaesthesia. The prototype of our DSS generates a list of five relevant diagnoses based on the measured patient data and indicates probabilities for or against the displayed diagnoses, so that the anaesthetist can evaluate the suggested diagnoses of the patient without being overruled (cf. section ‘personal strategies’). Accordingly, for every familiar state of the patient, decision support can be generated by displaying a list of reasonable diagnoses. No further input of the anaesthetist is required. A first prototype of the knowledge system was tested against the judgement of a panel of 9 anaesthetists. In 91% of all test cases (11 cases) the knowledge system generated the same most probable diagnosis as the panel (le Feber, 2004).

To conclude, even in familiar situations, in which anaesthetists as expert decision makers should be capable of making good decisions, it may be possible with a DSS to improve the SA of anaesthetists, and, in turn, patient safety. As a change of the patient state from stable to unstable is displayed by the DSS, most likely the SA of the anaesthetist in low vigilance contexts will be improved and the change will be detected earlier. Furthermore, familiar states of the patient are identified by the DSS and displayed with their arguments for and against. So the chance of misinterpretation of patient data probably will be reduced.

In the **urgent contexts**, the situation of the patient is not familiar, and therefore no single therapy is available to solve all patient problems at once. To support SA in the urgent context, we will integrate already existing alarm systems in the DSS. As limits of patient variable values are stored in existing alarm systems, within which the state of the patient changes to unstable, they can also be used to detect urgent situations. Information about the patient state (cf. section ‘patient state’) and previous actions of the crew (cf. section ‘previous actions’) will be integrated in the DSS to improve SA in urgent contexts. This is done by transferring data generated by already existing monitoring systems to the knowledge system and categorising the data according to information about the patient state stored in the patient record (e.g., age, weight, or smoker). The raw data from the monitoring devices will be put in a category, e.g. the blood pressure of the patient will be sorted in one of the following categories: ‘low’, ‘low-normal’, ‘normal’, ‘high-normal’ or ‘high’. Adding to the functionality of state-of-the-art alarm systems, previous actions of the crew will also be integrated to reduce the amount of false alarms. Furthermore, data will be checked e.g. for plausibility with our DSS. Some patient variables are measured with different measurement devices at the same time (e.g., heart rate), so that in case of a loose sticker of a ECG, no urgency has to be indicated because of a heart failure, as the heart rate can be crosschecked, e.g., by the pulse oximeter (the measurement device indicating the heart rate and the oxygen saturation). Thus, the complexity of the anaesthesiology context can also be reduced in the urgency context and the use of such a DSS will be helpful as it will improve the SA of the anaesthetist.
The process of diagnosing unfamiliar situations can hardly be taken over by a computer system. In this context, the special human abilities of problem solving are required. In the diagnosing context, the development of DSSs following common approaches for requirements engineering reaches its limits, as the problem space in infinite. However, according to our opinion, our DSS based on a cognitive process model of decision making in anaesthesiology will improve the SA of anaesthetists by presenting information on a higher level of interpretation. The DSS generates, like in familiar situations, a list of reasonable diagnoses. Yet, the probabilities of those diagnoses are not as high as in familiar contexts and/or much controversial information is displayed. Furthermore, a history of the five most relevant diagnoses is displayed. In addition, the anaesthetist can select from the complete list of diagnoses a diagnosis and its history, accordingly. This will facilitate the decision making process as well as communication with other actors in the OT. For newly arrived experts, we expect it will be easier to get SA and the state of the patient is easier to diagnose, accordingly, if a history of reasonable diagnoses with their indicators and counter indicators is presented. Besides, all diagnoses are colour labelled as they are belonging to one of the tree different groups: the respiratory system, the cardiovascular system, and problems concerning anaesthesia. Therefore, even if the anaesthetist is not familiar with the patient problem, many probable diagnoses from one group (colour) indicate, in which particular subsystem of the patient the diagnosis could be found. The searching of the anaesthetist for more relevant information will be facilitated in the diagnosing context. By using the framework of SA and its determinants in anaesthesiology, we developed a prototype of a DSS tailored to information requirements of anaesthetists in the diagnosing context. Further research is necessary, especially testing our prototype in the field, to examine the benefits of using our DSS for the work of anaesthetists in repair situations.

DISCUSSION

In this paper, we demonstrated the benefits of applying the framework of SA in system engineering for a DSS in anaesthesiology. The decision support requirements of anaesthesiologists in repair situations could be identified using the cognitive process model of decision making together with the determinants of SA. The information presented by the prototype of our DSS is therefore tailored according to the information requirements of anaesthetists, and these are based on the state of the patient. No further input of the anaesthetist or of measurement devices is required. This tailored information supply our DSS offers will improve the situation awareness of the anaesthetist and, as a consequence, his or her decision making. However, our next challenge is to develop a scale to measure SA of anaesthetists during repair tasks and to test our prototype of a DSS in an anaesthesia simulator environment. Anaesthesia is an ideal example of a complex and dynamic environment that can reach an infinite number of states. The benefits of using the framework of SA can be used for other system design, where complex decision making under uncertainty takes place.

REFERENCES


Robertson, S., Robertson, J. (1999). Mastering the requirements process. Addison-Wesley, Amsterdam.
