MONASH University

# *Application of Cognitive Systems Engineering in anaesthesia: developing a decision support tool for airway management*

*Raphaela Schnittker*

*Psychology (BSc, MSc)*

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## Abstract

The goal of this research was to study decision-making processes of anaesthesia teams for the purpose of identifying a suitable decision support tool for airway management. Current decision support tools for airway management have until now been derived from guidelines and best practice protocols. The lack of a Human Factors Psychology approach resulted in inflexible design formats that do not accommodate the need for context-sensitivity and flexibility as required by the complex sociotechnical nature of anaesthesia. Consequently, the aim of this research was to fill this gap and examine how anaesthesia teams actually make decisions during airway management challenges. Based on this understanding, a decision support design tool was developed.

This research followed the phases described by Decision-Centred Design (DCD), a framework from Cognitive Systems Engineering: domain understanding, knowledge elicitation, analysis, design identification and evaluation. Participants were anaesthetists and anaesthetic nurses with varying experience. Observations were conducted as part of the domain familiarisation phase. Critical Decision Method (CDM) interviews and focus groups were conducted to elicit knowledge from subject-matter-experts. The CDM interviews and focus groups were conducted to identify key decisions und underlying cognitive pathways, decision requirements, enablers and barriers, and decision support design concepts. A follow up survey was conducted to prioritise design concepts. A scenario-based co-design process was then followed to identify design requirements for the chosen concept, resulting in a first digital prototype.

The CDM interviews identified many key decisions that were made by anaesthesia teams throughout the operative period. The majority of key decisions (90%) followed a prototypical pathway typified by a direct link between cue recognition and action generation. Only 7.5% of decisions involved option comparison. The key decisions ranged from preparation and planning (pre-operative) to change and adjustments of techniques in the face of difficulties (intra-operative) to abandoning surgery and post-operative care (post-operative). Many environmental cues were used to inform the key decisions, for example: the patient, technology, awareness of previous failure and team communication. Triangulation with focus groups and a decision selection process identified the most challenging and safety-critical decisions to focus on when designing support for in the remaining phases: preparation of airway equipment and transitioning between airway techniques in the face of failure and risk of hypoxia. Based on the triangulation, five potential decision support design concepts were identified. A design prioritisation survey identified the standardisation of airway equipment as the most desired and feasible decision support tool.

The final study was a scenario-based co-design process that elicited layout preferences and design requirements from subject-matter-experts. Based on that, a digital prototype of an airway equipment tray was developed. An evaluation framework was proposed to fulfil the final phase of the DCD framework.

This research filled a gap in theory and practice by applying DCD in anaesthesia for the purpose of identifying decision support. The findings demonstrated the relevance of undertaking a Naturalistic Decision Making approach when it comes to system design of complex sociotechnical environments such as anaesthesia. Limitations as well as future research following this PhD were discussed.

## Publications during enrolment

**Schnittker**, R. & Marshall, S. (2015). Safe anaesthetic care: Further improvements require a focus on resilience. *British Journal of Anaesthesia, 115*(5), 643-645

**Schnittker**, R., Marshall, S., Horberry, T., Young, K., Lintern, G. (2016). Examination of Anesthetic Practitioners' Decisions for the Design of a Cognitive Tool for Airway Management. In *Proceedings of the Human Factors and Ergonomics Society 60th Annual Meeting* (pp. 1763–67). Washington D.C.

**Schnittker**, R., Marshall, S., Horberry, T., Young, K., & Lintern, G. (2017). Exploring Decision Pathways in Challenging Airway Management Episodes. *Journal of Cognitive Engineering and Decision Making, 11*(4), 353–370.

**Schnittker**, R., Marshall, S., Horberry, T. & Young, K. (2018). Human factors enablers and barriers for successful airway management – an in-depth interview study. *Anaesthesia, 73*(8), 980-989.

**Schnittker**, R. & Marshall, S. (2018). Decision making in a 'cannot-intubate, cannot-oxygenate' scenario. A reply. *Anaesthesia, 73*(9), 1172-2273.

**Schnittker**, R., Marshall, S., Horberry, T. & Young, K. (2018). The co-design process of a decision support tool for airway management. In Bagnara S., Tartaglia R., Albolino S., Alexander T., Fujita Y. (eds), *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018, pp. 111-120). Advances in Intelligent Systems and Computing (vol 818).* Florence, Italy: Springer, Cham

**Schnittker**, R. & Lintern, G. A comparison of design solutions emerging from the recognition-primed decision model and the decision ladder. Currently 2nd round of review in *Journal of Cognitive Engineering and Decision Making*

**Schnittker**, R., Marshall, S., Horberry, T. & Young, K. (2019). Decision-centred design in healthcare: the process of identifying a decision support tool for airway management. *Applied Ergonomics, 77,* 70-82.

## Thesis including published works declaration

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes four original papers published in peer reviewed journals, one manuscript accepted for publication and one submitted manuscript. The core theme of the thesis is the application of methods from Cognitive Systems Engineering with the goal to design a decision support intervention for airway management in anaesthesia. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the student, working within the Monash University Accident Research Centre under the supervision of Dr. Stuart Marshall, Prof. Tim Horberry, and Dr. Kristie Young; as well as the mentoring of Dr. Gavan Lintern.

(The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.)

In the case of chapter 1, 3, 4, 5, 6 and 7 my contribution to the work involved the following:

| Thesis Chapter | Publication Title | Status *(published, in press, accepted or returned for revision)* | Nature and % of student contribution | Co-author name(s) Nature and % of Co-author's contribution* | Co-author(s), Monash student Y/N* |
|---|---|---|---|---|---|
| 1 | Safe anaesthetic care: Further improvements require a focus on resilience | Published | 90%, co-conceived idea of editorial, responsible for write up of first draft and consequent editing | Stuart Marshall, co-conceived idea of editorial, critical revision of draft, 10% | No |
| 2 | Examination of Anesthetic Practitioners ' Decisions for the Design of a Cognitive Tool for Airway Management | Published | 75%, co-conceived idea of the study, responsible for write up of the first draft and subsequent editing. | Stuart Marshall, co-conceived idea, critical revision of manuscript, 10%; Tim Horberry, co-conceived idea of study, critical revision of manuscript, 5%, Kristie Young, co-conceived idea of study, critical revision of manuscript, 5%; Gavan Lintern, critical revision of manuscript, 5%. | No |
| 3 | Exploring Decision Pathways in Challenging Airway Management Episodes. | Published | 75%, co-conceived idea for study, data collection, analysed the data, write up of 1st draft of paper and | Stuart Marshall, co-conceived idea of study, guidance and critical revision of data analysis and manuscript write up, 10%; Tim Horberry, guidance and critical revision of data analysis and manuscript write up, 5% | No |

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|---|---|---|---|---|---|
| | | | subsequent editing | Kristie Young, guidance and critical revision of data analysis and manuscript write up, 5%; Gavan Lintern, critical review of manuscript 5% | |
| 4 | Human factors enablers and barriers for successful airway management – an in-depth interview study | Published | 80%, conceived idea for study, data collection, data analysis, write up of 1st draft of paper and subsequent editing | Stuart Marshall, critical revision and guidance of data analysis and manuscript write up, 10%, Tim Horberry, critical review of data analysis and manuscript write up, 5%, Kristie Young, critical review of data analysis and manuscript write up, 5% | No |
| 5 | Decision-centred design in healthcare: the process of identifying a decision support tool for airway management. | Published | 85%, co-conceived idea for study, data collection, data analysis, write up of 1st draft of paper | Stuart Marshall, co-conceived idea of study, critical review of data analysis and revision of manuscript 5%, Tim Horberry, co-conceived idea of study, critical review of data analysis and manuscript write up, 5%, Kristie Young, co-conceived idea of study, critical review of data analysis and manuscript write up, 5% | No |
| 6 | A comparison of design solutions emerging from the recognition-primed decision model and the decision ladder. | Under review (2nd round, completed minor revisions) | 65%, co-conceived idea for study, data collection, joint data analysis with 2nd author, write up of 1st draft of paper and subsequent editing. | Gavan Lintern, co-conceived idea for study, data analysis, critical review of initial draft and subsequent paper drafting and editing, 35% | No |

I have not renumbered sections, tables and figures of submitted or published papers in order to generate a consistent presentation within the thesis.

**Student signature:** **Date:** **6 June 2019**

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author I have consulted with the responsible author to agree on the respective contributions of the authors.

**Main Supervisor signature:** **Date:** **6 June 2019**

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The past (almost) four years of doing this PhD have changed my life. I embarked on a professional and personal journey that was seemingly unforeseeable, full of opportunities, exciting and daunting at the same time. I have further developed my research skills, received the opportunity to present at conferences and got to know some wonderful people. As part of this PhD I also moved to the other side of the world and could call Melbourne my home again, my favourite place since my exchange semester in 2011.

I would not be where I am at right now without a few people that supported me throughout the journey. For this, I want to express my immense gratitude.

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Raphaela, June, 2019.

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## Acronyms

| | |
|---|---|
| ANZCA | Australian and New Zealand College of Anaesthetists |
| BDM | Behavioural Decision Making |
| CDM | Critical Decision Method |
| CICO | Can't Intubate, Can't Oxygenate |
| CRM | Crises Resource Management |
| CSE | Cognitive Systems Engineering |
| CTA | Cognitive Task Analysis |
| DCD | Decision-Centred Design |
| DRT | Decision requirements table |
| DL | Decision ladder |
| DLT | Decision ladder table |
| EMAC | Effective Management of Anaesthetic Crises |
| FACES | Feasibility, Acceptance, Cost, Effectiveness and Sustainability |
| NDM | Naturalistic Decision Making |
| RPD | Recognition-primed decision (model) |
| SUS | System Usability Scale |

# 1 Chapter 1 – Introduction

***Paper 1***: Schnittker, R. & Marshall, S.D. (2015). Safe anaesthetic care: Further improvements require a focus on resilience. *British Journal of Anaesthesia, 115*(5), 643-645

## 1.1 General background of PhD research

Anaesthesia involves the administration of anaesthetic drugs in order to achieve a loss of sensation and consciousness. The central purpose of anaesthesia is to relieve pain for patients undergoing surgical procedures and support compromised physiological functions. During anaesthesia a loss of consciousness and paralysis of skeletal muscles usually leads to a loss of the patient's airway reflexes and their ability to breathe autonomously. Anaesthesia is an inherently complex and sociotechnical activity. 'Naturalistic environments' such as anaesthesia are typified by ill-structured problems, uncertainty, ill-defined or competing goals, action/feedback loops, time stress, high stakes, multiple players and organisational norms (Klein, Orasanu, Calderwood, 1993; Phipps & Parker, 2014).

Similar to other complex sociotechnical systems, the naturalistic nature of the anaesthetic environment affects the way clinicians make decisions (Lipshitz, Klein, Orasanu, & Salas, 2001). Contrary to the theory of classical decision making, decision-making in naturalistic environments ('Naturalistic Decision-Making') rarely involves a thorough evaluation of available options based on their relative merit. Instead, decisions are based on expertise by recognising typicality of situations, which in turn informs the selection of actions (Kaempf, Klein, Thordsen, & Wolf, 1996; Klein, 2008).

Consequently, decision support design for naturalistic environments based on classical models of decision-making typically do not accommodate how decisions are actually made in these environments. Unfortunately, healthcare design is still largely informed by this rational model that 'substitutes designer judgement for clinician judgement' (Lintern & Motavalli, 2018). The consequences are clumsy technology, ineffective work processes and clinical errors affecting patient safety (e.g. Clay-Williams & Colligan, 2015; Cook & Woods, 1996; Schein, Hicks, Nelson, Sikirica, & Doyle, 2009).

The aim of this thesis was to study the decision-making processes of anaesthesia teams in challenging airway management situations. Based on the findings, a decision support tool was proposed and designed in collaboration with anaesthetists and anaesthetic nurses. In order to consider the naturalistic nature of the anaesthetic environment, frameworks and methods from Cognitive Systems Engineering were employed (Militello, Dominguez, Lintern & Klein, 2009).

## 1.2 Anaesthesia and airway management

The support of a patient's breathing functions ('airway management') is one of the most critical activities in anaesthesia. Airway management can be performed using a variety of techniques and tools in order to accomplish artificial oxygenation and ventilation (Rall & Dieckmann, 2005). These can range from simple face masks to endotracheal tubes and surgical airways (Timmermann, 2011). Airway management is a process performed throughout the operative period and involves a variety of interrelated activities, all of them presenting their own challenges within the naturalistic setting. For example, the selection of an adequate airway technique; checking and preparation of airway equipment; insertion of the airway technique and adequately securing the airway; changing to a different airway technique if the current technique does not work, extubation and post-operative care (Phipps, Meakin, Beatty, Nsoedo, & Parker, 2008). Airway management is crucial for safe anaesthesia, since a prolonged absence of adequate oxygen levels will result in hypoxia, brain damage and eventually death (Cook & Macdougall-Davis, 2012).

## 1.3 Safety statistics in anaesthesia and airway management

Anaesthesia has been referred to as a 'model for patient safety in healthcare' (Gaba, 1999). It is approaching risk levels of ultra-safe environments: an 'average rate per exposure of catastrophes and associated deaths' of 10- 6 or less (Amalberti, Auroy, Berwick, & Barach, 2005). This has been exemplified by low incident and mortality rates. Between 2012 and 2014, 11.4 million anaesthetic care events took place in Australia with only 200 deaths solely or substantially related to anaesthetic factors over the same period (Australian and New Zealand College of Anaesthetists (ANZCA, 2017). Fatalities occurred at a rate of 1:57,023, a rate that has remained stable for nearly two decades. Despite this overall low mortality rate, problems with airway management are prominent when it comes to deaths and serious injuries. Eight of the 23 deaths directly attributed to anaesthesia resulted from problems with airway management (ANZCA, 2014). A nationwide anaesthesia claims analysis from 1995 to 2007 in England revealed that 102 (12%) of anaesthesia-related claims were related to the airway. Two third of these claims involved hypoxia and brain damage. Airway related problems contributed to 21 (53%) fatal events (Cook, Scott, & Mihai, 2010).

Another nationwide study in the United Kingdom, the Fourth National Audit Project (NAP4), investigated major airway complications critically affecting patient safety (death, brain damage, infraglottic rescue, unexpected prolonged stay at ICU) over a one-year period in 2008 (Cook et al, 2011). The report found an incident rate of one major complication per 22,000 general anaesthetics (0.005 %, 133 events). Thirty three of these cases involved brain damage and death (14.3%). While the primary cause of death was the aspiration of gastric contents, representing 50% of fatal events, the majority of airway complications were associated with tracheal intubations and extubations, including tracheostomies. Twenty-five percent of major complications were related to ‘can’t intubate, can’t oxygenate’ (CICO) events: situations where intubation and non-invasive rescue techniques fail and invasive approaches to the trachea are required.

The statistics illustrate that anaesthesia complications are ‘low frequency, high risk’ events. This combination is challenging for patient safety, since as critical situations occur rarely, there are few opportunities to learn from. Conversely, if they do occur, they need to be successfully managed under high stakes and time pressure.

### 1.3.1 Challenges in airway management

It is accepted that airway management is associated with a variety of cognitive and technical challenges (Flin, Fioratou, Frerk, Trotter & Cook, 2013). During these difficult airway management events, it is essential to change techniques to prevent a prolonged delay of oxygen to the patient. (Cook, Woodall, & Frerk, 2011; Paix, Williamson, & Runciman, 2005). Usually, difficult airway management events can be handled successfully by transitioning to a different airway strategy, without delaying oxygen delivery to the patient.

Nevertheless, CICO is a feared crisis in airway management (ANZCA, 2016). The last resort in this situation is the transition to a surgical airway (Watterson, Rehak, Heard & Marshall, 2014). While clear guidelines exist to cope with this situation, the time-pressured decision to move to a surgical airway can be extremely difficult (Marshall & Mehra, 2014). Cognitively - since it requires planning, situational awareness and functional team work, and technically - since it requires the technical skills to perform the procedure. Fatalities have occurred because a surgical airway was not initiated in a timely manner by experienced anaesthesia teams (Bromiley, 2009).

## 1.4 Aim of research

The overall aim of this research is to develop a decision support design tool for challenging airway management. A human-centred design approach was adopted that involved clinicians in every phase of the process. Thereby, this research aimed to close the gap between ‘work-as-done’ and ‘work-as-imagined’ (Blandford, Furniss, & Vincent, 2014) as much as possible. In order to accomplish this, frameworks and methods from Cognitive Systems Engineering (CSE) (Militello et al, 2009) were employed. Specifically, this research followed the process specified by decision-centred design (DCD) (Crandall, Klein, & Hoffman, 2006; Klein, Kaempf, Wolf, Thorsden, & Miller, 1997). As discussed in the editorial that forms the first paper of this thesis, a focus on positive performance rather than human error is required to further advance anaesthetic safety as these events now occur rarely (Schnittker & Marshall, 2015). This research examined how anaesthesia teams successfully adapted to challenges the majority of the time, instead of why failures occur occasionally.

## 1.5 PhD research program and thesis structure

The structure of the research program and this thesis is illustrated in Figure 1. Since this PhD applied DCD, the generic structure of this thesis is embedded in the stages described by Crandall et al (2006). This thesis contains nine chapters that will answer three overarching research questions (discussed in more detail in chapter 2):

1) What are the key decisions and their requirements for anaesthetists and anaesthetic nurses in challenging airway management incidents?
2) What type of decision support tool is best suited to support the most challenging key decisions and their requirements?
3) How does the decision support intervention need to be designed to support the most critical key decisions?

Most of the chapters clearly align with one of the distinct decision-centred design phases. However, as will be noticeable in the following chapter overview, a number of chapters cover content that overlaps with several phases or slightly depart from the phase's original intent. Figure 1.1 presents the overall PhD program based on the decision-centred design framework. Figure 1.1 is followed by a content summary of the nine chapters that form part of this thesis.

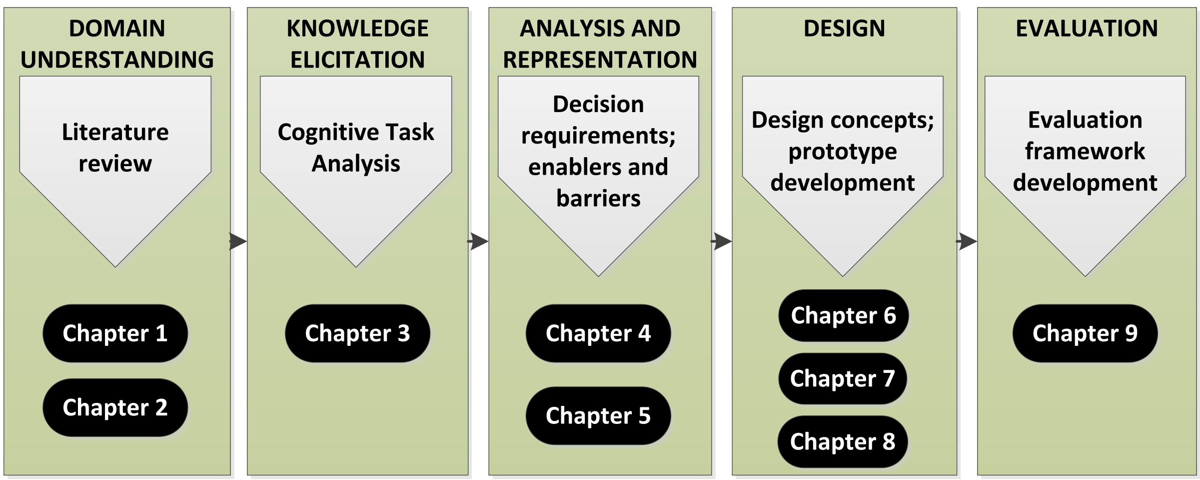


*Figure 1.1.* Overview of the present PhD research program as embedded in the decision-centred design process.

***Chapter 1 – Introduction (present chapter)***

This present chapter introduces the aims and main concepts of this thesis including a description of the background of anaesthesia and airway management, statistics on safety, and the challenges associated with airway management. It concludes with the overall aims and the research framework of this PhD.

- ***Chapter 2 – Literature review: Human Factors research in anaesthesia***

  This chapter provides a literature review on the theoretical framework and main concepts as introduced in chapter 1. The chapter includes a review of Human Factors Engineering and complex sociotechnical systems and its current applications in anaesthesia and reviews current decision support design in anaesthesia. The chapter concludes with the identification of gaps in knowledge and the specific research questions guiding this thesis.

- ***Chapter 3 - Cognitive Task Analysis methods for knowledge elicitation***

  This chapter discusses the Cognitive Task Analysis methods that form the knowledge elicitation framework of this thesis. The chapter discusses the rationale for the chosen methods and places them into context with the remaining research framework. It concludes with a preliminary data analysis approach.

- ***Chapter 4 - Decision pathways in challenging airway management episodes***

  This chapter discusses the first set of outcomes from the Critical Decision Method interviews: the cognitive pathways underlying the key decisions of anaesthetists and anaesthetic nurses. The application of the recognition-primed decision model is discussed in detail, and initial decision support design ideas are described. The chapter concludes with discussing the implications of the findings for the design of decision support.

- ***Chapter 5- Human Factors enablers and barriers to successful airway management***

  This chapter discusses a second set of outcomes from the Critical Decision Method interviews: the human factors enablers and barriers to successful airway management. The chapter describes the enablers and barriers experienced by anaesthetists and anaesthetic nurses. It concludes with providing specific recommendations for the decision support design for airway management.

- ***Chapter 6 – Decision-centred design: data triangulation, key decision selection and design prioritization***

  This chapter discusses the DCD process from knowledge elicitation to the selection of a decision support intervention, connecting the analyses from the previous chapters with the redesign activities of the remaining chapters. It describes the process of data triangulation, refinement of focus and key decision selection, as well as the prioritisation of design concepts. It concludes with the decision support design concept selected to be designed as part of this research.

- ***Chapter 7 - A comparison of the Recognition-primed Decision-Making model and the Decision Ladder to identify decision support for airway management***

  This chapter steps beyond the DCD activities and places it into context with another framework from CSE. It discusses the outcomes of a comparative analysis of the Recognition-Primed Decision model and the decision ladder model from Cognitive Work Analysis. Specifically, it compares the similarities and differences of the decision support design interventions identified with both methods. The chapter concludes with a discussion of the two models and practical implications for the choice of theoretical frameworks.

- ***Chapter 8 - The decision-support co-design process of an airway equipment tray****

  This chapter describes the scenario-based co-design process of the airway equipment tray, the chosen decision support intervention. It describes the process from identifying the specific design requirements to the design of an initial version of the tray. Therefore, this chapter is applied and creative. It concludes with a digital design of the initial prototype.

- ***Chapter 9 – Discussions and conclusions***

  This final chapter discusses the findings as well as the theoretical and practical contributions of this thesis. It also addresses the limitations and opportunities for future research arising from this thesis.

Supplementary materials, exhaustive tables and analyses outcomes are provided in the Appendices, as referred to in the chapters.

* Please note that, throughout this thesis, the term '*airway equipment surface*' and '*airway equipment tray*' are used interchangeably.

# 2 Chapter 2 – Literature review: Decision-making and decision support design in anaesthesia

## 2.1 Chapter outline

This chapter reviews the relevant theory of this research program, as well as its current application in anaesthesia. This chapter is part of the first phase of the DCD process (see Figure 2.2). Firstly, the literature on the study of decision-making and safety in complex sociotechnical environments is reviewed and frameworks suitable for this research program outlined. This is followed by a literature review on human factors research, specifically the study of decision-making, in anaesthesia. Currently used decision-support interventions in anaesthesia (specifically airway management) are reviewed. Based on the literature reviews, current gaps in decision-making research and decision support design in anaesthesia are identified. The chapter concludes with the aims and research questions of this PhD research program.

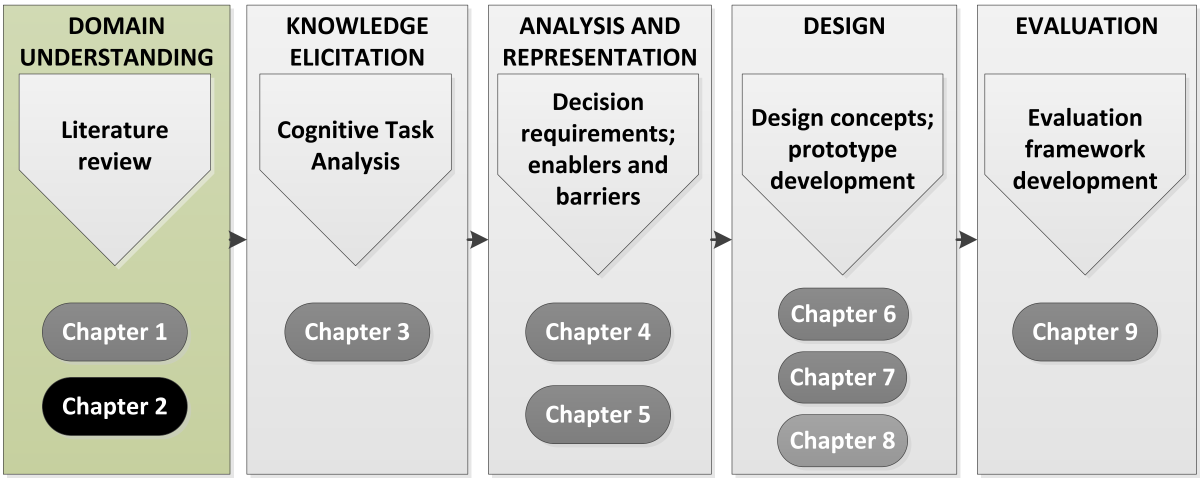


*Figure 2.2.* The decision-centred design process - chapter 2

## 2.2 Human Factors in complex sociotechnical systems

Human Factors refers to the study of interrelations between humans and other elements of a system that affect human performance in complex sociotechnical systems. The system refers to the different cognitive, physical and organizational artefacts that humans have to interact with (Carayon, 2007). The profession of Human Factors applies theory and methods to the design of systems with the aim to optimize human well-being and system performance (International Ergonomics Association, 2018). Human Factors Engineering is broad and classified by the IEA into Physical Ergonomics, Cognitive Ergonomics and Organisational Ergonomics. Each of these areas focus on different aspects of the system (IEA, 2018). Specifically Cognitive Ergonomics is characterised by a few sub-specialities that have emerged throughout the decades, for example Naturalistic Decision-Making. (Klein, 2008), CSE (Hollnagel & Woods, 2006) and Resilience Engineering (Hollnagel, Pariès, Woods, & Wreathall, 2004).

The study of system safety is central to Human Factors Engineering and has changed throughout the last decades from a ‘person approach’ to a ‘system approach’ (Reason, 2000). This change has been significant for healthcare, since it progressed safety improvements from solely preventing human error to more systemic views (Bogner, 2007; Carayon & Wood, 2010). The goal of this section is to provide a brief overview of how the safety of complex sociotechnical environments has been studied in the past. This is done to introduce and place the main theoretical frameworks and decision-making models used in this PhD program in context. Given the goal of this research program, specific emphasis is placed on the study of decision-making in complex sociotechnical environments as well as CSE.

### 2.2.1 Safety in complex sociotechnical systems

A variety of system models have emerged throughout the years with the aim to conceptualise safety and failure in complex sociotechnical systems (Toft, Dell, Klockner & Hutton, 2012). The majority of safety models adopt a ‘safety 1’ perspective, which views safety as the absence of failures, or a state with a minimum of negative events (Erik Hollnagel, 2013). The aim of this safety 1 perspective is pre-occupied with studying why events went wrong, identifying causes and prevent these from re-occurring. Early on, these models were simple and linear, conceptualising accidents as a chain reaction of unfolding events. Two examples are the Domino model (Heinrich, 1931, 1950) and the Loss Causation Model (Bird & Germaine, 1985). Both models encouraged root-cause analysis, with the solution to remove or modify the part of the system that caused an error. This approach was simplistic, although it is still common practice in healthcare (e.g. Lammers, Byrwa, & Fales, 2012; Nicolini, Waring, & Mengis, 2011).

In order to account for the complexity of sociotechnical systems, more complex and systemic approaches started to emerge. Instead of proposing that accidents occur due to a single cause, these models emphasize the role of latent failures in a system. Turner's 'man-made disaster' theory (1978) was one of the earliest foundational theories acknowledging systems did not fail due to a single 'unsafe act'. Instead, failures occur due to an accumulation of organizational decisions that have been made over a long period of time, the 'incubation period'. The Swiss Cheese Model (Reason, 1990) built on the man-made disaster theory and has been the most dominant model to explain system failures in complex systems to date. According to the Swiss Cheese Model, system failures occur due to a combination of latent conditions and active failures 'at the frontline' (Reason, 1990). Latent conditions are those further removed from the active failure at the front line, such as organisational policies, management, supervision and technology design (Woods, Dekker, Cook, Johannesen & Sarter, 2010). The different layers of a system (i.e. organisational, technology, team, human) are the 'layers of defence'. Only if deficiencies in each layer line up, an active failure can occur at the front.

In healthcare, a systems approach to safety has become more prominent since the Institute of Medicine published findings on preventable medical errors in their report 'To Err Is Human' (Kohn, Corrigan & Donaldson, 2000). They found that between 44,000 and 98,000 patients die each year due to preventable medical errors. The findings demonstrated that in order to improve patient safety, a system approach is necessary (Kohn, Corrigan & Donaldson, 2001). Since then, more system models specifically tailored to healthcare were developed in order to accommodate the complexity of healthcare. One of them is the Artichoke Model (Bogner, 2007), which conceptualises the interaction between clinicians and patients as the centre of the system. This interaction is affected by surrounding system elements, such as organisational management, technology, and even the government.

The growing complexity of sociotechnical systems progressed to an understanding that systems are not only complex, but also non-linear (Toft et al., 2012). Because elements of complex systems are tightly interrelated and coupled, this can lead to unforeseen and emerging interactions between system elements. Consequently, according to the Normal Accident Theory, Perrow (1984) argued that accidents are a normal side effect of complex sociotechnical systems. The paradigm of CSE (Hollnagel & Woods, 1999, 2006) and later Resilience Engineering (Hollnagel et al., 2004) embraced this observation by acknowledging that complex systems are not decomposable and more than the sum of its parts (Hollnagel, & Woods, 1999). Specifically Resilience Engineering adopted a 'Safety-II' perspective (Hollnagel, 2013). Safety-II is complementary to Safety-I and studies how systems succeed under varying conditions (Hollnagel, 2013). Rather than studying the presumed causes of failures, Safety-II studies how systems (including people) adjust to varying conditions emerging from complex systems, and how performance is necessarily variable (Braithwaite, Wears, & Hollnagel, 2015; Hollnagel, 2002).

In conclusion, in line with the growing complexity of sociotechnical systems, safety models have progressively become more complex. Accordingly, the study of decision-making has also evolved from solely focusing on human error to more systematic approaches and a focus on adaptation and successful performance.

### 2.2.2 The myth of human error

Human error is a ubiquitous concept when it comes to the study of human decision-making and safety science in general. In the search for causes of failures, the concept of human error is prominent in accident investigation and incident reporting. Early on, and still at present, human error was seen as a homogenous cause for failures. Failures involving humans that were studied in hindsight were often grouped under the label human error (Cook & Woods, 1994; Reason, 1995). Due to advances in the study of complex sociotechnical systems, human error is nowadays rather seen as a consequence of poorly designed systems, rather than as a (single) cause of accidents. Increasingly more research showed that failures are not solely due to a single cause but are a combination of latent failures in the system that affect how work is performed at the frontline (e.g. Rasmussen, 1983, 1986; Reason, 1990, 1995; Woods and Cook, 1999).

The man-made disaster theory (Turner, 1978) already proposed that human error is a symptom of organizational deficiencies, accumulated over time. Building on the man-made disaster theory, Reason (1990) distinguished the ‘sharp end’ and the ‘blunt end’. The sharp end is where active failures are made by the people ‘at the frontline’. However, active failures at the sharp end are affected by the blunt end of the system: constraints and resources provided by the organization. The blunt end carries ‘hidden pathogens’ (i.e. deficiencies) that affect cognition at the sharp end (Cook & Woods, 1994). Consequently, human error is shaped by, and a symptom of, system deficiencies. Rasmussen (1983) studied human error in the context of complex systems and machine interface design, shifting from the focus on human error to designing work interfaces to accommodate human performance. The Skills/Rules/Knowledge framework (Rasmussen, 1983) has been prominent to distinguish levels of human performance and human error, each level requiring different types of system support. Similarly, Reason (1995) distinguishes between different types of errors such as slips, lapses and mistakes; each occurring due to different underlying cognitive processes. According to Reason (1995, p. 88), the organization “create the conditions in the workplace that […] promote individual errors […]".

The previous work on human error and the complexity of accident causation shifted the focus from studying human error in the context of what went wrong and why, to more general studies on how people make decisions in complex sociotechnical environments and how this knowledge can be used to design complex systems more effectively (Toft et al., 2012). This is the foundation of CSE.

### 2.2.3 Cognitive Systems Engineering

CSE emerged as a discipline with the goal to study and design complex sociotechnical systems 'in terms of a cognitive system' (Hollnagel & Woods, 1999). More recently, CSE has been defined as 'an approach to the design of technology, training, and processes intended to manage cognitive complexity in sociotechnical systems' (Militello et al, 2009). CSE emerged because of the realization that decision-making in complex sociotechnical systems is not rational, and people are not 'simply deterministic input-output devices' (Rasmussen, 1986).

It has long been known that in situations of time pressure and uncertainty, human cognition is 'locally bounded' (Woods & Cook, 1999). The concept of 'local rationality' refers to how humans use their knowledge to achieve their goals (Simons, 1957; Newell, 1982). However, this knowledge is naturally limited, or bounded, by (1) the information available at that time, (2) the amount of information humans can extract within their cognitive limitations, and (3) the knowledge that can be activated at a particular instance in time bounded by multiple, conflicting goals (Woods & Cook, 1999). Information in complex environments is not readily available, but may unfold over the course of time, is cluttered and evolves from different resources (Woods & Cook, 1999). Hence, from the local perspective of the human practitioner their behaviour seems rational ('local rationality') and although it usually results in successful outcomes it may occasionally result in error.

Consequently, this required a change in approach to the study and design of complex sociotechnical systems. In order to cope with the demands of a complex system, people necessarily use heuristics (Rasmussen, 1986). Heuristics are 'mental shortcuts' or 'rules of thumbs' that have been acquired through experience (Nemeth & Klein, 2010; Woods & Cook, 1999). Woods and Hollnagel (1999) exemplified that in order to understand and design for complex system, heuristic rather than rational decision-making should be the focus of examination.

The goal of CSE is to support cognitive activities by reducing the complexity induced by the nature of the work environment for the people accomplishing work (Militello et al, 2009). Methods from CSE have been applied in a variety of complex environments, for example firefighting (Klein, Calderwood & Clinton-Cirocco, 2010), the navy (Kaempf et al., 1996), nuclear power plants (Klinger & Klein, 1999), healthcare (e.g. Cook, Woods & McDonald, 1991; Militello et al., 2016; Nemeth, Nunnally, O'Connor, Klock, & Cook, 2005) and more.

CSE comprises a variety of different frameworks to study cognitive work, such as Cognitive Work Analysis (CWA) or DCD (see Figure 2.3). These frameworks have different origins and approaches. CWA looks at how a cognitive system could work by abstracting and modelling systems functions on different levels (Lintern, 2009). DCD examines cognitive work from a Naturalistic Decision Making (Nemeth & Klein, 2010) perspective.

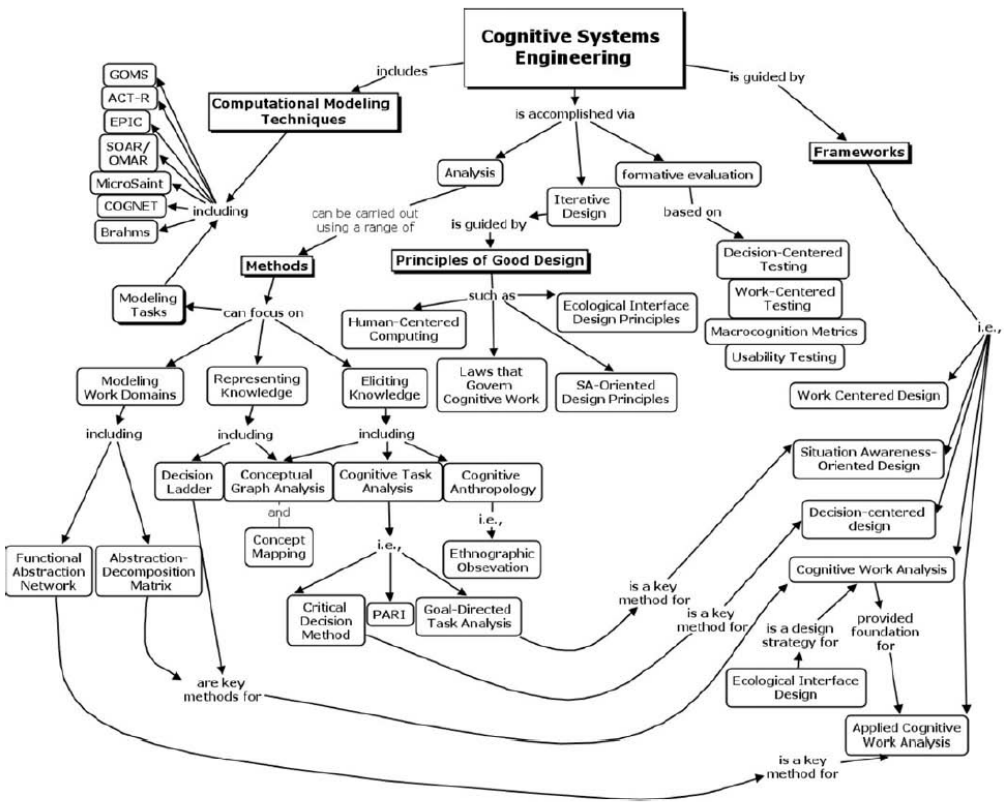


*Figure 2.3.* Cognitive Systems Engineering - concept map. From Militello, Dominguez, Lintern & Klein (2009). The role of Cognitive Systems Engineering in the Systems Engineering Design Process. Systems Engineering, 14(3), 305-326. Image re-used with permission.

### 2.2.4 Naturalistic Decision-Making

Naturalistic decision-making (NDM) is both a paradigm and a description of how decision-making takes place in real-world settings. The literature is not entirely clear on the relation between CSE and the NDM paradigm. Both are concerned with the study of how people perform in complex sociotechnical environments and employing these insights to the system's design (Endsley, Klein & Woods, 1995). Arguably, CSE is the umbrella term for a variety of frameworks studying and designing for cognitive work in complex environments (Militello et al, 2009). NDM is aligned to the DCD framework.

The paradigm of NDM emerged in the 1980's as a reaction to normative models on decision-making being inadequate to explain how decision-making unfolds in the real world, typified by time pressure and uncertainty (Lipshitz et al., 2001). The underlying premise of NDM is that human cognition is not rational in the sense that it is viewed in traditional decision theories, which assume that people employ probabilistic strategies and deductive logic (Nemeth & Klein, 2010). Instead, decision-making in complex real-world settings is heuristic and highly dependent on expertise and previous experience (Schraagen, Militello, Ormerod, & Lipshitz, 2008; Woods & Cook, 1999). Therefore, NDM aligns with the tenets from CSE.

The paradigm of NDM has evolved as the study of how decisions are made in the real world, and not how they should be made (Schraagen et al., 2008). Therefore, NDM captures 'work-as-done' and not 'work-as-imagined' (Hollnagel, 2015). The NDM paradigm has been increasingly prominent in healthcare, realising the need to shift focus from reducing variability in clinical work according to best practice guidelines to a better understanding of how work is actually performed in context (Catchpole & Alfred, 2018). Orasonu and Connolly (1993) have listed the characteristics of complex sociotechnical environments where naturalistic decision making typically occurs (see Table 2.1). Naturalistic decision making is a collective term and is part of the broader framework of macro-cognition. Macro-cognition, refers to the "*collection of cognitive processes and functions that characterize how people think in natural settings"* (Crandall et al., 2006). Thus, macro cognition refers to the description of the broader cognitive functions that are involved in naturalistic environments where decision-making is central (Klein, Klein, Hoffman & Hollnagel, 2003).

*Table 2.1.* Characteristics of environments where Naturalistic Decision Making occurs

| **Characteristics of environments where NDM occurs** |
|---|
| ▪ Uncertainty |
| ▪ Ill-structured problems |
| ▪ Ill-defined and competing goals |
| ▪ Action-feedback loops |
| ▪ High stakes |
| ▪ Time constraints |
| ▪ Organizational constraints in norms and goals |

### 2.2.5 Recognition-primed decision-making

One of the key decision-making theories associated with the NDM paradigm is the recognition-primed decision (RPD) model (Klein, Calderwood, & Macgregor, 1989). The RPD model was based on the study of how subject-matter-experts made decisions in the field, under naturalistic conditions. Most prominent, was the study of how firefighters made time-pressured critical decisions on the fire ground (Klein, Calderwood, Clinton-Cirocco & Klein Associates, 1988). Defining 'decision-making' as the selection of an option from a range of alternatives (Klein et al, 2010), it was found that firefighters rarely compared options in order to make decisions as predicated by laboratory studies. Instead, they made decisions by recognising situations as 'typical instances of general prototypes' they had acquired through their experience (Klein et al, 2010). The crux of the RPD model is the recognition of familiarity in situations. This recognition of familiarity links to actions that have worked in the past (level 1, 'simple match', Klein, 1995). It is known that during this process, performance is always approximate, and involves the seeking of a 'satisficing' solution (Simons, in Nemeth, 2010).

While the RPD model describes a heuristic process similar to pattern matching, the model is more complex. Indeed, it is a 'blend of intuition and analysis' (Klein, 2008). As Figure 2.4 illustrates, the RPD model has a second level of situational assessment that deals with situations that are not familiar. When subject-matter-experts encounter a situation that violates their expectations, subject-matter-experts engage in a more deliberate sense-making process by re-assessing the situation and seeking more information (level 2, 'diagnose the situation', Klein, 1995). Finally, the RPD model has a third level of deliberate analysis, concerning the mental simulation of the linked action before execution (level 3, mental simulation, Klein, 1995). Klein et al (1988) found that firefighters evaluate their course of action through mental simulation before implementing it. If the planned action seemed to work during mental simulation, the action was executed. If it did not work, another course of action was selected and again simulated, until an action that was deemed to work was found.  Due to this sequential evaluation of courses of actions, RPD can be made more rapidly 'on the fly' than concurrent option evaluation (Klein et al, 2010). Klein et al (1988) found that 80% of firefighter's decisions were 'prototypical', thus based on a simple match between the recognition of a familiar situation (i.e. 'as typical of their prototype') and implementation of a course of action that worked in the past.

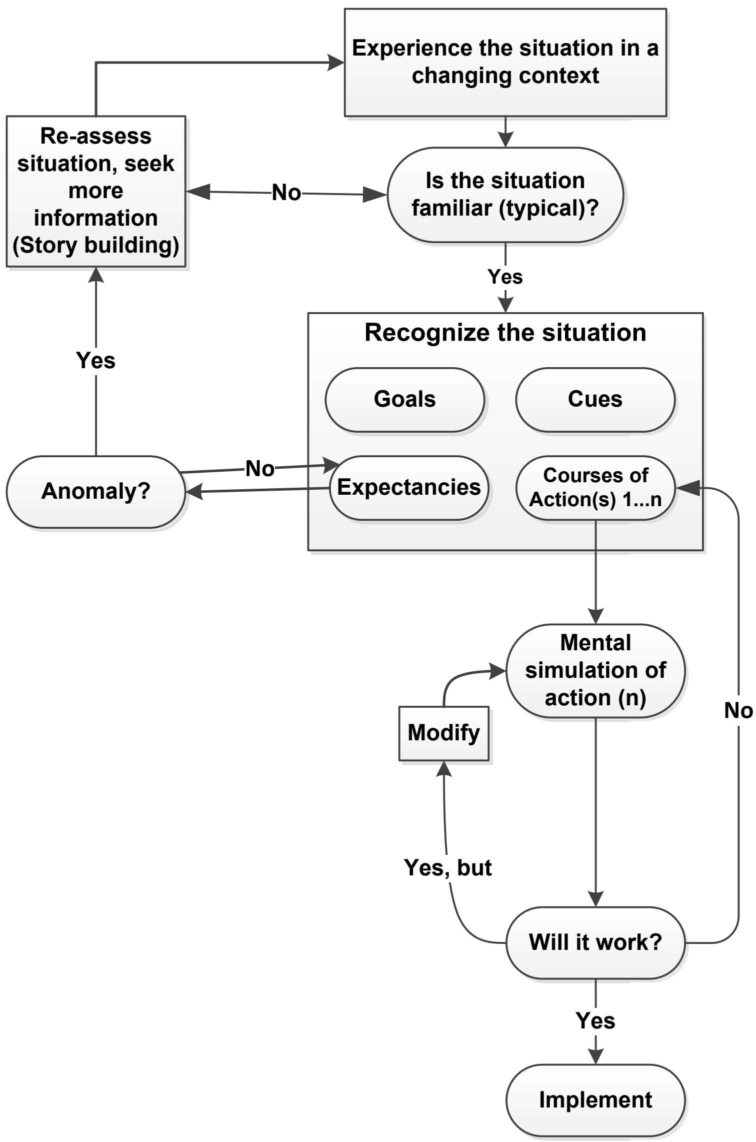


*Figure 2.4.* The recognition-primed decision model. From Klein (2008). Naturalistic Decision Making. Human Factors, 50(3), 456-460. Adapted with permission.

### 2.2.6 Heuristics: adaptations to complexity

The crux of CSE and NDM is the recognition that people use heuristic knowledge in order to cope with complexity. Heuristics are necessary for coping with complexity because they are simplifications of reality that aid with decision-making (Woods & Cook, 1999) by recognising a situation as typical instance of a situation encountered in the past. Thus, the core of recognition-primed decision-making is heuristic. In a different context, Hutchins (1995) describes this as *situated cognition:* people adapt their cognitive strategies to the constraints given by the specific situation, rather than retrieving stored conceptual knowledge. Hence, knowledge is highly context-dependent and centred around what has to be accomplished in a specific situation.

#### *2.2.6.1 Behavioural decision-making paradigm: heuristics and biases*

Heuristic decision-making was described before the emergence of the NDM paradigm. Tversky and Kahneman (1974) demonstrated that people use different routes of cognitive processing when they have to make judgements under uncertainty. They found that human cognition is not rational in the sense it is viewed in traditional decision theories, treating it as 'rational' using probability laws and deductive logic (Nemeth & Klein, 2010). The dual process theory (Kahneman, 2011) states that there are two routes, or systems, of cognitive processing underlying decision-making: system one is based on analytical, slow processing; and system two is based on fast, intuitive and heuristic processing. Their Behavioral Decision-Making (BDM) paradigm identified a series of heuristics and biases, most prominently the representativeness, availability heuristic and anchoring (Tversky, A., Kahneman, 1974). The finding that heuristics differ to rational judgements based on probability laws led to the study of the negative aspect of heuristics, 'cognitive biases'.

There are obvious similarities between the NDM and the BDM paradigm. Both paradigms acknowledge that decision-making is different under naturalistic decisions than in the laboratory. Klein (2008) refers to the BDM paradigm as an underpinning for NDM research by being the first one that challenged classical decision theory and revealing that people use alternative strategies to deal with uncertainty. However, there are also differences that are important for how research is conducted. Research driven by the behavioural paradigm is mostly focused on heuristics in the context of limitations (Klein, Orasanu, Calderwood, 1993, p. 13): what went wrong, how cognitive biases cause errors and how this can be improved by training (e.g. Stiegler, Neelankavil, Canales, & Dhillon, 2012). On the contrary, the NDM paradigm studies the power of heuristics and how heuristics are necessary to cope with work demands (Schraagen et al., 2008). Pliske and Klein (2003) view NDM as a 'second path' to BDM that looks at the power of heuristics and expertise in achieving successful outcomes. NDM has therefore been described as a ‘shift in paradigm’, with the aim being to explain how individuals exploit their expertise in order to make decisions in naturalistic environments.

### 2.2.7 Decision-Centred design and Cognitive Task Analysis

As mentioned previously, DCD is a framework from CSE (Militello et al, 2009). The goal of DCD is to explore how experienced people make decisions in challenging situations with the aim to identify system design solutions (Crandall et al, 2006, p. 173, 177). DCD is aligned to the NDM paradigm because it aims to identify how subject-matter-experts accomplish challenging work successfully by using their expertise and strategies (‘work-as-done’) and using this knowledge for the design of cognitive support. DCD consists of five overarching phases: domain familiarisation, knowledge elicitation, analysis and representation of findings, identification of design concepts and evaluation (Crandall et al., 2006; Militello & Klein, 2013). It can be viewed as being part of the broader Human-Centred Design framework, which follows similar stages (ISO 9251-20:2010).

DCD is based on three fundamental principles: (1) the knowledge elicitation of subject-matter-experts with the goal to identify cognitive requirements, (2) the use of Cognitive Task Analysis (CTA) and (3) the focus on particularly challenging situations (Militello & Klein, 2013). DCD utilises methods from CTA to elicit knowledge from subject-matter experts in order to guide the design process (Crandall et al., 2006). CTA is a collective term for a variety of explorative qualitative research methods that study how cognitive work is accomplished in context. It is employed to elicit knowledge from subject-matter-experts, as well as analyse and represent this knowledge in order to assist with the design of cognitive support (Crandall et al., 2006; Nemeth & Klein, 2010). Many CTA methods exist and their selection depends on the nature of the enquiry. Semi-structured interviews such as the Critical Decision Method (Klein et al., 1989) and field observations have been popular CTA methods in healthcare (e.g. Fackler et al., 2009; Gazarian, Carrier, Cohen, Schram, & Shiromani, 2015; Pauley, Flin, & Azuara-Blanco, 2013).

The principles of DCD suits goal of the present research program: the development of a decision support tool for challenging airway management situations based on the study of ‘work-as-done’. Therefore, DCD has been selected as a guiding framework for the present research program.

### 2.2.8 Conclusions

This literature review into sociotechnical systems identified CSE as a suitable conceptual basis for the study of complex environments. The NDM and the DCD framework were identified as adequate for the study of decision-making in challenging situations, as well as the design of decision support interventions. The next section reviews the literature on Human Factors research in anaesthesia.

## 2.3 Anaesthesia – a complex sociotechnical system

Anaesthesia has long been acknowledged as a complex sociotechnical system (e.g. Cook, Woods & McDonald, 1991; Cooper, Newbower, Long, & McPeek, 1978; Gaba, Maxwell & DeAnda, 1987). It has even been described as a 'paradigmatic field of activity in complex work environments' (Manser & Wehner, 2002). This complex and sociotechnical nature affects human performance (Cook, Woods & McDonald, 1991; Xiao, Hunter, Mackenzie, Jefferies, & Horst, 1996).

The *complexity* of anaesthesia refers to the variety of factors that induce the variability under which anaesthetic work is accomplished. These are time and resource constraints, high stakes, competing goals and dynamic patient conditions (Rall et al, 2014; Xiao, Hunter, Mackenzie, Jefferies & Horst, 1996). Many activities in anaesthesia have to be performed simultaneously, particularly during anaesthesia induction and emergence (Manser & Wehner, 2002). Furthermore, due to the dynamic nature of anaesthetic environments, the anaesthetic team constantly needs to adapt and coordinate their activities to situational demands (Wacker & Kolbe, 2014). For instance, clinicians have to deal with unstable and dynamic patient conditions that require immediate management, often with incomplete and changing evidence (De Keyser & Woods, 1990; Rall, Gaba, Howard, & Dieckmann, 2014; Xiao, Hunter, Mackenzie, Jefferies, & Horst, 1996).

Anaesthesia is *sociotechnical* because it is typified by a tight interaction with other system elements such as other clinicians, patients, the physical environment, advanced technology, equipment and boundaries set by management and the broader organisation (Bogner, 2007; Wacker & Kolbe, 2014). While the anaesthetic work itself is conducted by a small team comprising an anaesthetic practitioner and assistant, it is tightly interrelated with other medical professionals with different goals and priorities (Wacker & Kolbe, 2014). This requires coordination of activities, communication and mutual support. (Flin, Patey, Glavin, & Maran, 2010). Effective team work is essential for patient safety in the anaesthetic environment (Schmutz, Manser, & Mahajan, 2013). Furthermore, clinicians have to manage patients according to local protocols and national standards while accommodating design deficiencies of the physical environment as well as shortage of equipment and medical staff; all under throughput pressure (e.g. Phipps & Parker, 2014; Tsai, Steward, & Black, 2017).

The above demonstrates that anaesthesia exemplifies the characteristics of NDM environments (Phipps & Parker, 2014; Rall et al., 2014). Likewise, it demonstrates that anaesthesia is a *distributed cognitive system* (Hutchins, 1995).

### 2.3.1 Human Factors in anaesthesia

Both due to its paradigmatic and safety-critical nature, much research has been performed in anaesthesia. Human Factors shape performance in anaesthesia at all levels of the system (e.g. Phipps, Meakin, Beatty, Nsoedo, & Parker, 2008; Weinger & Slagle, 2002; Weinger, Herndon, Zornow, Paulus, Gaba & Dallen, 1994). Flin et al (2013) found that a median of 4.5 human factors variables contributed to complications in airway management. The majority of contributing human factors found in this study related to cognitive activities such as situational awareness and decision-making, job factors (e.g. time pressure and difficulty) and personal factors (e.g. fatigue and hunger). On the contrary, this study found that team work and communication were mitigating factors that were essential to manage complications. Fatigue due to shift work and sleep deprivation is another main human factor (i.e. latent condition) affecting performance in anaesthesia, especially during monotonous activities (Gregory & Edsell, 2014; Weinger & Englund, 1990). Environmental factors including noise, temperature, lighting, equipment arrangement and design also affect performance in anaesthesia (Weinger & Englund, 1990). Finally, decision-making in anaesthesia is affected by organisational pressure, specifically the trade-off between demands and throughput pressure (Tsai et al, 2017).

### 2.3.2 Recognition of Human Factors in anaesthesia

Anaesthesia is one of the leading medical disciplines in addressing patient safety (David M Gaba, 1999). The importance of Human Factors is recognized in the anaesthetic practice and emphasized in guidelines, national audit projects and training (Jones et al., 2018; The Royal College of Anaesthetists, 2011). In practice, the 'Anaesthetists Non-technical Skills' (ANTS) framework was one of the earliest frameworks emphasizing insights from human factors research in anaesthesia (Fletcher, Mcgeorge, Flin, Glavin, & Maran, 2002). ANTS describes four domains of non-technical skills relevant in anaesthesia: (1) task management (2) team work (3) situation awareness and (3) decision-making (Patey, Flin, Fletcher, Maran, & Glavin, 2011). The ANTS tool was developed based on analysis of interviews, incident reports and observations in anaesthesia and is used for training and research.

In the context of the present research program, the main focus of the literature review in the following sections will be on the study of decision-making in anaesthesia. Naturally, decision-making is tightly interrelated with cognitive and collaborative processes such as situational awareness (e.g. Endsley, 1995; Schulz, Endsley, Kochs, Gelb & Wagner, 2013) and team work (e.g. Manser, Harrison, Gaba, & Howard, 2009).

### 2.3.3 An integrative model of decision-making in anaesthesia

A first integrative model of decision-making for anaesthesia was proposed by Gaba (1989). The model has been extended over the years and prevails as a prominent model for the description of cognitive processes involved in decision-making (see Figure 2 5, Rall, Gaba, Howard & Dieckmann, 2014). The model illustrates the complexity of decision-making in anaesthesia. The crux is the integration of five possible cognitive processes that take place on five levels of cognitive control: the (1) resource management level, (2) supervisory control level; (3) abstract reasoning level; the (4) procedural level and the (5) sensorimotor level. These five levels of control guide the decision cycle, comprising cognitive elements such as observing, deciding, acting and re-evaluating (Gaba, 1994 in Rall et al., 2014). The model was developed based on consolidated research on decision-making in other complex sociotechnical environments. For instance, the different levels of cognitive controls were based on the skill/rule/knowledge classification of performance levels (Rasmussen, 1983). Cognitive processes on the 'procedural' level were based on the dual processing theory (e.g. Kahneman, 2003); recognition-primed decision-making (e.g. Klein et al., 1989) and situational awareness (Endsley, 1995).

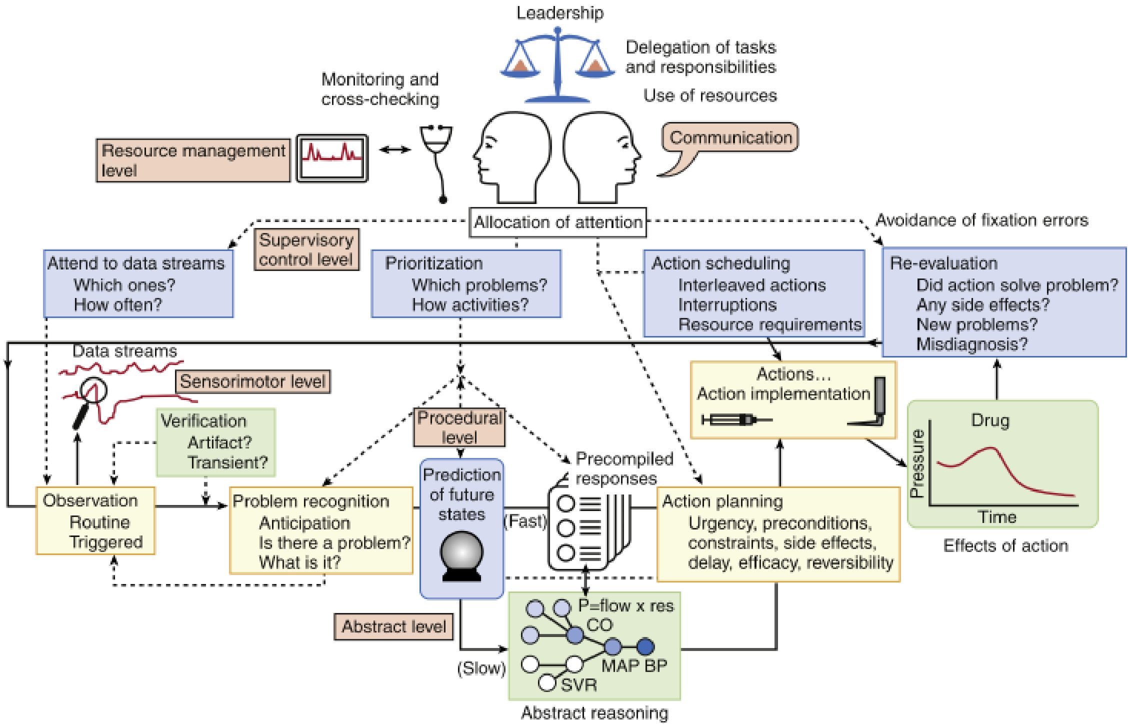


*Figure 2 5.* Integrative model of cognitive processes involved in decision-making in anaesthesia. From Rall, Gaba, Howard & Dieckmann (2014). *Human Performance and Patient Safety in Anesthesia*. In Miller, R.D., Eriksson, L.I., Fleisher, L.A., Wiener-Kronish,, J.P., Cohen, N.H. & Young, W.L. (Eds.). Millers Anesthesia 8th Edition. Philadelphia, PA: Elsevier. Image re-used with permission.

In the following sections, the literature will be reviewed on the study of decision-making in anaesthesia. This has been done in order to identify (1) how decision-making has been studied in anaesthesia in the past, (2) current gaps and opportunities, (3) current decision-support design interventions in anaesthesia and (4) current gaps and opportunities for the study of decision-making and decision support design in anaesthesia.

### 2.3.4 The study of decision-making in anaesthesia

Human Factors research surrounding decision-making in anaesthesia has evolved over almost five decades (Drui, Behm, & Martin, 1973; Gaba, 1999). In line with the general evolution of accident causation models, early Human Factors research in anaesthesia emphasized the role of human error. However, simplistic views of human error in anaesthesia were challenged early on with systemic approaches and consideration of anaesthesia as a complex sociotechnical environment. In the context of Normal Accident Theory (Perrow, 1984), Gaba, Maxwell and deAnda (1987) discussed that anaesthetic environments are naturally vulnerable to incidents because they possess both complex interactions and tight coupling. These characteristics lead to inevitable accidents, despite interventions to prevent them. In order to 'break the chain of accident evolution', the ability to recognise something is going wrong ('vigilance') and adequate responding is crucial.

However, this ability is affected by the time pressure and workload of anaesthesia. Consequently, anaesthetic safety cannot be addressed with simplistic solutions (Gaba, Maxwell & DeAnda, 1987). Progressively, research moved to a more positive, naturalistic decision-making based approach.

### 2.3.5 Human error studies in anaesthesia

One of the earliest Human Factors studies in anaesthesia already argued for ‘a systematic analysis of the current work conditions in the problem area’ such as human-machine interface design (Drui et al., 1973). Still, early studies assumed that around 80% of incidents in anaesthesia were due to human error (Cooper, Newbower, Kitz & 1984; Cooper., Newbower, Long, & Bucknam Mc Peek, 1978). Only 14% of these anaesthesia incidents were found to be equipment failures, although it was acknowledged that equipment design deficiencies were evident in many incidents involving human error. It was suggested that human error could be prevented from re-occurring through improved training, supervision, and also human factors design considerations (Cooper, Newbower & Kitz, 1984; Cooper et al, 1978). Much research has followed that primarily focused on the study of human error and cognitive activities related to decision-making (e.g. DeAnda & Gaba, 1990; D M Gaba, 1989; David M. Gaba & DeAnda, 1989; Xiao, Mackenzie, & Group, 1995).

### 2.3.6 Cognitive biases and fixation errors

The downside of heuristics, cognitive biases, and their impact on anaesthetic safety have received much attention in anaesthesia (Croskerry, 2005; Fomberstein & Ruskin, 2014; Stiegler et al., 2012). A range of heuristics have been identified that potentially impact decision-making in the anaesthetic practice. The four overarching heuristics are representativeness, adjustment and anchoring (e.g. Croskerry, 2005; Stiegler et al, 2012).

Biases related to anchoring have been well-described in anaesthesia (Croskerry, 2005). Anchoring describes the phenomenon of placing too much significance on one piece of information and disregarding other relevant information that suggest a different picture of the situation and associated course of actions than the current one (Stiegler, 2014). These ‘fixation errors’, the ‘failure to revise a plan in the presence of inconsistent cues’ (Schwid & O’Donnell, 1992) were frequently studied in the context of anaesthesia incidents. Behaviourally, they emerge as a persistence with inadequate strategies, and a failure to adapt these strategies despite evolving environmental cues suggesting their ineffectiveness (Woods & Cook, 1999). In airway management, the transition between different techniques is fundamental if the current technique does not result in adequate oxygenation. Hence, persistence with a particular strategy can be detrimental. Repeated unsuccessful attempts at tracheal intubation have been associated with hypoxia (Connelly, Ghandour, Robbins, Dunn, & Gibson, 2004; Mort, 2004). In other events, fixation has contributed to a lack of transition towards a surgical airway in a 'can't intubate, can't oxygenate' scenario, and resulted in fatal oxygen desaturation (Bromiley, 2009).

DeAnda and Gaba (1990) studied incidents of anaesthesia residents in simulation and classified incidents into human errors, fixation errors and equipment failures. He found that the vast majority of incidents were human errors (65.9%) and fixation errors (20.5%), and only a minority equipment failures (3%). Consequently, recommendations involved training and education to improve recognition of unfolding events. Another simulation study of anaesthesia incidents found that 63% of incidents involved fixation errors (Schwid & O'Donnell, 1992). Xiao, Mackenzie and the LOTAS group (1995) concluded that fixation errors are the consequence of the 'inherent nature of complex work environment' of anaesthesia, including time pressure, uncertainty, high stakes and the poor design of medical equipment. More recently, it has been suggested that fixation errors 'abound in everyday anaesthetic practice' (Fioratou, Flin, & Glavin, 2010) and contribute to airway management complications (Mackenzie, Xiao, Hu, Seagull, & Fitzgerald, 2007; The Royal College of Anaesthetists, 2011). It has been suggested that the provision of alternative options, simulation and additional help with a fresh perspective can mitigate fixation (Fioratou et al, 2010; Gaba, 1989; Patterson, Woods, Cook, & Render, 2007).

According to Chrimes and Fritz (2013), team work may even break fixations, especially when combined with well-designed cognitive support. In healthcare, cognitive support is a collective term for a variety of tools that aim to provide guidance for decision-making and management of significant clinical events (Chrimes, 2016). A variety of decision support tools exist in anaesthesia, ranging from preparation protocols to tools used at the time of performing clinical activities (Chrimes, 2016; Marshall, 2017). These will be discussed in section 2.4.

### 2.3.7 The naturalistic decision-making paradigm in anaesthesia

Only a few studies have examined how anaesthesia teams accomplished their work successfully, although research of this type rarely used methods from CSE (e.g. Knudsen et al., 2017; Larsson & Holmström, 2013). This is surprising, since anaesthesia in otherwise healthy patients is approaching ultra-safety (Amalberti, Auroy, Berwick, & Barach, 2005). Presumably, equally much can be learned from how difficult situations are managed successfully compared to how failure occurs occasionally. Heuristics are necessary for anaesthetic safety in order to cope with incomplete information, time pressure, organizational pressures and other characteristics shared by complex sociotechnical environments (Mildner et al., 2006). Consequently, the 'cognitive biases' that are erroneous occasionally, are usually powerful heuristics that result in successful anaesthetic care (Croskerry, 2005).

It is well-established that decision-making in routine and emergency situations in anaesthesia is recognition-primed (Bond & Cooper, 2006; Borges et al., 2010; Rall et al., 2014). However, while aspects of recognition-primed decision-making have been found in several studies, the naturalistic decision-making paradigm has been rarely explicitly employed in anaesthesia. In a simulation study, Schwid and O'Donnell (1992) found that experienced anaesthetists made their primary diagnosis of anaesthetic incidents by matching observed symptoms to known diagnostic patterns; using pattern matching instead of abstract reasoning and option evaluation. Through recognition of environmental and patient cues, 80%-100% of the participants diagnosed oesophageal intubation correctly. Another study found that practitioners use cues from both patient and technology as direct feedback to evaluate the effectiveness of bag mask ventilation (Mumma et al., 2018). Experts have a larger repertoire of cues they use compared to novices, which suggests that bag mask ventilation is a cognitive-perceptual skill. Borges et al (2010) found that experienced anaesthetists did not follow the content of an airway management algorithm but adapted it to the situation based on their own experience and knowledge.

Phillips and Parker (2014) studied anaesthetist's rule-related behaviour in the context of naturalistic decision-making. They found that following or not following protocols was related to how these rules match with other principles of their decision-making. These commonly involved efficiency-thoroughness trade-offs and beliefs on 'what was the right thing to do' in the situation (Phipps & Parker, 2014).

Another study found that anaesthetists vary widely in their willingness to take risks when it comes to go or no/go decisions (Tsai et al., 2017). While experienced anaesthetists were more likely to go ahead with a surgical procedure than junior anaesthetists, no scenario reached absolute agreement between subject-matter-experts. This was even in cases where guidelines recommend to not go ahead with a case. The study illustrates the trade-off anaesthesia teams have to make between efficiency and thoroughness, typically for naturalistic decision-making environments (Hoffman & Woods, 2011).

In order to support decision-making of anaesthesia teams adequately, decision support design intervention need to take into account the naturalistic nature of cognitive work in anaesthesia. As will be discussed in 2.4.6, to date this is insufficiently addressed in the clinical practice.

### 2.3.8 Adaptation and resilience to anaesthetic crises

A few studies have focused on the resilience and adaptation of anaesthesia teams to emergency crises. While the resilience engineering paradigm distinguishes itself from naturalistic decision-making, there is much overlap in how both paradigms have been used for the study of decision-making processes in anaesthesia.

Rudolph, Morrison and Carroll (2009) have used the sense-making and story building (Klein, Philllips,  Rall & Peluso, 2006) to explain how anaesthesia teams deal with unexpected anaesthetic crises. In these situations, the team has to quickly 'build a story' about what is going on and fit diagnoses into this story. The study suggests that (1) anaesthetic practitioners engage in sense-making processes when they face unexpected crises and they (2) continuously create meaning by acting, as an evolving process. Consequently, Rudolph et al (2009) found that anaesthetists engage in four different problem-solving modes: stalled, fixated, vagabonding and adaptive. In a stalled mode, clinicians had difficulties identifying diagnoses and suitable action plans; in a fixated mode clinicians stuck with erroneous diagnoses and action plans that were identified early in the process; the vagabonding mode was characterised by identifying a range of diagnoses without committing to any in particular nor using an algorithm; and clinicians in the adaptive mode generated a few plausible diagnoses and action plans and use of an algorithm. A simulation study found that only the 'adaptive' mode of sense-making could solve the encountered crises (Rudolph et al, 2009). The three other modes appeared to have an inadequate relation between 'plausibility of leading diagnosis' and 'weight on cues'. The study showed that anaesthetists engage in 'action-oriented problem solving' when they encounter anaesthetic crises. As such, adaptive sense-making is crucial to adequate decision-making, or in Rudolph's terms, 'adaptive problem-solving'.

Cuvelier and Falzon (2011) examined how anaesthesia teams cope with uncertainty. Interviews with anaesthetists identified two type of uncertain situations. Firstly, 'potential situations' that were not expected at the time but are generally well-known and prepared for (e.g. a failed intubation) and 'unthought-of-situations' that cannot be foreseen (e.g. technical breakdowns).  They found that the adaptability of anaesthesia teams was linked to their ability to 'define an envelope of potential variability' and prepare accordingly, as well as to recognize when complications exceed this envelope and require additional resources. It was found that the perception of uncertainty of events is closely associated with experience; and how frequently complications are protocolled in guidelines and algorithms.

Another study demonstrated that 'adaptive coordination' of anaesthesia teams is crucial for managing complex situations (Manser, Harrison, Gaba, & Howard, 2009). High and low performing anaesthetic teams differed in their nature of adaptation.  Coordination patterns related to high performance involved observation, a shared situational assessment and information transfer across the team early in the process (Manser et al., 2009). This 'distributed situational awareness' (Fioratou, Flin, Glavin, & Patey, 2010) obtained from environmental cues and shared across team members (also termed 'common ground' in Klein, Feltovich, Bradshaw & Woods, 2005). ) is crucial, before then performing the actual clinical tasks collaboratively. On the contrary, lower performance was related to extensive task management and communication, but less focus on performing the relevant clinical actions (Manser et al, 2009).

A failure of team adaptation has been linked to adverse outcomes (Cuvelier & Falzon, 2015; Thomas et al in Flin & Mitchell, 2009). In the case of Elaine Bromiley for example, there was a mismatch in situational awareness between members of the anaesthetic team. Anaesthetic nurses were aware of the progress of desaturation and made preparation for a surgical airway; however this was not explicitly communicated to the anaesthetists, who were fixated on tracheal intubation (Bromiley & Mitchell, 2009). This illustrates the preventative role team work has in anaesthetic care, as well as the potential impact when breakdowns in team work occur. It has even been suggested that team work may break fixations (Chrimes & Fritz, 2013; Fioratou et al,  2010), and 'speaking up' increases technical skills and, hence, patient safety (Kolbe et al., 2012).

Although particular coordination patterns have been related to high and low performance, there is no normative way of adaptation (Manser et al., 2009). This is in line with Cuvelier and Falzon (2015) who found that anaesthetic teams adapt differently to crises by trading off differently between 'understanding' and 'doing': some teams started with sharing an understanding and diagnosing the situation, followed by responding. Other teams firstly rescued the situation, before then taking time to comprehend the nature of the event. Other research has found that the balance between (1) gaining a shared understanding and (2) acting upon the situation is crucial for effective team functioning (Manser et al., 2009).

### 2.3.9 Conclusions

This literature review on human factors research in anaesthesia identified that anaesthesia is a complex and sociotechnical environment, and that human performance is affected by this complexity. As a complex and sociotechnical system, anaesthesia exemplifies the characteristics of environments where naturalistic decision-making occurs. While anaesthesia is considered safe and incidents occur rarely, the literature has shown that the complexity of the anaesthetic environment makes practitioners susceptible to cognitive biases, such as fixation errors. Likewise, the literature review identified that work is inherently collaborative and that team work necessary for adaptation and management of complications. Furthermore, it was shown that decision-making is based on experience and there is variability in how anaesthetists make decisions even in circumstances where clear guidelines exist. Based on research in other complex sociotechnical environments, it is accepted that decision-making in anaesthesia is recognition-primed rather than based on abstract reasoning and option evaluation. Nevertheless, no research has yet applied the NDM paradigm to the study of decision-making in anaesthesia.

The findings of the literature review suggest that decision-making in anaesthesia would benefit from decision support that considers the complex sociotechnical environment of anaesthesia, such as time pressure and the need to engage in heuristic decision-making to cope with demands. The decision support should further be supportive of team work and not only individuals. Finally, assuming decision-making in anaesthesia is primarily recognition-primed, it should support decision-making based on recognition rather than option evaluation and abstract reasoning. In the next section, current decision support interventions in anaesthesia will be reviewed. This will be followed by identifying gaps in the way decision support has been currently designed in anaesthesia.

## 2.4 Decision support design in anaesthesia

Safety in anaesthesia has been attributed to an ongoing commitment to address patient safety problems with multidisciplinary approaches (Gaba, 1999). It is therefore not surprising that much attention has been devoted to the support of decision-making in challenging situations, and the early recognition of clinical cues that indicate difficulties. Surprisingly, while Human Factors are acknowledged in the anaesthetic practice, most of the decision support tool designed for the point-of-care have not followed a Human Factors Engineering process. In the next section, current approaches to support airway management in anaesthesia are reviewed.

### 2.4.1 Training in Crisis Resource Management

Crisis Resource Management (CRM) was adopted from the aviation domain (‘Crew Resource Management’) to anaesthesia in the early 90s (Gaba, Fish & Howard, 1994 in Rall et al., 2014). CRM describes principles to help the anaesthetic team in and before crisis situations. These involve all resources available (human, technology, cognitive aids) to protect the safety of the patient (Rall et al., 2014). The concept of CRM endorses the Normal Accident Theory that human cognition is naturally limited, and therefore the occurrence of errors in complex environments is inevitable. The crux of CRM is to raise awareness of the natural occurrence of errors, and focuses on principles that mitigate or prevent errors from occurring in the first place. This active management of safety overlaps with the key concept of High Reliability Organizations (Rall & Dieckmann, 2005). Training on CRM takes usually place in simulated environments (Rall et al., 2014).

#### *2.4.1.1. Incorporation of CRM training in the Australian anaesthesia training*

In Australia, ANZCA provides training for the management of anaesthetic crises, the *Effective Management of Anaesthetic Crises* course (EMAC). This course is simulation-based and covers the principles of CRM and Human Factors in the context of airway management and other anaesthetic crises (ANZCA, 2018). The EMAC course is a mandatory part of the training curriculum; however, it is only a single two-and-a half day course during the five years of specialist training. Once becoming a fellow, anaesthetists have to undertake ‘continuing professional development’ only once every three years (ANZCA, 2018), which does not have to be CRM training.

Additionally, members of the anaesthetic team, nurses and anaesthetists, are trained separately. Hence, they do not receive the opportunity to embrace CRM principles with other practitioners of the system they are going to work with. This, however, is difficult to implement as the team composition in anaesthesia is flexible (Wacker & Kolbe, 2014). It is hence disputable that the EMAC provides enough opportunity for trainees to learn and embrace the principles of CRM on a skilful level. More frequent CRM training is difficult to mandate, and also not accessible to all members of the anaesthetic team, such as anaesthetic nurses. Therefore, other ways are needed to support the whole anaesthetic team in challenging situations.

### 2.4.2 Technology

The most important technological interventions in anaesthesia are the pulse oximeter and the capnography (ANZCA, 2015). The pulse oximetry indicates oxygen levels by a change in sound; the capnography reveals exhaled carbon dioxide. Technology indicating physiological changes are crucial for situational awareness on emerging difficulties (Schulz et al, 2013). The video laryngoscope is another device that has been designed to aid team situational awareness (Fioratou et al., 2010). The attached video screen provides an enhanced view of the patient's larynx. This assists the individual anaesthetist performing the intubation, but also makes it possible for other team members to see the view and guide the intubation process.

### 2.4.3 Cognitive aids

Cognitive aids are artefacts such as algorithms, checklists, mnemonics and symbolic representations. Cognitive aids have been implemented in anaesthesia to support decision-making of teams at the point-of-care (Marshall, 2013). Ideally, cognitive aids are simple and have minimal textual content to be suitable for time-pressured situations. Consequently, cognitive aids are designed to support skilful recognition and memory in time-pressured situations, rather than support novices with unfamiliar situations beyond their expertise (Marshall, 2017). Checklists are widespread in anaesthesia and are mainly intended being administered routinely, such as equipment checks and general safety aspects of surgical procedures (e.g. Krombach, Edwards, Marks, & Radke, 2015; Walker, Reshamwalla, & Wilson, 2012).

The vast majority of cognitive aids for difficult situations are algorithms but other types such as checklists, mnemonics and conceptual diagrams have also been developed.

#### *2.4.3.1 Algorithms*

Algorithms are derived from best practice guidelines and visualised as simplified decision trees or checklists that offer a stepwise guidance in challenging situations (Frerk et al., 2015). National societies such as the Difficult Airway Society in Australia and the UK, and the American Society of Anaesthesiologists in the United States developed their own algorithms which they promote and use in training. This resulted in many different algorithms developed to support practitioners in recognizing and responding to difficult airway management events such as difficult intubations or CICO crises (e.g. Heard, Green, & Eakins, 2009; Heidegger, Gerig, & Henderson, 2005; Runciman et al., 2005). For instance, there are algorithms for unexpected difficult intubation, ‘can’t intubate, can’t oxygenate’ events, difficult extubation and paediatric airway management (see Figure 2 6 for examples of airway management algorithms).

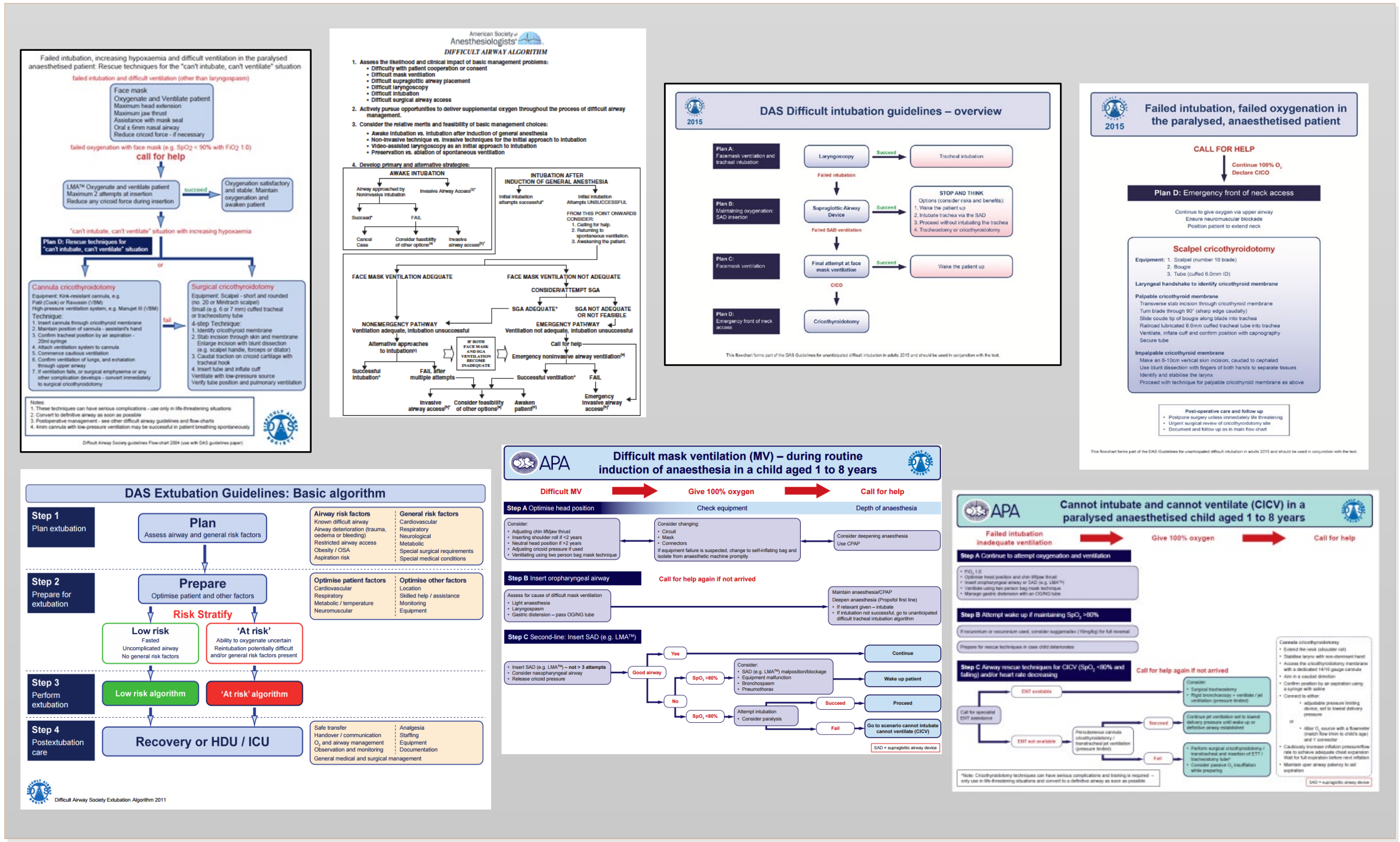


*Figure 2 6.* Difficult airway algorithms.

Reproduced from Popat M, Mitchell V, Dravid R, Patel A, Swampillai C, Higgs A. (2012). Difficult Airway Society Guidelines for the management of tracheal extubation. *Anaesthesia*, *67*, 318–340, with permission from the Association of Anaesthetists of Great Britain & Ireland/Blackwell Publishing Ltd; C. Frerk, V. S. Mitchell, A. F. McNarry, C. Mendonca, R. Bhagrath, A. Patel, E. P. O'Sullivan, N. M. Woodall and I. Ahmad, Difficult Airway Society (2015). Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *British Journal of Anaesthesia*, *115*(6), 827–848 (2015) doi:10.1093/bja/aev371 (images downloaded from https://das.uk.com/guidelines/downloads.html); Apfelbaum, J.L, Hagberg, C.A., Caplan, R.A., Blitt, C.D (2013). Practice Guidelines for Management of the Difficult Airway: An Updated Report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *Anesthesiology, 118*(2), 1-20. All images re-used with permission.

The Stanford Emergency Manual is a cognitive aid that has been designed and implemented in the operating theatre (see http://emergencymanual.stanford.edu/downloads.html). The manual consists of a variety of algorithms for anaesthetic emergencies and has been designed by the Stanford Anaesthesia Cognitive Aid Group, based on Crisis Resource Management and critical incident studies (Stanford Anesthesia Cognitive Aid Group, 2016). See Figure 2.7 for an example of an airway algorithm from the Stanford Emergency Manual.

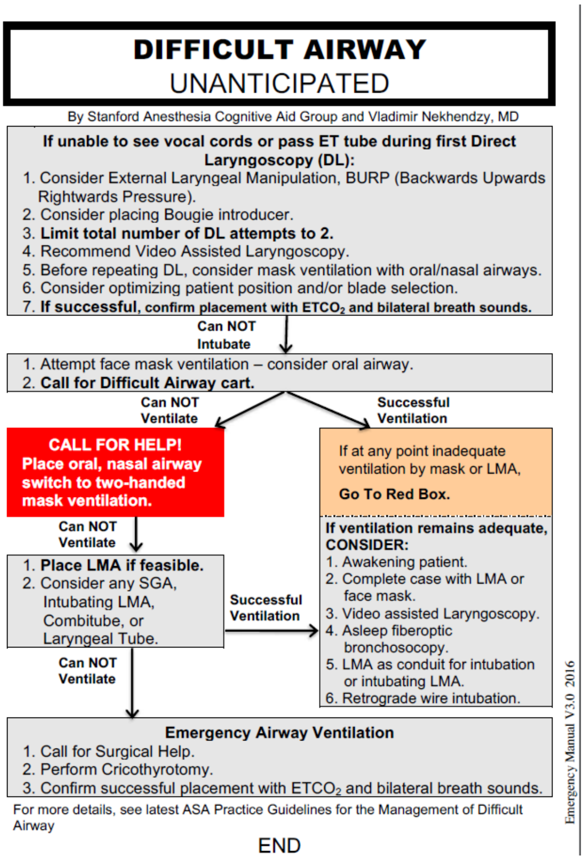


*Figure 2.7.* Stanford Emergency Manual – unanticipated difficult airway algorithm. From Stanford Medicine (2016). Retrieved from http://emergencymanual.stanford.edu/. Image reproduced with permission

### *2.4.3.2 Other cognitive aids*

As illustrated in Figure 2 6 and Figure 2.7, algorithms are frequently branched, lengthy and provide a rich amount of textual information (ANZCA airway management working group, 2014). Therefore, algorithms in their current form are useful for training as 'foundation tools' but less feasible to be used as an 'implementation tool' while actually performing the work (Chrimes, 2016). To address this discrepancy, alternative and less complex cognitive aids have been developed. Early on, mnemonics were considered as a useful strategy to aid memory in stressful situations (Runciman et al., 2005). Based on the Australian Incident Monitoring Study (AIMS), Runciman et al (2005) designed a range of mnemonics that, in theory, were able to correctly diagnose 60% of the incidents. However, the implementation demonstrated poor results, mostly related to ambiguity and a mismatch with decision-making approaches in anaesthesia (Marshall, 2017).

Another cognitive aid recently developed by two experienced anaesthetic practitioners is the Vortex™ (see Figure 2.8). The vortex is symbolic, representing a funnel as a metaphor for progressing to alternative airway strategies. The vortex is simpler and less rigid than algorithmic approaches (Chrimes & Fritz, 2013). As can be seen in Figure 2.8, the vortex majorly consists of symbols and has minimal text. The vortex has not yet been formerly evaluated.

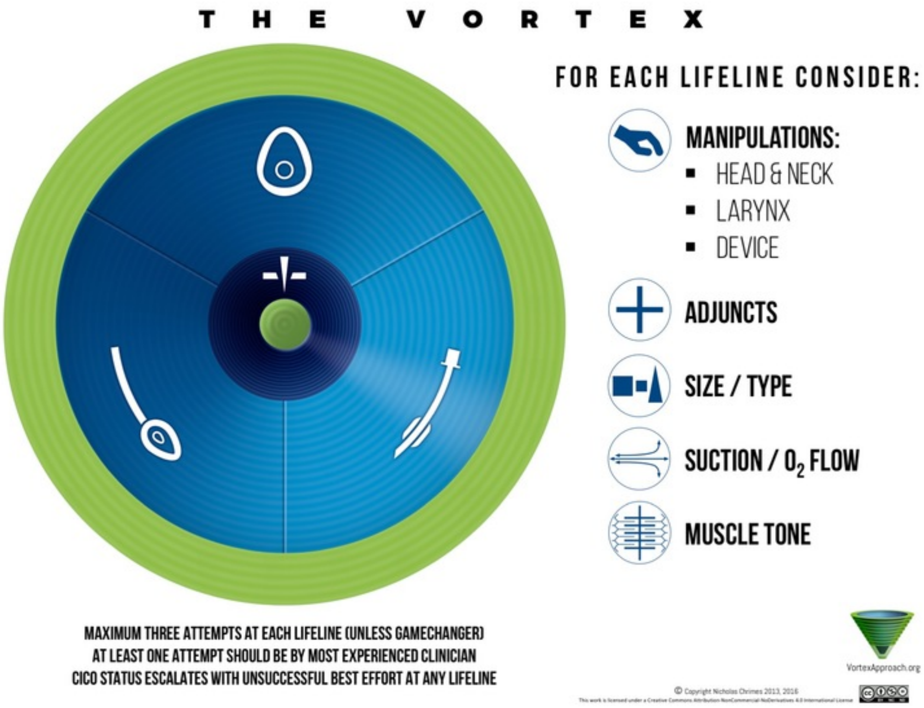


*Figure 2.8.* The Vortex approach. © Chrimes,N. (2013, 2016), retrieved from http://vortexapproach.org/. Image reproduced with permission.

### 2.4.4 Evidence on the use of cognitive aids

Principles of CRM advise use of cognitive aids for crisis management; generally assuming that cognitive aids have the potential to aid memory and reduce omissions while making decisions (Nanji & Cooper in Marshall & Mehra, 2014; Runciman et al., 2005). However, research has shown that cognitive aids in anaesthesia are not as successful as intended. Successful implementation depends on a variety of factors such as proper integration in practitioners' workflow, design, training in use and a shift in safety culture (Krombach et al., 2015; Walker et al., 2012).

A literature review on cognitive aids use in anaesthesia identified deficiencies in the design, evaluation and training of contemporary cognitive aids (Marshall, 2013). Out of 23 anaesthesia cognitive aids identified, only 13 were actually evaluated in some type of simulation, and training was only reported in 8 cases. The design process was not described for 11 out of 22 cognitive aids, only one followed an iterative design process (Stuart Marshall, 2013).

Out of the 13 cognitive aids evaluated, 10 suggested increased technical performance. Positive performance with a cognitive aid was related to improved team coordination during emergencies (Harrison, Manser, Howard, & Gaba, 2006), and in a more recent study a tendency to proceed to surgical techniques faster compared to having used no cognitive aid (Harrison et al., 2006; Marshall & Mehra, 2014). Another study found that the use of a linear algorithm resulted in better team performance than the use of a branched algorithm (Marshall, Sanderson, McIntosh, & Kolawole, 2016). Burden et al (2012) found that having a dedicated person reading the cognitive aid to the team improved the management of a rare emergency in simulation; although it decreased communication between team members.

Two other cognitive aid evaluation studies found no difference in performance while using a cognitive aid, and one even identified decreased performance (Marshall, 2013). Another study examining the management of difficult airways showed that 97% of anaesthesia residents could not recall the specific contents of a difficult airway algorithm (Rosenstock et al., 2004). Another simulation study with experienced anaesthetists found poor adherence to airway algorithms, however this was not due to a lack of familiarity (Borges et al., 2010). Instead, it was suggested that anaesthetists adapted the guidelines to their own knowledge and personal preferences. Deviations included omissions of certain airway techniques, multiple attempts with a similar technique and the lack of calling for help.

The findings seem to suggest that cognitive aids have the potential to improve both team functioning and technical performance. However, successful use depends on the design, training and implementation of the aid (Marshall, 2017; Marshall, 2013; Nanji & Cooper, 2012).

### 2.4.5 Equipment organisation

Difficult airway equipment is organised and stored with the goal of most efficiently and effectively assisting anaesthesia teams with difficult airway management. The aim of difficult airway trolleys is to stock equipment in a logical sequence in order to facilitate transitioning between airway techniques. The Difficult Airway Society endorses each department performing airway management should have an established difficult airway trolley which can be accessed by staff (NAP4, 2011).

However, there are no protocols or standards on how to organise difficult airway trolleys. The Difficult Airway Society does provide a list of equipment that should be available for difficult and routine airways (Difficult Airway Society, 2018). Also, the Difficult Airway Society does provide recommendations regarding the clinical content and organisation of difficult airway trolleys (https://www.das.uk.com/files/Difficult_airway_trolley_DAS.pdf). The DAS recommends that the difficult airway trolley is organised according to difficult airway algorithms, each consecutive drawer containing the next plan (see Figure 2.9). Based on the findings of the Fourth National Audit Project (The Royal College of Anaesthetists, 2011), it was recommended that the contents of the difficult airway trolley needs to be familiar to all clinical staff. Furthermore, it has been stressed that difficult airway trolleys should be similar across departments (The Royal College of Anaesthetists, 2011). Finally, the Royal College of Anaesthetists (2011) recommended that difficult airway trolleys should be standardised on a national level.

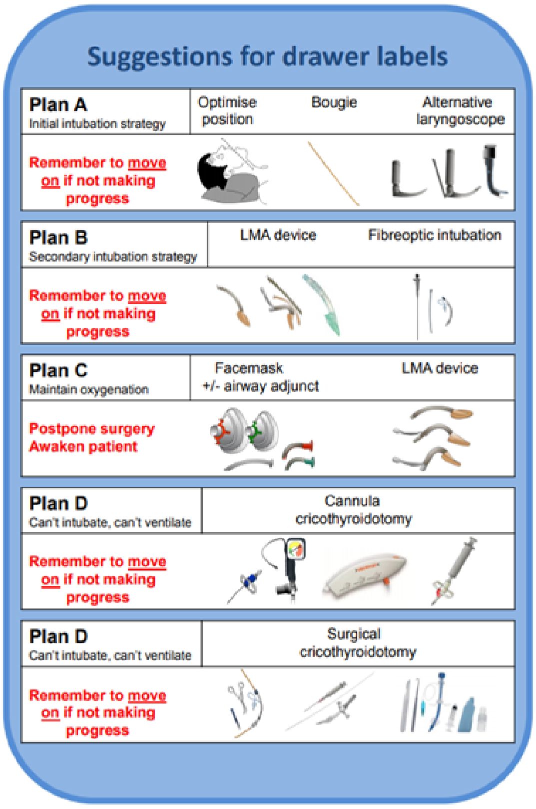


*Figure 2.9*. Difficult Airway Society recommendations on difficult airway trolley organisation. From the Difficult Airway Society, retrieved from https://das.uk.com/content/difficult_airway_trolley. Image re-used with permission.

The reality is different, and there is currently no national standard on how difficult airway trolleys have to be stocked or designed. Instead, difficult airway trolleys are organised locally by anaesthetic departments. Figure 2.10 shows the difficult airway trolley of an urban tertiary hospital in Melbourne. While the drawers are arranged consecutively as recommended, there are more drawers with different labels and individual colour coding.

Another example of difficult airway management equipment organisation is the CICO pack (see Figure 2.11). The CICO pack contains all pieces of airway equipment necessary to perform a surgical airway, as well as an algorithm visualising the steps involved. In the respective hospital, the CICO pack is placed on the wall in every operating theatre. Similar to the difficult airway trolley, the CICO pack, including the algorithm, has been designed locally by anaesthetists.

Consequently, there is much variability in how difficult airway trolleys are designed across departments and hospitals. This variability can cause problems because it hinders knowledge transfer and increases cognitive load when practicing in new environments (Bain, Symons, Bradley & Reilly, 2015). Familiarity with the airway equipment layout across locations is especially important in complex and time pressured situations (N. Chrimes, Bradley, Gatward, & Weatherall, 2018).

While clear efforts have been made to address human factors issues with difficult airway trolley design, these are still limited and could be improved from a Human Factors perspective. For instance, no research has yet been performed to identify if current versions of difficult airway trolleys are actually effective in difficult airway situations (DAS, 2018). Likewise, no Human Factors research has yet been involved in the design of difficult airways trolleys; which have currently been designed locally by anaesthetists themselves. Finally, the sequential order of difficult airway trolleys may be helpful in some airway difficulties, but likely do not apply to all cases. Hence, the flexibility and application of the sequence established by the difficult airway trolley is likely limited; similar to algorithms.


*Figure 2.10.* Difficult Airway Trolley example from an urban tertiary hospital in Melbourne

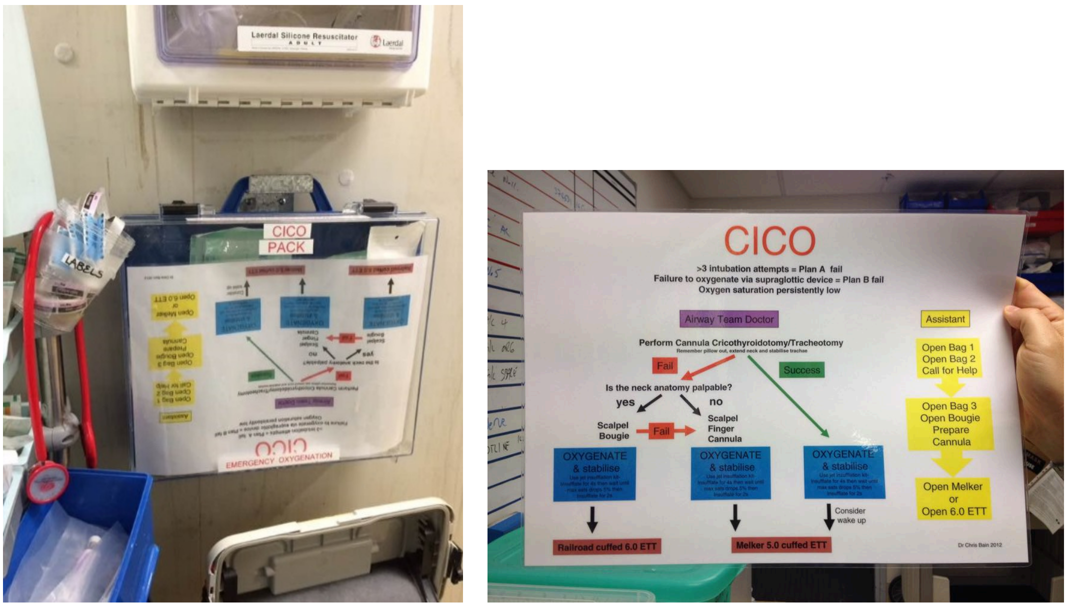


*Figure 2.11.* Can’t Intubate Can’t Oxygenate pack in the operating theatre

### 2.4.6 Limitations of decision support design in anaesthesia

The design of current decision support tools in anaesthesia have deficiencies from a CSE perspective. While they have been derived from best practice guidelines and an intention to consider Human Factors Engineering principles, they did not actually follow a Human Factors Engineering process. In other words, they were designed without an examination of the specific context and cognitive requirements of clinicians intended to use them (Lintern & Motavalli, 2018; Marshall, 2017). Thus, they have been designed with a top down approach and without a thorough understanding of decision-making processes in the anaesthetic environment. That is, current algorithms represent 'work-as-imagined', but are not designed to accommodate 'work-as-done' (Blandford et al, 2014).

The lack of a CSE driven approach resulted in inflexible, linear and standardised formats that focus on clinical content, but do not accommodate the complexity of decision-making in complex healthcare environments (Lintern & Motavalli, 2018). Since most decision-making in anaesthesia is presumably recognition-primed and based on experience rather than option analysis, the current formats of algorithms do not support the cognitive processes underlying decision-making adequately. Indeed, they may even impede the ability of teams to adapt resiliently (McLanders, Sanderson & Liley, 2015). This likely partly explains the large discrepancy between practitioners indicating they would use a cognitive aid in an emergency (80-90%) and practitioners actually accessing them in reality (7%), (Krombach et al., 2015; Marshall, 2017; Mills et al., 2004; Neily et al., 2007).

In healthcare, there is always a gap between how work is prescribed and how work is performed in reality (Cuvelier & Falzon, 2011). Anaesthetic practitioners show much variability in how they make decisions on patient safety, even in situations where clear guidelines exist (Tsai et al., 2017). Experience, production pressures and concerns for patient safety affect these decisions. Concerns for the patient's well-being has been found as one reason to 'violate' protocols (Phipps & Parker, 2014). Consequently, a gap between how work is prescribed and how work is performed in reality is inevitable. Any decision-support design should offer enough flexibility to accommodate this gap and variation in practice. This is exemplified by another study showing that only a small proportion of anaesthetic practitioners view algorithms as 'law-like rules' (Knudsen et al., 2017). Most anaesthetic practitioners view algorithms merely as cognitive aids that provide a plan and high level guidance through difficulties. In order to fulfil this function, they need to be 'simple and easy to follow' (Knudsen et al, 2017).

In conclusion, in order to identify a decision-support tool that is specific to the context in which it is intended to be used, but  considers the variability in work practices ('work-as-done'), a different approach is needed to what has currently been done. 'Work-as-done' can only be considered in the design process if it has been studied with methodological approaches that can elicit relevant knowledge and offer guidance for implementation into design. This the core of CSE (Militello et al, 2009).

## 2.5 Conclusions - current gaps in theory and practice

The literature review revealed that decision-making in anaesthesia is complex and that decision support may be beneficial to aid decision-making in challenging situations. More specifically, the two literature reviews on (1) the study of decision-making in anaesthesia and (2) the current approaches to decision support design in anaesthesia identified theoretical and practical gaps. Both theoretical and the practical gaps can be addressed through the application of CSE

In terms of theoretical gaps, the literature review into human factors in anaesthesia identified that the majority of decision-making studies in anaesthesia focused on human error and what went wrong, rather than studying how decisions were made that led to successful outcomes. A high-level model on decision-making in anaesthesia exists, which has been based on research in other complex sociotechnical environments. However, the RPD model has not yet been explicitly applied and studied in anaesthesia. Finally, the study of decision-making in anaesthesia has not yet been utilised to identify decision requirements for the purpose of decision support design. A CSE approach will address these gaps, specifically the NDM paradigm.

In terms of practical gaps, the literature review into decision support in anaesthesia demonstrated that current approaches to decision support design in anaesthesia is mainly driven by 'work-as-imagined', rather than being based on the study of how experienced anaesthetic practitioners actually make decisions ('work-as-done'). Consequently, current decision support design interventions mainly address knowledge-based reasoning. As identified in the literature review, presumably the current format of decision support tools are not suitable to support the decision-making as occurring in complex sociotechnical environments.

In conclusion, application of the NDM paradigm is currently lacking in anaesthesia, specifically to the design of decision support in airway management. This gap will be addressed and integrated by this research. As discussed in literature review 1, CSE offers suitable frameworks for the study of decision-making in complex sociotechnical systems as well as the development of adequate design interventions.

## 2.6 Theoretical framework and research questions

The aim of this research program is to develop a decision support tool for airway management, based on an enhanced understanding of challenging decisions and the requirements of anaesthesia teams. One key component of decision-making is the recognition of environmental cues which link to familiar actions that were successful in the past (Klein et al., 1989). Recognition of these cues is complex and often implicit, but identifying them can inform more effective equipment design and processes to maintain safety (Klein et al., 1997). For this purpose, critical decisions and their cues have not yet been examined in airway management.

In order to examine how anaesthesia teams make decisions in challenging airway management situations, this research program employed the NDM paradigm. The DCD framework from CSE was employed to identify decision-requirements and link these to potential decision support interventions. Methods from CTA were employed to elicit knowledge from subject-matter-experts as part of the DCD process. The following three overarching research questions guided the DCD process in this research program:

1) *What are the key decisions and their requirements for anaesthetists and anaesthetic nurses in challenging airway management incidents?*
2) *What type of decision support tool is best suited to support the most challenging key decisions and their requirements?*
3) *How does the decision support tool need to be designed to support the most critical key decisions?*

Throughout the PhD research program, two sub-questions were added to research question 1. These sub-questions emerged throughout the PhD research while being immersed with the anaesthetic environment. Therefore, these research questions were added post hoc as it was anticipated they would assist with the journey of identifying decision support for airway management:

*1a) What are the cognitive pathways underlying key decisions of anaesthesia teams?*
*1b) What are the Human Factors enablers and barriers affecting successful airway management?*

While this PhD follows a decision-centred design process, emphasis was placed on the knowledge elicitation phase of subject-matter-experts. Knowledge elicitation for the purpose of decision support design has not yet been performed in anaesthesia. In order to fill this gap, and thus inform theory and clinical practice, this research program placed emphasis on the early knowledge elicitation stages of the decision-centred design process. While a decision support intervention was identified and designed with subject-matter-experts, the iterative refinement of the decision support intervention and its final validation in the clinical setting was not part of this research.

## 2.7 Thesis structure

The main empirical findings of this research program are presented through peer-reviewed publications (chapter 1, 3, 4, 5, 6 and 7). The remaining chapters (2, 8 and 9) are individually written thesis chapters. The peer reviewed publications are briefly introduced and discussed here to link them with the thesis chapters. See Table 2.2 for an overview on the body of the PhD thesis.

*Table 2.2.* Body of PhD thesis – peer-reviewed publications and written chapters

| ***Thesis chapter*** | ***Presentation of empirical work*** | ***Status publication*** |
|---|---|---|
| Chapter 1 - Introduction | *Paper 1 (Editorial):* Schnittker, R. & Marshall, S.D. (2015). Safe anaesthetic care: Further improvements require a focus on resilience. *British Journal of Anaesthesia, 115*(5), 643-645 | Published |
| Chapter 2 – Literature review: Decision-making and decision support design in anaesthesia | *Written chapter* | |
| Chapter 3 - Cognitive Task Analysis methods for knowledge elicitation of anaesthesia providers | *Paper 2*: Schnittker, R., Marshall, S., Horberry, T., Young, K., Lintern, G. (2016). Examination of Anesthetic Practitioners' Decisions for the Design of a Cognitive Tool for Airway Management. In *Proceedings of the Human Factors and Ergonomics Society 60th Annual Meeting* (pp. 1763–67). Washington D.C. | Published |
| Chapter 4 - Key decision pathways in challenging airway management episodes | *Paper 3*: Schnittker, R., Marshall, S., Horberry, T., Young, K., & Lintern, G. (2017). Exploring Decision Pathways in Challenging Airway Management Episodes. *Journal of Cognitive Engineering and Decision Making*, *11*(4), 353–370. | Published |
| Chapter 5 – Human Factors enablers and barriers to successful airway management | *Paper 4*: Schnittker, R., Marshall, S., Horberry, T. & Young, K. (2018). Human factors enablers and barriers for successful airway management – an in-depth interview study. *Anaesthesia*, 73(8), 980-989. http://doi.org/10.1111/anae.14302 | Published |
| Chapter 6- Triangulation, key decision selection and design prioritization | *Paper 5*: Schnittker, R., Marshall, S., Horberry, T. & Young, K. Decision-centred design in healthcare: the process of identifying a decision support tool for airway management. *Applied Ergonomics,* 77, 70-82. | Published |
| Chapter 7 – A comparison of the Recognition-primed Decision-Making model and the Decision Ladder to identify decision support tools for airway management | *Paper 6*: Schnittker, R. & Lintern, G. A comparison of design solutions emerging from the recognition-primed decision model and the decision ladder. *Journal of Cognitive Engineering and Decision Making* | Currently under review (2nd round) |
| Chapter 8 - The decision-support design process of an airway equipment tray for anaesthesia teams | *Written chapter* | |
| Chapter 9 - Discussion & conclusions | *Written chapter* | |

# 3 Chapter 3- Cognitive Task Analysis methods for knowledge elicitation of anaesthesia providers

***Paper 2***: Schnittker, R., Marshall, S., Horberry, T., Young, K., Lintern, G. (2016). Examination of Anesthetic Practitioners' Decisions for the Design of a Cognitive Tool for Airway Management. In *Proceedings of the Human Factors and Ergonomics Society 60th Annual Meeting* (pp. 1763–67). Washington D.C.

## 3.1 Introduction

As already noted, the goal of undertaking this research program was to develop a decision support design intervention for challenging airway management. In chapter 2, a current gap in theory and practice was identified that concerns the link between study of decision-making of anaesthesia teams according to 'work-as-done' and the design of anaesthesia decision support. CSE was identified as the overarching conceptual framework suitable to address the goal of this research (Militello et al, 2009), NDM (Klein, 2008) and DCD (Crandall et al., 2006).

The aim of the study described in this chapter was to provide the rationale for the study framework of this PhD research program. Thereby, this chapter fills in the second phase of the DCD process: knowledge elicitation (see Figure 3.1). The publication associated with this chapter described the five studies associated with the DCD process of the research program. Specific emphasis was placed on how methods from CTA were chosen as the framework for knowledge elicitation and how they consequently formed the basis for the decision-centred design process. The peer-reviewed conference publication concludes with an initial approach of the data analysis of the CDM interviews. Following the publication, a brief retrospective discussion in light of the broader research is provided.

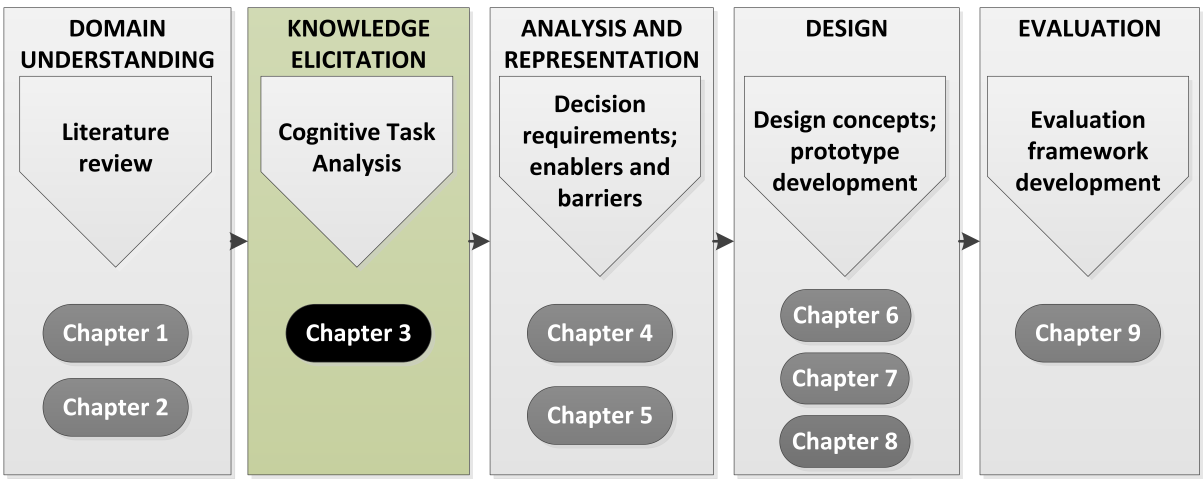


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*Figure 3 1.* The decision-centred design process – chapter 3

## 3.2 Paper 2: Examination of Anesthetic Practitioners' Decisions for the Design of a Cognitive Tool for Airway Management

# Examination of Anesthetic Practitioners' Decisions for the Design of a Cognitive Tool for Airway Management

**Schnittker, R.[1] Marshall, S.D[2]. Horberry, T[1]. Young, K. Lintern, G[1].**

**Monash University Accident Research Centre[1], Department of Anaesthesia and Perioperative Medicine, Central Clinical School[2], Monash University, Melbourne, Australia**

The goal of this research was to examine the decisions made by anesthesia providers in emergency and routine clinical situations relating to airway management. A key function of anesthesia is to ensure oxygen can be delivered to the lungs via a patient's airway. Failure to maintain adequate oxygen levels leads to brain damage and death. The anesthetic work environment is complex. Occasionally, stressful situations occur when difficulties in airway management arise. Members of the anesthesia team must then engage in complex cognitive activities such as rapid, collaborative decision-making. It is suggested that cognitive aids may support decision-making in these situations, although this has not yet been evaluated empirically from a Cognitive Systems Engineering perspective. This ongoing research combined two studies using Cognitive Task Analysis methods as part of a Decision-Centered Design process: observations and Critical Decision Method interviews. These will inform subsequent research phases concerning the development and evaluation of design concepts.

## INTRODUCTION

Anesthesia involves the inhalational or intravenous administration of an anesthetic drug agent in order to achieve either or both a loss of sensation and consciousness. The goal of anesthesia is the elimination of pain and distress to the patient caused by surgical procedures. The patient's airway management is a crucial part of the anesthetic practice, as it ensures oxygen delivery to the patient (Rall & Dieckmann, 2005). The anesthetic team's major concern is to establish an unobstructed airway that provides an opening for airway management support, which assists the patient's breathing mechanisms. (Berkow, 2004; Brodsky et al, 2002). Difficulties that may arise with a particular technique are ideally assessed and planned for pre-operatively (Birnbaumer & Pollack, 2002; Meachin, 2011). However, problems in passing a tube into the patient's trachea may arise due to technical or anatomical challenges. These problems are rare and termed 'difficult intubations' occurring without warning in over half of cases that present difficulty (Paix, Williamson, & Runciman, 2005). Occasionally the technique to manage the airway then needs to be (unexpectedly) adapted after anesthetic induction to secure the patient's oxygenation. Identifying the need and urgency to change techniques is fundamental to safe practice, as prolonged inadequate oxygenation can lead to hypoxia, brain damage, and even death (Cook, Woodall, & Frerk, 2011; Paix et al., 2005). Although complications with airway management are rare, they can precipitate a crisis. A recent nationwide study in the United Kingdom, the 4$^{th}$ National Audit Project (Cook et al, 2011), investigated major airway complications over a one-year period in 2008. Airway complications included were death, brain damage, the need for an emergency surgical airway and unexpected prolonged stay at the Intensive Care Unit. 133 reported events revealed an incident rate of one major complication per 22,000 general anesthetics (0.05%). 33 cases involved brain damage and death (14.3%).

A 'can't intubate, can't oxygenate' event is a feared situation in which a tube cannot be placed in the patient's trachea nor oxygen delivered by either of the other common techniques of facemask ventilation or laryngeal mask insertion. Situations leading up to 'can't intubate, can't oxygenate' events are scarce: both face mask and intubation fail in about 1:5,000-10,000 cases (Cook et al., 2011). Despite its rarity around 25% of all fatal cases as a direct result of anesthesia have been related to 'can't intubate, can't oxygenate' situations (Cook et al., 2011). The transition from less invasive to more invasive airway management techniques in order to rescue the situation is then crucial. These invasive techniques require either a scalpel or needle to be inserted through the front of the neck into the trachea which may result in additional serious complications such as bleeding (Watterson, Rehak, Heard & Marshall, 2014) .

The anesthesia environment is a complex sociotechnical system, where a variety of interacting factors such as dynamic patient conditions, pre-existing pathologies, conflicting activities, time stress, uncertainty, and high stakes, contribute to variability in operational processes (Rall et al, 2014; Xiao, Hunter, Mackenzie, Jefferies & Horst, 1996). Further, members of the anesthetic team have to interact with each other, with other medical professionals (i.e. surgeons and ward nurses), within organizational boundaries, and with patients as well as with advanced technology to accomplish their work. All of these contribute to performance variability. Consequently, a variety of related dynamics contribute to the adequate management of airway crises, ranging from organizational values and their endorsed guidelines of handling crises, to team and individual skills of frontline practitioners.

Complex cognitive processes such as situational awareness, decision-making, teamwork and task management are fundamental in order to accomplish work in the anesthetic environment. The complex nature of the anesthetic environment may induce behavioral patterns contribute to inadequate performance of the anesthetic caregivers. Examples are the tendency to fixate on one particular piece of information in a changing context, or uncoordinated team work (Manser, Harrison, Gaba, & Howard, 2009). Both were related to inadequate performance, and even to harmful patient outcomes in the past (Bromiley, 2009).

This research was undertaken to develop and evaluate a design concept for a cognitive aid for airway management. The aim was to design a cognitive aid able to be used at the time of patient care in a variety of airway management situations. Cognitive aids can be effective in supporting decision-making processes (Marshall & Mehra, 2014) and team coordination (Harrison, Manser, Howard, & Gaba, 2006) in anesthesia.

Cognitive aids such as airway algorithms are well-established in anesthesia (Heidegger, Gerig, & Henderson, 2005). However, they have been designed on the basis of best practice standards. So far, the complex sociotechnical nature of the anaesthetic environment and its impact on practitioners' decisions has not been considered in cognitive aid design (Marshall, 2013). The cognitive aid resulting from this research will be designed based on an analysis of how work is actually performed in the real world ('work as done') (Blandford, Furniss, & Vincent, 2014). Ideally, cognitive aids in this situation also support collaborative decision-making.

**Theoretical framework**

*Cognitive Systems Engineering.* Cognitive Systems Engineering is described as '*an approach to the design of technology, training, and processes intended to manage cognitive complexity in sociotechnical systems'* (Militello et al, 2009). Previously identified, to date no Cognitive Systems Engineering perspective has been applied to the development of decision support for airway management situations. However, airway management involves a variety of 'cognitively complex' activities (e.g. planning, decision making, attention, recognition, etc.) (Klein, 2003, in Militello et al, 2009; Rall et al., 2014). These activities take place in tight interaction with other humans and technology, making anesthesia a 'cognitive system' (Lintern, 2011). The goal of Cognitive Systems Engineering is to support these cognitive activities by reducing the complexity induced by the nature of the work (Militello et al, 2009) .

*Decision-Centered Design.* Decision-Centered Design examines cognitive work from a Naturalistic Decision Making point of view (Nemeth & Klein, 2010). Naturalistic Decision Making studies how decisions are actually made in the field under real world conditions, and how to support these decisions most effectively. Identification of cognitive functions surrounding key decisions offer the most useful information for the development of cognitive support (Crandall, Klein, & Hoffman, 2006). Therefore Decision-Centered Design focuses on the people that actually do the work as the primary source for knowledge gathering. According to Klein (2006), Decision Centered-Design consists of five stages: domain understanding, knowledge elicitation to examine key decisions, identification of leverage points, application of design concepts and evaluation of effectiveness.

*Knowledge elicitation.* Knowledge elicitation in Decision-Centered Design is commonly accomplished by employing methods from Cognitive Task Analysis. Interview and observational techniques are frequently used to explore the cognitive processes of experienced practitioners (Crandall et al., 2006). In anesthesia, the Critical Decision Method (Klein & Calderwood, 1989) was used to study the nature of resilient decision making (Cuvelier & Falzon, 2011). The method was also employed to identify the contributing environmental and psychological influences on human performance in airway management complications (Flin et al, 2013). Observational studies in anesthesia have successfully captured activities and performance shaping factors (Mackenzie, Jefferies, Hunter, Bernhard, & Xiao, 1996; Manser & Wehner, 2002).

While observations in anesthesia reveal few incidents (Cuvelier & Falzon, 2011), observation is a useful complementing method to identify the general strategies practitioners use to cope with actual work demands (Crandall et al., 2006). These processes may not be uncovered when discussing 'notable' incidents in the Critical Decision Method. It is hence useful to triangulate Critical Decision method data with other data collection methods to establish a broader account of the processes that contribute to successful safe anesthetic care. To date, no study in anesthesia has been identified that combined observations and interviews to study naturalistic decisions. No observational studies were identified that elicited knowledge from the anesthesia providers while accomplishing their work.

*The present research.* This research follows the five stages of Decision-Centered Design. Five studies were planned to conform to the Decision-Centered design strategy (see Figure 1). The present paper discusses study 1 and 2, both currently underway. Both studies examined anesthetic practitioner decisions and their requirements, hence how they were made during notable airway management situations during patient care before, during and after surgical procedures (the perioperative period). The two studies are conducted independently of each other, although some practitioners are participating in both.

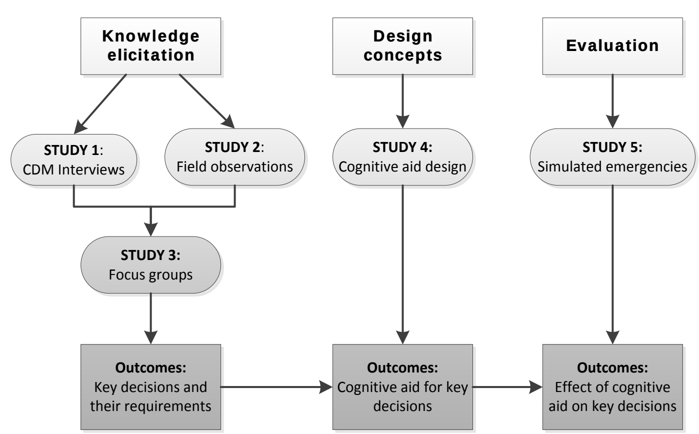


*Figure 1.* Overall research process and individual studies

## METHODS

### Study 1: Critical Decision Method

The aim of the interview study was to identify and understand the key decisions and their requirements in difficult airway management situations. These situations may be unexpected, or previously anticipated. Requirements refer to the cues, potential options and strategies related to the key decisions. Semi-structured interviews were used to elicit this information. The Critical Decision Method (Klein & Calderwood, 1989), a well-known method in Cognitive Task Analysis was used. The Critical Decision Method elicits knowledge within a notable incident the practitioner has experienced in the past. First, a suitable case is identified and described, followed by construction of an incident timeline. Then, a variety of cognitive probes are used to obtain an understanding of key decisions and involved cognitive processes. Generic Critical Decision Method probes found in the literature were adjusted to the anesthetic discipline to meet the goals of this research. Table 1 shows example probes.

- What did you notice when you got first involved in this situation?
- What information did you use in making this decision?
- Did you have any other options, and did you consider them in that moment of time?
- Why did you do it this way?
- Was there something you did that helped you in the situation that other people wouldn't do?
- Was there anything else you did to minimize the risk that this would fail?

*Table 1.* Example Critical Decision Method probes used in this study

*Sample.* Both anesthesiologists and anesthesia assistants were interviewed, as the constituents of the anesthetic team and primary practitioners responsible for airway management ('subject matter experts'). Estimation of required sample size is difficult in qualitative, non-probabilistic research (Guest, Bunce, & Johnson, 2006). Up to 12 interviews for each participant group have been calculated, as guided by the literature (Cuvelier & Falzon, 2011; Flin, Fioratou, Frerk, Trotter & Cook, 2013). Sample size may be adapted during the process, depending on the repetition of themes and airway complications discussed. Eleven interviews have been collected to date with anesthesiologists, and two with anesthesia assistants.

*Procedure.* Ethics approval was sought from and granted by two healthcare organizations and their anesthetic departments. RS (first author) conducted all knowledge elicitation interviews. Following her familiarization with the anesthetic domain, RS scheduled domain practitioners (anesthesiologists or anesthesia assistants) for individual knowledge elicitation sessions. These interviews were conducted in a quiet room within the hospital at which the domain practitioner worked. RS explained the purpose of the research after which, the domain practitioner read and signed an informed-consent form. Interviews were audio recorded for later transcription. Each interview lasted about 2 hours. Before start of the interview, the domain practitioner completed a brief questionnaire about general demographic background and years of experience in the anesthetic domain.

### Study 2: Field observations

The aim of the observations was the prospective identification of decision points and strategies in non-critical situations. This was done in order to complement data obtained from the Critical Decision Method interviews, which are collected retrospectively and focus on critical situations. An abbreviated version of the Critical Decision Method was used to identify decision-points in the actual clinical situation.

*Sample.* A broad range of surgeries were observed, as constrained by the hospitals' surgery schedules and availability of participants. Due to the variety and complexity of patients and type of surgeries, observations were highly varied. However, the observations aim to cover the range of airway management techniques in different surgical situations. A fixed number of observations was therefore difficult to pinpoint; and was instead based on the coverage of airway management techniques in different contexts. Earlier observational research suggests that 24 observations cover a broad spectrum of surgeries (Manser & Wehner, 2002). A similar number is anticipated in this study. Fourteen surgeries have been observed so far.

*Procedure.* Ethics approval was gained from the same two healthcare organizations. After participant information and signed informed consent, anesthesiologists and anesthetic assistants were accompanied during (parts of) the peri-operative period. Due to the nature of anesthetic training, not only attending anesthesiologists but also anesthesia residents were observed. Anesthesiologists and anesthetic assistants were accompanied during the peri-operative period, and intermittently questions concerning their decision-making were asked. The nature of the questions in the observation protocol were semi-structured, and therefore not standardized. Based on the observations that have been conducted so far it was realized that standardized question protocols were not feasible in the fast-paced operating room environment, which constantly requires attention of the anesthesia team. Therefore, the semi-structured questions were adapted to the specific context of the situation.

## ANALYSIS

### Current state of analysis

Transcription of interviews and field notes is ongoing and data analysis has commenced. As the first step in data analysis, key decisions have been identified by analysis of the incident trajectories that domain practitioners described in the Critical Decision Method interviews. Incident timelines obtained from individual domain practitioners to identify generic decision points. To isolate those key decisions that preserve the overall goal of safe airway management, the level of coding granularity was established by means of an activity hierarchy. Under the assumption that the concept of a goal is related to an activity that acts towards that goal (Vicente, 1999), key decisions were viewed as those that were aimed at preserving the high level goal of 'safe' or resilient airway management. Thus, critical decision points were defined as being directly related to airway management. As seen in Figure 2, most critical decisions identified through this analysis relate to the transition between airway management techniques.

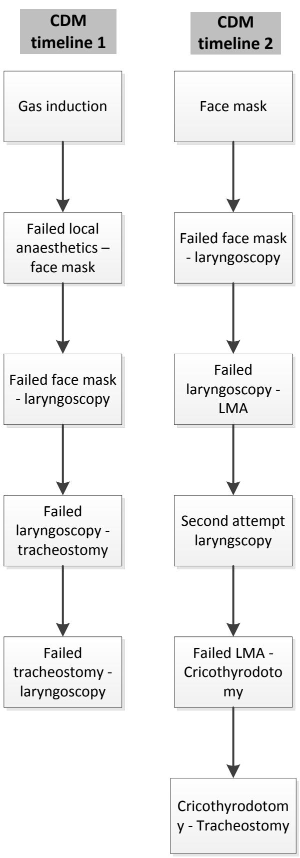


*Figure 2*. Two examples of incident trajectories collected from the Critical Decision Method interviews so far. Hyphens indicate transition between airway management techniques.

### Further analysis

After identification of the generic decision points, interviews were further coded to explore decision requirements such as cues, options and experience. Decisions will then be classified into decision types to identify the underlying cognitive mechanisms (Klein, Calderwood & Clinton-Cirocco, 2010). More abstract decision themes will be derived at a later stage to reduce the data on a more abstract level. Decision themes will relate to the clinical content and will most likely summarize type of transitions between airway management techniques. For example, 'transition between non-surgical techniques' and 'transition from non-surgical to surgical technique.

## WORK IN PROGRESS

Collection of interview and observational data are ongoing. Meanwhile, the data are being further analyzed and decision requirements for individual decision points are being coded in the transcriptions. These data will then be validated using focus groups; and will be the basis for the development of design concepts for a cognitive aid for airway management. It is anticipated that the design will then be evaluated in simulated emergencies with a relevant sample of anaesthetic care providers. We anticipate that examination of anaesthetic practitioner's decisions will lead to an appropriate cognitive aid for airway management.

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## 3.3 Discussion

This chapter provides a rationale for the chosen study framework of this research program. A CSE process has not yet been applied to the design of a decision support intervention for anaesthesia. The study framework proposed the CDM, field observations and focus groups as the basis for the knowledge elicitation of decision requirements. Therefore, this study fills a gap in both theory and practice.

As outlined in the publication, the CDM has been previously employed in healthcare, including anaesthesia, to study decision-making processes of clinicians (e.g. Cuvelier & Falzon, 2011; Fackler et al., 2009; Gazarian, Carrier, Cohen, Schram, & Shiromani, 2015; Gazarian, 2013; Pauley, Flin, & Azuara-Blanco, 2013). A literature review identified that the CDM has been useful to identify the subtle and context-specific cues nurses use during critical events (Gazarian et al, 2015; Gazarian, 2013). Flin et al (2013) and Cuvelier and Falzon (2011) successfully used the CDM in anaesthesia to study human factors contributing to airway management complications, as well as the nature of resilient adaptation in challenging situations.

The CDM has also been specifically applied with the goal to study cognitive processes underlying decision-making in clinical situations. Fackler et al (2009) studied cognitive activities of critical care physicians in the context of work flow and work hour limitations. The CDM identified that decision-making of critical care physicians was based on pattern matching, as well as a balance between strategic and tactical problem solving. Pauley et al (2013) examined cognitive processes underlying decision-making of ophthalmic surgeons. They found that half of the decisions made followed a recognition-primed strategy without comparing options, while the other half followed an analytical strategy that involved a concurrent comparison of alternatives. The particular decision strategy was not influenced by the presence of time pressure. Based on its successful use in healthcare to study cognitive activities such as cue perception, adaptation and decision strategies, it is anticipated the CDM will be beneficial to study decision-making processes of anaesthesia teams.

However, to date the CDM has been rarely employed to also identify decision support requirements for the design of a decision support design intervention. Militello et al (2016) examined critical incidents of experienced practitioners to identify design features for a colorectal cancer screening decision support. Fackler et al (2009) provided some high level suggestions for the re-design of critical care physicians work flow. However, Militello et al (2016) started off with the idea of a particular decision support tool (i.e. a software application embedded in electronic health records). Fackler et al (2009) only provided high level recommendations that were not specifically related to the outcomes of the CDM. In this regard, this research program will fill a gap in theory by directly linking outcomes of the CDM to decision requirements for the purpose of decision support design.

Furthermore, the triangulation of qualitative research methods such as interviews and focus groups is beneficial to enhance the richness of the data and to gain a better understanding of the specific context of the phenomenon under study (Lambert & Loiselle, 2008). In the context of decision support design for complex sociotechnical environments, triangulating data from different perspectives is particularly important (Papautsky, Crandall, Grome, & Greenberg, 2015). According to Papautsky et al (2015), triangulation should be embedded in the standard practice of Human Factors Engineering. Therefore, it is anticipated that the triangulation of multiple research methods with both anaesthetists and anaesthetic nurses will be of value for the identification of suitable design concepts.

### 3.3.1 Changes in study framework

A number of changes have been made to the study framework as proposed in this original publication. Despite the original goal to conduct field observations to collect data on 'the general strategies' subject-matter experts employ regularly in the real world, a systematic data collection has not proven to be fruitful. The field observations collected as part of this study did not uncover strategies that were extraordinary or acquired through particular personal experiences by the subject-matter-experts. Rather, the strategies were considered as standard routine care processes. This finding agrees with the highly protocolled nature of anaesthesia (Berkow, 2004). The collected data did not add greatly to the identification of decision requirements. Nevertheless, some observations of work processes and the anaesthetic environment were triangulated with the CDM and focus group findings at a later stage (see chapter 5).

DCD is concerned with the study of decisions in particularly challenging situations (Militello & Klein, 2013). While the prospective nature of field observations is beneficial to gain insight into the complexity of work environments (Roth & Patterson, 2002), they have been less fruitful to study infrequent challenging events in anaesthesia (Cuvelier & Falzon, 2011). Therefore, it was decided to use the observations for the domain familiarisation phase only. Consequently, the triangulation of the CDM interviews and the focus groups was used as the foundation for the identification of decision requirements and the development of decision support design concepts.

### 3.3.2 Conclusions

The study presented in this chapter further detailed the framework for the thesis' research program. As aligned to the DCD process, the knowledge elicitation of subject-matter experts is accomplished using methods from CTA. Based on the triangulation of the methods, decision support design concepts are developed. Therefore, in the next chapter, the findings of the CDM interviews are presented.

# 4 Chapter 4- Key decision pathways in challenging airway management episodes

## 4.1 Introduction

***Paper 3***: Schnittker, R., Marshall, S., Horberry, T., Young, K., & Lintern, G. (2017). Exploring Decision Pathways in Challenging Airway Management Episodes. *Journal of Cognitive Engineering and Decision Making*, *11*(4), 353–370.

This study presents the first set of findings emerging from the CDM interviews. The primary aim was to identify the decision pathways underlying key decisions made in challenging airway management situations. This study also describes some initial findings of the CDM interviews by presenting decision requirements tables as well as initial decision support design ideas. Thereby, this study addresses the first and second research question guiding this research program. Lastly, this study discusses the application of the RPD model in the context of the findings.

Based on decision-making research in other complex sociotechnical environments, decisions in anaesthesia are presumed to be recognition-primed (Gaba, Fish, Howard, & Burden, 2014; Mildner et al., 2006; Rall et al., 2014). However, the cognitive pathways underlying decision-making during challenging anaesthesia events have not yet been formally examined. In particular, the goal of this study was to identify if decision-making followed a recognition-primed pathway (indicated by an absence of alternative option assessment) or an analytical pathway (indicated by presence of alternative option assessment).

In order to examine the decision strategies, this study utilised the decision strategy coding framework from the original firefighter study finding evidence for recognition-primed decision-making (Klein et al., 1988; Klein,et al, 2010). This study is part of the third phase of the DCD process: analysis and representation (see Figure 4.1).

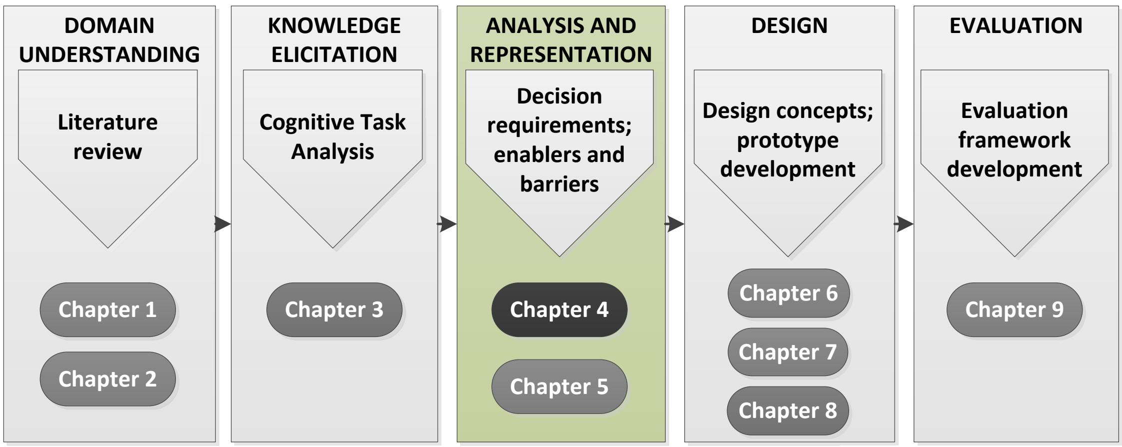


*Figure 4.1.* The decision-centred design process – chapter 4.

## 4.2 Paper 3: Exploring Decision Pathways in Challenging Airway Management Episodes

# Exploring Decision Pathways in Challenging Airway Management Episodes

**Raphaela Schnittker**, **Stuart Marshall**, **Tim Horberry**, **Kristie Young**, and **Gavan Lintern**, Monash University, Melbourne, Australia

Anesthesia takes place in a complex, high-stakes environment where humans and technologies interact to provide medical care to patients. Providing adequate decision support for individuals and teams in anesthesia emergencies is important because emergencies are infrequent and complex. Current designs of decision support in airway management are not context specific and lack a consideration of how decisions are made under time pressure. To fill this gap, this study used frameworks from cognitive systems engineering to explore decisions of experienced anesthesia providers. The goal was to identify the decision pathways used in challenging airway management situations. The critical decision method was employed to interview anesthesia providers about a challenging incident they had experienced. Results illustrated that decisions were based on prior experience and made through a process of recognition. The vast majority of decisions were recognition primed, characterized by a direct link between cue familiarity and action generation. A few decisions involved concurrent option comparison, which was still based on situation recognition. Different cues received through teamwork, technologies, and patients contributed to the decisions. As different cognitive pathways may require different design solutions, the findings of this study are being used to help develop decision support tools in anesthesia.

**Keywords:** recognition-primed decision making, topics, cognitive task analysis, methods, health care delivery, domains, cognitive systems engineering, topics

Address correspondence to Raphaela Schnittker, Monash University Accident Research Centre, 21 Alliance Lane, Clayton Campus, Clayton VIC 3800, Australia, raphaela.schnittker@monash.edu.

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## INTRODUCTION

*Airway management* refers to the support of a patient's breathing functions by oxygenating and ventilating the lungs (Rall & Dieckmann, 2005). It is an essential requirement for a patient under general anesthesia, when a reversible loss of consciousness and an inability of the patient to maintain autonomous breathing are induced. Apart from anesthesia in the operating room, airway management is also undertaken in other high-technology areas, such as the emergency room and intensive care unit. In Australia, activities are typically performed by an anesthetic or other critical care specialty–trained consultant and an anesthetic nurse who provides support (Rutherford, Flin, & Mitchell, 2012). Complications in airway management occur infrequently, in about one of 22,000 cases of general anesthesia (Cook, Woodall, & Frerk, 2011). However, despite their rarity, these are major complications related to death, brain damage, surgical airways, and prolonged stays at the intensive care unit. They therefore pose a high risk to patient safety.

We explored decisions made by anesthesiologists and anesthetic nurses in challenging anesthetic episodes. The study is part of a broader research program that is aimed at designing and evaluating decision support for airway management in anesthesia. This study framework has been described elsewhere (Schnittker, Marshall, Horberry, Young, & Lintern, 2016).

### Anesthesia as a Complex Sociotechnical System

The anesthetic environment shares common characteristics with other complex sociotechnical systems, such as an interaction between people, tools, and technology in dynamic, high-risk environments. Activities performed by people in such complex sociotechnical ("naturalistic") environments are typified by time constraints, uncertainty, high stakes, ill-defined goals, action feedback loops, multiple actors, and organizational influences (Orasanu & Connolly, 1993).

Due to the high-risk environment, both anesthesiologists and anesthetic nurses are required to have a high level of training before practicing. Before becoming a consultant, anesthesiologists must fulfill at least 5 years of training after obtaining their medical degrees (Australian and New Zealand College of Anaesthetists [ANZCA], 2012). In Australia, anesthetic assistants are often nurses and typically have to undertake further study in addition to their 3 years of basic nursing training.

## Airway Management Activities

The anesthetic team performs a variety of airway management activities occurring in four consecutive phases: preinduction, induction, maintenance, and emergence of anesthesia. Before induction of anesthesia, usually an airway assessment takes place. This assessment involves an examination of the patients' medical history and airway anatomy to estimate potential difficulties in managing the airway (Berkow, 2004). Airway assessment is done using a variety of tests, for example, extending the neck or examining visible airway structures. In this phase, decisions relate to the degree of airway assessment and the choice of appropriate airway techniques. The choice of technique depends on the patient's anatomy, physiology, and required surgery. Techniques differ in their degree of invasiveness and can involve face masks, breathing (endotracheal) tubes, or surgical airways (Berkow, 2004).

In the induction phase, the patient is put to sleep with anesthetic medications, and the patient's airway is established with the chosen technique. Most activities occur during the induction phase and regularly concern routine and procedural task steps (Manser & Wehner, 2002). While the surgery is being performed and anesthesia is maintained, the main activity is vigilant monitoring of the patient's physiology (Phipps, Meakin, Beatty, Nsoedo, & Parker, 2008).

After surgery is finished, the patient is woken up and the airway removed. This phase involves discontinuing the anesthetic agents, establishing autonomous breathing, and organizing adequate postoperative care and transfer (Berkow, 2004; Phipps et al., 2008).

## Airway Management Challenges

Although anesthesia is described as a "model for patient safety" (Gaba, 1999), occasionally challenges in airway management arise, such as when oxygenation of the patient is delayed because the insertion of an endotracheal tube is difficult, the placement of a face mask is difficult, or both (Apfelbaum et al., 2013). This situation usually occurs in the induction phase of anesthesia, and requires the anesthetic team to decide on courses of actions to secure the patient's oxygenation.

Airway management challenges can occur both expectedly and unexpectedly. About half of difficult airways are unexpected (Paix, Williamson, & Runciman, 2005), reflecting the degree of uncertainty apparent in the anesthetic environment. Whereas expected difficult airways can be well planned for, unexpected difficulties need to be handled by employing generic backup plans (Cook et al., 2011). Universally, forward planning is fundamental to broaden the safety margins related to successful oxygenation and ensuring backup strategies are in place (Rall & Dieckmann, 2005).

## Anesthetic Team Decision Support

A variety of tools and technologies are available for the anesthetic team to support decisions in airway management, both expected and unexpected ones. Next to direct patient observation, mostly important are the capnography, the measurement of exhaled carbon dioxide; pulse oximetry; and the measurement of blood oxygen content (ANZCA, 2015). Multiple guidelines and algorithms have also been developed locally and by national airway societies to support decision making in both unexpected and expected airway challenges (Apfelbaum et al., 2013; Frerk et al., 2015).

*Cognitive aids and algorithms.* Cognitive aids in the form of branched algorithms are often provided along with guidelines. Cognitive aids give a visual representation of the sequential steps to secure a patient's oxygenation and avoid fixation on a particular technique (Heard, Green, & Eakins, 2009; Heidegger, Gerig, & Henderson, 2005). The rare but crucial decision to transit to a surgical airway in a "can't intubate, can't oxygenate" situation is a ubiquitous part of guidelines and algorithms, and the final resort to secure a patient's airway (e.g., Heard et al., 2009; Marshall & Mehra, 2014; Watterson, Rehak, Heard, & Marshall, 2014).

Decision support in the form of cognitive aids has been suggested to be beneficial; however, the usefulness at the actual time of airway management has been challenged (Goldhaber-Fiebert & Howard, 2013; Marshall, 2013). Although around 80% of practitioners have positive attitudes toward using cognitive aids, such as emergency checklists (Marshall & Mehra, 2014; Ziewacz et al., 2011), only 7% actually utilized them in observational studies (Neily et al., 2007).

The limited use of cognitive aids and algorithms in emergencies has been attributed to their complex design. Cognitive aids have been designed according to how work should be done as intended by management (Blandford, Furniss, & Vincent, 2014). However, they are not always suitable to be used in stressful situations where decisions have to be made under time pressure (Marshall, 2015; Watterson et al, 2014).

## Decision Making in Complex Sociotechnical Systems

In complex sociotechnical environments, experienced people usually make decisions by recognizing familiarity (Klein, Orasanu, Calderwood, & Zsambok, 1993). This process of deciding is termed *recognition primed* (Klein, Calderwood, & Macgregor, 1989; Klein, Calderwood & Clinton-Cirocco, 2010). The recognition-primed decision-making (RPD) model (Klein et al., 1989) describes decision making as a situational assessment that is followed by the generation of typically successful actions based on prior experience.

The crux of recognition-primed deciding is that courses of action linked to recognition are evaluated serially, not concurrently. This process can occur in three variations. On the most basic level, situations are recognized as instances of prototypes, and the first course of action identified is used. Some situations may require some more clarification and "story building" before prototypical actions are matched. Finally, courses of actions can be evaluated by mentally simulating their outcome. If the identified course of action is not expected to work, the next option will then be identified (Lipshitz, Klein, Orasanu, & Salas, 2001).

The original RPD study showed that up to 80% of decisions made by experienced firefighters were recognition primed ("prototypical"). Rarely, concurrent option analysis was used (Klein et al., 1993). See Table 1 for the coding categories that were used to analyze decision pathways and their frequency of occurring in the original study.

Different decision pathways lend themselves to different types of decision supports (Bisantz & Roth, 2007; Klein et al., 2010). For example, decisions involving a high degree of deliberation or novel construction may require different supports than those that are recognition primed and involve rule-based knowledge (Rasmussen, 1983). Thus, current cognitive aids need to be improved to make them more suitable for the specific environment they are intended to be used in (Degani & Wiener, 1993; Marshall, 2013). Doing so requires an understanding of the decision strategies as they occur in the anesthetic environment where airway management is performed.

## Cue Recognition and Situation Awareness

The recognition of familiar cues is essential to RPD (Klein et al., 1989). It is part of the situation diagnosis and relies on *situation awareness*: a mental state of perceiving and comprehending critical elements in the environment and anticipation of their meaning for the future (Schulz, Endsley, Kochs, Gelb, & Wagner, 2013).

Identifying the cues people use to actually make decisions is relevant to gain insight into the design of adequate decision support tools (Klein, Kaempf, Wolf, Thorsden, & Miller, 1997). The decision support tools should then make these cues more salient to aid their recognition and action generation. As cue recognition is a nonverbal cognitive process, knowledge elicitation techniques are required to verbalize them for analysis.

**TABLE 1:** Decision Coding Categories Used to Analyze Key Decisions in Firefighter Study (Klein, Calderwood, & Clinton-Cirocco, 2010)

| Decision Type | Description of Strategy | Frequency of Occurrence in Original Study |
|---|---|---|
| Prototypical | Recognition of typical cues linked to typical actions that have usually been successful in the past. Rule based ("if *X*, do *Y*") and context specific. | 114 |
| Deliberate | Contrasting two or more options regarding their best match to the situation. No thorough analysis of all attributes but focus on a few important dimensions. Often involved in team decision making under reduced time pressure. | 10 |
| Analog | Pattern matching by drawing upon a specific experience. With increasing experience, analogues become prototypes instead of specific instances. | 3 |
| Procedural | Similar to a prototypical strategy; however, can be applied without context. | 0 |
| Constructed | Novel approach to solve a problem, typically in novel or ambiguous situations. Knowledge based, involves sensemaking and story building. | 7 |
| Total | | 134 |

## Knowledge Elicitation in Complex Sociotechnical Systems

The critical decision method (CDM) is an interview technique used to elicit knowledge from experts (Klein et al., 1989). The CDM has been useful to examine decision making in variety of complex sociotechnical domains, such as anesthesia (Flin, Fioratou, Frerk, Trotter, & Cook, 2013), nursing and surgery (Fackler et al., 2009; Gazarian, Carrier, Cohen, Schram, & Shiromani, 2015; Pauley, Flin, & Azuara-Blanco, 2013), mining (Horberry, 2010), and traffic safety (Cattermole, Horberry, & Hassall, 2016). Elicited knowledge from the CDM can provide the basis for the design of decision support (Crandall, Klein, & Hoffman, 2006; Klein et al., 1997). The usefulness of the CDM to identify decision requirements for the complex sociotechnical system of traffic incident management has recently been validated (Cattermole et al., 2016).

## Aim of Current Study

The goal of the present study was to identify the cognitive pathways underlying decisions in challenging airway management situations. This research was done by employing a similar decision type categorization as in the original firefighter study described in Klein and colleagues (2010). Specifically, the current study categorized cognitive pathways as *prototypical, deliberate, analog*, and *constructed* (see Table 1). The results of this study will be used to design a decision support tool for airway management.

Due to the high level of experience required to work in the anesthetic domain, it was expected that key decisions would mainly be recognition primed and involve a prototypical decision pathway. This result was expected because of the emphasis on rule-based procedures in anesthesia and the time pressure that typically underlie unexpected challenging situations. As teamwork is highly important in anesthesia, it was also expected that some decision pathways would be deliberate. Last, as anesthetic activities occur in an environment of high sensory and cognitive load, it was expected that many different environmental cues would contribute to the situation awareness of practitioners and the recognition of familiar events.

**TABLE 2:** Years of Experience of Participants

| Occupation | 0–5 Years | 6–10 Years | 11–15 Years | >15 Years | Total |
|---|---|---|---|---|---|
| Anesthesiologist | 1 | 1 | 2 | 8 | 12 |
| Anesthetic nurse | 1 | 0 | 1 | 2 | 4 |
| Total | 2 | 1 | 3 | 10 | 16 |

## METHOD

### Participants

Twelve anesthesiologists and four anesthetic nurses participated in the CDM interviews. Participants were recruited from two public hospitals in the greater Melbourne, Australia, area. Experience in anesthesia differed, but most participants had worked in the anesthetic domain for more than 10 years (see Table 2). Recruitment of participants was voluntary. E-mails were sent to anesthetic departments, and flyers were distributed in the hospitals and operating theaters. Participants then contacted the researcher and agreed to be interviewed. Some participants mentioned the study to colleagues, who then contacted the researcher for an interview (snowball sampling). The participants were not reimbursed for their participation.

Sample size was guided by the literature on data saturation in qualitative research. For a group sharing common characteristics, data saturation may be sufficient from six interviews (Guest, Bunce, & Johnson, 2006). Only four anesthetic nurses were interviewed due to a subjective estimation of data saturation. As anesthetic nurses are not the active decision makers, are mainly supportive in their role, and do share common characteristics with anesthesiologists, four interviews was deemed enough to explore the relevant themes.

### Procedure

Ethics approval was obtained from the human research ethics committees of both hospitals, the hospital anesthetic departments, and Monash University. The interviews were conducted by one interviewer (first author) using an audio-recording device for later transcription. All interviews were confidential. The participants were interviewed in their leisure time, usually before or after their shift or during their break. The duration of the interviews varied between 1 and 2.5 hr.

Before the interview commenced, participants were given an informed consent to sign. They were interviewed in their hospital of employment except that one participant was interviewed in her private home due to an injury that prevented her working. All interviews took place in a quiet environment to eliminate interruptions and to protect confidentiality. After participants signed the informed consent, the interview process of the CDM was explained.

The interview itself followed the traditional process of the CDM and therefore involved four "sweeps": *incident selection, incident timeline creation, deepening probes*, and *hypotheticals*. First, participants were asked to think about a notable airway management challenge they have experienced in their past. Some people acknowledged they have not been in an airway crisis but have experienced challenging situations that required expert decision making. The interviewer acknowledged that the case does not necessarily need to be a crisis but can also be a notable event that could have been potentially dangerous and where key decisions had to be made to keep the patient safe. Generally, the interview focused not on what went wrong in the airway challenges but on the decisions that kept the patient safe throughout the incident.

Some participants reported several challenges they had experienced. In these cases, the participant and interviewer then decided together which case was chosen for the interview. Incident selection was based on the participant's memory, his or her degree of active involvement in the decisions, and the variety of decisions relating to airway management. After selection of the incident, the participant gave a detailed summary. Subsequently, an incident timeline was created by the interviewer. Together with the participant, the interviewer filled the timeline

**TABLE 3:** Critical Decision Method Deepening Probes, Adapted From Klein, Calderwood, and Macgregor (1989)

| Theme | Example Questions |
|---|---|
| Cues | What did you notice? What did you see, hear . . . ? What alerted you to this? |
| Decisions and resilience | What decision did you make? Why? What exactly did you do to keep the patient safe? Who else was involved? Did you do anything in particular to ensure patient safety? |
| Options | Did you consider any other options? Would there have been other options in hindsight? |
| Experience | How did you know how to make this decision? Would you have done this decision with less experience? |
| Goals/expectations/consequences | What were your expectations when making this decision? Did you imagine any consequences? What were your goals? |
| What if | What would you have done if *x* had happened? |
| Decision support | Would it be helpful to support any of these decisions? How? What could help less experienced people/what would have helped you in your early years of training? |

with the key events that contributed to the unfolding and managing of the situation. It was focused on the primary decisions, but other events that contributed to the key decisions were also included on the timeline (e.g., observations and interactions with other people and technology). Once the incident timeline was created, decisions were explored with deepening probes to identify why and how decisions were made. The probes used in this study were derived from the CDM literature and adapted to suit the clinical context (see Table 3 for example probes).

The traditional CDM process indicates a final sweep, the probing of hypotheticals (“what ifs”). Although this probe was initially done as a separate sweep in the interviews, it was noticed that there was much repetition and a significant increase in duration of the interview. The probing of hypotheticals was consequentially merged with the general deepening probes from Sweep 3.

## ANALYSIS

The interview data were deidentified, transcribed, and uploaded in NVivo 10. After the transcripts were uploaded, the interviews were coded and further analyzed. To analyze patterns and relations in the data, crosstabs and framework matrices were created. The focus was on the coding of decision points, cues, and decision pathways.

### Decision Point Coding

The data coding followed the principles of a thematic analysis (Ryan & Bernard, 2003). Text fragments covering a particular theme (e.g., a fragment that was about a particular decision) were labeled with a code that was created in NVivo. The coding of the data was a complex multistage process, which resulted in a hierarchical coding structure.

First, all key decisions were coded throughout the interview transcripts. These decisions were often large fragments of text because each decision was discussed in great detail. The fragments were further coded for decision type category and other CDM probes (e.g., cues, expectations, mentioned options). Finally, these codes were further refined on a more detailed descriptive level. For example, environmental cues identified were further coded into the type of cues (e.g., noticing blood in the airway, noticing dropping levels of oxygen saturation).

### Defining and Classifying Decisions in This Study

Before coding of the data, definitions for decisions were developed and a coding book created. The term *primary decision* was used instead of *critical decision* to avoid any confusion with the term *critical care* prevalently used in health care. Although primary decisions for each interview were apparent, individual timelines varied in their level of detail. To reach consistency across interviews, decisions were coded in retrospect. In naturalistic decision making, deciding is described as a commitment to an action in a situation with multiple plausible alternatives, following a process of perception and recognition (Klein, 2008). These alternatives may or may not be conscious to the person at that time. This situational recognition initiates generation of adequate responses ("situation–action matching"; Lipshitz et al., 2001).

In this study, a *decision* was defined as any pathway taken by the anesthesia providers that impacted the management of the patient's airway. Alternatively, an activity that is part of a routine sequence to accomplish a chosen course of action (e.g., intubation of a patient) did not count as a decision (e.g., paralyzing the patient after anesthesia induction). However, if a course of action had been decided to be done differently for some reason (e.g., postponing an activity), it was counted as a decision because it deviated from a standard routine.

*Primary and secondary decisions*. Due to the complexity of the medical environment, it was necessary to distinguish between primary decisions and secondary decisions. Primary decisions were made independently and secondary decisions were directly related to primary decisions. Secondary decisions concerned the implementation of the primary decision through particular strategies. For example, if a primary decision was to have another attempt at intubating a patient, a secondary decision was then to use a different type of tube for that attempt. Hence, the secondary decision was related to the primary decision and could not have been made independently.

*Decisions made by anesthetic nurses*. The 16 interviews revealed that the decisions were mainly made by the anesthesiologists. The four interviews with the anesthetic nurses indicated that although they supported the anesthesiologists' decisions with specific behaviors, they were generally not active decision makers. Behaviors by experienced anesthetic nurses that contributed to the anesthesiologists' decisions were named *backup decisions* and were defined as actions oriented toward securing oxygenation that were not directly impacting airway management but that contributed to key decisions made by anesthesiologists. Examples included informing the anesthesiologist on oxygen saturation levels or suggesting additional equipment when airway management was observed to be difficult.

*Coding of decision types*. In order to code the decision types, we used a similar coding categorization as in Klein and colleagues (2010). Specifically, we distinguished between prototypical, deliberate, analog, and constructed decisions. The procedural and prototype categories from the original study were merged, because these decisions differ only in that the procedural decision can be implemented independent of context, whereas the prototype decision needs rich context (Klein et al., 2010). As anesthesia is a context-rich environment and decisions are highly context dependent, procedural decisions are therefore prototypical (see Table 1).

### Coding Process and Interrater Reliability

All interviews were initially coded by the first author. Reliability of the coding done by the first author was assessed on two levels: the clinical level and the coding of decision types.

On the clinical level, once key decisions were identified and coded in the transcripts, an experienced anesthesiologist validated them in respect to their clinical relevance ("Are these notable decisions or standard procedures?"). The first author developed a document that included a list of the decisions initially identified. Interview quotes were provided next to the decisions to give context and reflect their labeling. After validating the list, the anesthesiologist recommended that two decisions listed as two separate ones should be merged together, as they could be summarized as one unique decision. The coding of decisions was adjusted accordingly.

Next, the reliability of the coding of decision categories was independently assessed by a second coder experienced in human factors and coding CDM interviews. The first author prepared a document listing the key decisions with

**TABLE 4:** Number of Decisions/Strategies and Their Cognitive Pathway per Operative Phase

| Operative Phase | Prototype Decision | Deliberated Decision | Analog Decision | Constructed Decision |
|---|---|---|---|---|
| Preinduction | 18 | 1 | 2 | 0 |
| Induction | 66 | 7 | 0 | 0 |
| Maintenance | 0 | 0 | 0 | 0 |
| Emergence | 2 | 0 | 0 | 0 |
| Total | 86 | 7 | 2 | 0 |

*Note*. Two decisions were double coded as both prototypical and analog.

interview quotes that represent the decision types. These were already categorized by the first author but were not shown to the second coder. Additionally, a code book was prepared for use by the second coder that defined the decision types according to Klein and colleagues (2010).

Out of the 94 individual decisions to be coded, the two researchers had seven disagreements (κ = .64), an interrater agreement of 94%. The two coders disagreed about whether seven decisions were either deliberated or prototypical. The coders each explained their reasoning as to why they chose the particular decision type. In four cases, decisions that were coded as deliberate by the first author were changed to prototypical after discussion, as it was agreed that the practitioner had already made the decision and only briefly confirmed it through discussion with colleagues. This discussion with colleagues, however, did not involve deliberation about any options. For the remaining three cases, deliberate decisions coded by the first author were not changed after discussion.

## RESULTS

### Decision Points

A total of 73 primary decision points were extracted from the interviews. Moreover, a total of 16 secondary and four backup decisions were found. Out of these, the thematic analysis identified 39 unique primary, eight secondary, and two backup decisions. Anesthesiologists made the vast majority of primary decisions ($n$ = 68) and secondary decisions ($n$ = 16). Only two primary decisions (calling for help and declaring a difficult airway situation to attending staff) were made by both anesthesiologists ($n$ = 12) and anesthetic nurses ($n$ = 5). All backup decisions were made by anesthetic nurses. Twenty decision points were related to preinduction of anesthesia, 72 related to anesthesia induction, none related to anesthesia maintenance, and two related to the emergence of anesthesia. The majority of decision pathways were prototypical (91.4%), followed by deliberated (7.5%). Two analog (2.2%) decisions were found. None of the decisions discussed were constructed (see Table 4 for a summary of all decisions found).

### Decision Pathways

*Prototypical decisions*. The vast majority of decisions were recognition primed and thus revealed a process of prototypical matching. An example of a prototypical decision in this study is the transition from a failed laryngoscopy to ventilation with a bag mask (see Figure 1). The anesthesiologist planned to intubate a sick patient with a tube. After insertion, the tube was connected to the anesthetic machine. The anesthetic machine was connected to a bag that was first squeezed by the participant to “get a feel for how oxygen goes in” and then connected to the anesthetic machine. The participant noticed that the bag remained hard and it was impossible to squeeze and, hence, get oxygen into the patient through the tube. This situation was a typical one for the participant, as difficult intubations occur on a regular basis. The failed intubation was further confirmed by the low, nonimproving oxygen levels and no capnometry trace. All these cues lead to the typical action of removing the tube and transitioning to ventilate the patient with a bag mask.

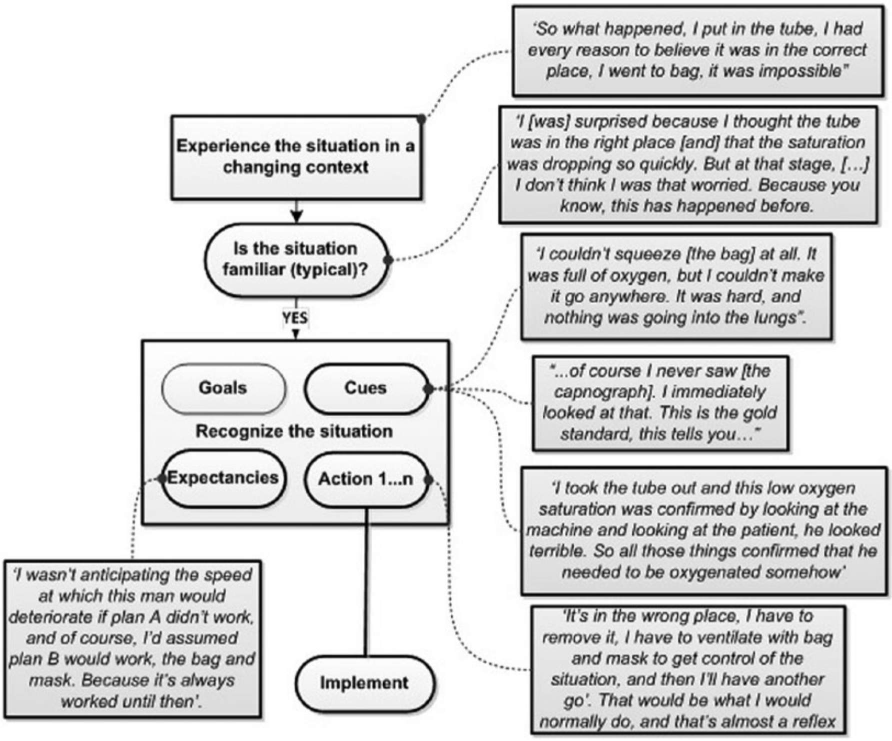


*Figure 1.* Example of a prototypical pattern-matching route for the decision to transit from a failed laryngoscopy to bag mask ventilation. Adapted with permission from Klein (1989).

*Deliberate decisions*. An example for a deliberate decision in this study was the decision to choose between waking the patient and aborting surgery versus employing an asleep fiber-optic approach. Both courses of actions were identified to match the situational assessment most appropriately and were discussed while the patient's oxygenation was secured with a bridging technique. Because this bridging technique reduced time pressure, it provided some time for deliberation.

*Analog decisions*. The two analog decisions found in this study were made in a situation similar to a case that had happened recently. The case involved a patient with severe breathing problems due to swelling in the throat. First, the anesthesia team decided to perform a fiber-optic examination of the airway to clarify the situation. Then, the team decided to induct the patient with anesthetic gas while also having the surgical airway equipment ready to be used in case this method failed. Both decisions were made in a similar scenario that, coincidentally, occurred on the same day. The anesthesiologist specifically drew on the experience with that previous case while making these decisions. The two decisions were also coded as prototypical (the only ones double coded). This coding was done because the anesthesiologist acknowledged that although the previous case was similar and therefore not much active decision making was involved, it would have been the "traditional method" of handling the situation.

*Constructed decisions*. None of the decisions found were based on a novel approach. All situations experienced were known to the anesthesiologists and anesthetic nurses, and generic actions could be adopted.

*Backup decisions*. The decision to call for help was made only during the induction phase and was the unique primary decision made by both anesthesiologists and anesthetic nurses. Otherwise, anesthetic nurses used what we

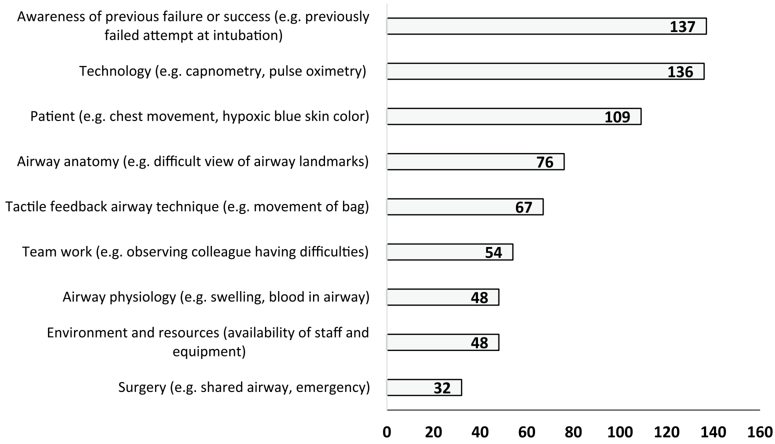


*Figure 2.* Cue categories related to key decisions discussed in interviews.

termed backup decisions to support the anesthetist's decision making. Most backup decisions of anesthetic nurses occurred in the preoperative phase, relating to the preparation of equipment and backups. During induction, supporting strategies concerned recommending and handing additional equipment in case of difficulties, and observation and communication of the patient's breathing functions.

## Cue Recognition and Situation Awareness

As expected, the recognition of familiar cues was essential for the situational assessment and identification of courses of action. Across key decisions, more than 40 different cues were used to diagnose the situation and develop courses of action. The cues came from different aspects of the anesthetic environment and have been aggregated and summarized into nine categories for the purpose of this study (see Figure 2). All of these social and technical cues were used to establish situation awareness on the state of oxygenation of the patient.

Awareness of previously failed attempts of airway management and feedback given by different technologies were most frequently used to diagnose the situation. Most often, capnometry and pulse oximetry were used. Important cues gathered from the patients themselves were skin color and chest rising. The most frequently used cues related to airway equipment was tactile feedback, such as feeling movement in the bag when oxygen exchange took place, or a leaking mask seal. During the preinductive planning, a variety of cues relating to the airway anatomy (e.g., ability to extend the neck or shape of chin) and type of surgery were mainly used for the situational assessment.

Other important cues used during anesthesia induction were airway physiology and the availability of staff and airway equipment. Teamwork, including observation of colleagues and communication, were important cues guiding the situational assessment. The backup decisions by anesthetic nurses alerted the anesthesiologists to the dynamics of the situation (e.g., being reminded of oxygen levels, receiving suggestions to try different equipment, or calling for help). See Table 5 for example decisions and strategy for each cognitive pathway, cues, and potential decision support interventions.

## DISCUSSION

This study identified decisions that related to airway management in challenging anesthetic episodes. The specific aim was to explore the decision pathways used as a first step to identify requirements for adequate decision support tools.

The research showed that the anesthetic team had to make a variety of decisions to secure the oxygenation of the patient throughout the operative period, reflecting the complex sociotechnical nature of the anesthetic environment. Furthermore, it points to the potential and unexpected variability of the anesthetic environment that has to be handled through continuous adjustment by

**TABLE 5:** Example Key Decisions, Cues, and Potential Decision Support

| Decision | Phase | Decision Type | Situational Assessment Cues | Potential Decision Support[a] |
|---|---|---|---|---|
| Additional attempt to intubate the patient | Induction | Prototype | Airway anatomy: Airway landmarks were difficult to visualize at first attempt of intubation<br>Technology/tactile feedback airway technique: Oxygenation was secured through successful ventilation with a bag mask establishing a safe zone for another attempt<br>Teamwork: Oxygen saturation was secured throughout surgery as communicated by the anesthetic nurses | Availability of video laryngoscopies in the anesthetic environment, awareness of their availability<br>Empowerment of nurses to speak up when oxygen desaturates<br>Pulse oximetry alarm that is time-sensitive to either encourage or discourage additional attempt |
| Additional attempt to intubate the patient after failure of all backup techniques while waiting for surgical airway help to arrive | Induction | Prototype | Look of patient/technology: Patient had low oxygen saturations, blue skin color<br>Awareness of previously failed attempts: There is no other option left than doing a surgical airway | Cognitive aid (chart) prompting transitions between techniques when low oxygen saturations are apparent |
| Call for help | Induction | Prototype | Look of patient/technology: Hypoxia and breathing struggle of the patient were noticed through oxygen levels<br>Awareness of previously failed attempts/Teamwork: Colleague had difficulties inserting any airway technique repeatedly | Empowerment of nursing/ancillary staff to call for help when observing difficulties<br>Cognitive aid (chart) that prompts to call for help, visible and accessible at point of care |
| Transition from failed bag mask ventilation to surgical airway | Induction | Prototype | Patient: No chest movement was noticed<br>Tactile feedback: Bag mask could not be squeezed despite oxygen running in<br>There was awareness of previously failed attempts at intubation<br>Laryngeal mask airway was not readily available to the anesthetist | Having other rescue devices in reach (e.g., laryngeal mask airways)<br>Cognitive aid prompting three options of oxygenation before surgical airway<br>Training of technical skill to do a surgical airway more frequently |

*(continued)*

**TABLE 5:** (continued)

| Decision | Phase | Decision Type | Situational Assessment Cues | Potential Decision Support[a] |
|---|---|---|---|---|
| Suggesting other equipment and airway maneuvers (secondary decision) | Induction | Prototype | Teamwork: Colleague was observed having struggle intubating the patient<br>Tactile feedback of airway technique: The tube was not felt going through the right angle | Sharing airway plan with anesthetic nurses before surgery and encouraging speaking up<br>Checklist with equipment for anesthetic nurse to follow and "tick off" until airway is secured<br>Cognitive aid (chart) guiding through transitions between techniques and prompting nurses to suggest different equipment |
| Transition from failed direct laryngoscopy to asleep fiber-optic intubation | Induction | Deliberate | Patient: Chest movement was observed after insertion of laryngeal mask airway<br>Technology: Capnometry indicating exhalation (successful ventilation) and pulse oximetry (oxygen saturation) indicated that patient was safe and there was time to think<br>Airway physiology: Blood in airway was noticed, indicating no further attempt at direct laryngoscopy to prevent further damage | Cognitive aid (chart) representing several courses of actions after secure oxygenation is achieved |

[a]Any cognitive aid mentioned needs to be trained to and encouraged to be used by the whole anesthetic team. Cognitive aids can be combined with other decision support tools, for example, a time-sensitive pulse oximetry.

the anesthetic team (Cuvelier & Falzon, 2011). These two types of variability explain why the majority of decisions were made in the preinduction (managing potential variability) and induction phases (managing both potential and unthought-of variability) of anesthesia.

## Decision Pathways

The research showed that airway challenges are regularly experienced by the anesthetic team and generally solved by applying rule-based knowledge to choose a course of action (Rasmussen, 1983). The majority of decisions made were prototypical, hence recognition primed, rather than concurrent option analysis. This finding replicates those from the original firefighter study and illustrates the impact of expertise on decision-making processes (Klein et al., 2010). Prototypical decisions did not occur only with the presence of time pressure. Even in the preinductive phase of planning or situations with less urgency, only one decision was found that involved contrasting of options. The seven remaining deliberate decisions that involved the contrasting of two options, both identified through experience, took place in situations of reduced time pressure when oxygenation was secured.

The findings are logical considering how highly trained anesthesiologists and anesthetic nurses are before working independently. Training in anesthesia places strong emphasis on perceptual learning and rule-based procedures. The latter often take the form of algorithms, especially in time-constrained situations (Watterson et al., 2014). Therefore, it is not surprising that prototypical decisions were observed most.

## Cue Recognition and Situation Awareness

Next to the decisions and their pathways, this study also identified the cues that were used to make such decisions. Studying the cues that are used to gain situation awareness and generate courses of action is important when designing decision support for complex sociotechnical environments (Klein et al., 1997). Any decision support should emphasize or prompt the most relevant cues that were used to make decisions.

We found that a large number of cues from different sources was used by the anesthetic team. The awareness of a previous failed attempted acted as an important cue to transit to a different airway technique. This finding is not surprising, as the number of attempts with a certain technique is an important part of training and discussed in various airway management guidelines (e.g., Apfelbaum et al., 2013; Frerk et al., 2015). Cues provided by medical technology or direct patient feedback were further used mostly to make key decisions related to airway management.

*Teamwork and situation awareness*. Teamwork of anesthesiologists and anesthetic nurses also played an important role in decision making. Anesthetic nurses backed up key decisions by deciding to call for help and pointing to cues related to the state of oxygenation. Anesthetic nurses thereby functioned as cue providers for anesthesiologists. These social cues are important as they have the potential to break fixation that may occur when focusing on a particular task (e.g., getting the tube in the correct position). This "fixation" has been associated with repeated attempts to intubate a patient and the loss of awareness of dropping oxygen levels (Bromiley, 2009; Fioratou, Flin, & Glavin, 2010).

## Designing Decision Support for Challenging Airway Management

Studying decisions, their cognitive pathways, and cues during challenging airway management provides insight into suitable decision support design. Due to the recognition-primed nature of most decisions, the decision support should act as a "signal" (Rasmussen, 1983) by alerting the practitioners to the state of oxygenation through highlighting cues and prompting transitions.

Only 7% of practitioners currently use a cognitive aid that is available in emergencies, although 80% of practitioners indicate they would use one if accessible (Marshall & Mehra, 2014; Ziewacz et al., 2011). It has been suggested that the rare use is due to overly complex design, which does not match the recognition-primed, quick nature of decisions in stressful situations. Decision support should align with this type of decision making and therefore provide simpler and less complex guidance.

## Design Ideas

The majority of decisions were related to the planning and securing of the patient's airway after induction of anesthesia. Therefore, decision support tailored to these phases may offer the most leverage. This support especially concerns transitions between airway techniques when oxygenation is inadequate and when calling for help. Although design concepts have not yet been fully conceptualized, a number of examples are presented in Table 5. For example, transitions between airway techniques could be supported by a paper-based cognitive aid visualizing transitions in a serial manner. The cognitive aid should be located near or on the anesthetic machine and the anesthetic team trained in its use. In addition, or in combination, airway devices could be made more visible to the anesthetic team and within reach of anesthetic nurses to support transition between airway techniques. Another design idea contained in Table 5 is to add a time sensor to current pulse oximeters, thereby making the time elapsed during additional attempts more apparent to the anesthetic team. This design could potentially promote transitions between techniques in a timelier manner. As anesthetic nurses also play a relevant role, the whole anesthetic team should be involved in any decision support to promote shared situation awareness. The need to empower nurses to speak up is a general cultural change required to further improve this aspect of teamwork.

## Design Challenges

The design of decision support tools presents some challenges that need to be considered. Any additional element in the anesthetic environment, even if intending to support decisions, can add more complexity and noise. For example, alarm fatigue because of perceptual overload is a well-known phenomenon (Gazarian et al., 2015; Sendelbach & Funk, 2013). Perceptual overload is a continuum and the design needs to fit into the given constraints of the complex environment. In the current research program, this will be addressed by involving experienced practitioners in the design process.

Further, valuing the contribution of anesthetic nurses as a key part of the anesthetic team remains challenging. Although role hierarchy is being increasingly questioned in health care (Bromiley, 2009; Rutherford et al., 2012), empowerment of nurses needs to be further encouraged.

Finally, it will be a challenge to familiarize the anesthesia team with a new decision support tool that is designed to assist in challenging situations. Airway management difficulties occur infrequently (Cook et al., 2011), and the decision support may be needed only occasionally. Thus, the decision support may not reach that level of familiarity needed to become ingrained in people's decision-making process. To help mitigate this challenge, the decision support needs training from an early stage in the curriculum.

## Using the RPD Model

The RPD model was useful to represent the majority of decision pathways in challenging anesthetic episodes. Still, this study encountered some challenges with the application of the model relating to teamwork and option comparison in deliberate decisions.

*Teamwork*. The RPD model was developed to represent the decision-making process of individuals, and it currently does not have a teamwork component. This lack of a teamwork component is not necessarily problematic when purely analyzing the pathways of decisions, which were similar for both individuals and teams. However, it may lead to an underestimation of the relevance of collaborative work. Although a model for team decision making (TDM) has been suggested (Klinger & Klein, 1999), it does not align with the RPD model. The RPD model is a process model, and the model for TDM is structural. Based on the findings of this study, it can be argued that TDM can be similarly represented in a process model. In fact, an identical RPD model for individual decision making and TDM may be warranted. Regardless, it would be desirable to acknowledge the potential impact of teamwork in recognition-primed deciding in the model.

*Deliberate decisions*. The crux of the RPD model is the sequential evaluation of options and the lack of an element for concurrent option evaluation (Klein et al., 2010). Therefore, the cognitive pathway of deliberate decisions could not be represented by the RPD model. The deliberate decisions involved the discussion about which of two options best matched the situation and solved the airway management challenge. The situation itself did not require further clarification or story building (Level 2), nor was there evidence of a sequential mental simulation process (Level 3). As described in Klein and colleagues (2010), deliberate decisions occur with reduced time pressure. The deliberate decision example given in Table 5 took place after the airway was temporarily secured with a rescue technique. The two options that were discussed (either waking the patient or using a fiber-optic approach) were well-known procedures to resolve that type of situation. Both options were not compared with each other but with the situation in order to find the most adequate match. Therefore, it was not a sequential evaluation (Level 3) but a pairwise concurrent evaluation of well-known courses of action. Hence, the selection between both options was still based on situation–action matching rules (Lipshitz et al., 2001) rather than a comparison of the relative merits of both.

Given this finding, extending the third RPD level (action evaluation) to accommodate option analysis is proposed. An additional element here may be called “pairwise comparison of courses of action” following the recognition of typicality. The pairwise comparison is solved through situation–action matching and, potentially, team discussion. Alternatively, Lintern (2010) illustrated that the decision ladder can be used to represent recognition-primed decisions. In contrast to the RPD model, the decision ladder accommodates option analysis as a cognitive process (Lintern, 2010).

Either way, based on this finding, striving for a comprehensive model that includes both recognition-primed deciding and option analysis is warranted. Deliberate decisions may also require different decision support tools. Although the discussion primarily focused on the decision support design for recognition-primed decisions, deliberate decisions may be supported by presenting options concurrently. For example, when time pressure is reduced while oxygenation is secured temporarily, the anesthetic team could consult a flow chart that presents several possible courses of action (see Table 5).

## Limitations

As with all qualitative research involving one-on-one interviews, this study may present limitations related to voluntarily participation, self-reports, experimenter bias, and data exploration. Participants who volunteered may be particularly interested in patient safety and airway management or had distinctive memories associated with challenging airway management. All may bias the nature of airway management challenges discussed. Self-reports are known to be prone to biases related to social desirability (Guest et al., 2006). In order to reduce this limitation, participants were informed that the interviews were confidential and no identifying would be reported. Experimenter bias may have been present because the researcher conducting the interviews and analysis was not blind to the aims of the study. The first author coded the full transcripts for decisions, cognitive pathways, and cues. In order to address this limitation, text fragments were given to an experienced anesthesiologist for validation and a second coder for the analysis of decision types. Although no completely uncoded interview transcript was provided, it is believed that text fragments were enough to reach a reliable interrater reliability, because the interviews exclusively focused on decision points and how they were made. Therefore, the terminology and chronological discussion made it very clear which part of the transcript reflected a decision.

Finally, although data saturation is generally achieved by 12 in-depth interviews (Guest et al., 2006), some airway challenges were not covered in interviews. For example, aspiration is a well-known high-risk factor in airway management (Cook et al., 2011). However, none of the interviews covered aspiration as a major challenge. Similarly, newer advanced techniques were not discussed in all interviews, perhaps because individual narratives differed in how long ago incidents occurred. If participants mentioned they would use newer techniques as an option nowadays, it was noted in the analysis that involves options and potential design concepts. Most importantly, as this study will be combined with another observational study that has been conducted recently, we expect to cover the broad variety of airway challenges and techniques.

## Follow-Up Research

This study was the first occurrence of a decision-centered design process that was intended to develop decision support for airway management (Schnittker et al., 2016). To complement knowledge gathered from challenging anesthetic episodes, clinical observations have recently been conducted to find out about strategies and decisions made routinely. Both will be triangulated to get a comprehensive overview of a variety of situations. Decisions and strategies used routinely may not come up in interviews that focus on challenging episodes. It is expected that decisions and strategies in routine and challenging situations will overlap to a degree. However, whereas decisions in challenging situations frequently deal with recovering the situation, decisions in non-eventful situations may be more related to planning for potential variability (Cuvelier, Falzon, Granry, Moll, & Orliaguet, 2012).

The next step in the decision-centered design process will be to refine the findings of the interviews and observations for the decision support design phase. Therefore, focus groups with members of anesthetic teams will be conducted. Focus groups will discuss the decisions that are hardest to make under stressful circumstances and that may benefit from additional decision support. Input will also be gathered regarding the particular design of the decision support tool and how it may fit into the current work system to optimize its functionality. After designing the decision support tool, it will be evaluated in simulated conditions with members of an anesthetic team. Specifically, the effectiveness of the anesthetic teams' key decisions will be evaluated.

## CONCLUSION

The anesthetic environment is a complex sociotechnical system. This study illustrated that a variety of decisions were made by the anesthetic team to handle potential variability related to airway management. We further found that most key decisions were recognition primed, involving prototypical pattern matching and application of rule-based knowledge to generate an adequate course of action. The designers of a decision support tool need to consider both the decision pathways and the cues practitioners use in order to adequately support decisions in challenging airway management situations.

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Raphaela Schnittker holds a bachelor and a master in psychology from the University of Twente, in which she specialized in human factors. She is undertaking her PhD in psychology at the Monash University Accident Research Centre. In her PhD, she researches in human factors and patient safety.

Stuart Marshall is a practicing anesthesiologist with an interest in airway management and education. In addition to his medical degree and specialist training in anesthesia, he has a master's degree and a PhD in human factors from the University of Queensland. He teaches courses on patient safety, human factors, and perioperative medicine at Monash University and is also an associate professor in medical education at the University of Melbourne

Tim Horberry leads the Human Factors and Simulation team at Monash University Accident Research Centre, Australia. His background is in safe design, human factors, and transport. Since completing his PhD in transport safety, he has worked on many applied projects in the transport, medical, industrial, and defense domains.

Kristie Young is a research fellow with the Monash University Accident Research Centre. She holds a bachelor of applied science (psychology) (honors) and a PhD in human factors. She has over a decade of experience in applied human factors research, primarily in the road transport domain.

Gavan Lintern retired in 2009 and now holds an adjunct position at the Monash University Accident Research Centre. He has a PhD in engineering psychology (University of Illinois, 1978). His primary research area is in the use of cognitive work analysis to identify cognitive requirements.

## 4.3 Discussion

The goal of this study was to examine the cognitive pathways that underlie the decisions anaesthesia teams have to make in challenging airway management situations. The study found that the vast majority of the decisions (> 90%) followed a prototypical (i.e. recognition-primed) pathway. This finding is in line with the original firefighter study by Klein et al (1988), which identified that around 80% of decisions followed a prototypical pathway.

This is the first study that has identified underlying pathways of decision-making in anaesthesia in the context of recognition-primed decision-making. The findings of this study build an important foundation for the process of designing decision-support for challenging airway management. As discussed in chapter 2, the majority of currently existing decision support interventions in airway management, such as algorithms, are textual and prescriptive. In other words, they support knowledge-based decision-making according to 'work-as-imagined'. Knowledge-based performance occurs during unfamiliar situations where no rules and grounds for pattern matching exist (Rasmussen, 1983).

However, this study showed that human performance of experienced anaesthetic practitioner does not occur on the knowledge-based level. Consequently, there is a presumable mismatch between the design of current decision support design interventions and the nature of decision-making in anaesthesia teams.

### 4.3.1 Decision support for recognition-primed decisions

One of the fundamental premises of CSE is that the study of human performance and the design of decision support should be linked instead of being independent from each other (e.g. Bisantz & Roth, 2007; Rasmussen, 1983). As discussed in the publication, different types of decisions lend themselves to different types of decision support interventions. Consequently, based on the findings of this study, decision-support design in anaesthesia should support recognition-primed decision-making. Based on the RPD model, decision support design interventions should then focus on supporting situational assessment and present environmental cues in a way that facilitates recognition.

This should be done in order to support the recognition of appropriate courses of action. According to the RPD model, this should be in a in a sequential rather than concurrent manner. The output of the DCD process can include, but reaches beyond, rule-based alert systems (Militello et al., 2016). Indeed, the RPD model refers to more than just rule-based performance. Due to its three levels, it represents a combination of analysis and intuition (Klein, 2008).

According to Hoffman and Yates (as cited in Flach et al, 2017), '*people are not engaging a cause-effect chain or a rule-based process. They're navigating a space of constraints and issues, involving contingencies and contextual dependencies'*. As this study illustrated, anaesthesia teams use a variety of context-dependent cues to inform their decision-making process.

### 4.3.2 Application of the RPD model

While the vast majority of decisions were prototypical, a small number of decisions were deliberate. The decision makers did discuss a limited number of options, mainly two, in order to identify which option most likely solved the challenge successfully. As discussed in the publication, this type of deliberation is still a matching process, matching the two options to the situational assessment. As discussed in this study, this process involves an option comparison but is still a matching process (Klein et al, 2010).

In the publication, this process was described as a ‘pairwise *comparison* of courses of actions’. Alternatively, it could be described as a ‘pairwise *matching* of courses of actions’ to highlight the process of matching rather than concurrent, relative comparison. Since the RPD model does not accommodate any type of option comparison, the pairwise matching process could not be mapped on the model. As observed in this study, as well as by Klein et al (2010), the pairwise matching process is especially obvious during collaborative work. Anaesthesia is characterised by team work and collaboration (e.g. Cuvelier, Falzon, Granry, Moll, & Orliaguet, 2012; Manser, Harrison, Gaba, & Howard, 2009). Consequently, the RPD model is currently not able to accommodate a small but significant portion of decisions as they occur in anaesthesia. Figure 4.2 shows a proposed extension to the RPD model of the pairwise matching process, which would accommodate the deliberate decision strategy as found in this study.

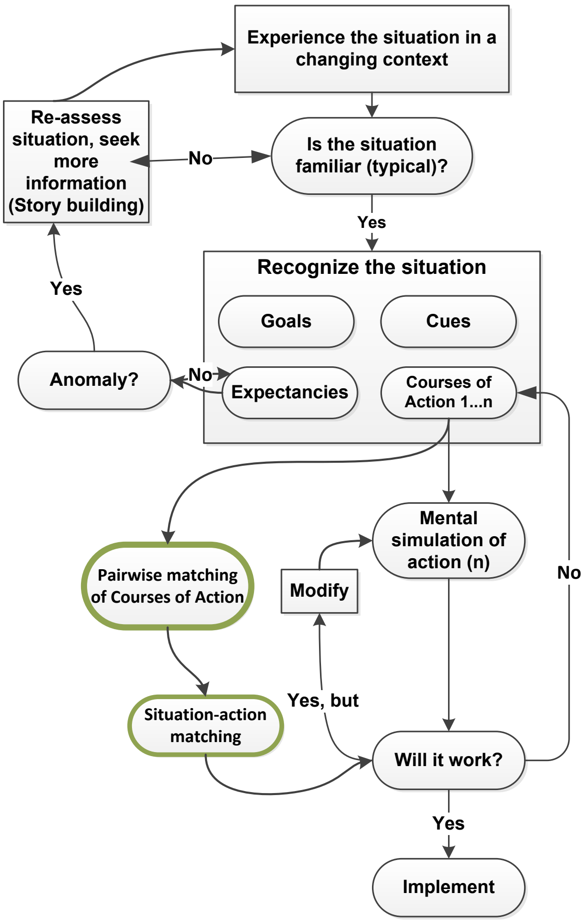


*Figure 4.2.* Proposed addition to the RPD model to accommodate a deliberate decision pathway

### 4.3.3 Decision support design concepts

Based on the findings of the CDM interviews, this study identified some initial decision support design concepts. The majority of decisions under time pressure concerned the changing of airway management techniques when the current technique failed. Therefore, ideas for decision support interventions mainly evolved around how to support the change in transitions between airway management techniques through the (re)design of system elements. This is particularly important for the transition to rescue airways such as the laryngeal mask and to more invasive techniques, such as surgical airways.

In particular, transitioning to surgical airways is known to be an extremely difficult decision (Watterson et al, 2014). As previously discussed, in order to accommodate recognition-primed decision-making, decision support should focus on the support of situational assessment to aid the recognition and matching process of appropriate courses of actions. As the literature review in chapter 2 identified, decision support interventions should offer enough flexibility to accommodate for the variability in practice.

Initial design ideas were, amongst others, a cognitive aid visualising airway transitions in a serial but flexible fashion; enhancing the visibility and reach of airway equipment further to facilitate transitions, and a pulse oximeter that provides alerts based on the passaged time in addition to oxygen saturation. A few of the ideas mentioned in the publication are of generic nature, which would facilitate the collaborative work specifically between nurses and anaesthetists. These mostly concern a cultural shift, such as the flattening of hierarchies in healthcare to empower nurses to share their situational assessment (Bromiley, 2009; Wacker & Kolbe, 2014). While this may not be able to be achieved through the design of a decision support tool as part of this research program, it is a necessary change required to improve the quality of healthcare (Beament & Mercer, 2016; Kolbe et al., 2012). Finally, as discussed in the publication, deliberate decisions may require different types of decision support interventions due to their collaborative nature and option matching. Decision support interventions that support the situation-action matching of several courses of actions could be appropriate, although are not currently supported by the RPD model.

### 4.3.4 Conclusions

The primary goal of this study was to examine decision pathways of anaesthesia teams in challenging airway management situations. The secondary goal was to present initial outcomes of the decision requirements analysis of the CDM interviews. The study identified that the vast majority of decisions made in challenging airway management situations follow a prototypical pathway. Based on the decision requirements tables (DRT's), this study identified initial decision support design concepts for challenging airway management. At this stage, these are at a high-level conceptual stages only and are refined in the subsequent studies.

Finally, this study found that the RPD model adequately represents most decision pathways occurring in anaesthesia. However, it does not cover some fundamental decision strategies by anaesthesia teams; those that involve an element of option comparison. Chapter 7 will discuss a comparison of the RPD model with the decision ladder model from CWA. Specifically, this chapter examined the differences and similarities in decision support design interventions by both methods. Since the decision ladder accommodates option analysis, the chapter will discuss the implications on the design of decision support interventions in anaesthesia.

In the next chapter, a second set of findings of the CDM interviews are presented by means of a peer-reviewed publication: the human factors enablers and barriers to successful airway management. Examining the human barriers and enablers for successful airway management was necessary to further refine concepts and identify leverage points for the decision support design.

# 5 Chapter 5 - Human Factors enablers and barriers to successful airway management

***Paper 4***: Schnittker, R., Marshall, S., Horberry, T. & Young, K. (2018). Human factors enablers and barriers for successful airway management – an in-depth interview study. *Anaesthesia*, 73(8), 980-989.

## 5.1 Introduction

The goal of this study was to identify the human factors enablers and barriers to successful airway management, as experienced by anaesthesia providers. This study presents the second set of findings emerging from the CDM interviews. The study was performed to examine elements of the complex and sociotechnical anaesthetic environment that enable and/or hinder successful airway management. Identifying the barriers and enablers was relevant in order to identify leverage points for the later design of decision support for airway management. This study contributes to the previous study on decision pathways in airway management by specifically emphasizing the enablers and barriers of the current work environment of anaesthesia teams. Thereby, this study examines 'work-as-done' (Blandford et al, 2014).

This study was published in a medical journal because the findings of this paper are more practical and have an applied, clinical focus compared to the other studies that have been published in Human Factors journals. The clinically applied nature of this study was useful to identify more concrete and detailed leverage point for decision support design. Since this study is primarily concerned with analysis, it is part of the third phase of the DCD process (see Figure 5.1). However, specific design recommendations for the design of airway management decision support are provided, thereby providing a bridge to the fourth phase.

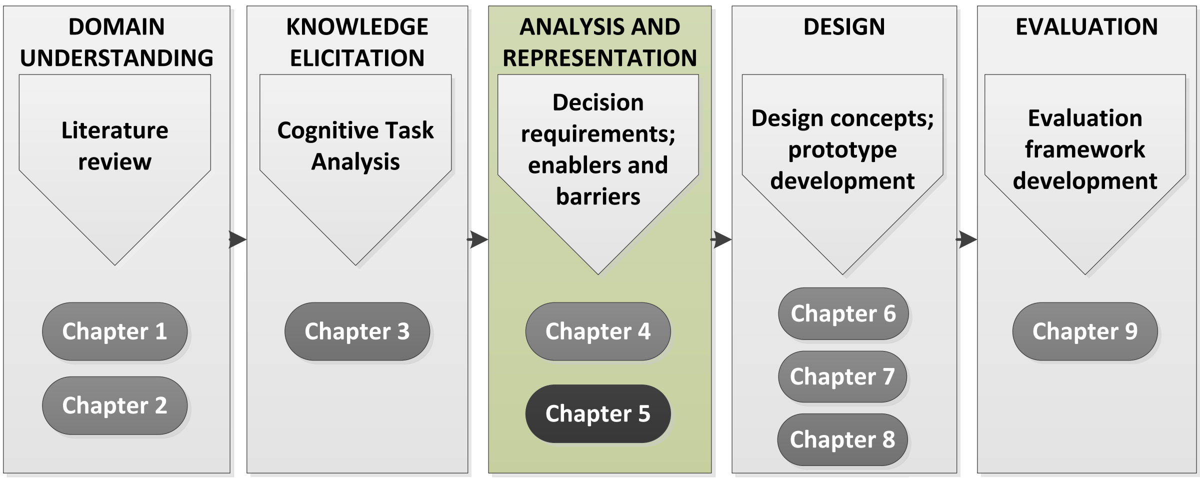


*Figure 5.1.* The decision-centred design process – chapter 5

## 5.2 Paper 4: Human Factors enablers and barriers for successful airway management – an in-depth interview study

# Original Article

## Human factors enablers and barriers for successful airway management – an in-depth interview study

**R. Schnittker,[1,2] S. Marshall,[3] T. Horberry[4] and K. L. Young[5]**

*1 PhD Candidate, 4 Professor, 5 Senior Research Fellow, University Accident Research Centre, Monash University, Melbourne, Victoria, Australia*
*2 Assistant Lecturer, 3 Senior Research Fellow, Department of Anaesthesia and Peri-operative Medicine, Central Clinical School, Monash University, Melbourne, Victoria, Australia*

## Summary

Human factors are the individual, team, environmental and organisational aspects of the anaesthetic environment that affect performance and decision-making of anaesthesia teams. This study aimed to identify which human factors were enablers and/or barriers to anaesthesia teams during airway management challenges. Sixteen interviews were conducted with experienced anaesthetists and anaesthetic nurses using an in-depth interview technique (the Critical Decision Method) to identify human factors enablers and/or barriers during successful management of a significant airway challenge. Thematic analysis identified three overarching enablers: equipment location and storage; experience and learning; teamwork and communication. Five overarching barriers were also identified: time and resource limitations; teamwork and communication; equipment location and storage; experience and learning; insufficient back-up planning; and equipment preparation. This study showed that a variety of human factors issues affect the handling of airway challenges, ranging from individual and team to organisational and environmental aspects. Recommendations for the design of airway management decision support tools that relate to equipment standardisation, decision support complexity, inclusive mutual learning and teamwork are discussed.

*Correspondence to: R. Schnittker*
*Email: raphaela.schnittker@monash.edu*
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## Introduction

Anaesthesia is one of the safest healthcare disciplines, and is known as a 'model for patient safety' [1]. Although deaths directly related to anaesthesia are rare they still occur, chiefly in situations where anaesthetists consider themselves expert, such as medication administration and airway management [2–4]. To a large extent, anaesthetic safety not only lies in the training and decision making of those that provide anaesthetic care but also in technology such as monitoring that is designed to support that care. Proactive management in anaesthesia often lacks visibility due to continuous effective prevention of notable incidents. Safety in anaesthesia can therefore be regarded as a 'dynamic non-event', with proactive management by clinicians constantly contributing to patient safety [5].

In the last decade, the impact of human factors on safe anaesthetic care has been well established [6, 7]. Human factors refers to the individual, team, environmental and organisational aspects of a system that influence human performance. In anaesthesia, this includes medical devices, staffing and procedures (among other factors) that support the safe care of patients by anaesthesia teams. In airway management, at least one of these factors (and on average three other factors) were implicated in a sub-group analysis of 12 adverse events from the UK Fourth National Audit Project (NAP4) [8].

One component of human factors, non-technical skills, has received a lot of attention in recent years [9–11] due to high-profile cases such as that of Elaine Bromiley [12]. Non-technical skills include interpersonal skills such as situational awareness, leadership and teamwork, but do not explicitly encompass the whole multiple-layered environment in which anaesthetic work is embedded. The anaesthetic system needs to be more broadly defined than solely referring to the (inter)personal level. According to Bogner's artichoke model [13], the patient–anaesthesia team interaction is at the core, but is surrounded by multiple layers that influence interactions: the social and physical environment; ambient conditions and the organisation. Thus, the practitioner's cognition is affected by factors at different layers of a complex system. For example, cues for action from the patient and technology, the availability and design of equipment, and a culture in which junior staff members feel able to speak up if they feel that patient safety is threatened.

Anaesthesia team members typically show excellent adaptive capabilities in difficult situations [9, 14]. However, although the presumed causes for human error have been studied frequently, there is a scarcity of research that looks into how anaesthesia teams have managed airway management challenges successfully. Furthermore, as noted above, most human factors research has focused on non-technical skills rather than adapting a broader perspective.

Consequently, the primary aim of this study was to identify human factors enablers and barriers that clinicians experienced when they successfully resolved airway management challenges. A secondary aim was to provide recommendations for the design of a decision support tool for airway management. Existing decision support tools such as cognitive aids and checklists have often been designed using a 'top down' approach. Guidance for the design of a decision support tool for airway management that is based on interview findings with anaesthesia providers has the potential, therefore, to add significantly to current knowledge. Input from a variety of experienced anaesthetic team members, who have solved similar problems, guards against assumptions of how activities are optimally performed [15, 16]. Consideration of environmental enablers and barriers experienced by practitioners working at the frontline are rarely incorporated into the design of decision support. This study attempts to address this gap by providing guidance on design that is based on an improved understanding of how human factors issues affect airway management.

## Methods

Ethics approval was obtained from the Human Ethics Research Committee and Nursing Research Advisory committee of the two participating organisations, one large hospital and one medium-size metropolitan hospital in the greater Melbourne area. Recruitment of anaesthetic consultants and anaesthetic nurses was initially done via email invitation, and further participants were recruited through word-of-mouth. An information statement and consent form were sent to all participants, and written consent was obtained before commencement of the study. Apart from one experienced trainee, all participants were qualified specialists at the time of interview.

A total of 16 interviews were conducted: 12 with anaesthetic consultants and four with anaesthetic nurses (see Table 1). The sample size was based on two considerations. First, a sample size of six or more has previously been identified as adequate to reach data saturation in an in-depth interview study [17]. Second, on reviewing published healthcare interview studies, a sample size of 16 was in the upper range, with a median of 13 respondents [8, 18–21].

We employed the Critical Decision Method [22], a specific interview technique that has been used in healthcare and other safety-critical industries to obtain tacit knowledge from domain experts [18, 19, 21]. The participants described a critical incident in which they were an active decision maker. The interviewer and participant reconstructed the key events to determine: cues in the environment that were important; what the difficulties were; what the goals were; factors that

 

**Table 1** Experience of participants.

| Role | 0–5 years | 5–10 years | 10–15 years | > 15 years | Total |
|---|---|---|---|---|---|
| Anaesthetist | 1[a] | 1 | 2 | 8 | 12 |
| Anaesthetic nurse | 1 | 0 | 1 | 2 | 4 |
| Total | 2 | 1 | 3 | 10 | 16 |

[a]Experienced trainee at the time of the interview.

helped them make decisions; how the participants knew what to do in the situation. In the final phase, related hypothetical situations were presented to determine what (if anything) would have helped with making key decisions at the time, or if a certain tool or environmental change could have supported someone with less experience to successfully handle the airway challenge.

The Critical Decision Method interviews have previously been analysed to identify key decisions made by anaesthesia team members in challenging airway management incidents, and the cognitive processes and environmental constraints that these decisions rely upon [23].

In this study, interviews were analysed with regard to what factors facilitated and/or impeded successful airway management during the critical incidents. Enablers and barriers were broadly defined as any human factors issue related to cognition, teamwork, the physical environment and the organisation that was mentioned as facilitating or impeding successful airway management.

The interviews were transcribed and relevant excerpts extracted manually for further analysis. The extracted data were then uploaded into NVivo (version 10, QSR International, Burlington, MA, USA) and coded. An ‘open coding’ strategy was used, guided by the content of the interviews rather than an existing theory [24]. Overarching themes were identified, with specific codes forming subcategories that were confirmed by a second author (with examples) for critical review. Discussion between the two authors resulted in one minor adjustment to the coding; one quote was moved to a different subcategory. Finally, the coding hierarchy was further analysed using descriptive analysis in NVivo and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

**Table 2** Types of airway challenges discussed in the Critical Decision Method interviews.

| Interview | Type of airway challenge |
|---|---|
| 1 | Swelling in the neck and infection after neck surgery, transferred from ICU (emergency) |
| 2 | Thyroid removal due to airway compression with difficult anatomy (elective) |
| 3 | Bypass graft surgery (emergency) |
| 4 | Laparoscopic cholecystectomy (elective) |
| 5 | Neuro surgery due to bleed and traumatic head injury (emergency) |
| 6 | Laryngocoele (emergency) |
| 7 | Oesophagus rupture (emergency) |
| 8 | Mandibular abscess (elective) |
| 9 | Airway obstruction in recovery after thyroid surgery (emergency) |
| 10 | Neck fusion surgery with unexpected difficult airway (elective), participant was called for help |
| 11 | Drug confusion (anxiety drug and muscle relaxant drug) before surgery (emergency) |
| 12 | Laparoscopy, unexpected difficult airway (elective) |
| 13 | Acute epiglottitis, transferred from emergency department (emergency) |
| 14 | Acute appendectomy, unexpected difficult airway (emergency), participant was called for help |
| 15 | Angioedema, transferred from emergency department (emergency) |
| 16 | Acute appendectomy (emergency) |

## Results

Interview lasted between one and two-and-a-half hours. A diverse range of airway challenges were discussed (see Table 2). Thematic analysis identified a broad range of environmental, team and individual human factors that affected successful airway management. These were categorised into three overarching enablers and five overarching barriers to successful airway management (Fig. 1). Although more barrier themes than enabler themes were identified, these were mentioned less frequently; the three enabler themes were discussed in most interviews (13–16), whereas barriers were only mentioned in four to eight interviews.

Figure 2 presents an overview of the subcategories for the three enabler themes 'equipment location and storage', 'experience and learning' and 'teamwork and communication'. Enabler themes had a different number of subcategories. Location and storage of equipment was the most frequently discussed enabler, mentioned in all interviews as being fundamental to successful airway management. Specifically, equipment that was readily available to be used, and the knowledge of where to locate this equipment immediately. For example, ready availability of a supraglottic airway (for airway rescue), or airway adjuncts such as a bougie. Similarly, smoother transition to front-of-neck access techniques was possible in cases where the relevant equipment was immediately at hand. This in turn depended on prior preparation of airway equipment, most often by the anaesthetic assistant. Another example was the importance of knowing the location of a specific item of equipment within the difficult airway trolley, and being able to quickly hand it to the person managing the airway. Several respondents suggested that rescue equipment taped visibly to the side of the anaesthetic trolley acted as an important reminder of alternative options when airway difficulties occurred. Close proximity of the difficult airway trolley supported a smooth transition between airway techniques when difficulties arose.

The importance of teamwork and communication between anaesthesia team members and the broader medical team (ranging from surgeons to technicians) was another frequently discussed theme (in 15 of the 16 interviews). Most frequently, the communication of difficulties, what was going on at the time and future plans with the anaesthetic nurse, the surgeon and other medical staff was discussed as being crucial for a dynamic and successful process. It was acknowledged that speaking out loud helps involve everyone ("*share the wisdom of people in the room*", Anaesthetist #10), for example, when repeated attempts at intubation were necessary. The crucial role of the anaesthetic assistant in suggesting and offering alternative equipment was regarded as beneficial in supporting the transition between techniques, and avoiding tunnel vision ('fixation'). Likewise, after calling for help other clinicians offered a fresh perspective and provided what was perceived as crucial support. The availability of an Ear, Nose and Throat surgeon (to assist with surgical airways) helped with making decisions, as did general discussion with the attending surgeon. It was further mentioned that other medical team members (such as technicians) are often better trained than in the past, and so were perceived as being helpful when anaesthesia staff had limited experience. Knowing the nursing staff and their level of experience was also mentioned as being important to task allocation.

The relevance of experience and learning to successful management of airway challenges was discussed

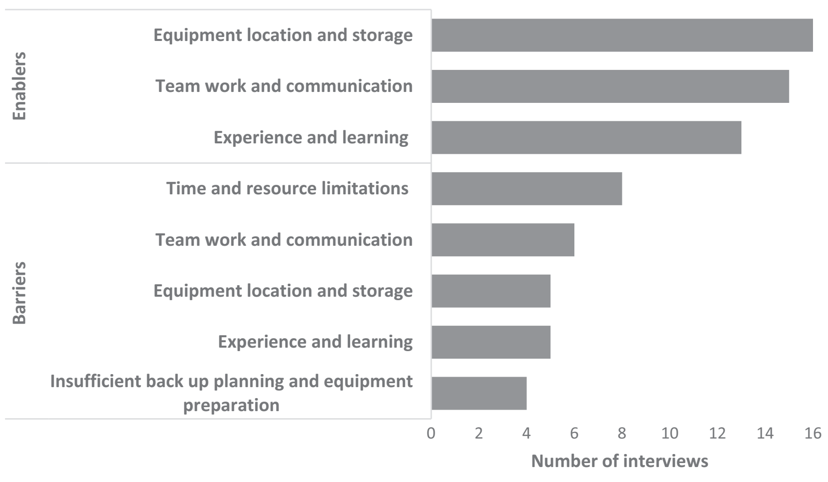


**Figure 1** Enabler and barrier themes for successful airway management, as identified in the Critical Decision Method interviews.

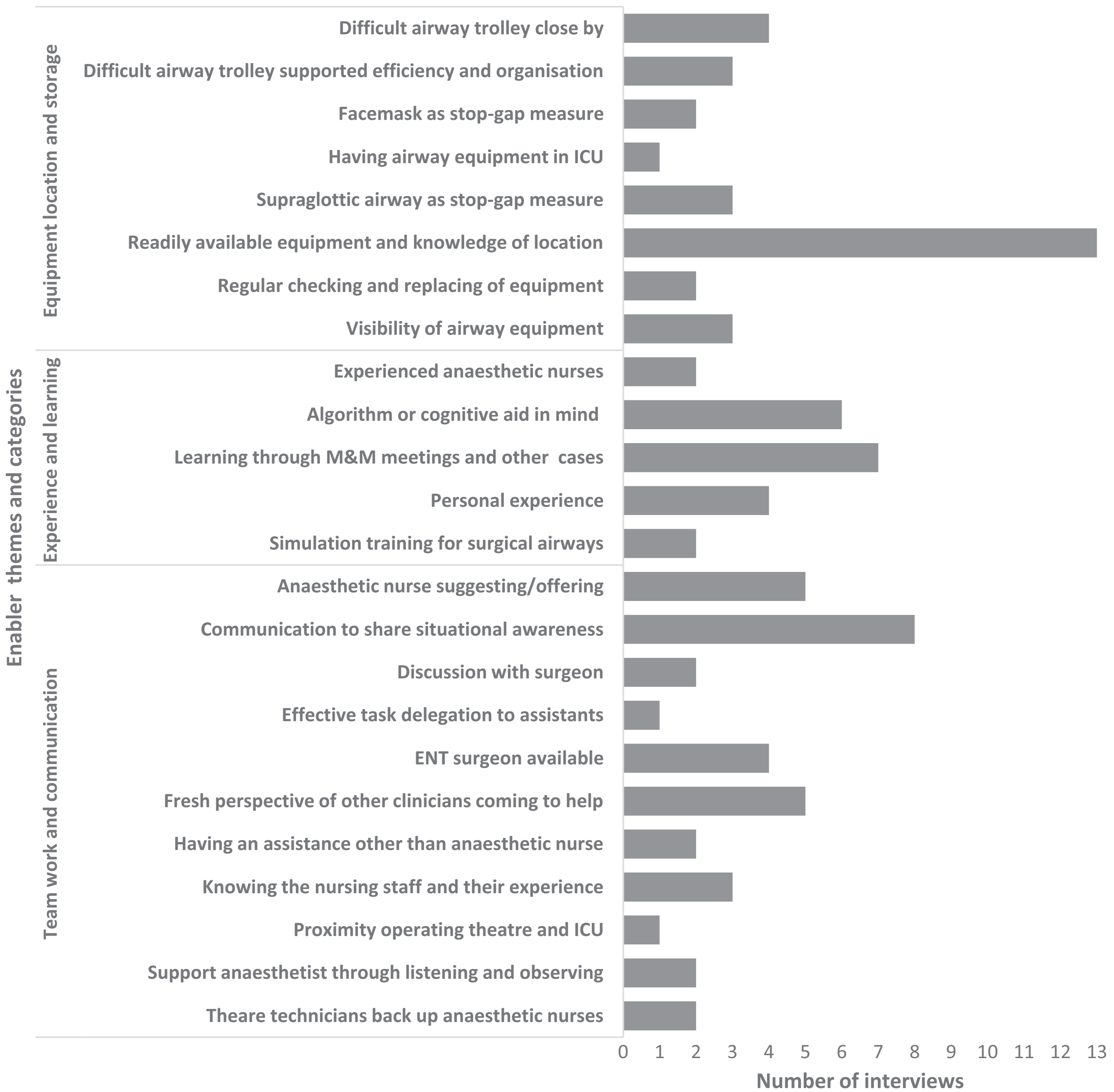


**Figure 2** Enabler themes and their subcategories, as identified in the Critical Decision Method interviews. M&M, morbidity and mortality; ENT, Ear, Nose and Throat.

in 12 interviews. Most frequently, it was stated that departmental morbidity and mortality meetings and discussion of high-profile cases were powerful means to learn, and therefore helped in managing challenging cases. Having algorithms or mental models to fall back on in time-pressured situations supported practitioners by reminding them of alternative management options and strategies ("*I was just trying to go down the algorithm!*", Anaesthetist, #9; "*I just remember: mask, LMA, knife. That's all I remember. And then all of these other fine tunings can come later or, you know, more supplementary*", Anaesthetist, #15).

Figure 3 displays an overview of the subcategories of the five barrier themes 'teamwork and communication', 'equipment location and storage', 'experience and learning', 'time and resource limitations' and 'planning'. Although teamwork and communication are powerful enablers, they can also be barriers. In four interviews, individual personalities and culture were noted to negatively impact on airway management. For example, an impatient surgeon can create production pressure that can be a challenge to junior staff. Furthermore, although there has been much improvement in recent years, hierarchical barriers still exist between anaesthetists and nurses. Both anaesthetists and anaesthetic nurses reported that these hinder adequate communication, and can impair successful airway management.

In five incident narratives, the location of airway equipment and the way it was stored was discussed. No single dedicated location for airway equipment was mentioned as a barrier for successful airway management. For example, supraglottic airways were stored in different locations and had to be searched for before they could be used. The fact that some rescue equipment was not in visible proximity contributed to not considering it as an option in a can't-intubate-can't-oxygenate crisis.

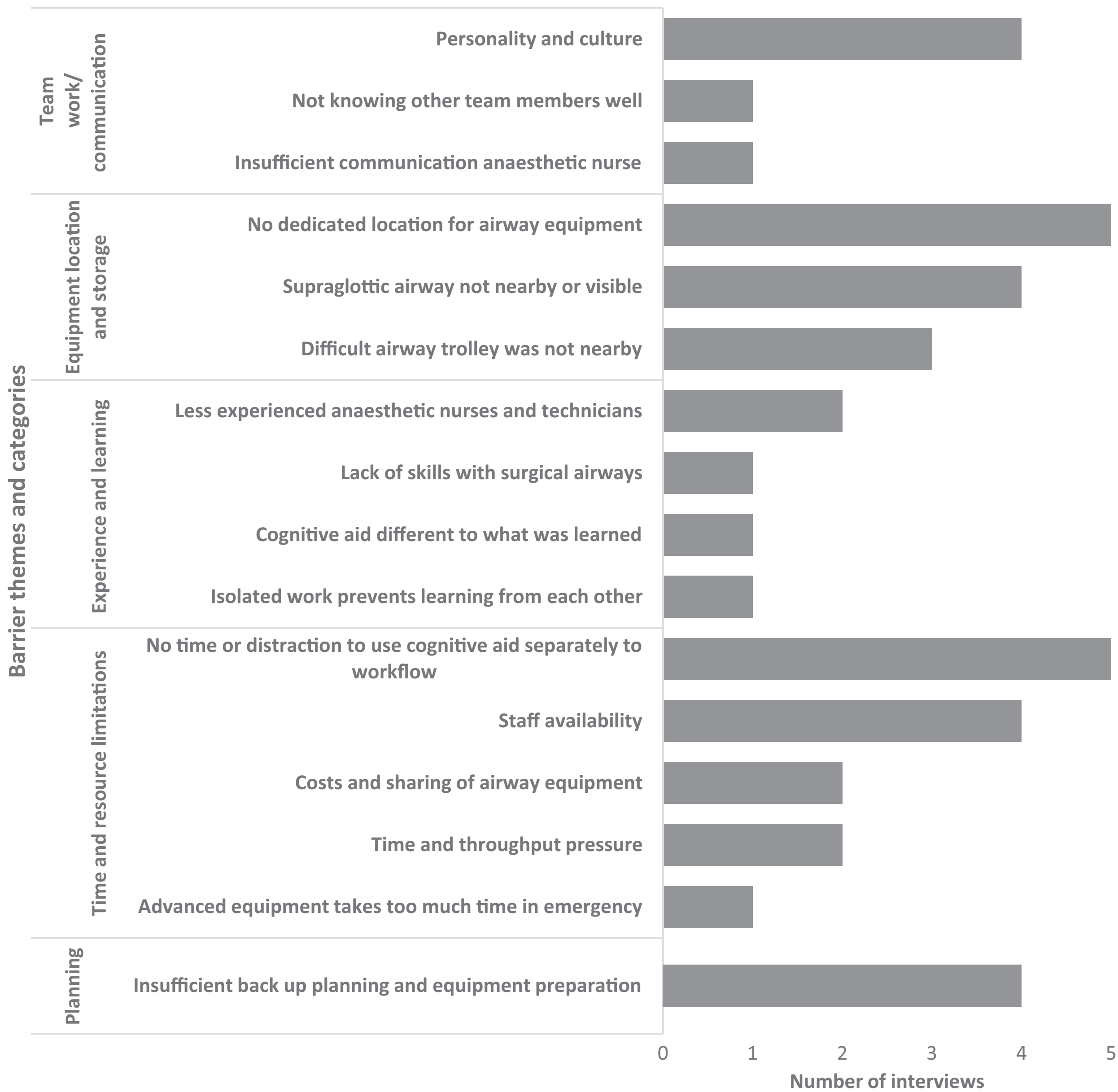


**Figure 3** Barrier themes and their subcategories, as identified in the Critical Decision Making interviews.

Lack of experience of anaesthesia team members was mentioned twice as a barrier. This related to less experienced anaesthetic nurses that were not yet familiar with airway equipment, or patterns of transitions between techniques. On a few occasions, surgical nurses and technicians helped out in difficult situations where limited staff were available. Their relative inexperience with airway management was also perceived as a barrier, although in general they were helpful.

Most barriers discussed were related to time and resource limitations. Time pressure was the main reason why anaesthetists were negative about cognitive decision aids in the form of flow charts or models; they were perceived as a distraction from the workflow of airway management rather than a support. Another barrier mentioned was the limited staff available, especially on the weekend or after hours; mostly this referred to the limited availability of anaesthetic nurses and ENT surgeons at these times. The fact that some expensive items of airway equipment such as fibreoptic or videolaryngoscopes had to be shared across theatres was also identified as a barrier, since they generally had to be obtained in advance.

In four of the interviews, inadequate planning and preparation led to required equipment not being immediately available or visible to practitioners. Inadequate planning was also highlighted in lack of back-up plans, and over-reliance on videolaryngoscopy was also discussed ("*...probably that the anaesthetist should have had a set of back up plans, there should have been an airway plan that was there, I think there was an over-reliance on the video laryngoscope*", Anaesthetist, #10).

## Discussion

This study has identified key decision-making enablers and barriers for anaesthetic teams when handling challenging airway management situations. In general, more enablers were identified than barriers. One reason for this finding may be that all the airway cases were solved successfully, so discussion concentrated on enablers rather than barriers. However, the findings clearly reflected extremely effective coordination in anaesthesia teams. The interaction between anaesthetic team members and the clinical environment (including technology, physical set-up and other medical team members) enabled successful airway management. This is an important finding that needs to be emphasised: despite awareness of a variety of systemic and equipment factors that can constrain decision making, there is still a tendency to focus on erroneous individual behaviour when there is a poor clinical outcome [5, 25].

This study takes the conversation beyond the importance of non-technical skills [6], acknowledging that decisions are a result of complex interactions between anaesthetic team members and the clinical environment (which includes technology, physical set-up and other medical team members). The identified human factors enablers and barriers had some common themes, such as teamwork and communication, experience and learning, and equipment availability. These findings are congruent to those identified by Flin and colleagues [8] who found similar human factors contributing to critical incidents: 'job factors' such as time pressure and staffing and 'competence and training'. It is likely that the findings of this study can be applied to similar healthcare settings, and may help to initiate further discussions on how to improve support for successful airway management by anaesthesia and other medical teams.

This study provides unique insights into human factors enablers and barriers for airway management. There are specific aspects of the physical and organisational environment that could be improved effectively and cost-efficiently. For example, visibility and location of airway equipment, and availability of rescue equipment such as supraglottic airways. The relevance of morbidity and mortality meetings for mutual learning was also highlighted. This study showed that human factors at different levels of the complex anaesthesia system affected patient care across boundaries in the physical and social environment [13]. These boundaries included limited availability of certain types of airway equipment, limited staff availability and throughput pressure. They are a natural part of complex social technical systems, and the goal of system design should be to support humans to perform challenging work successfully in these environments. In other words, safety in anaesthesia should be viewed as an emergent, systems-level phenomenon that is made possible by the integration of people, tasks, equipment, organisation and the wider anaesthesia environment.

The Critical Decision Method interviews were undertaken in two large metropolitan, publicly funded teaching hospitals in Australia. Therefore, the findings might not necessarily be able to be extrapolated to dissimilar contexts. However, we believe that the enablers and barriers identified are likely to be similar in nature in any hospital where complex airway cases are undertaken. The interviews concentrated on difficult cases where emergency procedures were required, and so might not reflect normal decision making in anaesthetic practice. For instance, simulation training for front-of-neck access was mentioned twice, which may indicate an underestimate of the importance of this topic in emergency management, but an overestimate for routine clinical care given the rarity of need for these actions.

Our study had a small sample of participants and was qualitative, so the findings cannot easily be generalised in a traditional sense. Although our sample size picked up themes that fit well with past research, quantitative data from this study may not fully represent large-scale findings as found in nationwide audit projects such as the NAP4. However, generalisation to the wider population is often not the desired goal of qualitative enquiry; our aim was to examine human factors enablers and barriers through the lens of a few experienced anaesthesia team members.

Another potential limitation of our study is that the numbers of anaesthetists and nurses were not balanced. There were more anaesthetists than anaesthetic nurses in this study, as the tasks and activities undertaken by the nurses were less diverse and more repetitive than those of anaesthetic specialists. Furthermore, the nurses' actions were guided by anaesthetists to a large degree, with the majority of decisions being made by the specialist anaesthetists. For this purpose, data saturation was achieved with a lower number of interviews with anaesthetic nurses. Furthermore, the study's prime purpose was to study key decisions in challenging airway management situations, with a minor aspect being the supportive actions of nursing and other staff.

Finally, interviews are fundamentally retrospective and introspective. The fact that practitioners had to discuss in length how they managed a difficult case successfully may have encouraged a self-serving bias or (unconscious) self-preservation. As it was not possible to interview different team members involved in the same case to identify agreement of how the narrative unfolded and was managed, the findings of this study are based on individual practitioners' points of view. However, we believe that the particular focus on how difficult cases were managed successfully (rather than trying to identify 'human error') has helped in creating a non-judgemental atmosphere. The fact that teamwork and communication was a key enabler seems to indicate that there was mutual agreement on how the case was managed.

The present study provided further insights on human factors barriers and enablers, and thereby recommendations for decision support design for airway management. These recommendations reveal that supporting decisions can occur at different system levels of the anaesthetic environment: the physical environment, the organisation and the interpersonal environment, all interacting jointly.

Recommendations from this study are:

1 Any decision support tool should not interrupt or distract from the actual workflow of airway management. Complex charts or posters mandating a specific approach could potentially be perceived as another barrier rather than enabler.
2 Standardisation of the available equipment and how it is presented to the anaesthetic team may help to break down this barrier and support anaesthetic teams more effectively. A majority of barriers discussed were related to the location, storage and availability of airway equipment.
3 If possible, a decision support tool should be designed in a way that makes it accessible to the whole medical team and not only anaesthetic team members. Occasionally, other team members outside the anaesthesia team such as technicians and scrub nurses assist with airway management.
4 Insufficient planning and preparation is a barrier, and a consequence of throughput pressure and staff limitations. Although the relevance of appropriate planning and preparation is a crucial part of the training, a decision support tool should focus on

 

how to maintain patient safety margins when planning and preparation are inadequate.

5 Morbidity and mortality meetings and case studies enable anaesthetists to learn about difficult cases from each other. Involvement of the whole team, including anaesthetic nurses and other medical team members who occasionally assist with airway management may help teamwork, mutual learning and, if thoughtfully conducted, may break down hierarchical barriers.

Decision making processes in anaesthesia are complex and often implicit. However, the knowledge and thought processes underlying decisions and identifying what helped and what impeded them can be made explicit through interview techniques such as the Critical Decision Method. This knowledge can then be used to inform more effective system design [26]. Insights gained from this study will be used to design a prototype for a decision support tool for airway management. Key decisions, how they were made and what information and resources they required were previously identified as part of a decision-centred design process [27]. Examining human factors enablers and barriers to decision making is fundamental to the design of decision support tools to be used by healthcare clinicians.

## Acknowledgements

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## 5.3 Discussion

The goal of this study was to identify the human factors elements anaesthesia providers experience as enabling and hindering successful airway management. This study was unique because it examined human factors in the context of successful performance, rather than in the context of incidents. These insights were then used to provide concrete recommendations for decision support design for airway management. The findings of this study were relevant as they further specified the focus of the high level decision support design ideas identified in the previous study.

This study demonstrates that the location of airway equipment plays an essential role for the successful management of airway challenges. This is in line with previous research that demonstrated the benefits of equipment organisation and accessibility to support workflow and efficiency (Grundgeiger et al., 2014). The layout of the physical environment does not only benefit workflow and efficiency, it is an essential mediator for collaborative work (Yan Xiao, 2005). The findings of the present study reflected that the most frequent enabler for successful airway management was readily available equipment and knowledge of its location. On the contrary, barriers to successful airway management were situations where there was no dedicated location for airway equipment, rescue airway equipment was not visible nor accessible, and the difficult airway trolley was not in reach.

The findings of the study further demonstrated that learning through discussions of other critical cases and departmental meetings, as well as simulation training were beneficial to successfully cope with airway management difficulties. Cognitive aids and algorithms were found to be important mental models that guide airway management in challenging situations. This finding is line with Knudsen et al (2017), who found that the majority of anaesthetic practitioners view algorithms as a cognitive aid that is ‘in the back of your mind’. On the contrary, one of the most frequently mentioned barriers to successful airway management concerned cognitive aids that, in its current form, were distracting from the work flow and actual airway management. This finding reflects the previous inconclusive research on the usefulness of cognitive aids, suggesting that the effectiveness of cognitive aids depends on the way they have been designed (Marshall, 2013). Consequently, as evident from this study, one important design aspect of cognitive aids is the workflow integration.

## 5.4 Conclusions

The study presented in this chapter identified specific recommendations for the design of decision support for challenging airway management. These were related to (1) workflow integration and simplicity of cognitive aids, (2) presentation and standardisation of airway equipment, (3) shared access of decision support intervention across the medical team, (4) support of time-pressured situations that result in cutting corners and a trade-off between thoroughness and efficiency, and (5) learning from difficult cases.

In combination with the previous study identifying decision pathways and initial design concepts based on the decision requirements tables, these recommendations form part of the foundation for the development of the decision support intervention. The next chapter will describe the triangulation of the CDM interviews with the outcomes of the focus groups discussions. This triangulation resulted in the identification of five dominant decision support design concepts. Subsequently, the five design concepts were rated by subject-matter-experts to specify the preferred design intervention.

# 6 Chapter 6 – Data triangulation, key decision selection, and design prioritization

***Paper 5.*** Schnittker, R., Marshall, S., Horberry, T. & Young, K. Decision-centred design in healthcare: the process of identifying a decision support tool for airway management. *Applied Ergonomics*, *77*, 70-82.

## 6.1 Introduction

The previous chapters discussed the outcomes of two set of findings from the CDM interviews. Chapter 4 described the cognitive pathways underlying key decisions made in challenging airway management situations. It found that the majority of decisions follow a prototypical route characterised by a direct match between situation recognition and action generation. Chapter 5 described the human factors enablers and barriers to successful airway management, as experienced by anaesthetists and anaesthetic nurses. Both chapters also identified preliminary decision support design concepts and recommendations.

This chapter will discuss the triangulation of the field observation, the decision requirements tables (DRT's) emerging from the CDM interviews and the focus group outcomes. This triangulation involved two processes that are relevant for the subsequent phases of the DCD process: data analysis and the selection of a design intervention. The start of this chapter reports on the process of meaningful reduction of the large amount of qualitative data arising from the CDM interviews and focus groups. Meaningful data reduction is a fundamental process in qualitative research (Miles & Huberman, 1994; Namey, Guest, Thairu, & Johnson, 2008). Yet, no human-centred design research describing the process of data reduction in-depth going beyond brief descriptions of coding procedures could be identified.

This chapter also describes the process of selecting one decision support concept to be designed as part of this research program. There is no commonly accepted method on the selection process of decision support design concepts when multiple concepts were identified. In fact, most human-centred design research reporting on a bottom-up design process already starts with a broad concept idea (e.g. Militello et al., 2016; Nemeth et al., 2016).

In the case of multiple identified design concepts, Shappell and Wiegmann (2010) developed a structured approach that involves subject-matter-experts in the decision support selection process. This approach is 'FACES', an acronym that refers to the perceived feasibility, acceptability, cost, effectiveness and sustainability of proposed design interventions (Shappell & Wiegmann, 2010). FACES has been originally used in aviation with subject-matter-experts being safety managers. To date, this approach has not yet been applied in healthcare with clinicians working at the frontline as subject-matter-experts. Since this research program aims to approach work-as-done (Blandford et al., 2014) as closely as possible, the present chapter used FACES with anaesthesia providers as subject-matter-experts to identify the preferred decision support design intervention.

In summary, this chapter combines outcomes of the knowledge elicitation methods with the decision support concept selection. By combining previous work with the prospective decision support design, this chapter stands central to this thesis. In terms of the DCD process, this study bridges the 'Analysis and Representation' and 'Design' phase. However, because the end goal of the present chapter is the selection of a decision support design concept, it has been put under the design phase (see Figure 6.1). The outcomes of this study will be the selected decision support concept and will thus shape the remaining content of this research program.

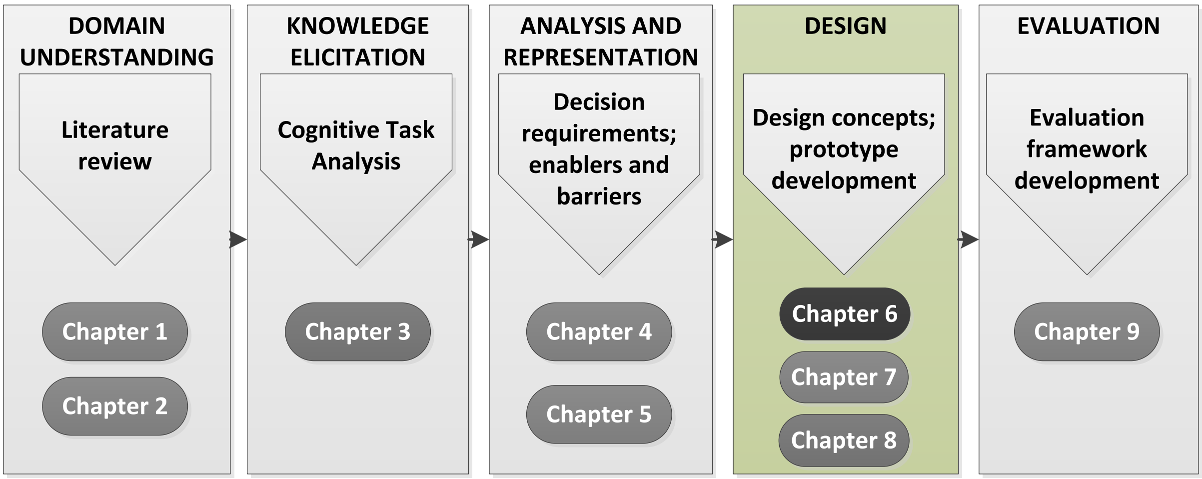


*Figure 6 1.*The decision-centred design process – chapter 6

## 6.2 Paper 5: Decision-centred design in healthcare: the process of identifying a decision support tool for airway management

## DECISION LETTER PAPER 5

Dear Miss Raphaela Schnittker,

I am pleased to inform you that your paper "Decision-centred design in healthcare: the process of identifying a decision support tool for airway management" has been accepted for publication in Applied Ergonomics.

Below are comments from the editor and reviewers.

Your accepted manuscript will now be transferred to our production department and work will begin on creation of the proof. If we need any additional information to create the proof, we will let you know. If not, you will be contacted again in the next few days with a request to approve the proof and to complete a number of online forms that are required for publication.

Thank you for submitting your work to Applied Ergonomics.

We hope that we can count on you in the future for reviewing manuscripts submitted to Applied Ergonomics. This is an important service to our community.

Yours sincerely,

Ayse Pinar Gurses, PhD, MS, MPH
Scientific Editor
Applied Ergonomics

Comments from the editors and reviewers:

Reviewer #1: The authors did a great job on revising the paper. I see that the authors addressed the comments well. I am convinced with the scientific contributions this paper made to the human factors field. Thank you.

Reviewer #2: Thanks much for the detailed revision. At this point, this Reviewer has no further comments.

Reviewer #3: The rewritten introduction is much appreciated, as it very clearly describes existing evidence regarding application of CTA/DCD in the healthcare field and the current gaps, particularly in the field of anesthesia. The "work-as-imagined" and "work-as-done" is an excellent way to describe the challenges faced by physicians when making life-changing decisions under pressure. This work's contribution to HFE knowledge is also better delineated.

The methods describe a good fusion of 3 different CTA methods to form a complete picture of the challenges faced by anesthesiologists in difficult cases. The section is descriptive enough to enable others to recreate the study, which is very helpful in this methods-based manuscript (allowing others to find their own solutions to similar problems in healthcare).

Results are complete and represent the data collected without being overly burdensome. Table 8 was particularly helpful in summarizing the analyzed results.

Discussion adequately describes the strengths and weaknesses of the research, including the use of inexperienced practitioners as SMA's (although I would argue that the point of CTA is to elicit the decision-making points from an experienced SMA, even if they're not aware of them).

Conclusions are concise and summarize the intent of the paper, if not the end result (the decision to develop a standardized airway trolley).

Overall, I believe this paper adds to the current HFE literature by providing guidance for others to solve similar low-frequency/high-risk scenarios in healthcare. I agree that this is a very challenging subject matter to study, and the methods described here are thorough and would be beneficial for others to follow. The standardized airway trolley is a good example of the use of HFE in healthcare and the methods behind its design process would be of interest as well.

Title: Decision-centred design for airway management

**Abstract**

Current decision support interventions for airway management in anaesthesia lack the application of Human Factors Engineering; leading to interventions that can be disruptive, inefficient and error-inducing. This study followed a decision-centred design process to identify decision support that can assist anaesthesia teams with challenging airway management situations. Field observations, Critical Decision Method interviews and focus groups were conducted to identify the most difficult decisions and their requirements. Data triangulation narrowed the focus to key decisions related to preparation and planning, and the transitioning between airway techniques during difficulties. Five decision-support interventions were identified and positively rated by anaesthesia team members in relation to their perceived effectiveness. An organised airway equipment trolley was chosen as the most beneficial decision support intervention. This study reiterated the key importance of both Human Factors Engineering and data triangulation when designing for healthcare.

**Keywords:** Decision-centred design, Airway Management, Cognitive Task Analysis

Title: Decision-centred design for airway management

# Introduction

Anaesthesia is a complex socio-technical system where humans interact with each other, advanced technology and organizational boundaries to provide anaesthetic care to patients (Manser & Wehner, 2002). An integral part of general anaesthesia is the effective support of a patient's breathing functions through artificial oxygen supply, a process termed 'airway management'. Decision-making during difficult airway management events is complex and often characterized by time pressure, high stakes and unexpected difficulties (Flin, Fioratou, Frerk, Trotter & Cook, 2013; Paix, Williamson, & Runciman, 2005).

Anaesthesia is a safe system (Amalberti, Auroy, Berwick, & Barach, 2005; Gaba, 1999) with major airway management complications occurring in only about one in 58,000 cases of general anaesthetics (The Royal College of Anaesthetists, 2011). However, these major complications can severely affect the patient safety as the potential outcomes include hypoxia, brain damage and death (Cook, Woodall, & Frerk, 2011). One feared airway management crisis is a 'can't intubate, can't oxygenate' (CICO) event where a patient's airway cannot be secured with any non-invasive airway technique, requiring a surgical airway as the last resort to provide oxygen and save the patient (Watterson, Rehak, Heard & Marshall, 2014). CICO events occur rarely in about 1 in 5000 cases, but contribute to 25% of all anaesthesia-related deaths (The Royal College of Anaesthetists, 2011, p. 13). CICO is an emerging crisis that involves (unexpected) difficulties leading up to the event, requiring immediate response to avoid a CICO event from occurring. Since around 50% of intubations are unanticipatedly difficult, anaesthesia teams need to be able to make decisions on the fly to effectively manage emerging crises (Australian and New Zealand College of Anaesthetists, 2016; Paix et al., 2005).

Similar to other complex sociotechnical environments, Human Factors play a key role in the successful management of airway challenges (Phipps, Meakin, Beatty, Nsoedo, & Parker, 2008). Loss of situational awareness, suboptimal teamwork and environmental factors have contributed to major airway management complications in the past (e.g. Bromiley, 2009; Flin, Fioratou, Frerk, Trotter & Cook, 2013). Consequently, the goal of the present study was to identify potential decision support design solutions for challenging airway management situations. Decision-Centred Design, a Human Factors Engineering approach from Naturalistic Decision-Making, was followed.

## Decision making in anaesthesia

Anaesthetists are highly skilled medical practitioners that received at least five years of training before practicing independently (Australian and New Zealand College of Anaesthetists, 2012). Since anaesthesia teams have to be able to manage unexpected challenges successful, their decision-making is typically naturalistic (Orasanu & Connolly, 1993; Phipps & Parker, 2014). The core of Naturalistic Decision Making is that, under time pressure and high stakes, experts assess situations and make decisions based on their experience (knowledge-based approach) rather than through a rational process of option analysis (Klein, 2008; Klein, Calderwood & Clinton-Cirocco, 2010).

One of the most well-known NDM models is the recognition-primed decision (RPD) model. The core of the RPD model is a situation assessment based on recognition of familiarity, which is then linked to familiar actions that were successful in the past (Klein, Calderwood, & Macgregor, 1989; Klein, Orasanu, Calderwood, 1993). Recognition-primed decision-making is typical in complex healthcare environments such as anaesthesia (e.g. Craig et al., 2012; Flin & Mitchell, 2009; Pauley, Flin, & Azuara-Blanco, 2013; Phipps & Parker, 2014). A previous study showed that more than 90% of critical airway management decisions were recognition-primed (Schnittker, Marshall, Horberry, Young, & Lintern, 2017a).

## Guidelines and decision support in anaesthesia

Anaesthesia is highly protocoled with guidelines by national professional organisations for anaesthetists setting the normative standards for many aspects of anaesthetic practice. In particular, clear guidelines exist for difficult airway management (e.g. Australian and New Zealand College of Anaesthetists, 2016; Berkow, 2004). Algorithms have been developed to improve compliance with guidelines in daily anaesthetic practice. Algorithms are abbreviated versions of guidelines that prescribe a step-wise process to aid decision-making in challenging situations. In airway management, algorithms prescribe transitions between airway techniques when the current technique fails (Heidegger, Gerig, & Henderson, 2005). Algorithms are considered as an important system element to support decision-making (e.g. Cook, 2018; Marshall & Mehra, 2014; Marshall, 2013). While guidelines and algorithms build the foundation for education and training, their textual format is less effective for performing clinical activities under time pressure (Chrimes, 2016; Marshall, 2017). In other words, they are tools for learning rather than implementation (Chrimes, 2016). Even experienced anaesthesia clinicians did not adhere to national airway management guidelines when handling airway emergencies (Borges et al., 2010). Another study showed that only a small proportion of anaesthetists view algorithms as 'law-like rules' (Knudsen et al., 2017). The mismatch of complex information systems for stressful, dynamic situations is well-recognised in healthcare and has been discussed elsewhere (Lintern & Motavalli, 2018; Patel, Zhang, Yoskowitz, Green, & Sayan, 2008; Sheehan et al., 2013).

## Design implications for naturalistic decision-making in anaesthesia

There is a mismatch between the naturalistic decision-making occurring in anaesthesia and the current design of decision support to be used at the point of care. The linear, textual and inflexible design of algorithms does not align with the naturalistic decision-making and healthcare work-flow (Chrimes, 2016; Marshall, 2017; Maviglia et al., 2003). Consequently, there is inconclusive evidence regarding their effectiveness to support challenging situations. Some studies have even shown a negative effect on decision-making (Marshall, Sanderson, McIntosh, & Kolawole, 2016; Marshall, 2013). While less cognitive aids have been designed to address this problem (Chrimes, 2016; Goldhaber-Fiebert & Howard, 2013; Paix et al., 2005), their benefit has not yet been identified (Cook, 2018).

The problem with current decision support interventions in anaesthesia is that they have been designed without a Human Factors approach (Marshall, 2017; Marshall, 2013). This resulted in healthcare decision support that does not appropriately consider the work flow and decision-making in complex healthcare environments (Lintern & Motavalli, 2018; Militello et al., 2016; Schnittker, Marshall, Horberry & Young, 2018, Sheehan et al, 2013). The consideration of cognitive requirements is especially important when it comes to decision support design for complex environments such as anaesthesia (Marshall, 2017). Due to the complexity and dynamicity, interventions that aim to support decision-making by offering too complex or too simplified inflexible tools do not optimally support the nature of naturalistic decision-making (Klein, Calderwood & Clinton-Cirocco, 2010; Lintern & Motavalli, 2018; Schnittker, Marshall, Horberry, Young, & Lintern, 2017). In other words, the 'situated nature of decision-making' in healthcare does not need to be supported on the rational knowledge level but needs to enhanced for recognition of important cues that assist with the 'muddling through' process (Flach, Feufel, Reynolds, Parker, & Kellogg, 2017).

## Human Factors and clinical decision support design

The importance of Human Factors Engineering for the design of healthcare environments has been largely recognised (e.g. Carayon & Wood, 2010; Karsh, Holden, Alper, & Or, 2006; Woods, 1999). A large proportion of Human Factors research focuses on high-level design recommendations and guidelines for healthcare decision support design. Most of these are related to the design of medical interfaces and their integration into the healthcare environment (Miller et al, 2018a). Many of these guidelines overlap with classic usability heuristics of user interfaces and also frequently endorse the importance of workflow integration (Miller et al., 2018; Nielsen, 1994). For example, Bates et al (2003) identified generic design recommendations for effective clinical decision support such as speed and efficiency, anticipation of user needs, adequate integration into clinician work flow and design simplicity. Kuperman et al (2007) and Horsky et al (2012) discussed information requirements in the context of medical prescription systems and identified the relevance of meaningful alerts and notifications, consistency and logical grouping, interface design and workflow integration. Miller et al (2018) identified generic design requirements for the management of patients with uncommon conditions such as cirrhosis. Amongst others they found that decision support should account for work distributed across practitioners, location and time and appropriate integration with previous clinical assessment. Recommendations on the integration of clinical decision support into electronic healthcare records has also been provided (Sheehan et al., 2013). Hence, the HFE literature provides ample high level guidance on design requirements of healthcare decision support systems.

## Context-specific decision support design

Other Human Factors studies on healthcare decision support design have been more context specific and focused on the design of a particular decision support system. For example, Escoto, Karsh and Beasley (2006) identified design requirements for a medical error reporting IT system through focus group discussions with physicians and clinical assistants. Ward, Buckle and Clarkson (2010) studied design requirements of medical packaging and labelling for a safe use at home through interviews and observations. Identifying design requirements to support general work flow and ergonomics has also been frequently performed, for instance in the context of ergonomic design requirements for surgeons and nurses (Sheikhzadeh, Gore, Zuckerman, & Nordin, 2009) and emergency department design (Zhang et al., 2017). Much research has performed to identify design requirements of medical interfaces such as pulmonary displays (Wachter et al., 2003) and infusion pumps (Lin, Vicente, & Doyle, 2001; Schraagen & Verhoeven, 2013). All these studies have in common that they reported design requirements in reference to a clear design goal. Thus, they followed a top down approach.

Only a few studies followed a bottom-up approach that started with a cognitive challenge without a clear design goal in mind. Since these studies identify decision design requirements through the study of cognitive challenges, they typically employ Cognitive Task Analysis (CTA). CTA refers to qualitative knowledge elicitation methods employed to study cognitive processes and identify suitable decision support design solutions (Crandall, Klein, & Hoffman, 2006; Klein, Kaempf, Wolf, Thorsden, & Miller, 1997). Nemeth et al (2016) employed interviews, observations and surveys to identify the design requirements for a cognitive and communications tool for a burn intensive care unit clinicians. Furniss and Blandford (2006) identified design requirements for emergency medical dispatch using observations and interviews. Steege and Dykstra (2016) identified a broad range system factors that could support fatigue management of nurses employing semi-structured interviews.

The Critical Decision Method (CDM) is an interview technique focused on the study of expert decision-making processes during notable incidents and elicitation of design requirements (Klein, Calderwood, & Macgregor, 1989). Therefore, it is closely aligned with CTA (Militello & Klein, 2013). It has been employed to study intra-operative decision-making of ophthalmic surgeons (Pauley et al., 2013), cognitive activities in the Intensive Care Unit (Fackler et al., 2009), factors affecting performance of registered nurses in the critical care (Patterson, Render, & Chalko, 2003) and alarm management of nurses (Gazarian, Carrier, Cohen, Schram, & Shiromani, 2015). However, most healthcare studies employing the CDM did not use their findings to identify decision support requirements. This is surprising, since this is one of the main goals of the CDM and has been done in other complex sociotechnical environments (e.g. Klinger, Klein, 1999; Crandall, Klein & Hoffman, 2006; Kaempf et al, 1996). Only Militello et al (2016) reported on the process of identifying a decision support system for colorectal cancer screening using critical incidents accounts. The use of the CDM is considered as beneficial for decision support design in anaesthesia, yet this approach is still in its infancy (Marshall, 2017).

## Decision-centred design in healthcare

Decision-centred design (DCD) is one framework from Human Factors Engineering. DCD focuses on supporting decision-making of experts under time-pressured, high-stakes and challenging conditions. Consequently, decision-centred design is traditionally applied in naturalistic decision-making environments. It aligns most closely with cognitive ergonomics and is part of the specialisation Cognitive Systems Engineering (Militello, Dominguez, Lintern, Klein, 2009). DCD can be seen as a specialisation within Human-Centred Design, which follows similar stages (ISO 9241:210, 2010). It is different to other HFE approaches in that it emphasizes the cognitive support of critical decisions in time-pressured, high-stakes situations; puts emphasis on difficult decisions and extraordinary incidents rather than routine situations; is focused on subject-matter-experts rather than novices, and is context-specific (Militello & Klein, 2013). In regards to the latter, it is similar to contextual design (Beyer & Holtzblatt, 1998). DCD has been employed in other areas such as traffic incident management (Cattermole, Horberry, & Hassall, 2016), the navy (Kaempf, Klein, Thordsen, & Wolf, 1996) and nuclear power plant safety (Klinger & Klein, 1999). Only a few studies have employed DCD in healthcare (Militello et al., 2016; Nemeth et al., 2016).

## Goal of this study

There are important gaps in the human factors literature on clinical decision support design. Firstly, the majority of studies reported on a top-down approach that started off with a clear decision support design goal; rarely studies reported on a bottom-up approach starting off with a cognitive challenge. Consequently, Human Factors studies addressing the necessity of reducing large amounts of qualitative outcomes for the purpose of identifying decision requirements and design concepts could not be identified. Finally, Human Factors studies in healthcare using the Critical Decision Method did not usually link outcomes to potential decision support requirements and design concepts. Since this is one of the main purposes of the CDM, further research is needed to fill this gap.

The goal of the present studies is to fill these theoretical gaps and address another practical gap: the identification of an appropriate decision support intervention for airway management with the goal to support decision-making at the point of care. As with all decision support design interventions, the aim is to support decision-making according to best practice guidelines as much as possible. However, due to the naturalistic nature of healthcare environments there always remains a mandatory gap between 'work-as-imagined' and 'work-as-done' (Anderson et al., 2016).

The 'work-as-imagined' in this instance is the adherence to established clinical practice guidelines. However, despite their creation by content experts and support by organizations, these are often flawed. For example, the difficult airway society guidelines presuppose that the initial aim of management is tracheal intubation, but with the advent of new technology over 60% of general anaesthesia episodes do not start with this aim (Marshall & Pandit, 2016). The present study therefore aims to augment existing top-down guidelines with 'work-as-done' decision making experience. Three methods from Cognitive Task Analysis were triangulated to study key decisions, their requirements and infer decision support concepts: field observations, in-depth interviews and scenario-based focus groups discussions (Schnittker, Marshall, Horberry, Young, & Lintern, 2016).

# Methods

## Decision-centred design activities

A decision-centred design process was followed to identify anaesthesia providers' key decisions and their requirements (Klein et al., 1997). The general DCD process and main activities undertaken are represented in Table 1. The initial domain familiarisation was achieved through field observations. Field observations are have been used in the past to study healthcare environments (Burtscher & Manser, 2012; Ozkaynak & Brennan, 2013; Palmer et al., 2013). Next, the key decisions of subject-matter experts (anaesthetists and anaesthetic nurses) were identified by employing CDM interviews. Consecutively, two focus group discussions were conducted to validate key decisions and generate ideas for decision support tools. A follow up survey was conducted as the final method to rate selected decision support design along an established usability scale. Triangulation of the three methods (plus field observations) resulted in the selection of a decision support tool which was consequently designed and evaluated with a small group of participants. This paper reports the outcomes of the data triangulation and decision support tool selection.

*Table 1*. Decision-centred design process and activities

**Note*. While activities are listed as a linear process, they involved iteration within each phase

| | *Decision-centred design phases* * | *Activities* |
|---|---|---|
| 1 | **Domain understanding** | • Identifying focus<br>• Selection of suitable methods<br>• Field observations |
| 2 | **Knowledge elicitation** | • (Field observations)<br>• Critical Decision Method interviews<br>• Focus groups |
| 3 | **Analysis and representation** | • Decision and design requirements of key decisions<br>• Decision pathways<br>• Triangulation |
| 4 | **Decision support design** | • Decision selection<br>• Identifying decision support design concepts<br>• Design prioritisation survey<br>• Selection of particular design<br>• Rapid prototype design process |
| 5 | **Evaluation** | • Cognitive walk-through<br>• Simulated evaluation<br>• Improving design |

## Triangulation of qualitative knowledge elicitation methods

The qualitative data was triangulated to identify decision requirements and design solutions. The triangulation of qualitative research methods is a common strategy in healthcare, especially the combination of interviews and focus groups (Valdez, McGuire, & Rivera, 2017). Triangulating different qualitative research methods is beneficial for enhanced data richness, data comprehensiveness and confirmation of findings across methods and participant groups (Lambert & Loiselle, 2008). It is especially important in applied Human Factors when it comes to the design of healthcare technologies, tools and spaces (Papautsky, Crandall, Grome, & Greenberg, 2015).

## Procedure

The field observations, interviews, focus groups and follow up surveys were conducted at two teaching hospitals in Melbourne, Australia. Ethics approval was obtained from the Human Research Ethics committees of the two participating healthcare organizations and Monash University. Participants were recruited via emails sent to the respective anaesthetic departments and via the second author who is affiliated with both hospitals. Participants were also recruited by word of mouth ('snowball sampling'). Before commencing the study, all participants signed a participant information and informed consent form and completed a demographic questionnaire.

## Field observations

The first author performed the first three days of observation with the second author (a consultant anaesthetist) to become familiar with the anaesthetic environment and procedures and to refine the observation protocol. Field observations provide the opportunity to obtain a real insight into the full complexity of a work environment (Roth & Patterson, 2005). The field observations were unstructured and exploratory; therefore, the questions asked were broad and tailored to the circumstances and opportunities that arose in the specific surgery observed. The observation protocol focused on the anaesthetist and the anaesthetic nurse and their activities related to airway management. This included interaction with the patient, the environment and other care providers who were present. Questions were an abbreviated version of the cognitive probes asked in the CDM and addressed key decision points made by the anaesthesia team. After the initial familiarisation, 27 cases were observed. A variety of surgery types were observed, including ear nose throat surgery (N=7), general (N=6), plastic (N=5), cardiothoracic (N=3), neuro (N=1), paediatric (N=1, plastic surgery case) and orthopaedic cases (N=5). An estimated total of 50 hours of surgery cases were observed. The length of surgery differed widely, depending on the type of surgery observed. For example, a few plastic and general surgery cases took only 30 minutes, whereas cardiac surgery lasted several hours. The aim was to observe a variety of airway management techniques used; which was possible with the selected surgery types. Anaesthetist consultants and anaesthetic nurses were observed while performing activities related to airway management throughout the operative period. The first author closely followed the participants around to study what decisions they made in the process of airway management and the environment where these decisions took place ('Shadowing', Ozkaynak & Brennan, 2013; Quinlan, 2008; Wolf et al., 2006). Shadowing started with seeing the patient in the pre-holding anaesthetic bay to perform the pre-assessment. Sometimes, the patient was already in the operating theatre ready to be inducted. In the operating theatre, the researcher was introduced to the operating theatre team and placed herself in an unobtrusive location and ask questions if the opportunity arose. The researcher made field notes on a piece of paper, and no audio or video recordings were taken. To protect patient confidentiality, no identifying patient data was collected.

## Critical Decision Method interviews

The Critical Decision Method (Klein et al., 1989) was employed to explore key decisions in challenging airway management situations the participants experienced in their past. The interview followed four phases. Initially, the participant chose and summarized a notable past challenging airway management situation in which the participant was actively involved. Secondly, the incident was verified by putting all key decisions and other events contributing to securing the patient's safety on a timeline. In the following two rounds, cognitive probes were employed to explore the key decisions and how they were made in detail. The interview was semi-structured and the set of cognitive probes was used as guidance. See Table 2 for an overview of the used cognitive probes. The length of the interviews varied between one and two and a half hours. The interviews were conducted in a private space at the participating hospitals. The first author, a PhD researcher with three years of experience in Human Factors research conducted the interviews. The researcher has no clinical background but has been researching in the anaesthetic discipline for more than a year. This included field observations, literature reviews and information discussions with anaesthesia providers to familiarise with the domain. All interviews were audio-recorded for later transcription.

*Table 2.* Cognitive probes used in Critical Decision Method interviews

| *Theme of cognitive probe* | *Example questions* |
|---|---|
| **Cues** | What did you notice? What did you see, hear…? What alerted you to this? |
| **Decisions and resilience** | What decision did you make? Why? What exactly did you do to keep the patient safe? Who else was involved? Did you do anything in particular to ensure patient safety? |
| **Options** | Did you consider any other options? Would there have been other options in hindsight? |
| **Experience** | How did you know how to make this decision? Would you have done this decision with less experience? |
| **Goals/Expectations/consequences** | What were your expectations when making this decision? Did you imagine any consequences? What were your goals? |
| **What if** | What would you have done if x would have happened? |
| **Decision support** | Would it be helpful to support any of these decisions? How? What could help less experienced people/what would have helped you in your early years of training? |

## Scenario-based focus groups

Two focus group discussions were conducted at the anaesthetics department of one of the two participating hospitals. The first author conducted the focus group with an assistant. The focus groups had two separate elements. Firstly, a difficult airway management scenario was discussed to identify the most important key decisions to solve the situation. The scenario chosen was derived from a CDM narrative that involved an airway challenge requiring transitions between a variety of airway techniques (see Table 3). The airway management challenge chosen for the scenario involved a 'can't intubate, can't oxygenate' (CICO) situation. CICO is one of the most critical airway management challenge, associated with high morbidity and mortality (Australian and New Zealand

College of Anaesthetists, 2016; T. M. Cook, 2018). Human Factors play a key role in the successful management of CICO, as it requires decision-making under high stakes and time pressure to initiate the transitions between a series of airway management techniques (Watterson, L., Rehak, A., Heard, A., Marshall, 2014). The initial situation was shown on a PowerPoint presentation to the point where the anaesthesia was initiated. From that point the group discussed what the key decisions would be if airway techniques fail and how to secure the patient's airway. The first author facilitated the discussion by probing through the scenario. The second part of the focus group involved a discussion about potential decision support tools, and gathering design ideas for each of the key decisions discussed. Both focus group discussions were audio-recorded for later transcription and analysis.

*Table 3.* Focus group scenario provided to participants

| *Focus group scenario* |
|---|
| *Context: 60-year-old male for repair of oesophageal tear* |
| • Septic, HR 120/min BP 100/50 T=38.1°C |
| • Unable to lie flat due to dyspnoea |
| • Plan relaxant general anaesthetic with rapid sequence |
| *Airway assessment:* |
| • Weight 120kg, BMI 38, |
| • Neck circumference 36.9cm (normal <35.5cm) Mallampatti 2, TMD 6.5cm |
| • Own dentition, no loose, Neck extension >90° |
| • Advised anaesthetic nurse- potential difficult a/w |
| • Saturations up at 45° and ramped with Oxford pillow |
| *Anaesthesia induction:* |
| • Preoxygenated 5 mins, EtO2 85%, SpO2 100% |
| • Propofol 250mg, Suxamethonium 150mg given |
| • Grade 2b view with size 4 McIntosh blade |
| • ETT passed easily |
| *Probes: What now? Discuss the next decision you would make. (And if that decision would fail…)* |

## Design prioritisation survey

Based on the outcomes of the interviews and focus groups, five potential decision support tools were suggested. The design concepts were drafted descriptively and prepared for the design prioritisation survey. The aim of this survey was to establish which design concept would be the most suitable. The survey listed a detailed, but not definite, description of the five decision support tool ideas. Participants were asked to rate each decision support tool on several dimensions utilizing a systematic approach called 'FACES' (Shappell & Wiegmann, in O'Connor and Cohn, 2010). The original rating scale consists of five dimensions (feasibility, acceptance, cost, effectiveness, and sustainability), each rated from 1 (poor) to 5 (excellent) by subject-matter-experts that would use the intervention in the future. Horberry and colleagues (2004) employed criteria to reduce the number of possible interventions for forklift technologies. This study used similar criteria that were adapted to suit the anaesthetic environment:

1. Effective in addressing a safety problem that was prominent in cases discussed in the CDM and other previous incidents
2. Feasibility of the design concept
3. Likely to be accepted by practitioners, managers and the healthcare organization
4. Able to be integrated within the anaesthetic environment (other equipment, processes and training)
5. Be reliable and produce few false alarms

The design concepts were independently rated by anaesthetic practitioners that had previously participated in one of the three knowledge elicitation studies. The survey was sent and returned via email and was completed by participants in their own time.

## Participants

Anaesthetic practitioners and anaesthetic nurses with varying experience participated in the four studies, including the preliminary field observations (see Table 4). Frequently, anaesthetic practitioners in training (anaesthetic registrars) were observed in addition to the anaesthetic practitioner because they usually perform the anaesthetic care under supervision. Some participants were shadowed for several cases in a row, which is why this study involved more cases than participants. Anaesthetic practitioners in training participated in the focus group studies.

*Table 4*. Participants and their experience in the present research per study

| | Experience in airway management | | | | |
|---|---|---|---|---|---|
| **Participants per method** | **0-5 years** | **5-10 years** | **10-15 years** | **>15 years** | **Total** |
| **Observations** | | | | | |
| Anaesthetic practitioners | 4 | 3 | 6 | 6 | **19** |
| Anaesthetic nurse | 1 | 1 | 0 | 0 | **2** |
| **Interviews** | | | | | |
| Anaesthetist | 1 | 1 | 2 | 8 | **12** |
| Anaesthetic Nurse | 1 | 0 | 1 | 2 | **4** |
| **Focus groups** | | | | | |
| Anaesthetic practitioners** | 4 | 7 | 0 | 0 | **11** |
| **Survey** Anaesthetic practitioners | 1 | 1 | 1 | 3 | **6** |

**Note*. Some anaesthetic practitioners participated in more than one study, i.e. interviews, observation and/or focus groups ** One Emergency Department/Intensive Care registrar participated.

## Analysis

### Individual analysis of interviews, focus groups and follow up surveys

All studies were analysed independently. Firstly, the CDM interviews were analysed in the qualitative data software program *NVivo 10 QSR international*. Focus groups were analysed manually. The 16 CDM interviews were transcribed and then uploaded in NVivo. Consequently, text fragments were coded using an inductive and deductive coding strategy. Some of the codes were previously planned and derived from the RPD model (e.g. cues, options, decision pathways and expectations). Others were 'inductive' codes which were explorative and guided by the interview narratives themselves. The development of the coding framework was an iterative process. Consequently, decision requirement tables were created for each key decision discussed in the CDM interviews. The tables contained information about the context of the decision and why it was a challenge, the critical cues and expertise involved, underlying cognitive pathway and decision support ideas. The focus groups were analysed separately by employing thematic analysis of the key decisions and design ideas discussed.

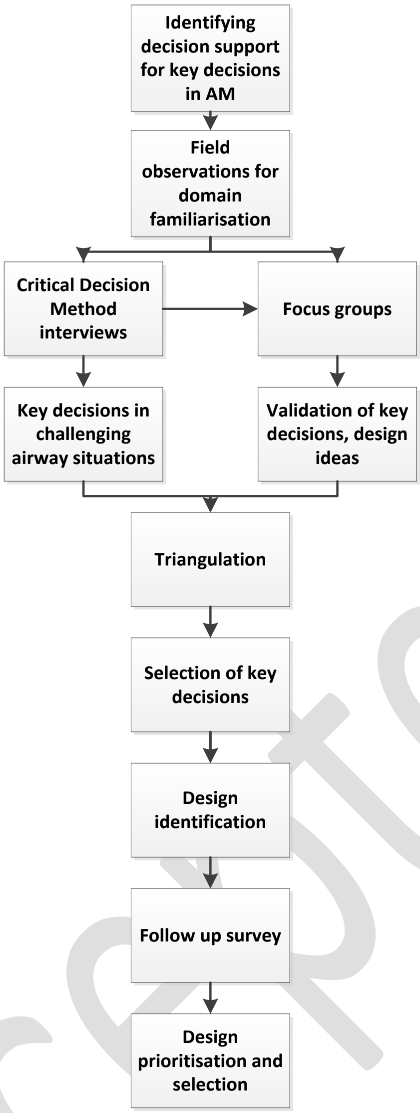


*Figure 1*. Flow of research activities discussed in the present study

## Categorization, reduction and selection of key decisions

After analysing the CDM interviews and focus groups separately, the key decisions found in each study were compared by grouping them into seven distinct categories. These categories reflected the clinical nature of the key decisions. For example 'planning, anticipation and preparation' was a main category with several sub-categories such as 'suggesting other equipment and airway manoeuvres'. The categories were created by the first author, and independently reviewed by the second author, as well as the third and fourth authors for clarity and consistency. Due to the complex nature of airway management and the initial open approach undertaken in this study, many key decisions were found across the whole operative period. Therefore, as a next step, the authors narrowed down the key decisions that should be targeted in the decision support design. Rather than selecting individual key decisions, the authors selected the key decision categories that were created previously. Categories adhering to the following selection criteria were included:

1. **Re-occurrence**: Common key decisions categories made in each interview case to solve the airway management challenge; i.e. their re-occurrence reflect their universal importance
2. **Method overlap**: Key decision categories discussed in both CDM interviews and focus groups as mostly important and challenging
3. **Feasibility**: Key decision category can be supported by an environmental re-design/decision support tool
4. **Past incidents**: Key decision category has been identified in past research and documentation as being (1) challenging, (2) prone to affecting patient safety and (3) in need for decision support.

Table 5 shows presents the key decision categories that were included based on the selection criteria.

*Table 5*. Outcomes of decision selection process: selected key decision categories

| Decision categories | Sub-categories (in bold, individual decisions under sub-categories not shown) or individual decisions if no sub-categories |
|---|---|
| **Planning, anticipation and preparation (nurse)** | ➢ Having equipment ready to be used<br>➢ Suggesting other equipment and airway manoeuvres<br>➢ Reading oxygen saturation levels out loud |
| **Repeating and optimizing attempts with similar airway technique** | ➢ **Additional attempt using similar technique**<br>➢ **Additional attempt using optimization strategy**<br>➢ **Facilitative strategies used throughout techniques and transitions** |
| **Transition between non-surgical techniques after failure** | ➢ **Transition to laryngeal mask**<br>➢ **Transition to face mask**<br>➢ **Transition to other type of intubation**<br>➢ **Transition to awake techniques** |
| **Transition from non-surgical to surgical techniques** | ➢ Transition from failed laryngoscopy to surgical airway<br>➢ Transition from failed gas induction to asleep tracheostomy<br>➢ Transition from failed bag and mask to surgical airway<br>➢ Transition to a surgical technique when laryngoscopy, face mask and LMA failed<br>➢ Transition from a needle cricothyroidotomy to tracheostomy |

## Rationale for selection of key decision categories

The selection of key categories was informed by relevant literature in the field of anaesthesia. It was decided to focus on supporting the transition between techniques as it was one major decision category found in the interviews and focus groups and discussed as the most important and difficult one depending on the transition. The transition between techniques, or failure of so, is essential to prevent patient harm and has been linked to fatal outcomes; especially CICO situations where transition to a surgical airway is the last option to save the patient (Bromiley, 2009; Marshall & Mehra, 2014; Watterson, Rehak, Heard & Marshall, 2014). Strongly related to this was the theme of preparation and the support by the nurses to offer equipment and having it readily available to be used. In fact, prevention of time pressure through initial ‘planning for failure’ and other strategies is the key to successful airway management (Cook et al., 2011).

### Identification and prioritization of decision support tools

Decision support tools were identified from the interviews and focus group discussions. The decision support tools were either directly mentioned by participants as desirable, or derived from the decision requirements tables and a thematic analysis of the focus group discussions. Knowledge obtained from the preliminary field observations additionally informed on already existing support tools and their use in context, generic work flow and the (physical) fit of design concepts to the anaesthetic environment. The following design prioritisation survey presenting the dominant decision support tools identified was scored by calculating average ratings for each decision support design concept. Individual averages for each criteria were also calculated.

# Results

## Critical Decision Method interviews

The interviews revealed that anaesthesia teams make a variety of decisions throughout the operative period. A total of 86 decisions were found. The majority of these key decisions were made during the induction phase (N=66), followed by the pre-induction phase (N=18). Only two decisions were made in the emergence phase of anaesthesia and zero during maintenance. Before induction, decisions usually concerned the planning, preparation and transferral of the patient. During the induction of anaesthesia, decisions mainly concerned the transition between techniques or abortion of procedures when difficulties arise. The two decisions post-surgery were related to the transferral to other care units.

### Decision requirement tables

The anaesthesia team used a variety of cues to inform their decisions. These included direct patient cues (anatomy, physiology, known medical conditions, skin colour), technology (pulse oximeter, capnography), visibility and availability of alternative airway equipment, awareness of previous failed attempts with techniques and communication. Table 6 presents an example decision requirement table for one interview narrative. In this example, after preparing and anaesthetising the patient, the anaesthetic practitioner experienced difficulties in oxygenating the patient and had to change airway techniques, call for help and make available staff aware of the situation. The situation was challenging because the patient’s oxygen saturation dropped and different airway techniques did not improve the oxygen levels. The cues used mostly came from technology (e.g. the anaesthetic machine displaying exhaled carbon dioxide and the pulse oximeter), the patient (e.g. skin colour, chest movement) and awareness of previous failure (e.g. previous failed attempt at intubation).

Table 6.
*Decision requirements table for example key decisions for each decision category included in this study**

| No | Decision category | Decisions | Challenges | Critical cues | Knowledge/Critical expertise | Potential decision support design |
|---|---|---|---|---|---|---|
| **1** | **Planning, anticipation and preparation (nurse)** | Planning/Preparation – Having equipment readily available | A potential difficult patient needs to be intubated | Anaesthetist communicates to the nurse that the patient might be difficult, which triggers preparation | Knowing what could possibly go wrong in the process and have equipment ready to be used for plan A,B,C | Support planning procedure by a standardized equipment trolley that acts as a cognitive aid for the inclusion and visibility of equipment |
| **2** | **Repeating and optimizing attempts with similar airway technique** | Additional attempt at video laryngoscopy (use bougie) | The intubation was difficult with a standard laryngoscope because airway landmarks could not be visualised | Anaesthetist could not see the vocal chords to insert the tube<br><br>Bag mask ventilation worked and the patient was well oxygenated; LMA would have been possible; therefore it was safe to have another attempt | Knows she could have reverted to a laryngeal mask If intubation with bougie wouldn't have been possible<br><br>Continue with trying to insert the endotracheal tube if oxygen saturations are established<br><br>Don't persist on a strategy if it is not working but move on to a different strategy<br><br>Knows her assistant had extra equipment (bougie) ready to go for her because of earlier communication | Encourage to move on to a different strategy (e.g. bougie) by having it visible and easily accessible.<br><br>Have LMA and other rescue airways visibly available as a back-up in case bougie does not work<br><br>Advanced pulse oximeter that alerts on passed time in addition to oxygen saturation to assist in moving between strategies |
| **3** | **Transition between non-surgical techniques after failure** | Transition from failed bag and mask to LMA | Time pressured situation where face mask and intubation failed, LMA not thought of originally (colleague put LMA in after | Failed intubation, failed face mask ventilation, a desaturating patient with blue skin colour | Know that the laryngeal mask is available as a rescue technique when the bag and mask does not work<br><br>Knowing the impact of tunnel vision and the importance to call for help for a fresh perspective<br>Knowing not to persist on an unsuccessful strategy | Planning tools used for training that are simply designed to be used in the emergency that indicate transitions as reminders<br><br>Have different airways readily and visibly available so they can be accessed easily/are not forgotten |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | being called for help) | | | Advanced pulse oximeter<br>Other members of the team proactive with suggesting different equipment/techniques |
| | | Transition from failed intubation to bag and mask (with adjunct) | Intubation of sick patient not successful, patient not oxygenated and with dropping oxygen saturations | Could not squeeze bag and mask after connecting to anaesthetic machine, no capnograph, pulse oximetry alarm, patient looked blue, could not see chest moving | Knowing when to revert to back-up technique to re-oxygenate, know not to persist with particular strategy if not successful<br><br>Knowing which back-ups to use | Planning tools used for training and simply designed to be used in an emergency that indicate transitions as reminders<br><br>Have different airways readily and visibly available so they can be accessed easily/are not forgotten<br><br>Encourage other team members to be proactive with offering different equipment/techniques |
| 4 | **Transition from non-surgical to surgical techniques** | Transition from failed bag and mask to surgical airway | Failed bag mask ventilation and failed intubation, time pressured situation | Failed attempt at intubation and bag mask ventilation | Know when to go back to a back-up technique to re-oxygenate, know not to persist on a particular strategy and move on<br><br>Know that the laryngeal mask would have been available as a rescue technique<br><br>Have the technical skills to perform surgical airway<br><br>Know to call for help and support for the additional equipment | Planning tools used for training and simply designed to be used in the emergency that indicate transitions as reminders<br><br>More practical training on technical skills in performing a surgical airway<br><br>Having a surgical airway kit readily available and everyone knows where it is and how to use it (already initiated in theatre) |

**Note*. Originally, an individual DRT was created for each CDM interview. This table was reconstructed for the purpose of this paper to show example decisions for each included decision category. Therefore, the decisions listed in this table come from different CDM narratives.

## Triangulation of interviews and focus groups

After creating the decision requirements tables, the key decisions were further categorized according to their clinical content (see Table 7, column one). This categorization was used as the basis for triangulating the data with the focus groups. Significant overlap was found between key decisions found in the CDM interviews and focus groups. Specifically, important key decisions related to the transition between airway techniques, optimizing attempts and planning were found in both interviews and focus groups (see Table 7). The transition between airway techniques was the most relevant decision discussed, next to team communication and planning and preparation for failure.

*Table 7*. Included key decision categories in the present studies and their overlap between CDM interviews and focus groups

| Decision categories | CDM interviews | Focus groups |
|---|---|---|
| **C1: Planning, anticipation and preparation (nurse)** | ▪ Having equipment ready to be used<br>▪ Suggesting other equipment and airway manoeuvres<br>▪ Reading oxygen saturation levels out loud | |
| **C2: Repeating and optimizing attempts with similar airway technique** | **Sub-cat: ADDITIONAL ATTEMPT USING SIMILAR TECHNIQUE** | |
| | ▪ Additional attempt at laryngoscopy after failure of surgical airway<br>▪ Additional attempt at laryngoscopy after failure of previous techniques | ▪ Additional attempt at laryngoscopy as primary airway technique |
| | **Sub-cat: ADDITIONAL ATTEMPT USING OPTIMIZATION STRATEGY** | |
| | ▪ Additional attempt at laryngoscopy as primary airway technique using a bougie<br>▪ Additional attempt with an LMA using a different type of LMA<br>▪ Additional attempt at video laryngoscopy using a d-blade<br>▪ Additional attempt at face mask ventilation with two-hands<br>▪ Additional attempt at face mask ventilation with Guedel airway | ▪ Additional attempt at laryngoscopy as primary airway technique using a bougie |
| | **Sub-cat: FACILITATIVE STRATEGIES USED THROUGHOUT TECHNIQUES AND TRANSITIONS** | |
| | ▪ Use guedel airway to facilitate face mask ventilation<br>▪ Bag mask ventilation as an initial attempt to improve oxygen levels<br>▪ Provide continuous positive airway pressure to facilitate face mask ventilation | ▪ Use guedel airway to facilitate face mask ventilation |
| **C3: Transition between non-surgical techniques after failure** | **Sub-cat: TRANSITION TO LARYNGEAL MASK** | |
| | ▪ Transition from failed face mask ventilation to LMA<br>▪ Transition from failed laryngoscopy to LMA as temporary airway<br>▪ Temporary ventilation with laryngeal mask as a bridge to buy time | ▪ Transition from failed laryngoscopy to LMA<br>▪ Transition from failed face mask to LMA |
| | **Sub-cat: TRANSITION TO FACE MASK** | |
| | ▪ Transition from failed laryngoscopy to face mask<br>▪ Transition from failed LMA to face mask ventilation<br>▪ Transition from failed awake fiberoptic intubation to face mask ventilation | ▪ Transition from failed laryngoscopy to face mask ventilation |
| | **Sub-cat: TRANISITION TO OTHER TYPE OF INTUBATION** | |
| | ▪ Transition from direct laryngoscopy to video laryngoscopy<br>▪ Transition from failed direct laryngoscopy to asleep fiberoptic intubation | ▪ Transition from failed laryngoscopy to video laryngoscopy |
| | **Sub-cat: TRANSITION TO INTUBATION** | |

| | | |
|---|---|---|
| | ▪ Transition from failed face mask ventilation to laryngoscopy | |
| | **Sub-cat: TRANSITION TO AWAKE TECHNIQUES** | |
| | ▪ Transition from failed gas induction to awake fiberoptic intubation<br>▪ Transition from failed laryngoscopy to awake fiberoptic intubation | |
| **C4: Transition from non-surgical to surgical techniques** | ▪ Transition from failed laryngoscopy to surgical airway<br>▪ Transition from failed gas induction to asleep tracheostomy<br>▪ Transition from failed bag and mask to surgical airway | ▪ Transition to a surgical technique when laryngoscopy, face mask and LMA failed |
| | **Sub-cat: TRANSITION TO MORE SECURE SURGICAL AIRWAY** | |
| | ▪ Transition from a needle cricothyroidotomy to a tracheostomy | |

## Identification of decision support design ideas

The five dominant decision support tools are described below. Table 8 presents the key decisions and knowledge the decision support tools address and how they have been inferred.

### Standardization of airway equipment- improved difficult airway trolley

The relevance of having back-up equipment such as Guedel and laryngeal mask airways in reach and them being offered by the anaesthetic nurse was a theme in all three studies. In some cases, the laryngeal mask was overlooked. The interviews revealed that the visibility and offering of airway equipment is a powerful back up and positively affected the transition between airway techniques and optimization techniques. In order to support this, an option was to standardize the airway equipment of the difficult airway trolley according to generic back up plans. Also, the design of the trolley can be potentially improved by colour coordinating and labelling the compartments of the difficult airway trolley more clearly. The difficult airway trolley could also be designed to coordinate with training and simplified cognitive aids.

### Organized airway trolley for anaesthetic nurses

The idea to standardize the presentation of airway equipment to the anaesthetic team was inferred from all three knowledge sources. The interviews revealed that the visibility and offering of airway equipment to the anaesthetic practitioner is a powerful back up and positively affected transition between airway techniques and optimization techniques. The relevance of having equipment available and it being offered by the anaesthetic nurse was discussed in both interviews and focus groups. Additionally, the invisibility of the rescue airway device (laryngeal mask) has contributed to it being overlooked and omitted. A standardized representation of airway equipment that is visible to the anaesthetic team, and even the whole surgical team, would support the transition between airway techniques, optimization of attempts and mitigate the omission of techniques. To realise this, a surface with airway silhouette-like representations that serve as templates would be created. These templates can be filled with the airway techniques and thereby serve as reminder for preparation and offering of equipment, as well as visibility for the whole team. They can take the form of a mat that can be rolled up, or an adaptation of the anaesthesia trolley that holds the airway equipment used by the anaesthetic nurse.

### Time sensitive pulse oximeter

The concept of a time sensitive pulse oximeter was inferred from the interviews and focus groups. A time sensitive pulse oximeter not only indicates de-saturation of oxygen levels, but also considers and alerts on the time that is passing while attempting to secure the airway. The time-sensitive pulse oximeter would support the transition between techniques and could become an additional trigger point for the anaesthetic team to stop attempting a certain technique and move on.

### Symbolic chart

The idea of simplifying algorithms into symbolic charts has been introduced before. One model is the ‘vortex’ (Chrimes, 2016), a conceptual chart that represents the transition between airway techniques as a vortex. It provides a simplified visual guide that is used for training and intended to be used as a cognitive aid at the point of care. The key message it conveys is to only have a certain number of attempts with the three major airway techniques and optimization strategies before transitioning to the next technique. The end of the funnel is a surgical airway as the last resort to secure the airway. The vortex is currently used locally for training, but its impact on decision-making has not been studied yet.

### Training

Training on specific trigger points that indicate the need to change the current strategy was raised in the focus group discussions. Trigger points discussed were the number of attempts with a certain technique and a certain level of oxygen saturation. The training would involve a coordinated responding of different members of the team. This would include the organization of the difficult airway trolley, calling for additional help and a person dedicated to oversee the process. As the training on trigger points align with the aim of the other suggested decision support tools, the training may be combined with one of the other decision support tools.

Table 8 *Decision support design concepts and their relation to key decision categories**

| Design ideas | Knowledge source | Addresses key decisions in category* | Supports cues/knowledge (retrieved from DRTs*) | Design implementation |
|---|---|---|---|---|
| **Standardization of airway equipment-improved difficult airway trolley** | Directly suggested in focus groups, derived from interviews | ▪ **C1**: Planning, anticipation and preparation<br>▪ **C3/4**: All Transitions | ▪ Having equipment ready to be used<br>▪ Have equipment ready to be used for plan A,B,C and support smooth transitions | Pre-existing idea will be extended (difficult airway trolley concept already implemented in many hospitals, however not universal) |
| **Organized airway trolley for anaesthetic nurses** | Directly suggested in focus groups, derived from interviews | ▪ **C1**: Planning, anticipation and preparation<br>▪ **C2**: Repeating and optimizing attempts with similar technique<br>▪ **C3/4**: All Transitions | ▪ Awareness that laryngeal mask and other rescues are available as a back-up<br>▪ Aids preparation of airway equipment and omission of equipment<br>▪ Recognition and memory of alternative strategies in times of stress avoid persisting on current strategy<br>▪ Team awareness of available airway equipment | Pre-existing idea will be extended (similar idea to 'dump kits' used in pre-hospital emergency care) |
| **Time sensitive pulse oximeter** | Derived by research team from interviews and focus groups | ▪ **C2**: Repeating and optimizing attempts with similar technique<br>▪ **C3/4**: All Transitions | ▪ Trigger to transition between techniques under time pressure and decreasing oxygenation of patient | Novel idea; technology |
| **Simplified symbolic chart for decision guidance** | Directly suggested in interviews, discussed in observations and focus groups | ▪ **C1**: Planning, anticipation and preparation<br>▪ **C2**: Repeating and optimizing attempts with similar technique<br>▪ **C3/4**: All Transitions | ▪ May assist with preparation of equipment and planning of transitions in case of failure<br>▪ Visual reminder of the alternative strategies available when current strategy does not work | Pre-existing concept may work (vortex model, a symbolic chart |
| **Training on specific trigger points** | Directly suggested in focus groups | ▪ **C1**: Repeating and optimizing attempts with similar techniques<br>▪ **C3/4**: All Transitions | ▪ Additional training on the specific triggers points where transitions need to be initiated will hopefully support this in the real world | Defining trigger points and supporting these through something (not specific yet) and training them |

**Note*. For brevity, only examples are presented in this table.

## Prioritization of design ideas for decision support

The results of the prioritization survey are presented in Table 9. On average, all decision support design concepts were perceived as better than satisfactory. The training on specific trigger points and organized airway trolley for anaesthetic nurses received the highest ratings; followed by the standardization of the difficult airway trolley. The time sensitive pulse oximeter received the lowest ratings.

*Table 9*. Prioritization of design ideas for decision support – ratings*

| Design concept | Effectiveness | Feasibility | Acceptance | Environmental fit | Reliability | Cost | Total |
|---|---|---|---|---|---|---|---|
| **Standardization of airway equipment-improved difficult airway trolley** | 4.3 | 4 | 3.8 | 4 | 4 | 4.6 | **4.1** |
| **Organized airway trolley for anaesthetic nurses** | 4.3 | 4.5 | 4.2 | 4 | 4.2 | 4.4 | **4.3** |
| **Time sensitive pulse oximeter** | 3.8 | 3.4 | 3 | 3.8 | 3 | 2.8 | **3.3** |
| **Simplified symbolic chart for decision guidance** | 4 | 4.2 | 3.3 | 4 | 4 | 4 | **3.9** |
| **Training on specific trigger points** | 5 | 4.2 | 3.8 | 4.3 | 4.6 | 4.6 | **4.4** |

**Note*. Ratings adjusted to one decimal points

# Discussion

The goal of this study was to identify a decision support tool for challenging airway management situations in anaesthesia. The study followed a decision-centred design process where anaesthesia practitioners were involved at every stage of the process starting from domain familiarisation to the actual selection, design and evaluation of the decision support tool. Thereby, this study filled a gap in the clinical practice of airway management. The study started off with the study of airway management (cognitive) challenges by employing field observations, CDM interviews and focus groups. Based on the triangulation of the qualitative findings and their meaningful reduction to enable a more specific focus on the most difficult decisions, suitable design concepts were identified and prioritised. In contrast to previous studies utilizing top down approaches, bottom-up approaches as reported in this study have rarely previously been done in the context of healthcare decision support design. Therefore, this study filled a theoretical gap in the practice of Human Factors research.

## Data reduction and identification of decision support concepts

The study findings revealed that various key decisions have to be made by the anaesthetic team to successfully solve airway management challenges relating to all phases of the operative period. The key decisions relating to the transition between airway management techniques, as well as preparation and planning, were chosen due to their difficulty and relevance to successful airway management (Schnittker et al., 2017; Watterson, Rehak, Heard & Marshall, 2014).

Due to its bottom-up, data driven nature, this research required much refinement and specification throughout the research phases. However, limited research is available to guide triangulation of qualitative data (Lambert & Loiselle, 2008), especially in the context of human factors research on healthcare design (Papautsky, Crandall, Grome, & Greenberg, 2015). The performed process of categorisation, selection and reduction of key decisions was beneficial to make the large amount of qualitative data more manageable for the purpose of this study.

The FACES approach by Shappell and Wiegmann (2010), originally employed in aviation, was helpful in prioritising the five decision support design concepts. The rating scale offered a degree of quantitative evaluation to this purely qualitative research. To some extent, it served as a simple version of member checking (Birt, Scott, Cavers, Campbell, & Walter, 2016), since participants of the FACES survey participated in both CDM interviews and the focus groups. More practically, the easy and efficient administration of the rating scale was useful for the data collection from healthcare clinicians who are busy and difficult to access. The positive ratings of the five decision support design concepts emerging from the CTA confirmed that the process of data reduction was sensitive and included the key decisions with most leverage. More generally, it shows that the decision-centred design process was useful in identifying decision-support interventions that are likely effective, supportive of key decisions that are vulnerable to failure, and accepted by clinicians. Thereby, it addresses the challenge of designing decision support for healthcare that is sensitive to decision requirements and work flow as discussed by Lintern and Motavalli (2018).

### Using the CDM to identify decision support requirements

The use of the CDM was beneficial for the identification of decision support design requirements. The cognitive probes, which were adapted for the purpose of this study, were useful to elicit relevant information for each critical decision point during the airway management incident. Traditionally, the CDM is used with experienced subject-matter experts to identify their expertise and strategies to handle critical incidents successfully (Militello & Klein, 2013). In the context of utilising the CDM for the elicitation of decision support design requirements, it may have been useful to also interview less experienced clinicians. While interviewing experts was beneficial to identify strategies that have been successful in the past, less experienced clinicians' likely experience more challenges than experts. Therefore, they likely still make many decisions in a knowledge-based mode rather than a skill-based or rule-based mode (Rasmussen, 1983). Therefore, less experienced clinicians may likely be able to verbalise the cognitive processes underlying these challenges more clearly compared to subject-matter-experts whose knowledge is tacit. In this context, less experienced clinicians may also be more open to decision support design innovations and being able to provide more effective feedback than experts. In this study, the insight from junior clinicians was gained from the focus groups: therefore it is argued that the research adequately considered both expert and less experienced points of view. However, future studies with a similar goal only using one knowledge elicitation method should carefully consider the experience of their participants.

## Limitations

This study has a few limitations. First of all, the categorization and data triangulation was performed by members of the research team. This has likely increased the risk of susceptibility to biases in the interpretation of the findings. Members checking, the validation of the data analysis through participants, would have likely improved the robustness and validity of the findings (Birt et al., 2016; Coombs, Davidson, Nunnally, Wickline, & Curtis, 2017). Furthermore, the fact that only two methods were triangulated may have likely affect the outcomes of this study. The field observations were initially planned to be included in the triangulation. However, while they were necessary to develop an understanding of the reality of the clinical work including the work flow, procedures and interactions; they did not prove useful for the systematic study of infrequent, challenging key decisions. This problem with field observations in anaesthesia has been recognised previously (Cuvelier & Falzon, 2011). This suggests that retrospective methods such as the CDM may be more suited for the study of difficult decisions during notable incidents in safety critical environment. However, as the CDM interviews and the focus groups provided a rich amount of data, we believe to have mitigated this limitation as much as possible. Finally, the design concepts identified from the triangulation of CTA are conceptual at this stage and lack detail. The concrete development of the airway equipment trolley prototype is the goal of a future study following this triangulation.

## Follow up research

The findings of this study suggests that the decision support design concept of a standardized airway equipment trolley will likely benefit the key decisions related to planning and preparation, as well as transitioning between airway techniques in the face of failure. Disorganised equipment and a lack of standardisation has been identified as one of the main Human Factor barriers in airway management (Schnittker, Marshall, Horberry & Young, 2018). The design of an airway equipment surface tool that is standardized and makes omissions of equipment preparation obvious will be helpful for the preparation and planning of airway strategies. The trolley will also likely support the transitioning between airway techniques by improving the visibility and accessibility of airway equipment to the anaesthesia team; and the broader medical team. The advantage of an organised airway equipment trolley is that it does not mandate a specific approach or inflexible rule-based instructions; a major problem with decision support design that does not suit the complex nature of healthcare (Flach et al., 2017; Lintern & Motavalli, 2018; Marshall, 2017). Instead, it will be a decision support that is flexible, accessible and likely not produce any interruptions to the work flow. In order to make sure that the prototype development of the trolley will consider the practitioners' requirements, a co-design process will be followed. Suitable design recommendations for clinical decision support as identified in the literature will be considered at this stage (e.g. Miller et al., 2018).

# Conclusions

The design of healthcare decision support is challenging. In order to understand the cognitive challenges of healthcare clinicians and consider these in the design of the decision support intervention, practitioners have to be involved throughout the design process. When starting the study of cognitive challenges without clear design goals, the qualitative research methods offered by CTA are relevant to identify critical decisions, strategies and leverage points for decision support. This study illustrated how large qualitative amounts of triangulated qualitative data can be used to identify potentially beneficial decision support design interventions. We anticipate this approach will be helpful to future Human Factors design-oriented research with a similar outset. While this study provided another example of the importance of human-centred design, it remains a challenge to fully integrate Human Factors approaches like these in the healthcare domain. A joint effort by professionals, researchers and educators is required for their successful diffusion, dissemination, implementation and ongoing sustainability (Carayon, 2010).

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## Declarations of interest

None

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## 6.3 Discussion

The primary goal of this chapter was it to identify a decision support concept to be pursued in the design phase that follows as part of the DCD process. This was based on the triangulation of the knowledge elicitation methods, a meaningful reduction to select the key decisions to be included in the decision support design, and lastly the selection of the decision support design concepts with subject-matter-experts. Therefore, this chapter presents the crux of the research contained in this thesis. The exhaustive list of DRT's is presented in Appendix 2.

By triangulating the outcomes of the field observations, CDM interviews and focus groups, the most challenging key decisions made by anaesthesia providers were identified. Based on the data triangulation and selection process, two key decision categories were selected: (1) the transition between airway management techniques in the face of failure and (2) the planning and preparation of airway equipment to allow for potential airway transitions due to anticipated or unforeseeable variability (Cuvelier & Falzon, 2011). Particularly the timely transition between airway management techniques in the face of decreasing oxygen levels is one of the most important decisions in airway management affecting patient safety (Watterson et al, 2014. It is therefore assumed that the process of key decision selection was successful in identifying the most important decisions that could benefit from decision support.

Next, the triangulation of the CDM interviews, focus groups and field observations identified five potential decision support design concepts. As presented in Table 8 in the manuscript, most of the decision support design interventions were directly suggested by subject-matter-experts in at least two knowledge elicitation methods. The only decision support design concept that was derived solely by the research team was the time-sensitive pulse oximeter. This study was the first in the context of decision support design in healthcare that involved subject-matter-experts in ranking decision support design concepts using a structured approach.

The outcomes of the FACES approach showed that subject-matter-experts positively rated the five identified decision support interventions. The FACES approach was useful to obtain feedback from subject-matter-experts on the current state of the decision-centred design process. While the FACES approach served as a good indicator for the sensitivity of identified decision support design concepts, it remains a slightly insensitive measurement tool. In that regard, FACES has similarities with other survey scales utilised in the context of system design, such as the System Usability Scale (SUS) (Brooke, 1996). Both FACES and the SUS are easy to administer and understood by subject-matter-experts without expertise in Human Factors. They are also short and quick to administer as well as applicable to a wide range of interventions. Particularly in healthcare this is beneficial, since involving clinicians in research is often challenging due to time-constraints (Shorrock & Williams, 2016).

Contrary to the SAS, the FACES approach has yet to be validated and the findings thus have to be interpreted with caution. Particularly because the decision support design interventions to be rated were high level concepts at that stage, ratings are coarse and based on subjective estimations. Nevertheless, they provide a valuable insight and would likely indicate a decision support design intervention perceived as inappropriate. Finally, the present study conducted the FACES approach with anaesthesia providers only. However, utilising the FACES approach with one group of subject-matter-experts is not with limitations. While subject-matter-experts can likely provide feedback on feasibility, acceptability and effectiveness, they may have less knowledge regarding cost and sustainability. In future, if possible, FACES ratings should also be obtained from staff experienced in these areas, such as from administration and management.

## 6.4 Conclusions

The organised airway equipment cart for anaesthetic nurses was selected as the decision support intervention to be designed as part of this research program. The airway equipment cart was chosen because it was directly suggested in the focus groups, as well as derived from the CDM interview analysis discussed in chapters four and five. Furthermore, next to training focusing on cue recognition, it was rated most positively in the FACES approach. Particularly the findings presented in chapter 5 demonstrated the relevance of equipment location, visibility and accessibility. The design of an airway equipment cart following a Human Factors approach will be likely beneficial to the selected key decisions relating to preparation, planning and airway management transitions.

The design process of the airway equipment cart will be described in chapter 8. The next chapter goes beyond the phases prescribed by the DCD framework. It has a methodological focus and will examine the findings emerging from the decision-centred design activities with another framework from CSE: Cognitive Work Analysis.

# 7 Chapter 7 - A comparison of the Recognition-primed Decision-Making model and the Decision Ladder to identify decision support for airway management

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|---|
| ***Paper 6 (under 2nd round of review)*:** Schnittker, R. & Lintern, G. A comparison of design solutions emerging from the recognition-primed decision model and the decision ladder. *Journal of Cognitive Engineering and Decision Making* |

## 7.1 Introduction

The study described in this chapter extends beyond the original phases of the decision-centred design framework. The study has a methodological focus and reflect on the RPD model as the most prominent model of the NDM and the DCD frameworks (Militello & Klein, 2013). The goal of this study was to compare the decision support design concepts emerging from the RPD model with those arising from another framework from CSE: Cognitive Work Analysis (CWA) (Vicente, 1999). Like DCD, CWA is a framework from CSE with the goal to identify system design solutions for complex sociotechnical environments (Militello et al, 2009). Whereas DCD specifically focuses on supporting decision-making of experts under time-pressured, high-stakes and challenging conditions, CWA focusses on modelling the systems' constraints and identifying design solutions that support the capabilities of a system within these constraints.

The decision ladder (DL) is a product from Control Task Analysis, the second stage of CWA. The goal of Control Task Analysis is to identify the goals that need to be achieved within a given system, independently how, or by whom, these goals are accomplished (Vicente, 1999, p. 109). Consequently, one of the main differences between the DL and the RPD model is that the DL offers to represent how a system *could* work, whereas the RPD model describes actual, naturalistic decision pathways that could be leverage points for decision support design (Lintern, 2010).

Since both the DL model and the RPD model are concerned with mapping decisions, they have been subject to comparison in the literature (e.g. Jenkins, Stanton, Salmon, Walker, & Rafferty, 2010; Lintern, 2010; Naikar, 2010). Naikar (2010) claimed that the RPD model and the DL have similarities, but also important differences. These differences are mainly related to the RPD model's focus on expert decision-making in well-known situations, whereas the DL is concerned with decision-making across a variety of situations and actors, including option analysis. On the contrary, Lintern (2010) has mapped similar decisions on both the RPD model and the DL and concluded that both approaches are compatible.

Naikar (2010) concluded that due to the differences in both approaches, the emerging system design solutions would also be different. Based on the RPD model, the emerging system design would primarily support situation assessment and option evaluation using mental simulation. System design interventions emerging from the DL would focus on other aspects such as situation and option analysis and goal selection. To date, no study in healthcare has directly compared the system design solutions emerging from the RPD model and the DL.

One aim of this study was to fill this gap in the literature and compare the design solutions emerging from the RPD model and the DL using a selection of CDM narratives that were collected as part of this research program. Another rationale was to address a finding previously described in chapter 4, which discussed the application of the RPD model to the decision pathways of anaesthesia teams in challenging airway management situations. The study on decision pathways found that the RPD model could not accommodate some fundamental decision pathways by anaesthesia teams: those that involved some degree of (pairwise) option comparison.

Consequently, the goal of the present study was to identify if the DL, which accommodates option comparison, will identify different decision support design interventions for challenging airway management than the RPD model. This was done to examine if the DCD framework chosen for this research program restricts the type of decision support design interventions identified; and if employing the DL would reveal additional or different insights. The study concluded with a discussion on the choice of system design framework and its implications on the identification of decision support design interventions (see Appendix 3 for the supplementary material of the manuscript). Due to the focus on design concepts, the present study has been situated seven under the design phase of the DCD process (see Figure 7.1).

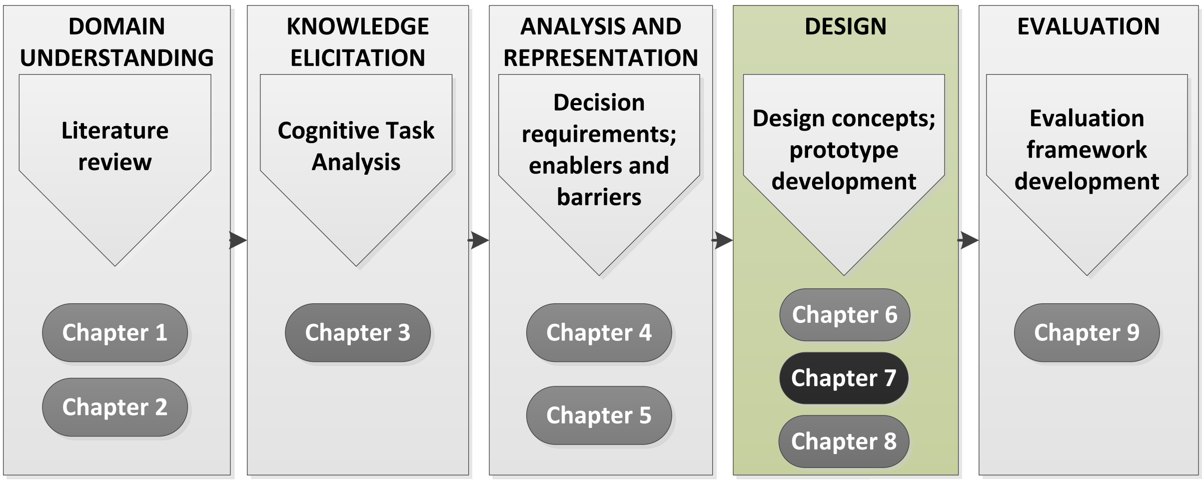


*Figure 7.1.* The decision-centred design process – chapter 7

## 7.2 Paper 6: A comparison of design solutions emerging from the recognition-primed decision model and the decision ladder

# A comparison of design solutions emerging from the recognition-primed decision model and the decision ladder

**Schnittker, R.[1,2] & Lintern, G[1].**

**Monash University Accident Research Centre[1], Department of Anaesthesia and Perioperative Medicine, Central Clinical School[1], Monash University, Melbourne, Australia**

## Abstract

The Recognition-Primed Decision model and the Decision Ladder model are both concerned with identifying decision support solutions for cognitively complex systems. The literature reveals a discrepancy regarding their compatibility. Some argue there are no substantial differences in the underlying concepts while others argue that they have different implications for system design. The goal of this study was to directly compare design solutions emerging from the theoretical underpinnings of the DL and the RPD model in the context of anesthesiology. Six Critical Decision Method narratives about airway management challenges experienced by anesthesiology providers were analysed using both models. The results revealed differences in both model's abilities to accommodate common courses of actions. The Decision Ladder model accommodated both serial and concurrent evaluation of options, whereas the Recognition-Primed Decision model was confined to serial evaluation of options. Moreover, the Recognition-Primed Decision model is confined to a serial evaluation of options via mental simulation, but does not explicitly account for repeated attempts after failed executions following a prototypical route. This implies that the Recognition-Primed Decision model does not account for one key feature of time-pressured, high-stakes work of which anesthesiology is an example. This suggests the model would benefit from further development.

**Raphaela Schnittker**:

Raphaela Schnittker is a PhD student in Human Factors Psychology at Monash University (Australia). Her PhD investigates decision-making of anesthesiology teams with the goal to identify a decision support intervention for challenging airway management. Raphaela is also a lecturer at the Monash University Department of Anaesthesia and Perioperative Medicine, where she teaches the subject Human Factors for Patient Safety.

**Gavan Lintern**:

Gavan Lintern retired in 2009 and now holds an adjunct position at the Monash University Accident Research Centre. He has a PhD in engineering psychology (University of Illinois, 1978). His primary research area is in the use of cognitive work analysis to identify cognitive requirements.

**Contact information corresponding author:**

Raphaela Schnittker
21 Alliance Lane, Building 70
Clayton Campus, 3800
Monash University
Email: raphaela.schnittker@monash.edu
Phone: (+61) 03 99055809

## Introduction

Decision-Centred Design (DCD) and Cognitive Work Analysis (CWA) are two frameworks from Cognitive System Engineering. Both are concerned with the analysis of cognition in order to identify system design solutions for sociotechnical work systems (Militello, Dominguez, Lintern & Klein, 2010). DCD emerged from naturalistic investigation of recognition-primed decision making (Crandall, Klein, & Hoffman, 2006). It investigates how operational experts, when faced with critical, time-constrained situations, use their experience to resolve problems. Since its early development, the study of naturalistic cognition has expanded beyond decision making to include other macrocognitive processes such as planning, sensemaking and coordinating (Klein & Wright, 2016).

Naturalistic methods of knowledge acquisition are used to identify support requirements for macrocognition, which are then translated into design solutions for support of operational cognitive work (Klein, Kaempf, Wolf, Thorsden, & Miller, 1997). For example, Militello et al (2016) identified decision support for colorectal cancer screening. In their study, they expanded their focus on macro-cognitive processes beyond decision-making to include sense-making and problem detection. Schnittker et al (2017) identified decision pathways and requirements of anesthesiologists and nurses to generate design ideas for airway management decision support.

CWA is a multi-stage systems approach with a similar goal; to design solutions for support of operational cognitive work. It is a formative analysis which, in contrast to a normative (rational) analysis that establishes how workers should act, or a descriptive analysis that establishes how workers do act, seeks to establish the reasonable limits of worker action (Vicente, 1999). CWA is focussed on modelling constraints (Rasmussen, Pejtersen & Schmidt, 1990; Vicente, 1999; Naikar, 2017), where a constraint can be viewed as a boundary or an envelope of effective action. The goal of CWA is to develop the basis for design of cognitive support systems that reveal to workers their full range of acceptable action. Instead of supporting a well-defined trajectory through a work problem, as does normative design, a formative design allows variations that constitute multiple trajectories, any of which can unfold naturally to accommodate subtle variations in goals, worker capabilities and situations.

Especially in unanticipated and critical situations, a design based on CWA should encourage flexible and effective adaptation (Naikar & Elix, 2016). Effken et al (2011) employed CWA to identify the system constraints that would affect the use of decision support tools by nurse managers. They found that nurses balance multiple demands and goals to preserve patient safety and quality of care. They found that nurses combine many sources of (electronic) information to inform their decisions and that an effective decision support tool would ideally streamline and summarise the various electronic information more effectively and present it in one location (e.g. a dash board).

**Origins of Decision-centred Design and CWA**

Both DCD and CWA were developed partly in reaction to a normative-rational design approach that is common in modern work environments. In normative-rational design, those who do not actively engage in the work processes establish work procedures for those who do, using an appeal to the logic of the problem as the basis of design. Typically, the procedures that result do not anticipate the complexity of contextual contingencies and do not accommodate the need for time sharing when multiple tasks are concurrently active (Rasmussen & Svedung, 2000). Normative-rational design addresses ‘work-as-imagined’, rather than ‘work-as-done’ (Blandford, Furniss, & Vincent, 2014). Within healthcare, the use of algorithms offers an example. Algorithms are guidelines condensed to short, linear decision-trees that aim to support clinician decisions in difficult situations (Heidegger, Gerig, & Henderson, 2005). The assumption is that they offer step-wise guidance to solution of a clinically challenging situation. However, their inflexible, linear design does not accommodate the complex and ill-structured nature of clinical challenges (Lintern & Motavalli, 2018; Rall, Gaba, Howard, & Dieckmann, 2014; Schnittker, Marshall, Horberry, Young & Lintern, 2016). A similar problem has been recognized with the use of checklists, which has been a successful tool in aviation, but less so in healthcare due to  complex and variable healthcare processes (Clay-

Williams & Colligan, 2015). Normative procedures are fragile and clumsy. They can lead to the anomalous “work-to-regulations” strike whereby workers punish their management by following the rules (Rasmussen, 1997) or can generate a management accusation directed at workers of malicious rule compliance (Vicente, 1999). The former has overlap with the cognitive constraints that arise with the application of ‘best practice approaches’ (Klein, Woods, Klein, & Perry, 2016). One cognitive challenge here is a potential mismatch between ‘best practice’ and professional expertise. This can lead to approaching complex problems with simplistic solutions.

While DCD is based on a descriptive analysis and CWA is based on a formative analysis, it is unclear whether the two progress to different types of design solutions. Vicente’s (1999) argument for a formative analysis is aligned with Rasmussen’s (1989) assumption that regularity in terms of causal relations is found between kinds of events (prototypes), not between single events (tokens). Rasmussen was reacting against the common approach within risk management of proposing safety interventions by analysis of one incident. He sought regularity by abstracting commonalities between multiple events (Rasmussen & Svedung, 2000). Nevertheless, although those subscribing to Decision-Centred Design do not explain their strategy in this manner, their common approach is to combine information from multiple narratives. Furthermore, the design statements that emerge from Decision-Centred Design (Crandall, Klein, & Hoffman, 2006; Klein, 1998) do not appear to be of a character that would unnecessarily constrain worker action to a well-defined trajectory.

**The Recognition-Primed Decision Model versus the Decision Ladder**

We take our understanding of the Recognition-Primed Decision (RPD) model from Crandall, Klein and Hoffman (2006) and Klein (1998). The RPD model is one element within naturalistic decision research. It describes how workers can use their experience to make difficult, often time-pressured decisions. An observation that shaped the development of the RPD model is that experienced workers, if in doubt regarding the efficacy of a proposed course-of-action, evaluate it by mental simulation. If mental simulation suggests that a course-of-action will resolve the issue at hand, the worker executes it. Where the result of the mental simulation is unsatisfactory, the worker selects another course-of-action and mentally simulates it, continuing in this serial selection and assessment until a satisfactory course-of-action is found.

The RPD model does not account for teamwork or concurrent assessment of options (Klein, 1998). However, updated versions of the RPD model do accommodate macro-cognitive processes such as sense-making and story-building (Klein, Moon, Hoffman, & Associates, 2006). This extension does account for contrasting alternative situational assessments, but still does not allow for the comparison of options (Klein, Calderwood & Clinton-Cirocco, 2010). The RPD model does, however, account for sequential option evaluation when it comes to mental simulation of potential action plans (Klein, Calderwood & Clinton-Cirocco, 2010) but sequential implementation of actions (as opposed to mental simulation) is not explicitly accounted for in the model.

We take our understanding of Work Task Analysis (also known as Control Task Analysis) and its analytic product, the Decision Ladder (DL), from Lintern (2010), a treatment that follows Rasmussen (1986) but that adjusts some confusing terminology and adjusts conceptual interpretation to be more consistent with contemporary views on the nature of situation awareness. Work Task Analysis is one stage within the framework of CWA. It describes the cognitive processes and cognitive states involved in work-related decisions. It does not cover teamwork but can take account of both serial and concurrent assessment of options. It allows assessment of a proposed course-of-action by different methods, including mental simulation.

The RPD model and the DL are both models of cognitive states and cognitive processes involved in work-related decisions. Vicente (1999, p. 186) has noted that the DL is not a model but rather, a template on which a work task narrative can be mapped. Lintern (2010) has argued that Vicente meant that in the sense that the DL does not imply a fixed sequence of cognitive states and cognitive processes for a work task as does, for example, the general information processing model. The DL does, however, specify all cognitive states and cognitive processes that are potentially available for a work task and, in that sense, constitutes a theoretical model. The RPD model constitutes a model on the same grounds and is also a template on which a work task narrative can be mapped. One distinction is that the DL specifies all cognitive states and cognitive processes that can be involved in a work task whereas the RPD model would seem to allow additional states or processes if they were found to be generally important in naturalistic investigations of work. The field of Naturalistic Decision-Making expanded their study to a range of macro-cognitive functions and processes such as sense-making, planning and managing uncertainty and risk (G. Klein & Wright, 2016). A few of these macro-cognitive functions have been connected to the second level of the RPD model, which is concerned with sense-making (Klein et al., 2006).

In that they are both models of cognitive processes involved in work-related decisions, the RPD model and the DL model offer a point of comparison between Decision-Centred Design and CWA. Although from different cognitive systems frameworks (Militello et al, 2010), they are similar in two important ways: both analyse decisions made in sociotechnical environments and both aim to support the cognitive activities involved in decisions. Naikar (2010) argued, however, that there are important differences. She noted that the RPD model has typically been used to explain expert decision-making in familiar situations, whereas the DL model accommodates expert and novice behaviour in familiar and unfamiliar situations. Lintern (2010) has countered that although expert decision-making in familiar situations has been its traditional focus, the RPD model could comfortably accommodate novice decision-making and decision-making in unfamiliar situations especially since the second level of the RPD model is concerned with situation re-assessment and sense-making (Klein, Philllips, Rall & Peluso, 2006). In summary, Lintern (2010) has argued that there are no substantive differences between the two while Naikar (2010) has argued that they have different implications for the design of decision support systems. While the theoretical underpinnings of the DL model and the RPD model have been subject to comparison (e.g. Jenkins, Stanton, Salmon, Walker, & Rafferty, 2009; Lintern, 2010; Naikar, 2010), no study yet compared the practical design solutions emerging from both methods.

**Teamwork**

Teamwork can be investigated within the DCD framework with methods that are like those used to investigate individual cognition (Crandall et al, 2006). Information gathered from team members interviewed on their own is combined to provide multiple perspectives on the work as a route into developing cognitive requirements. Klinger and Klein (1999) report on a cognitive design effort directed at improving the performance of an emergency response team. They observed an exercise in progress and, following the exercise, interviewed several staff. They identified delays due to hand-offs and information bottlenecks. They observed that the flow of information to key decision-makers was inefficient and that some staff had a poor appreciation of their own roles, of who made key decisions, and how information was supposed to flow through the team. These data prompted several redesign recommendations with the result that team performance was shown to improve in a subsequent exercise.

Naikar, Pearce, Drumm & Sanderson (2003) have explained how teamwork can be investigated within the CWA framework. Work domain analysis is used to develop an abstraction-decomposition space, followed by an activity analysis to identify the essential work situations or work problems. A simulation exercise is then used to explore how scenario-specific work demands as identified by the activity analysis can be distributed across different teaming arrangements. Team concepts are evaluated in terms of how well the alternative distributions of work problems satisfy the functional requirements of the work domain given the set of available physical resources. The insights generated through this process are translated into a new team design that can be empirically evaluated.

**Aims of this study**

In this paper, we explore whether the design solutions emerging from the RPD model are qualitatively different that those emerging from the DL model within the context of anesthesiology. We build on Naikar's observations to offer the following hypotheses:

1. Both models accord situation assessment an important role;
2. The RPD model focuses on sequential evaluation of options whereas the DL model allows concurrent evaluation of options;
3. The RPD model restricts plan evaluation to mental simulation whereas the DL model does not;
4. The RPD model does not reference what happens after a failed execution whereas, in the event of a failed execution, the DL model maps the continuing decision activities.

Our data do not conform to the requirements of either of the teaming approaches from the DCD or CWA frameworks, but we will reflect on those data to identify team issues that could be explored.

## Methods

**Subject-matter experts**

Six anesthesiology care providers participated in this study. Four of them were experienced anesthesiologists and two were experienced anesthetic nurses (all >10 years of experience). Anesthesiologists and anesthetic nurses were chosen as subject-matter experts because they are the primary and presumably most experienced anesthesiology care providers. The six narratives of the subject-matter experts in this study were selected from a previous interview study with sixteen participants (Schnittker, Marshall, Horberry, Young & Lintern, 2017). The six narratives were chosen for this study because they presented extraordinary but yet common airway management challenges. Furthermore, the narratives involved a range of cognitive activities and thereby suited the purpose of this study well.

**Procedure**

The participants were recruited from two hospitals; one large urban and one medium-sized teaching hospital in the greater Melbourne area. Ethics approval was obtained from the two participating hospitals, nursing departments, and the University. All participants read and signed an informed consent form before commencing the study. All interviews were confidential, audio-recorded and took place in a quiet, isolated office at the respective hospital. Participants were invited to participate in the study via an email that was sent out by the anesthesiology departments, as well as word-of-mouth. Participation in the study was voluntary and no reimbursement was provided. The length of individual interviews varied between one and two-and-a-half hours.

**Knowledge elicitation with the Critical Decision Method**

The Critical Decision Method (CDM) was employed to elicit knowledge from the subject-matter experts. The first author (RS) conducted all interviews and followed the typical four phases of the CDM (1) Incident selection, (2) timeline summary, (3) deepening cognitive probes and (4) hypotheticals. Firstly, the participants were asked to choose a prominent airway management challenge from their past. The participant could freely choose the case, as long as they were actively involved in making the critical decisions, had a detailed memory of the case, and considered the case as an extraordinary one from their professional career. The participant then summarized the case in detail and clarified questions from RS until a mutual understanding was reached. Next, the critical decisions and all other major events that contributed to the unfolding of the incident (e.g. changes in patient conditions, input from technology such as alarms and monitoring, communication with teams, etc.) were put on a timeline in a chronological order. This timeline then served as the basis for the next phase, where each key decision was further discussed in detail with cognitive probes. Lastly, participants were posed a few hypothetical questions.

Table one provides on overview on a few generic cognitive probes employed in this study. We assumed, within this study, that the purpose of the CDM is to develop interventions that will support the cognitive work of anesthesiology teams to accomplish safe, effective and efficient airway management. Those interventions will necessarily come in the form of technological support, procedures, training, or teamwork. The primary reason for developing any form of summary of the narrative generated within the CDM is to support that design.

*Table 1*. Critical Decision Method deepening probes, adapted from Klein, Calderwood, and Macgregor (1989)

| *Theme* | *Example probes* |
|---|---|
| **Cues** | What did you notice? What did you see, hear…? What alerted you to this? |
| **Decisions** | What decision did you make? Why? What exactly did you do to keep the patient safe? Who else was involved? Did you do anything in particular to ensure patient safety? |
| **Options** | Did you consider any other options? Would there have been other options in hindsight? |
| **Experience** | How did you know how to make this decision? Would you have made this decision with less experience? |
| **Goals/Expectations/consequences** | What were your expectations when making this decision? Did you imagine any consequences? What were your goals? |
| **What if** | What would you have done if x would have happened? |
| **Decision support** | Would it be helpful to support any of these decisions? How? What could help less experienced people/what would have helped you in your early years of training? |



**Analysis**

*Comparison of the Recognition-primed Decision model and the Decision Ladder*

For this study, we analysed narratives from four anesthesiologists and two anesthetic nurses. Within this manuscript, we showed the results for one anesthesiologist and one anesthetic nurse. We present summaries of the narratives in three forms; an edited narrative, a Decision Requirements Table (DRT), and a Decision Ladder Table (DLT). The DRT and the DLT were built from the raw narratives and based on an implicit mapping of the narratives on the two models. The edited narratives, as presented in this paper, were not analysed but were edited for reading clarity by eliminating redundancy and unnecessary detail. We developed a table format for the DL model for consistency with the DRT to facilitate the goal of this study: the direct comparison between both methods. Having both methods in a table format offers a structured comparative approach to explore whether one of the two methods generates distinctive and/or more or better design insights than the other. The first two columns of the DRT and the DLT are specific to the method while the last two columns have the same headings (see Table 2). Within the literature, the last column of a

DRT is often given over to design ideas. We adjusted that to design challenges because, for anesthesiology, we believe that the generation of design ideas requires more subject matter expertise than we have from the data presented in this paper. Nevertheless, we did feel comfortable in identifying design challenges as revealed by the RPD model and the DL model.

*Table 2*. Columns used for both knowledge representation methods

| *Decision Requirement Table* | *Decision Ladder Table* |
|---|---|
| Incident | Description |
| Critical Information | Process |
| Critical Expertise | Critical Expertise |
| Design Ideas | Design Ideas |

For the DRT, we identified types of expertise in the narrative by searching for concepts consistent with the RPD model (see Figure 1). Design ideas were developed by reference to critical information and critical expertise. For the DLT, we classified activities in terms of DL processes as shown in Figure 2 taken from Lintern et al (2018). This figure was developed by reference to the DL model of Rasmussen (1986) and Rasmussen et al (1994). Design ideas were developed by reference to processes and critical expertise.

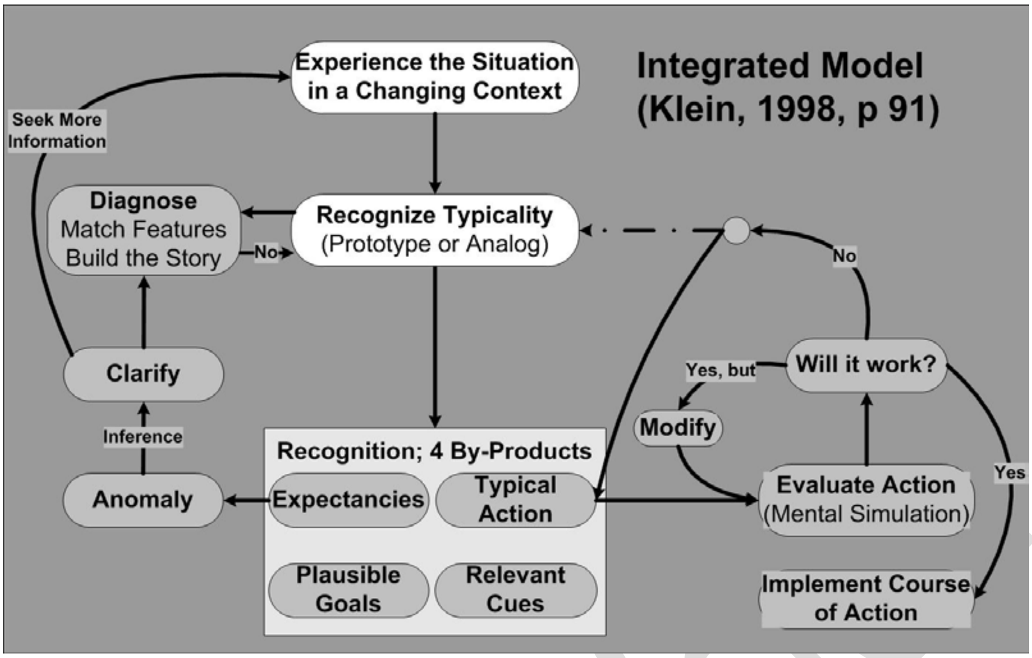


*Figure 1.* The Recognition-Primed Decision model. From Klein, G. (1998). *Sources of Power: How People Make Decisions* (p. 27). Cambridge, MA: MIT Press. Copyright 1998 by MIT Press. Adapted with permission.

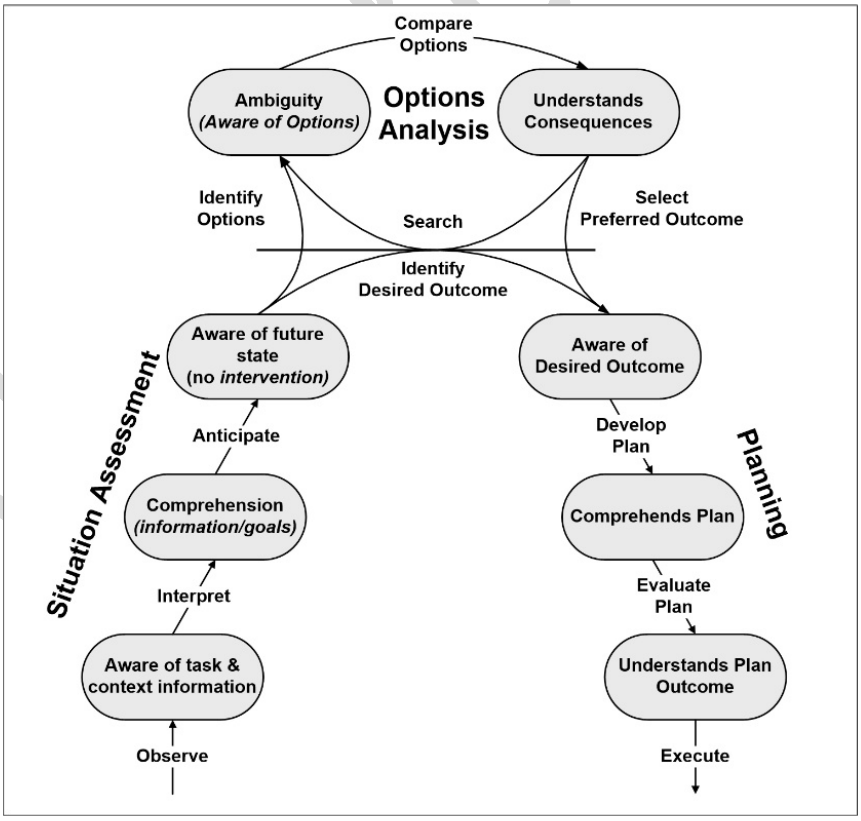


*Figure 2*. The Decision Ladder model (Lintern et al, 2010).

*Decision selection from the CDM narratives*

R.S. summarized the CDM interviews into detailed narratives that chronologically covered all the events and (cognitive) activities involved in the storyline. Then, R.S. and G.L. independently selected what they identified as the critical decisions from each narrative by adhering to the following definition: *a critical decision is a choice among different pathways that has impact on the way a non-routine situation unfolds. In the context of this study, it is any pathway taken by the practitioner(s) that directly acts upon the way the airway is managed, hence directly impacts the patient's safety.* R.S identified a total of 52 critical decisions and G.L identified a total of 58. Forty-one critical decisions identified by both authors were identical. From these critical decisions, a few decisions were selected for the further analysis. The decisions were selected in line with the purpose of this study: a comparison between the design solutions emerging from the theoretical underpinnings of the DRT and the DLT. Therefore, we purposely selected decisions that would result in distinctive design solutions from both methods and thus provide a good illustration of their differences. Consequently, we did not select the critical decisions for further analysis that we thought were the most difficult, but those that offered the most leverage to test the hypotheses of this study.

*Analysis of Critical Decision Method narratives*

The analysis of the CDM narratives was an iterative and collaborative process. Firstly, the authors analysed two narratives independently. We then compared their outcomes and made a few adjustments to the analyses. After both authors agreed they had developed a common strategy, the RS created all DRTs and the first two columns of the DLTs for the remaining narratives. GL critically reviewed these and made amendments, and then filled in the last two columns of the DLT's. These were again critically reviewed by RS and again, a few adjustments were made until agreement was reached between both authors.

## Results

The edited narrative, the DRT and the DLT are shown here for one anesthesiologist and one anesthetic nurse. The same analysis artefacts are provided for three other anesthesiologists and one other anesthetic nurse in an online supplementary resource. That online supplementary resource also includes the raw narratives for all four anesthesiologists and both anesthetic nurses. References to the anesthesiologist are abbreviated as **A**, the patient as **P**, and the anesthetic nurse as **AN**. Where a second anesthesiologist or second anesthetic nurse is involved, references to them are abbreviated as **A2** and **AN2**.

**Anesthesiologist**

*Edited narrative 1, anesthesiologist*

On seeing **P** just before the scheduled surgery, **A** realized that this **P** might be difficult to intubate and had minimal respiratory reserve. **A** decided to prolong pre-oxygenation to optimize **P**'s respiratory reserves. On prior advice from the surgeon, **A** had planned a routine endotracheal intubation. On seeing **P** just before the scheduled surgery, **A** realized that this **P** might be difficult to intubate and had minimal respiratory reserve. **A** decided to prolong pre-oxygenation to optimize **P**'s respiratory reserves. He decided to intubate **P** by video laryngoscopy because of **P**'s difficult looking airway and would use a short-acting muscle relaxant because he wanted to get the tube down as quickly as possible. **A** advised **AN** that this may be a difficult intubation and ordered some extra equipment as a backup.

The laryngoscope view of the airway was compromised but **A** thought it good enough to insert the tube. However, when he connected the tube to the bag, he could not squeeze the bag to get oxygen into **P**'s lungs, and capnography showed no exhaled carbon dioxide. These signs revealed that ventilation had been unsuccessful. **A** removed the tube. At this stage, **P**'s oxygen saturations were low (as indicated by pulse oximetry) and **P** looked terrible. **A** then attempted face-mask ventilation with a bag mask, but that did not work, as indicated by **P**'s chest not moving up and down. **A** called for help, got the extra equipment and announced that a surgical airway may be needed. He announced, ‘I can’t intubate, I can’t face mask ventilate’. Colleagues came running in. He

| | *Incident* | *Critical Information* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | Change intubation method after seeing **P** face-to-face | This may be a difficult intubation because **P** is obese with fat neck; airway landmarks may be difficult to see | **Recognize Typicality;** be aware that assessments by a non-**A** may be superficial | **Procedure**: face-to-face meeting with **P** before surgery<br>**Technology**; a virtual meeting that has face-to-face fidelity where a face-to-face meeting is not possible |
| 2 | Decide to intubate by video laryngoscopy | Laryngoscope view of the airway | **Recognize Typicality;** airway is suitable for intubation (failed) | **Technology**; improved video assessment of airway<br>**Training**; difficult case experience & training (observation of experienced **A**’s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, simulations of difficult cases) with emphasis on assessing situational suitability of intubation method and on mentally simulating different intubation methods for different **P** conditions |
| 3 | Unable to intubate **P** with face mask & bag, eventually calling for assistance | **P**’s condition | **Recognize Typicality, Mental Simulation;** most suitable intubation method for a **P** in this condition (a failure of mental simulation of successive possibilities) | |

selected a colleague who he believed was decisive and competent. The colleague intubated **P** successfully with a laryngeal mask, which had not yet been attempted.

*Table 3*. Decision Requirements Table, narrative 1, anesthesiologist

*Table 4*. Decision Ladder Table, narrative 1, anesthesiologist

| | *Description* | *Process* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | Call from surgeon | Observe | Direct observation is best means of assessing **P**, advisory from surgeon may not reveal factors that complicate anesthesiology | **Procedure**: face-to-face meeting with **P** before surgery **Technology**; a virtual meeting that has face-to-face fidelity where a face-to-face meeting is not possible |
| 2 | Routine situation | Interpret | | |
| 3 | Intubate **P** | Develop Plan | | |
| 4 | Observe **P**; obese, fat neck, has difficulty breathing lying flat | Observe | | |
| 5 | Possibly a difficult-intubation | Interpret | | |
| 6 | Pre-oxygenate, use video laryngoscopy & rapid sequence intubation with short-acting muscle relaxant, order back-up equipment | Develop Plan | **A** unable to establish in advance which method would work with this **P** | **Training**; difficult case experience & training (observation of experienced **A**'s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, simulations of difficult cases) with emphasis on assessing situational suitability of intubation method **Technology**; improved video assessment of airway |
| 7 | Initiate execution of plan | Execute | | |
| 8 | Can see **P**'s larynx during the laryngoscopy | Observe | | |
| 9 | View of larynx imperfect but good enough to insert tube | Interpret | | |
| 10 | Insert tube, connect it to anesthetic machine & squeeze bag (routine) | Execute | | |
| 11 | No feedback from squeezing the bag | Observe | | |
| 12 | Intubation not successful | Interpret | | |
| 13 | Extract tube | Execute | It is unclear from this narrative whether **A** is insufficiently experienced with a **P** in this condition or whether **A** was unable to identify or remember the most suitable method | **Technology**; airway equipment trolley design to standardize & organize airway equipment to display options so that they can be easily remembered & deployed when needed, and to guide |
| 14 | Notice sound of pulse oximetry, **P** looks terrible | Observe Interpret | | |
| 15 | Attempt face-mask intubation | Execute | | |
| 16 | Chest moving, nothing changes | Observe | | |
| 17 | Face-mask intubation not working, this is a crisis | Interpret | | |
| 18 | Call for help, get extra equipment, announce crisis to team | Execute | | |
| 19 | Other clinicians respond to call – come running in | Observe | | |

| | | | |
|---|---|---|---|
| 20 | Select one colleague to assist – he inserts laryngeal mask, situation improves | Execute | an efficient strategy for working through them<br>**Training**; as above |



**Anesthetic nurse**

*Edited narrative 2, anesthetic nurse*

**A** attempted to intubate **P** by video laryngoscopy. Although an emergency case, **P** did not look difficult to intubate, until **A** said he was finding it difficult to insert the tube because he couldn't see anything when he looked inside **P**s' throat. **AN**, assisting with the intubation at the time, applied pressure to **P**'s cricoid, which often helps intubation. A scrub nurse (**SN**) was also assisting by handing equipment to **A**. **A** went back to face mask ventilation to re-oxygenate **P** and then again attempted to intubate **P** with a different laryngoscope blade. This attempt also failed. **AN** continued applying cricoid pressure. She also observed the oxygen levels on the monitors and advised **A** they were dropping slightly between attempts. After his second unsuccessful attempt, **A** called for the difficult intubation trolley. **AN**, being more senior and more experienced than **SN**, told her what equipment to get from the airway equipment trolley and where it was (e.g. top drawer). At this point, **A** asked **SN** to change what she was doing with the **AN**. **SN** was now standing next to **P** applying cricoid pressure and **AN** was ready to assist **A** by finding and handing over the right equipment quick and smoothly and by offering suggestions to make sure **A** does not forget the different options under time pressure. At the time the difficult airway trolley came in, **A** was ventilating **P** with a face mask, which worked well. He realized at that point he had attempted intubation enough times and to intubate **P** fiber-optically while awake, which was successful.

*Table 5*. Decision Requirements Table, narrative 2, anesthetic nurse

| | *Incident* | *Critical Information* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **AN**, being more senior & more experienced than **SN**, told her what equipment to get from the airway equipment trolley & where it was. | **AN** is aware that the inexperienced scrub nurse does not know exactly where the equipment is in the airway equipment trolley & is also aware of what to offer **A** | **Recognize Typicality;** know layout of airway equipment trolley | **Technology;** airway equipment trolley to store equipment logically, with minimal non-essential items, and with more critical items conveniently at hand so that even inexperienced nurses can find them quickly; organised to guide an efficient strategy for working through the available options |
| 4 | **AN** suggests other equipment & other intubation methods | **AN** has the responsibility to ensure that **A** does not ignore the different options under time pressure | **Typical Action;** suggest options, prepare to get equipment quickly | **Technology;** airway equipment trolley to store equipment logically, with minimal non-essential items, and with more critical items conveniently at hand so that even inexperienced nurses can find them quickly; organised to guide an efficient strategy for working through the available options |

*Table 6.* Decision Ladder Table, narrative 2, anesthetic nurse

| | *Description* | *Process* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **A** advises **AN** he cannot see landmarks when looking down **P**'s throat | Observe | | |
| 2 | **AN** realizes **A** is having trouble inserting the tube | Interpret | | |
| 3 | **AN** applies pressure to Cricoid to assist with tube insertion | Execute | | |
| 4 | **AN** hears pulse oximeter change its beeping sound & sees oxygen saturation level falling | Observe | | |
| 5 | **P** is desaturated; airway strategy needs to be changed | Anticipate | | |
| 6 | **AN** informs **A** of falling oxygen levels & reads out saturation level as a running countdown | Execute | | |
| 7 | On second attempt, **A** continues to struggle with tube insertion | Observe | | |
| 8 | **AN** continues to apply cricoid pressure; **AN** advises scrub nurse which drawers in the airway equipment trolley hold the needed airway equipment | Execute | Distribute attention over assisting **A** & advising **SN** where to find items in the trolley | **Technology;** Airway equipment trolley to store equipment logically, with minimal non-essential items, and with more critical items conveniently at hand so that inexperienced nurses can find them quickly and so that **A** and **AN** can contrast available options at a glance |
| 9 | **AN** swaps role with scrub nurse as **AN** directs | Execute | | |
| 10 | **AN** prepares herself to hand equipment to **A** quickly & smoothly. | Develop Plan | **AN** has the responsibility to ensure that **A** does not ignore different options under time pressure | |
| 11 | **AN** observes **A** still having difficulties with intubating **P** | Observe | | |
| 12 | **AN** suggests & offers equipment from the airway equipment trolley to **A** to ensure he won't forget certain options | Develop Plan Execute | | |

**Comparison of design interventions**

Table 7 summarizes the design ideas that appear in the DRT's and the DLT's for the four anesthesiologist narratives analysed for this study. Four technology interventions, a virtual meeting between anesthesiologist and patient, improved video assessment of the patient's airway, improved systems for monitoring patients in recovery after surgery, and systems that can enhance situational assessment of patients for different ventilation methods are common outcomes of the two methods. Redesign and standardization of the airway equipment trolley decision support for comparing options and for assessing trade-offs associated with pursuing different goals were confined to the DLT's. This is primarily because these two interventions are aimed at supporting concurrent comparison of options, a cognitive process that is not referenced in the RPD model. The two procedural interventions, a face-to-face meeting with the patient before surgery and improved procedures for monitoring patients in recovery after surgery, are common outcomes of the two methods.

Both methods recommend simulation training for the technical skills required to perform a surgical airway and both recommend difficult case experience and training possibly via observation of experienced anesthesiologists handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, and simulations of difficult cases, with emphasis on assessing situational suitability of intubation methods. The recommendations from the two methods diverge in relation to mental simulation training of different intubation methods for different patient conditions. Mental simulation was not referenced in the difficult case interventions for the DLT. The single mention in the DLT of mental simulation referred to a unique situation in which an anesthesiologist had to decide whether to treat a distressed patient in an elevator on the way to the surgical theater or to delay until the patient was in the surgical theater. This involved a clear comparison of options, but it is unrealistic to imagine that anything other than a mental simulation would be available in this sort of situation.

Table 8 summarizes the design-related ideas that appear in the DRT's and the DL's for the two anesthetic nurse narratives that were analysed for this study. Two technology interventions, the airway equipment trolley to store equipment logically, and airway equipment standardized and organized are common outcomes of the two methods. However, those two interventions differ slightly in relation to how they support performance. In addition to aligning with the Decision Requirements Table in organizing equipment trolley so that inexperienced nurses can find things quickly, the DLT recommends this as a means of supporting the contrast of available options. While the DRT recommends that the airway equipment standardized and organized to guide an efficient strategy for working sequentially through the available options, the DLT makes the same recommendation but does so to support anticipatory planning. A third technology intervention, a readily accessible information system that shows consultant availability and consultant expertise, was confined to the DLT.

*Table 7.* Comparison of design ideas as taken from the Decision Requirements Tables and the Decision Ladder Tables for four anesthesiologists*

| *Intervention* | *Decision Requirements Table* | *Decision Ladder Table* |
|---|---|---|
| Technology | A virtual meeting that has face-to-face fidelity where a face-to-face meeting is not possible<br>Improved video assessment of airway<br>Improved systems for monitoring **P**s in recovery<br>Systems that can enhance situational assessment as it applies to evaluating patients for ventilation methods | A virtual meeting that has face-to-face fidelity where a face-to-face meeting is not possible<br>Improved video assessment of airway<br>Improved systems for monitoring **P**s in recovery<br>Systems that can enhance situational assessment as it applies to evaluating patients for ventilation methods (2)<br>Airway equipment trolley design to standardize & organize airway equipment to display options so that they can be easily remembered & deployed when needed, and to guide an efficient strategy for working through them<br>Decision support for comparing options & for assessing trade-offs associated with pursuing different goals |
| Procedures | Face-to-face meeting with **P** before surgery<br>Improved systems for monitoring **P**s in recovery | Face-to-face meeting with **P** before surgery<br>Improved procedures for monitoring **P**s in recovery |
| Training | Simulation training on technical skills to perform a surgical airway (2)<br>Difficult case experience & training (observation of experienced **A**s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings (1), simulations of difficult cases) with emphasis | Simulation training on technical skills to perform surgical airway (2)<br>Difficult case experience & training (observation of experienced **A**s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, simulations of difficult cases) with emphasis |

| | | |
|---|---|---|
| | on assessing situational suitability of intubation methods and *on mentally simulating different intubation methods for different* ***P*** *conditions* (3) | on assessing situational suitability of intubation method (3)<br>Training on mental simulation (1) |

**Note*. The narrative summaries for three other anesthesiologists together with the associated Decision Requirements Tables and Decision Ladder Tables are available in the online supplementary material.

*Table 8*. Comparison of Design Ideas as taken from the Decision Requirements Tables and the Decision Ladder Tables for two anesthetic nurses

| *Intervention* | *Decision Requirements Table* | *Decision Ladder Table* |
|---|---|---|
| Technology | Airway equipment trolley to store equipment logically, with minimal non-essential items, and with more critical items conveniently at hand so that even inexperienced nurses can find them quickly; organized to guide an efficient strategy for working through the available options (1) | Airway equipment trolley to store equipment logically, with minimal non-essential items, and with more critical items conveniently at hand so that inexperienced nurses can find them quickly and so that **A** and **AN** can contrast available options at a glance (1)<br>A standardized equipment trolley in which the various anesthetic technologies are readily visible & organized to support anticipatory planning (1)<br>A readily accessible information system that shows consultant availability & consultant expertise (1) |
| Procedures | None | None |
| Training | None | None |

**Note*. The narrative summary for the second anesthetic nurse together with the associated Decision Requirements Tables and Decision Ladder Tables is available in the online supplementary material

**Teamwork**

A high standard of teamwork was demonstrated in our narratives. See Table 9 for examples from four narratives.

*Table 9*. Team work in Critical Decision Method narratives

| *Narrative* | *Team work aspect* |
|---|---|
| 2 | The anesthetic nurse described how she assisted the anesthesiologist with a difficult intubation without any spoken request from the anesthesiologist and how she was able to coordinate smoothly with a scrub nurse who was also assisting. |
| 3* | The anesthesiologist described how he, before responding to emergency buzzer from an adjacent theater, had ensured that his own anesthetic nurse would be able to handle his case while he was absent. On entering the adjacent theater, he coordinated well with the anesthesiologist in that theater, deferring to him when necessary. In addition, as the plan became more complicated, the two anesthesiologists in coordination, ensured that all in the theater understood what they were about to do. Finally, the two anesthesiologists ensured that the intensive care unit that would receive the patient understood the special requirements for this patient. |
| 6* | The anesthetic nurse described how she worked closely with the anesthesiologist, first listening attentively to understand his plan and then continuing to assist him throughout a difficult intubation. When the need arose, she directed another nurse to assist on a task that would divert her from directly assisting the anesthesiologist. |
| 1 | The anesthesiologist who was called by the anesthesiologist in charge for help was able to immediately recognise the situation and secure the patient's airway by inserting a rescue airway device that has been omitted. |

**Note*. Narratives are provided in the online supplementary material

In that this study was not oriented towards investigation of teamwork, we found no specific implications for design in these observations except that they do indicate that teamwork is important in anesthesiology.

## Discussion

The goal of this study was to compare the decision support design solutions emerging from DCD and CWA. Specifically, we explored the nature of the design solutions generated by analysis based on the RPD model versus the DL model within the context of anesthesiology. One issue we raised in the introduction to this paper was whether design solutions that emerge from an analysis based on the RPD model might constrain expert behaviour. A review of Tables 8 and 9 reveals no qualitative distinction between design interventions emerging from the two methods.

**Individual Cognition in the RPD model and the decision ladder**

As per our first hypothesis, design solutions emerging from both models put strong emphasis on situation assessment. Consequently, the design solutions in relation to situation assessment were similar, focusing on technology, procedures and training with the potential to support the assessment of successful airway management.

We confirmed our second hypothesis that the RPD model focusses on sequential evaluation of option comparison whereas the DL allows concurrent comparison of options. This difference between the two models became especially clear in the design implications of failed intubations. The work narratives for anesthesiology reveal that a failed intubation is followed by another attempt with a variation on the airway management technique used, a different technique, or a change in goal. The DL model accounted comfortably for those serial courses-of-action because it allows both sequential and concurrent evaluation of options. The RPD model is constrained to three pathways. Firstly, a chosen course of action may be executed without option assessment ('prototypical' pathway), involving a simple match between recognition and action execution. In a previous study we have identified that more than 90% of decisions in anesthesiology follow a prototypical decision pathway (Schnittker, Marshall, Horberry, Young, & Lintern, 2017). The potential second pathway is the search for more information if an anomaly is encountered ('diagnosing'), which may involve story building and feature matching. Although this pathway may involve alternative accounts of a situation, it still does not involve option comparison (Klein, Calderwood & Clinton-Cirocco, 2010).

The third pathway concerns the mental simulation of the likely efficacy of a course of action before its execution. If the mental simulation reveals that the plan is likely to be unsuccessful, it is rejected and the next plan is evaluated; a sequential process. Contrary to the DL, the sequential mental simulation presents the only way in which a plan can be evaluated with the RPD model. This was proposed by our third hypothesis. Consequently, the theoretical basis of the RPD could not accommodate the 'trial and error' approach of repeated attempts at securing a patient's airway with different airway techniques, as found in this study.

The former also confirms our fourth hypothesis that the RPD model does not reference what happens after the execution of an action, whereas the DL models continues decision activities. More specifically, the RPD model does not take explicit account of failed executions or of concurrent comparisons of options. Subsequently, the design solutions emerging from the DL model supported options comparison and repeated attempts to execute, which the design solutions emerging directly from the RPD model did not. While options analysis is treated as a valid cognitive process within the naturalistic decision literature (Klein, 1992, 1998), we found no paper in that literature that discusses means of supporting options analysis via design solutions. Nevertheless, repeated attempts to execute are time-consuming and may injure the patient's endotracheal tube (Online Resource; anesthesiologist, narrative 3), thereby compromising further attempts at intubation and exacerbating patient discomfort in recovery. Mental simulation, if feasible, rather than physical execution of a course-of-action, would be more efficient and would benefit the treatment of the patient. Presumably, anesthesiologists have not converged on this means of proactively assessing the likelihood that a method will be successful because, within anesthesiology, it is not reliable. This has one implication for theory, and another for design.

The theoretical implication is that the RPD model does not account for one form of time-pressured, high-stakes work, of which anesthesiology is an example, thereby suggesting that the model would benefit from further development. The design implication is that there may be some sort of technological, procedural, or training enhancement that could improve the effectiveness of mental simulation for anesthesiology. A mental simulation needs information to support situation assessment and the knowledge of how to execute. Presumably, our experienced anesthesiologists had the knowledge of how to execute but the information available to them was not adequate to anticipate conclusively that they could execute effectively.  An information problem suggests the need for a better viewing system for the intubation or possibly better calibration of the anesthesiologist to the available information via training. A skill problem suggests some form of simulation training.

**Teamwork in the RPD model and the decision ladder**

Neither model explicitly addresses teaming issues, but it was apparent, within the narratives, that teamwork is important. That teamwork relates to the anesthetic team working together and to their interactions with other theater staff. The teamwork identified in these narratives was of a high standard, suggesting that no redesign was necessary. Nevertheless, it remains possible that less experienced teams would struggle, thereby suggesting that some form of team training might be useful. It is also possible that experienced teams have adapted at some cost in workload to non-optimum team structures. In that there is already a team structure, the methods used by Klinger and Klein (1999) seem more immediately appropriate, but the formative approach outlined by Naikar et al (2003) could be adapted to redesign of existing teams and might provide important insights. The comparison we have undertaken here might be extended to identify the relative contributions of these two approaches to addressing team issues.

The issue of finding a suitable consultant, as described in anesthetic nurse narrative 6, is one that distinguished the two methods. It produced a design idea only via the DL Table. This additional task could be handled by the DL because Work Task Analysis makes no assumptions about assignments to individuals or technology. In that respect, a convenient, at-hand information system might allow even a busy member of the team to locate the appropriate consultant and to request their assistance. Within the CWA framework, a requirement for an information system is likely to prompt the development of functional (ecological) interface (Lintern, Waite & Talleur, 1999; Vicente & Rasmussen, 1992) based on a strategies analysis and a cognitive-modes (skills, rules, knowledge) analysis. Within the DCD framework, this is a team issue that might have been explored within a team analysis of the form described by Klinger and Klein (1999). The design idea would probably have been like that achieved via the DLT. The DCD framework is silent on the principles that would be used to design that information system, although iterative prototyping and participatory design have been used to good effect in development of visual-graphic interfaces following naturalistic work analyses (Militello et al., 2016; Nemeth et al., 2016)

## Limitations

This study only used a small number of narratives from a very specific domain of expertise. Therefore, generalization of the findings and application to the context of other complex sociotechnical environments (e.g. military, aviation, nuclear plants) must be done with caution. As anesthesiology is heavily reliant on training and expertise, designing interventions in this domain is likely much more difficult than it may be for other disciplines. Naturally, system design for anesthesiology may have a tendency to focus on training rather than systems re-design. However, the cognitive activities analysed are fundamental to decision-making in complex, sociotechnical environments. Hence, we believe this case study was informative for other domains employing decision analyses.

## Conclusions

No human systems analysis can be said to specify a design solution. There is always a gap that must be bridged by the designer. The goal of a structured design framework is to close the gap so that the design solutions are more responsive to the work demands than would be the case absent a systematic analysis of the work. In seeking to assess how well the Decision Requirements Table and the DLT close that gap, we sought to be rigorous in the way we interpreted the models, relying on the cognitive elements of each model, as presented in the scientific literature, for that interpretation. We recognize that this sort of rigor is not always necessary and that designers are at liberty to propose a design feature that responds to an observed work issue not covered by their model. Nevertheless, to remain consistent with our aim of comparing the implications of the two models, we did not take the liberty. Within those constraints, we agree with Naikar (2010) that there is a difference, although our data suggest that the types of issues that might be missed by one of the RPD model or the DL model will be resolved in another part of the respective framework.

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## 7.3 Discussion

The goal of this study was to compare the system design solutions emerging from the RPD model and the DL. Firstly, this was done to fill a gap in the literature comparing the design solutions emerging from both frameworks. Secondly, this study was conducted to address the previous finding that the RPD model could not accommodate key decision pathways by anaesthesia teams that involved a degree of option comparison. Building on this finding, the aim of this study was to identify if the DL would identify additional or different design solutions than the RPD model.

The study found differences in the way both methods were able to accommodate the specific nature of decision-making in anaesthesia within the identified system design interventions. This particularly concerned challenges involving failed airway management. Next to the comparison of options, as found in chapter 4, which did not directly emerge from the RPD models' design interventions, the RPD model could also currently not accommodate for repeated attempts of different courses of actions when the current course of action failed. On the contrary, the DL could account for repeated attempts and thus accommodate for the form of work flow typical for airway management challenges.

The study further demonstrated that the RPD model and DL overlapped in the type of decision support design interventions identified. Both models identified system design solutions related to training, technology and procedures. For instance, both approaches found that training specifically focused on difficult cases and discussions in departmental meetings would be beneficial. Also, both methods found that an intervention that organises airway equipment logically, specifically for decisions involving the transitioning between airway management techniques, would be useful. However, the study found differences in the way both methods aim to support decision-making with similar interventions. Decision support design interventions directly emerging from the RPD model aimed at supporting working through options sequentially and efficiently. On the contrary, the airway equipment trolley that emerged from the DL was aimed to be a means for assessing options concurrently and aiding situation analysis. Thus, while this study identified that there is overlap in the decision support design interventions identified with the RPD model and the DL model, it found substantive differences in the nature of performance support emerging from both methods. Thereby, this study supports claims made by Naikar (2010).

## 7.4 Conclusions

The study illustrated that decision support design interventions directly emerging from the RPD model do not account for one type of essential work activity observed in challenging airway management. Therefore, further development of the RPD model may be warranted to accommodate the repeated attempts at managing a patient's airway in the face of failure.

In conclusion, the findings of this study indicate that employing both models in a complementary fashion would be beneficial in order to identify how (similar) system design interventions can support different cognitive activities. Nevertheless, while central, the RPD is not the only model that is associated with DCD (Lintern, 2010). In fact, the DCD framework relates to the broader paradigm of macrocognition that includes other complex cognitive functions such as sense-making, planning and coordination (Klein et al., 2003; Schraagen et al., 2008). NDM, and thus the RPD model, are only one part of this broader paradigm.

# 8 Chapter 8 – The decision support design process of an airway equipment tray for anaesthesia teams

## 8.1 Introduction

The former chapters discussed the journey from eliciting knowledge from subject-matter-experts to the identification of their decision requirements and potential design solutions. The previous chapter concluded with the selection of the decision support tool that will be designed as part of this research program. Based on the results of the FACES survey, an organized airway equipment tray for anaesthesia teams was selected as the decision support tool to be developed. The present chapter discusses the first round of development of this prototype. As illustrated in Figure 8.1, the prototype development phase represents the fourth stage of the DCD framework. A scenario-based co-design process was chosen as the methodological approach. This chapter presents the process and outcomes of this co-design process and conclude with an initial prototype design of the airway equipment tray.

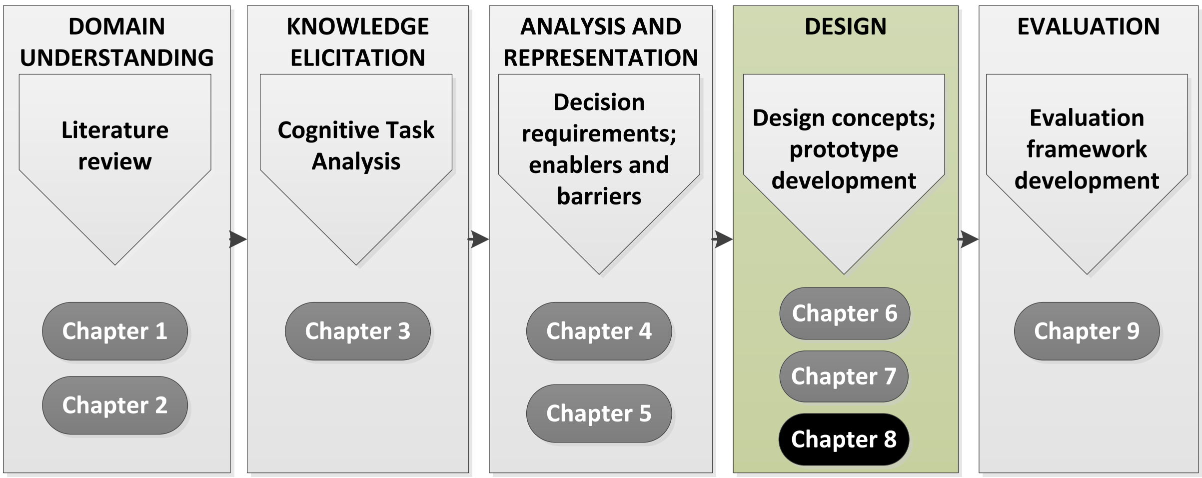



*Figure 8.1.*The decision-centred design process- chapter 8

## 8.2 Airway equipment tray as decision support tool: summary

As described in the previous chapter, the triangulation of the critical decision method interviews and the focus groups identified five potential decision support concepts:

- a standardized difficult airway trolley
- a standardized organised airway surface for routine airway equipment
- an advanced pulse oximeter
- symbolic chart as a cognitive aid

- training specifically focused on cue recognition and transitioning between airway techniques.

The five design concepts were then evaluated on a conceptual level with a small sample of anaesthetists by using an adaptation of a standardized approach called FACES (Shappell & Wiegmann, 2010). Participants were provided with a summary of the decision support concepts and asked to rate those on a scale from 1 to 5 according to five criteria: perceived effectiveness, feasibility, acceptance, environmental fit, reliability and costs. All design concepts received high ratings (above 3.3). The highest rankings received were for training (4.4) and an organized airway equipment surface for nurses (4.3). The airway equipment surface for anaesthetic nurses was chosen for further research here because (1) it has not been designed previously and (2) is relatively low cost, whereas simulation training is already part of the curriculum, expensive and designed by experienced clinicians. The outcomes of the study described in chapter 5 underlined the relevance of equipment location and accessibility and reflected the need for more standardization and uniformity when it comes to the design of equipment representation (Schnittker, Marshall, Horberry & Young, 2018).

## 8.3 Physical environment design in healthcare

The structure and design of the physical 'tangible' environment plays an essential role in supporting collaboration and work flow in healthcare (Xiao, 2005). It is important to note that the physical environment is only one aspect of the healthcare environment- which is complex and characterised by a tight interaction between different system layers including individuals, teams, patients, equipment, advanced technology and organisational boundaries.

Since the healthcare environment is rich in external artefacts (e.g. equipment, charts, whiteboards etc.), cognition such as situational awareness is distributed across (and dependent upon) these information sources (Fioratou et al, 2010). According to distributed cognition (Hutchins, 1995), cognitive activities in complex environments take place through the interaction between external artefacts and clinicians. In order to optimally support this interaction between clinicians and artefacts, adopting a Human Factors approach is essential when it comes to the design of medical equipment (Carayon & Wood, 2010). The benefits of adopting a Human Factors approach has been shown in many studies and is officially recognised by government agencies such as the FDA (U.S. Department of Health and Human Services, 2016).

There are many healthcare examples where artefacts were designed to support clinical collaboration and workflow. These examples include colour coded medications (Porat, Bitan, Shefi, Donchin, & Rozenbaum, 2009); whiteboards (Xiao, Lasome, Moss, Mackenzie, & Faraj, 2001); bedside mayo stands (Zhang et al., 2017); guidelines and algorithms (Henderson, Popat, Latto, & Pearce, 2004; Runciman et al., 2005); or more recently cognitive aids (Chrimes, 2016; Marshall, 2017).

Physical objects, such as medical equipment, act as a communicating medium (Xiao, 2005); provided they are used or laid out in a manner universally understood by all team members (Xiao et al., 2001). In other words, their design needs to support establishing a 'common ground' between the team members including a shared understanding of the situation and its potential limitations (Klein, Feltovich, Bradshaw & Woods, 2005).This is essential, since time pressure or interruptions may occasionally prevent team communication, for instance during handover (Laxmisan et al., 2007) or anaesthesia induction (Burtscher & Manser, 2012; Manser & Wehner, 2002).

### 8.3.1 Medical equipment layout in critical care environments

The layout of medical equipment is one of many aspects of the physical healthcare environment that affects decision-making and collaborative activities (Yan Xiao, 2005). Consequently, designing equipment layout with a Human Factors approach is important to optimise their use and effectiveness. Grundgeiger and colleagues (2014) found that standardising the organisation of bedside emergency equipment with a divider increased completeness of preparation and decreased preparation time and workload. In another study, a paediatric resuscitation cart with colour coded draws and organised according to patient categories increased equipment retrieval time and clinicians' satisfaction (Agarwal, 2005). A comparative study on emergency airway equipment found that a template guiding the preparation of equipment according to plans improved completeness of preparation and less variation in the location of airway equipment (Long, Fitzpatrick, Cincotta, Grindlay, & Barrett, 2016).

The principle of having a template to guide preparation has also become increasingly popular in pre-hospital care. The 'kit dump' is a rollout pack with airway equipment templates prints, to be used in emergency airway management (Mackenzie, French, Lewis, & Steel, 2009). In anaesthesia, most anaesthetic departments nowadays have difficult airway trolleys that are designed to support decision-making and workflow in challenging airway management situations. This is realised by stocking the trolley in a logical sequence to support decision-making and common transitions between techniques. The former is done according to algorithms and published guidelines (Heard et al., 2009). While there is room for hospitals to design their local version, professional societies recommend national standards (The Royal College of Anaesthetists, 2011).

### 8.3.2 Filling the gap: standardisation of routine airway equipment

While efforts have been made to improve the layout of emergency airway equipment, this has not yet been done for routine airway equipment. ANZCA does provide recommendations on type of airway equipment that should be available whenever anaesthesia is administered (ANZCA, 2012). However, there are no recommendations on how to organise this airway equipment effectively to support work flow and decision making for clinicians of all levels of experience. Previous findings of this research program identified that the layout of airway equipment affects successful airway management (Schnittker et al., 2018; Schnittker et al, 2017, discussed in chapter 4 and 5). Other research has also recommended standardisation of airway equipment to better support successful airway management (Chrimes, Bradley, Gatward, & Weatherall, 2018; Long et al., 2016; Eley, Lioyd, Scott & Greenland, 2008). Based on the previous research findings and the FACES prioritisation survey, the aim of this study was to fill this gap and design an airway equipment surface to be used routinely.

## 8.4 Scenario-based co-design to identify design requirements

To make sure practitioners were involved at every stage of the DCD process, the design requirements for the airway equipment surface were established in collaboration with clinicians. Firstly, participants were probed about the preferred layout of the airway equipment surface. This was done with an airway management scenario, thus following the principles of a scenario-based design approach (Rosson & Carroll, 2002).

Scenario-based design is a method from Human Factors Engineering used to identify system design requirements by describing how people will ‘use a system to accomplish work tasks and other activities’ (Rosson & Carroll, 2002). The use of scenarios is a widely recognised technique in Usability Engineering. In their guidance protocol ‘Applying Human Factors and Usability Engineering to Medical devices’, the FDA endorses the use of scenarios for the usability validation of medical devices. On the contrary, scenario-based design has not yet been frequently used to identify design requirements for medical equipment (Vincent & Blandford, 2015). Scenarios benefit the design phase since they support knowledge elicitation, exploration of likely equipment usage, revealing differences between work-as-done and work-as-imagined and insight from different professions (Blandford et al., 2014; Vincent & Blandford, 2015).

The second part of the study concerned a general discussion about the equipment layout on the surface and how this layout can be realised in practice. Based on both parts, the design requirements were established taking into consideration Human Factors principles and environmental requirements (i.e. hygiene, size, etc.).

### 8.4.1 Process from gathering user requirements to prototype development

The present study is the last of a DCD process with the goal to identify a decision support tool for airway management. The DCD framework covers the four linked design activities specified in the latest document on human-centred design for interactive systems by the *International Organisation for Standardisation* (ISO 9241-210:2010): understanding and specifying the context of use, specifying the user requirements, developing design interventions and the evaluation thereof (ISO, 2010). Table 8.1 summarises the methods conducted in this research program in relation to the human-centred design activities. As the table illustrates, a number of the methods conducted as part of the DCD cover several activities.

*Table 8.1.* Human-centred design activities (ISO, 2010) performed in the decision-centred design process of present research program

| ***Human-centred design activities (ISO, 2010)*** | ***Human Factors methods performed in DCD*** | ***Outcomes*** |
|---|---|---|
| **Understanding and specifying context of use** | Field observations (preliminary) | Understand context and work flow of airway management |
| | CDM interviews | • Identify critical decisions and their requirements (i.e. cues, expertise, context): decision requirements tables<br>• Identify potential decision support tools: decision requirements tables |
| **Specifying user requirements** | CDM interviews | • Decision requirements tables |
| | Scenario-based focus groups | • Validation of critical decisions and their requirements<br>• Group discussion on beneficial decision support tools and their requirements<br>• Thematic analysis of discussed decision support tools |
| | Design prioritisation survey | • Prioritisation of discussed decision support tools with small sample of subject-matter experts (standardised airway equipment surface) |
| | Scenario-based co-design | • Specifying lay out of airway equipment surface<br>• Specifying design requirements for airway surface (usability/human factors and generic, e.g. hygiene) |
| **Developing design intervention** | Scenario-based co-design | • Specifying lay out of airway equipment surface |

| | | |
|---|---|---|
| | | • Specifying design requirements for airway surface (usability/human factors and generic, e.g. hygiene) |
| **Evaluating design intervention** | *Yet to be commenced* | *Yet to be commenced* |

## 8.5 Aim of this study

The goal of this study was to identify the design requirements for the airway equipment tray that was identified as the decision support tool to be developed. A co-design process was followed with anaesthetists and anaesthetic nurses to ensure that the airway surface tray was designed according to their needs and to adequately support 'work-as-done' (Blandford et al, 2014). It was anticipated that generic patterns in the way participants set up airway equipment would be revealed and thereby identify leverage points for the bottom up design of the surface.

## 8.6 Method

### 8.6.1 Participants

A sample of six subject-matter experts took part in this study. Three of these participants were anaesthetists (one female, two males), and three were anaesthetic nurses (one female, two males). Their experience ranged from less than three years to more than 25 years of experience. There was no requirement for a particular level of experience to participate in this study. All participants were recruited from the same healthcare organisation, an urban tertiary hospital in Melbourne, Australia. However, all participants have previously worked in other hospitals.

### 8.6.2 Materials

#### *8.6.2.1* Airway management scenario

An airway management patient scenario was developed for the purpose of this study (see Table 8 2). The scenario involved a patient requiring an emergency laparoscopic appendectomy. The case was chosen because it presents a common, generic clinical situation and thus requires a generic set up of standard airway equipment including back up plans in case of failure. The case was chosen carefully to ensure that the standard airway equipment required in most cases was included. The patient scenario was developed by an experienced anaesthetist.

*Table 8 2.* Patient scenario used for the present decision support design study

| |
|---|
| *The next patient on the list is a 25-year old male for an emergency laparoscopic appendectomy. Please set up the airway equipment you think you will need in the order/arrangement that you think is the most appropriate for this case.* |

#### 8.6.2.2 Airway equipment

For external and face validity, real airway equipment was provided for the present study. The decision of what is regarded as 'standard airway equipment' and should be included in the study was informed by discussions with senior anaesthetists and consulting the Australian and New Zealand College of Anaesthetists (ANZCA) guideline PS55 on *Recommendations on Minimum Facilities for Safe Administration of Anaesthesia in Operating Suites and Other Anaesthetising Locations* (Australian and New Zealand College of Anaesthetists, 2012). The airway equipment provided for the present study were: two face masks, oropharyngeal (Guedel) and nasopharyngeal airways, three laryngeal masks, two laryngoscopes, two endotracheal tubes, stylet, bougie, cuff inflating syringe and connector (see Figure 8.2). As the patient scenario concerned an adult, all airway equipment sizes were for adults.

*Figure 8.2.* Airway equipment provided in the decision support design study

## 8.7 Procedure

Human ethics research approval was obtained from the Human Ethics Research Committee and the Nursing Advisory Committee of the participating hospital organisation. After approval was obtained, the anaesthetics department and the nursing department sent out a letter of invitation to all anaesthetists and anaesthetic nurses. Additionally, flyers were distributed around the hospital and in the operating theatre suits. Anaesthetists and anaesthetic nurses interested in the study contacted the PhD student. Participant Information and Consent Form were sent to the participant and a date and time for the study was arranged.

The study took place in an isolated room at a simulation centre that is part of the hospital organisation the participants were recruited from. After the purpose of the study was outlined to participants, they signed the consent form and completed a short demographic questionnaire. All interviews were audio-recorded for later transcription. During the first part of the study, participants were provided with the airway management patient scenario (see Table 8 2). Based on the patient scenario, the participant was asked to prepare and lay out the airway equipment as they would in the real clinical setting. In particular, participants were asked to lay out the airway equipment on a surface (a white sheet of paper) according to how it would most effectively support their flow of work and decision-making in the present scenario. After participants laid out the equipment, photographs were taken for later analysis. In the second part of the study, the participant was probed to explain their lay out, how it would support their workflow and decision-making and how this layout could be transferred and realised to be used in the clinical setting. The interviews lasted approximately one hour each. Participants were reimbursed with a gift voucher to compensate for their travel and time.

## 8.8 Analysis

On the basis of the interviews, lay out preferences and user (design) requirements for the airway equipment surface were identified. On the basis of that, a first prototype was developed. Due to the nature of this enquiry and the iterative nature of this design process, the data analysis was descriptive and qualitative.

*Equipment layout based on airway management scenario*

The first part of the analysis concerned visualising how participants laid out the airway equipment on the airway surface. This was done to identify common patterns in how participants preferred to lay out equipment. In order to do so, the photographs taken from each participant were compared and collated. A colour coded dot was assigned to each individual piece of airway equipment. Using *Microsoft Visio*, a master version of the airway equipment layouts provided by all participants was then created to identify patterns.

### 8.8.1 Design requirements

The second part of the analysis concerned the more in-depth specification of design requirements based on the audio-recorded interviews. The PhD researcher took notes from the audio-recorded interviews about all parts of the discussion that concerned the design of the airway cart surface. The notes were taken in *Microsoft Word* and consequently analysed to identify the specific design requirements. The analysis followed the principle of a thematic analysis where design requirements were treated as overarching themes. Additionally, associated Human Factors principles were matched to each coded design requirement (based on Nielsen's usability heuristics, 1994). This was done in order to establish a link with the literature and ensure a level of consistency. After the design requirements were coded in the interviews, they were further specified on the basis of the interviews (see Appendix 4 for the coding of design requirements). A method following a situated Cognitive Engineering approach (Neerincx & Lindenberg, 2008) has been previously used to specify and validate user requirements (Schnittker, Schmettow, Verhoeven, & Schraagen, 2016). The core of this method is the description of use cases, requirements and claims. Use cases describe the generic behaviour requirements for the designed tool, which can relate to several requirements (for the user-device interaction) and claims (evidence from the literature or research to justify the requirement that is testable). We adapted the generic structure of the method to fit the objective of this study by having a consistent table format for each design requirement, i.e. design requirement tables. Each design requirement table entailed (1) the decision or function supported, (2) a detailed description, (3) evidence (i.e. part of this research or HF principles), (4) its realisation, and (5) constraints and anticipated challenges.

*Prototype development with digital designer*

The insights gained from the equipment layout visualisation and the design requirements were used to generate an initial airway surface prototype. A summary of the key requirements was collated and sketched. A serious of sketches were drawn until all design requirements were adequately considered in the prototype. The initial sketch and the summary of design requirements was then taken to a digital designer from *Monash Art Design & Architecture*. The PhD researcher and the digital designer discussed the sketch and the design requirements. During the meeting, the size of the individual pieces of airway equipment was also measured to determine their exact location and fit on the airway surface.

In addition to the design requirements, ergonomics standards were considered throughout the design process (Tilley & Dreyfuss Associates, 1993). For instance, this concerned the size of the overall tray to ensure that clinicians can comfortably reach every piece of equipment as well as the depth and width of grips. Based on that, an initial digital design of the prototype was developed in *SolidWorks.*

## 8.9 Results

### 8.9.1 Airway equipment layout

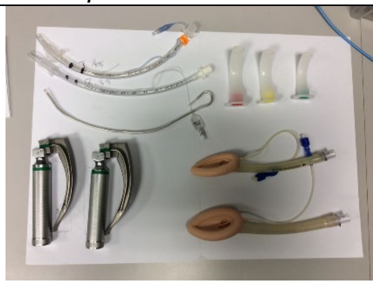
Figure 8.3 and Figure 8.4 show the photographs taken of the individual airway equipment layouts per participant. Based on these photographs, Figure 8 5 and Figure 8 6 illustrate the comparative location of equipment as laid out across participants. As shown in the legend, the coloured dots refer to the specific airway equipment pieces. The numbers in the dots refer to the participant numbers. They are shown to illustrate how airway equipment pieces were laid out across but also within participants. The cluster of dots outside the box represent the 'bougie', a long stick-like airway equipment piece that was stuck along the side of the airway equipment tray by all participants.

A clear pattern emerged in regards to how airway equipment was located across the surface, as well as how airway equipment was grouped in relation to each other. Certain airway management tools were grouped together and placed next to each other. Equipment was grouped together according to (1) the sequence of how it was going to be used (on the left laryngoscopes, followed by tubes, syringes and connector), (2) their sizes (back up size of the same method placed next to anticipated size), (3) their general method and functions (e.g. LMA's were grouped together) and (4) according to their expected necessity (equipment not immediately needed tended to be placed at the back, such as the Guedel airways). All participants sticky-taped the bougie on the side of the trolley.

Most participants preferred to separate primary equipment from back-up equipment (see Figure 8.5). They intuitively organised the primary equipment to sit on the top shelf of an airway cart in order to be accessible immediately; and the back-up equipment on the bottom shelf which is still accessible but 'out of the way'. People slightly differed in regards to how much equipment was placed on the top shelf. The majority preferred 'the less, the better' with only those pieces of airway equipment on the top that is definitely needed, and only one back-up airway (the Guedel). However, a few participants added more back-ups in case of failure, such as different sizes of airways and more rescue airways (the laryngeal mask).

The bottom shelf containing back-up equipment revealed a less clear pattern-participants varied more in where they put the back-up. Differences mainly occurred in terms of equipment being placed in the back or the front; likely because there was more space to choose from in the first place and less equipment to organise. There was still agreement in terms of how the equipment was grouped together according to their function.

*Figure 8.3.* Original photographs of airway equipment layout based on scenario – top shelf

| | | |
|---|---|---|
|  *Participant 1* |  *Participant 2* |  *Participant 3* |
|  *Participant 4* |  *Participant 5* |  *Participant 6* |

*.Figure 8.4.* Original photographs of airway equipment layout based on scenario - bottom shelf

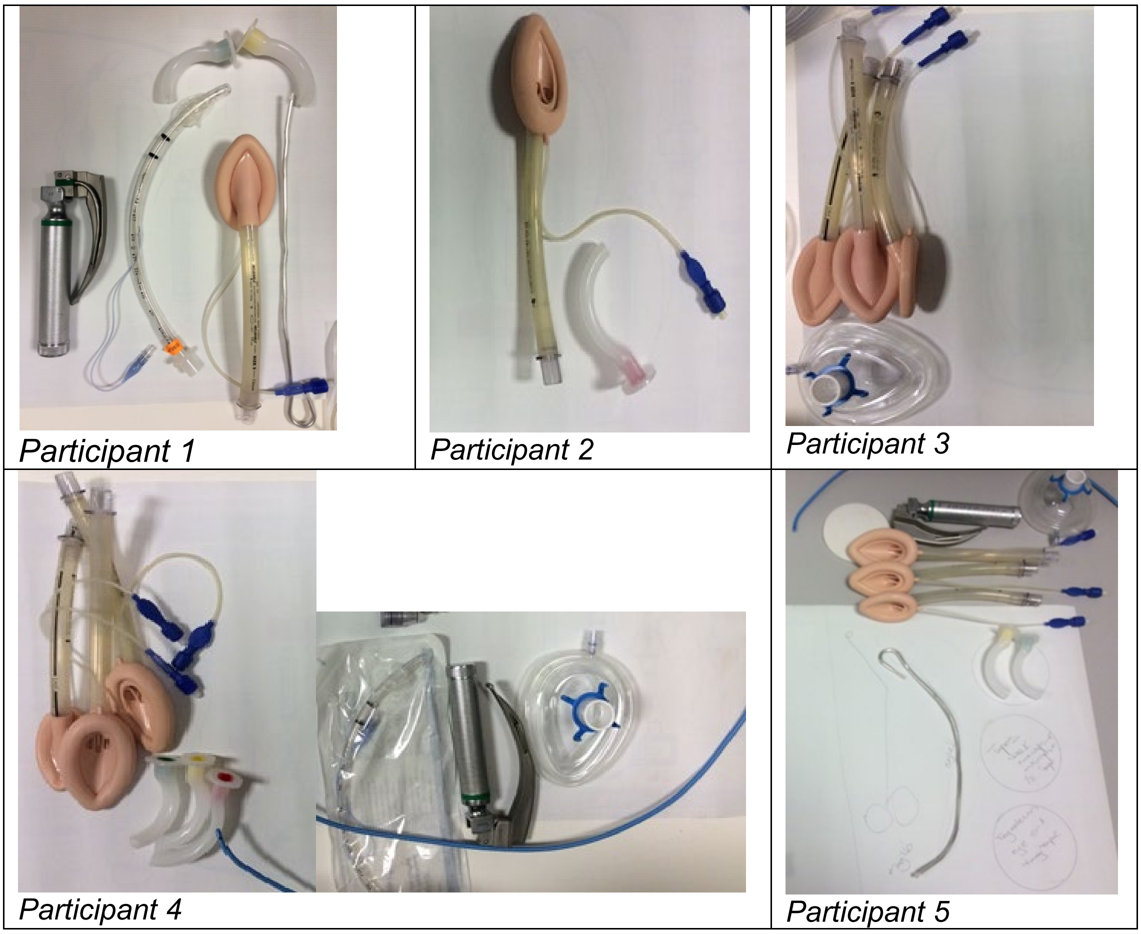
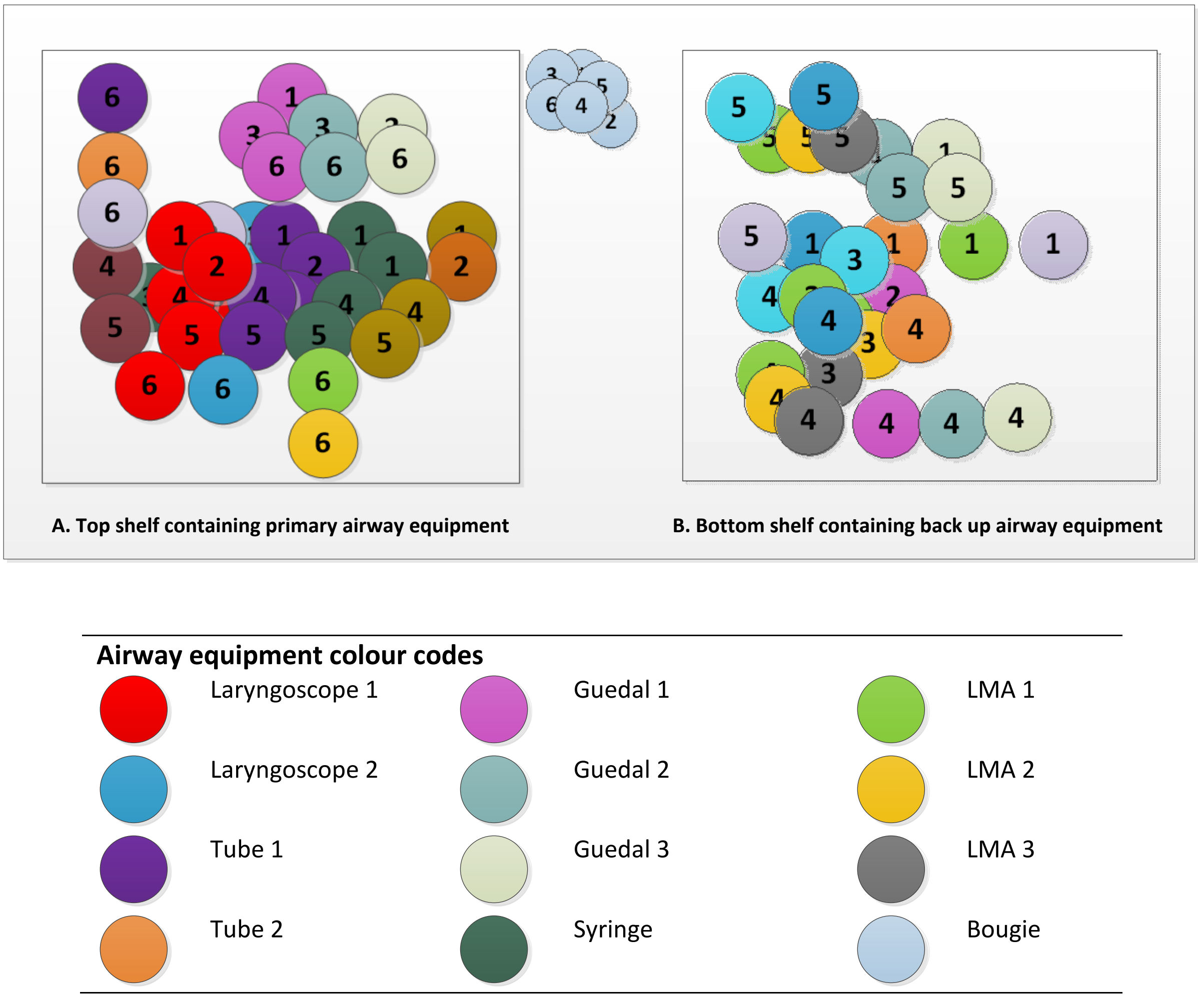


*Figure 8 5.* Airway equipment location across participants




## 8.9.2 Design requirement tables

The thematic analysis of the interviews identified a total of 11 design requirements (see Appendix 5 for a more detailed description of the design requirements according to the situated Cognitive Engineering approach). A brief summary of the requirements is provided in Table 8 3. The design requirements emerging from the thematic analysis were supplemented by analysing the preferred airway equipment layouts described before.

*Table 8 3.* Summary of design requirements for airway equipment surface

| No | Design requirement | Description | Supports decision/functions |
|---|---|---|---|
| 1 | *Surface dedicated for airway equipment* | A surface that is dedicated to airway equipment to ensure that airway equipment is kept together even if relocated | Preparation and retrieval of equipment, general work flow |
| 2 | *Separation of primary and back up equipment* | Provide a possibility to separate primary and back up equipment to minimalize clutter and a crowded space | Preparation and retrieval of equipment (recognition; visibility) |
| 3 | *Layout, categorisation and visibility* | Provide a surface that lays out and categorises equipment in a logical, visible manner | Preparation and retrieval of equipment (recognition; visibility) |
| 4 | *Flexibility and standardisation trade-off* | While standardise, provide some degree of flexibility in terms of equipment arrangement | Preparation and retrieval of equipment (endorse flexibility and efficiency) |
| 5 | *Proximity and accessibility of airway equipment* | Airway surface should be in the same space and accessible for the whole team | Retrieval of equipment (accessibility for the whole team) |
| 6 | *Airway equipment should not move or fall off trolley* | Prevent airway equipment to roll off or fall off trolley when surface is moved | General requirement |
| 7 | *Space to grasp equipment versus general space constraints* | Provide enough space to properly grasp equipment but be aware of the general space constraints in the operating theatre | Preparation and retrieval of equipment; general ergonomics requirement |
| 8 | *Airway surface easy to move/relocate* | Airway surface needs to be moved easily (flexibility in location) | General work flow, retrieval of airway equipment (by the whole team) |
| 9 | *Airway surface easy to clean* | The surface needs to be wiped clean quick and easily between cases | General hygiene requirement |
| 10 | *Separate contamination area* | Provide a contamination area that is separated from but yet close to clean equipment | General hygiene requirement |
| 11 | *Account for equipment that is still packaged to avoid waste* | Provide a bit more space so back up equipment can be left in the package to avoid unnecessary waste | Waste management |

### 8.9.3 Summary of decision support tool

The insights gained from this study were used to create an initial prototype design for the airway equipment surface. This was a creative process involving brainstorming and a variety of sketches (see examples in Figure 8.6). A subject-matter experts provided input at this stage to assure the design requirements were interpreted adequately from a clinical point of view. The key criteria for the airway equipment surface based on the findings of the study are summarised in Table 8.4.

*Table 8.4.* Key design criteria for airway equipment surface

| **KEY DESIGN CRITERIA FOR AIRWAY EQUIPMENT SURFACE BASED ON CO-DESIGN STUDY** |
|---|
| **1.** A surface for airway equipment to be used in the operating theatre to assist anaesthetic nurses and anaesthetists with the preparation and retrieval of airway equipment (in challenging, time pressured situations).<br>**2.** The surface will be a light clear plastic tray with handles on the sides that can sit on top of surfaces in the operating theatre (i.e. the existing airway cart, anaesthetic machine, the patient). It will have legs, thus if put on a flat surface the space below it can be used as a second area to store back up equipment.<br>**3.** The edges of the tray will be elevated (like a low 'wall') to prevent airway equipment from falling off when the tray is moved around. Thus, it enables to be moved flexibly where needed<br>**4.** The top of the surface will have 5 sections that divide the different pieces of airway equipment. The sections will be grooves (i.e. indented) to ensure the airway equipment can't move or fall off the trolley. The sections will be slightly shaped according to the airway equipment that belongs in the respective section.<br>**5.** The sections will accommodate the following equipment:<br>**a.** Back right corner: LMA's<br>**b.** Back left corner (not shaped specifically): space for lubricants, tapes, etc.<br>**c.** Back middle: Three guedel airways standing up so their colour can be seen<br>**d.** Front left: laryngoscopes (space for two, indented between them)<br>**e.** Front middle: tubes (space for two, indented between them)<br>**f.** Front right: syringe (mostly already connected to tube, though) and connector.<br>**6.** The sections will have a simplified sketch in them of the particular airway equipment (in black and white, to not confuse with other colour coding).<br>**7.** The left side of the tray will have an indented area for the contaminated equipment<br>▪ The plastic tray will be easy to wipe off and disinfect with fluids between surgery cases.<br>▪ Dimensions: around 70 cm x 50 cm |

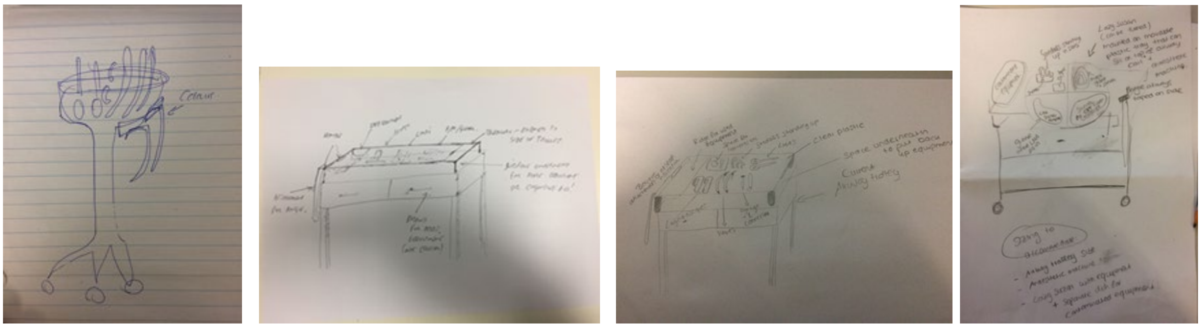



*Figure 8.6.* Airway equipment surface- initial sketches

### 8.9.4 Airway equipment prototype – initial digital design

The airway equipment prototype design is presented in Figure 8.7, Figure 8.8 and Figure 8.9. Additional renderings and exact measurements are provided in Appendix 6. Figure 8.7 shows the airway equipment tray without equipment from a top and angled view. The airway equipment tray lays out airway equipment in an organised way with stickers placed underneath the airway grooves providing guidance for preparation (design requirement 4). While offering structure, the tray still provides flexibility on how many back-ups to prepare and where to place additional pieces of equipment (an optional section for 'miscellaneous' pieces such as tape and gel tubes is provided at the top left, design requirement 4). It also provides the option to place equipment underneath the tray to separate (design requirement 2). Due to the clear plastic, equipment placed underneath would still be visible. As Figure 8.8 shows, the airway equipment tray is also able to accommodate both packaged and unpackaged pieces of airway equipment (design requirement 11) and offers enough space to grasp equipment (design requirement 10). As per design requirement 10, the ridge on the left provides enough space for contaminated airway equipment. Figure 8.9 demonstrates a few example of contexts the airway equipment can be used in by carrying it around (e.g. on the anaesthetic machine or another trolley). This provides flexibility depending on individual need and environmental constraints. Finally, the tray was designed to be held in multiple ways by the clinicians, in order for them to be able to grasp it from any angle. For instance, the tray can be hold from the bottom, held by the legs or the front, back and along the sides.

*Figure 8.7.* Final prototype of airway equipment tray- plain angle and top view

*Figure 8.8.* Final prototype of airway equipment tray stocked with airway equipment- top view

*Figure 8.9.* Final prototype of airway equipment tray- different contexts of use in the operating theatre

## 8.10 Discussion

The present study was the last study of this PhD program that followed a DCD process to identify a decision support tool for airway management. The goal of the present study was to design the initial prototype of an airway equipment surface. Previous studies conducted as part of this research program identified this as a beneficial design intervention to support key decisions of anaesthesia teams relating to the preparation of airway equipment and transitioning between techniques in challenging situations. In order to identify the design requirements for this prototype, a scenario-based co-design approach was followed (Rosson & Carroll, 2002). This was done to ensure clinicians are involved in the design process, which is the core of human-centred design (ISO 9241:210, 2010). The scenario-based co-design process identified a range of design requirements for the airway equipment surface. The design requirements ranged from logical categorisation of equipment to hygienic requirements specific to the healthcare environment, such as an easy to clean surface and a separate contamination area. Based on these design requirements, an initial digital design was produced.

The design requirements discussed by the clinicians reflected the need to incorporate standard Human Factors design principles such as consistency, visibility, minimisation and flexibility and efficiency (Nielsen, 1994; Zhang, Johnson, Patel, Paige, & Kubose, 2003). The visibility and accessibility of the airway equipment as a visual cue to support preparation and transitions between techniques supports findings from our previous studies on cognitive pathways underlying decision-making (Schnittker, Marshall, Horberry, Young, & Lintern, 2017). Subject-matter experts further confirmed the need for adequate grouping of airway equipment according to their method and usual sequence of use. This reflects that clinicians strive to match the airway equipment surface with their work flow in the real world.

In other words, the design requirements discussed by clinicians reflect that the airway equipment surface is used as a decision support tool, or cognitive aid, to support the recognition of options to successfully manage the patient’s airway. The design requirements discussed have similarities with the underlying principles of difficult airway trolleys. Difficult airway trolleys categorise airway equipment in horizontally colour-coded draws and thereby guide clinicians through a sequence of steps. Often, they are designed according to locally endorsed algorithms (Heard et al., 2009). While standardised difficult airway trolleys are endorsed in national airway management recommendations (The Royal College of Anaesthetists, 2011), they are not without problems. Their design is linear and thus requires clinicians to work through a certain sequence of steps. Since anaesthesia is complex and each situation different, this design may not accommodate the highly context-specific nature of difficult airway management. This has been recognised as a general problem when it comes to the design of healthcare information systems (Lintern & Motavalli, 2018).

On the contrary, the airway equipment surface designed in the present study does not dictate a certain sequence, while offering a logical categorisation of equipment at the same time. As anticipated, there was a clear pattern in the way participants laid out their primary airway equipment. This finding was incorporated in the design and supported to identify an adequate categorisation of airway equipment according to their method and anticipated use. However, the design is not linear and thereby provides enough flexibility for clinicians to adapt to their specific situation. It merely provides a ‘road map’; but no specific navigation instructions. A similar approach has been taken by recent designed cognitive aids, such as the ‘vortex approach’ (N. Chrimes, 2016). One key characteristic of the vortex is that its starting point is flexible, and thus can be applied to most situations. A similar principle was achieved with the design of this initial airway equipment surface prototype.

## 8.11 Conclusions and next steps

The present study discussed the initial prototype development of a decision support tool identified as part of a decision-centred design process. We described the process from identifying design requirements to the creation of the initial prototype. The final chapter of this thesis will outline the final research activities required to fulfil the DCD process. Firstly, this will be the completion of an iterative design process. The current prototype will be taken back to subject-matter-experts for further design-related feedback. This will also involve formative evaluations such as a cognitive walkthrough (Wharton, Rieman, Lewis, & Polson, 1994). The design improvement will be accomplished in an iterative fashion, and finished once it has successfully identified the final design. The former will be achieved once the participant feedback has been saturated and accommodated in the prototype. The final step is the evaluation of the airway equipment surface. Recommendations on the particular evaluation framework will be made including a discussion on evaluation in simulated and clinical settings.

# 9 Chapter 9 - Discussion and conclusions

## 9.1 Aim of this research

The need to view healthcare as a sociotechnical system is now widely recognised. Nevertheless, the uptake of CSE techniques is still slow in clinical practice (Catchpole & Alfred, 2018). Many concepts and approaches to training and design in anaesthesia have been adopted from other complex domains, particularly aviation (e.g. Gaba, 2010; Gaba, 2011; Helmreich & Davies, 1997). The present study addressed the scarcity of Human Factors Engineering applied to systems design in airway management in anaesthesia.

The overarching goal of this research was to design an intervention that supports the decision-making of anaesthesia teams in challenging airway management situations. DCD was chosen as the guiding framework as it assisted with the goal of following a human-centred design process with a particular focus on decision-making in challenging situations. By transitioning through the phases of the DCD process, this thesis discussed the evolution from knowledge elicitation to the development of a decision support design intervention for challenging airway management. CDM interviews, focus group discussions and observations were conducted to identify key decisions and their requirements of anaesthetists and anaesthetic nurses. As part of this process, this PhD research studied the cognitive pathways underlying the key decisions to support the identification of suitable decision support. Furthermore, the human factors enablers and barriers that affected successful airway management were identified to examine leverage points for decision support design. The outcomes of the knowledge elicitation phase and design prioritisation survey led to the development of a decision support tool that considered the context and decision requirements of anaesthesia teams. An airway equipment surface was selected as the decision support tool to be developed as part of this research. In the final study of this research program, the airway tray was designed following co-design process. A scenario was used to identify design requirements and preferences of anaesthetists and anaesthetic nurses. The final outcome of this scenario-based co-design study was a first digital prototype of the airway equipment tray.

This chapter will synthesise the findings and conclusions of this research. Firstly, this chapter summarises how each research question posed in chapter 2 was addressed throughout the thesis. In a broader context, I will then discuss the contributions this research made both theoretically and practically. This includes a discussion of the application of the RPD model in anaesthesia, as well as the designed decision support tool. I will then evaluate the application of the DCD process in this research program and reflect on limitations. Finally, this chapter will discuss future research which involves the proposal of an evaluation framework for the decision support design intervention. As illustrated in Figure 9.1, this chapter is part of the last phase of the DCD process.

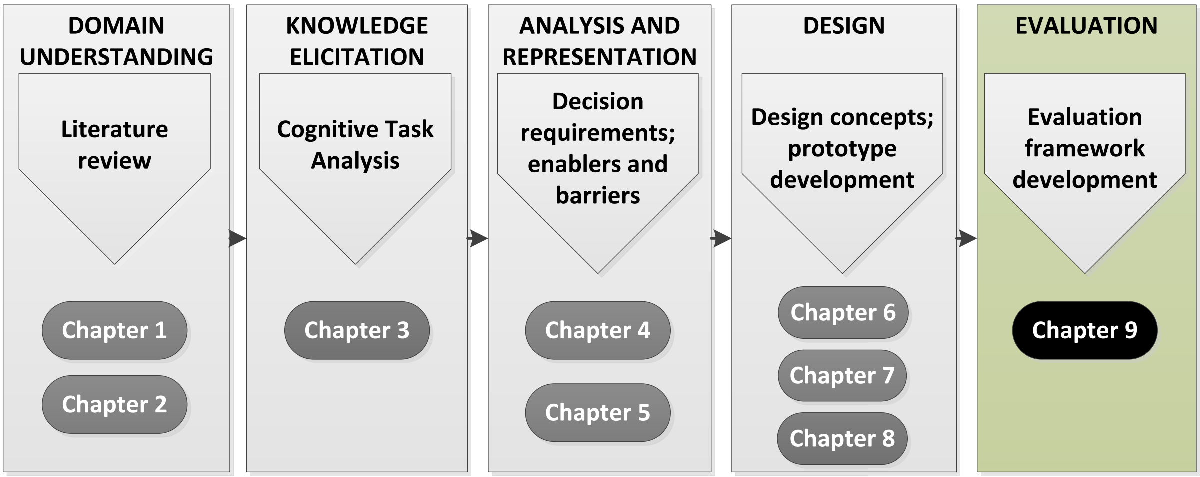



*Figure 9.1.*The decision-centred design process – chapter 9

## 9.2 Reappraisal of research questions

This section discusses and re-appraises the research question answered in this thesis. An overview on the research questions is provided in Table 9.1. Research questions 1a and 1b were not specifically part of the original three research questions but emerged as sub-questions throughout the PhD research, as discussed in chapter 2.

*Table 9 1.* Research questions of the research program

| *No* | *Research question* | *Discussed in chapter* |
|---|---|---|
| **1** | What are the key decisions and their requirements for anaesthetists and anaesthetic nurses in challenging airway management incidents? | 3, 4, 6 |
| **1a** | What are the cognitive pathways underlying key decisions of anaesthesia teams? | 4 |
| **1b** | What are the Human Factors enablers and barriers affecting successful airway management? | 5 |
| **2** | What type of decision support tool is best suited to support the most challenging key decisions and their requirements? | 4 to 7 |
| **3** | How does the decision support tool need to be designed to support the most critical key decisions? | 8 |

### 9.2.1 Research question 1: What are the key decisions and their requirements for anaesthetists and anaesthetic nurses in challenging airway management incidents?

As indicated in chapter 2, the first research question related to the determination of key decisions made by anaesthetists and anaesthetic nurses. The elicitation of knowledge from subject-matter-experts is the core of human-centred approaches such as DCD. The link between knowledge elicitation of subject-matter-experts and decision support system design is far from common practice in healthcare (Catchpole & Alfred, 2018). This research was the first to establish this link for the purpose of decision support design in anaesthesia. Methods from Cognitive Task Analysis were employed to identify the key decisions and their requirements of anaesthesia teams during airway management challenges. The outcomes were mainly reported in chapters 3, 4 and 6.

It was found that key decisions were made during the whole operative period. Key decisions in the pre-operative period were related to preparation and selection of an airway management plan. Key decisions related to the post-operative period were related to extubation and post-operative care. The most universal key decisions identified across interviews were related to the transitioning between airway management techniques during difficulties, specifically challenging being the transition to invasive surgical techniques. It was found that anaesthesia teams heavily rely on environmental cues and their own expertise in interpreting these cues when making decisions. One of the most prevalent cues were patient signals such as change in skin colours and chest movement, feedback from technology as well as the awareness of previously failed attempts which triggered a change in techniques. Other requirements included knowing and recognising when to move to a different strategy, what back up equipment is available and where, and when to call for help.

#### *9.2.1.1 Sub question 1: What are the cognitive pathways underlying key decisions of anaesthesia teams?*

As discussed in chapter 2, one of the fundamental goals of CSE is to '*provide the designer with a realistic prototypical image of how the operator functions cognitively'* (Hollnagel & Woods, 1999). Consequently, one goal of the knowledge elicitation phase was to study the key decision pathways of anaesthesia teams. The results of this study have been described in chapter 4. As hypothesized, it was found that the majority of key decisions in anaesthesia follow a prototypical pathway (> 90%). This replicated findings from the original firefighter study by Klein et al (2010). Rarely, anaesthesia teams compared available options to arrive at solutions; contrasting how clinical decision-making is currently embodied in anaesthesia decision-support. However, we found that a small proportion (7.5 %) of key decisions were made by comparing a small number of options and their suitability to the situation in pairs. It was concluded that this pairwise comparison of options is still mainly based on matching rather than calculation.

The findings from chapters 4 and 6 reflected that algorithmic approaches are ingrained in the decision-making process of anaesthesia teams. Many key decisions were made by applying a 'if x, then do y' rule and can thus be compared to a skill-based and rule-based level of performance (Rasmussen, 1983). At the same time, we found that decisions were context-sensitive and could thus not be made by simply applying 'if x, then y' rules independently. This is in line with Flach et al (2017) who decision-making in healthcare as an '*adaptive muddling through process'* characterised by a '*closed-loop perception-action dynamic'*. It is also in agreement with Knudsen (2017) who found that many anaesthetists view airway algorithms as a fundamental basis which is able to be flexibly adapted to individual situations.

##### 9.2.1.2 Sub question 2: What are the Human Factors enablers and barriers affecting successful airway management?

In addition to studying key decisions and their requirements, the enablers and barriers in the complex sociotechnical environment that affected successful airway management were also examined. The findings of this research question have been addressed in chapter 5. The rationale was to identify the system elements that support or mitigate successful performance of anaesthetists and anaesthetic nurses and use this information to develop recommendations for decision support design interventions.

While the factors contributing to airway management complications have been examined (Flin et al, 2013), no research to date has examined enablers and barriers to successful performance with the purpose of identifying design recommendations. Studying system enablers and barriers as experienced by subject-matter-experts has contributed to the design of system interventions for healthcare challenges such as incident reporting (Braithwaite, Westbrook, Travaglia, & Hughes, 2010), recognition and assessment of acute mental states in older patients (Hosie, Lobb, Agar, Davidson, & Phillips, 2014) and medication prescription errors (Anderson, Stowasser, Freeman, & Scott, 2014).

As discussed in chapter 5, the identified human factors enablers and barriers were related to different system levels such as equipment location and storage (physical environment), time and resource limitations (organisational), team work and communication (team work) as well as experience and learning (individual). The Human Factors enabler that was mostly mentioned by subject-matter-experts was 'readily available and accessible airway equipment'. In contrast, the barrier mostly discussed was a lack of standardisation in equipment location and cognitive aids that are not ingrained in the clinical work flow. Interestingly, human factors enablers and barriers on the individual level were mentioned infrequently by subject-matter experts. In contrast, enablers and barriers to successful airway management were primarily related to the team, environmental and organisational level. These findings support the need to address healthcare design from a sociotechnical systems perspective (Catchpole & Alfred, 2018; Kilsdonk, Peute & Jasper, 2017).

### 9.2.2 Research question 2: What type of decision support tool is best suited to support the most challenging key decisions and their requirements?

The identification of a suitable decision support design intervention was a journey described throughout chapters 4 to 7. Chapter 4 started with initial, broad ideas and improvements that could potentially support the key decisions identified in the CDM interviews. These initial design concepts were adapted and specified in chapters 5, 6 and 7.

As summarised previously, chapter 4 identified that the majority of key decisions in challenging, time-pressured situations follow a prototypical pathway that is typified by a direct link between cue recognition and action generation. Only 7.5% of decisions involved a pairwise option comparison. We discussed how these findings of the underlying cognition has implications for the design of decision support: decision support should focus on supporting the recognition of critical cues that indicate the need for an action. Since anaesthesia teams were experienced and could rapidly make decisions on what do to, the intervention does not need to dictate a step-wise approach on how to solve the situation. Instead, the decision support should offer flexibility and enable teams to adapt it to the specific context. Since anaesthesia teams rarely compare options when making decisions, an intervention focusing on the support of option analysis would likely be unsuccessful.

Preliminary decision support design ideas identified in chapter 4 were cognitive aids that support the transitioning between airway techniques, availability and accessibility of airway equipment, involvement of the whole medical team to share their situational awareness and more frequent practice of performing surgical airways. Chapter 5 identified more specific clinical design recommendations emerging from the thematic analysis of enablers and barriers to successful airway management. These were related to different system levels of the anaesthesia environment: equipment standardisation, team work, improved design of cognitive aids and shared learning through difficult case discussions. Chapter 6 specified ideas discussed in chapters 4 and 5 and selected five dominant design interventions based on the triangulation of observations, interviews and focus groups. The organised airway equipment surface was chosen as the decision support design intervention to be developed as part of the DCD framework.

An organized airway equipment surface was selected because (2) it emerged from the three studies that equipment organisation is essential to successful airway management, (2) was rated positively by anaesthesia providers as a decision support intervention and (3) would likely support the key decisions identified as part of this research process.

### *9.2.3* Research question 3: How does the decision support tool need to be designed to support the most critical key decisions?

The design process of the airway equipment cart prototype was described in chapter 8.The chapter described in detail the co-design process that was followed to identify design requirements for the decision support design tool. In addition to the general DCD framework, the chapter discussed the requirements of the ISO 9241:210 (2010) and how their recommended human-centred design activities were followed as part of the design study and was also embedded in the previous research phases. The ISO 9241:210 (2010) particularly emphasises the relevance of end-user involvement in every aspect of the human-centred design activities. Chapter 8 laid out the scenario-based co-design process that was followed in order to identify the design requirements for the airway equipment tray. A scenario-based co-design process was chosen in order to provide a specific clinical context and support creativity in design suggestions (Bødker, 2000). The design study successfully identified 11 design requirements which were accounted for in the subsequent development of the prototype.

## 9.3 Contribution of PhD research

This PhD research offered contributions to theory, methods and the clinical practice. This section discusses these contributions in detail.

### 9.3.1 Contribution to theory: applying the recognition-primed decision model

This research program addressed a theoretical gap by firstly applying and evaluating the RPD model in the domain of anaesthesia. We found that the RPD model applies to the majority of decision pathways in anaesthesia. However, the research also revealed that, in some specific situations, the RPD model could not hold in its current form.

First of all, we found that a small proportion of decisions in airway management involved a degree of option comparison. While these situations had reduced immediate time pressure, they were still time compressed and exhibited the characteristics of NDM environments (Orasanu & Connolly, 1993). This research found that in these situations, clinicians engaged in a process of pairwise option comparison in team discussion. This type of option comparison still involved a situation-action matching process: subject matter experts still compared the options and their suitability in reference to the unfolding situation rather than in regard to their relative merit. Thus, there was no evidence for the occurrence of a ‘hybrid decision-making’, which postulates that experts employ both analytical and naturalistic decision strategies (Pfaff et al., 2013). Since the pairwise option comparison strategy found still relied on a recognition-primed process, this was proposed as a possible extension of the second level of the RPD model in chapter 4.

Secondly, it was found that the RPD model was not able to account for the sequential ‘trial and error’ approach clinicians occasionally adopted when the current airway management technique failed (see chapter 7). The RPD model accounts for sequential option evaluation; however only imaginative through mental simulation. The fact that the RPD model was developed based on decision-making processes of firefighters may explain why the model does not include this type of action process. Carrying out an action plan in the context of firefighting likely takes much longer and extends over a larger physical space. In contrast, trying a different approach in airway management will only take a few seconds, with resources (ideally) being in close proximity. Therefore, the need for mental simulation before committing to an action plan is likely more important in firefighting than in the more spatially confined environment where airway management takes place. As we discussed in the publication, repeated attempts at intubation may still cause trauma to the patient and is thus not an approach without consequences. However, a number of airway techniques in airway management are less invasive and attempting these is essential when facing failure of oxygenation before moving to more invasive techniques.

A tension was perceived between the representation of sequential versus concurrent options emerging from the RPD model (Klein et al, 2010) and the need for flexibility and context sensitivity in healthcare. The layout of the designed airway equipment tray does present a range of airway equipment concurrently and thus may not flow entirely naturally from the implications of the RPD Model in isolation. Indeed, it may even encourage a degree of option awareness, the ‘perception and comprehension of the relative desirability of available options’ (Pfaff et al., 2013). We have discussed this in chapter 7 in the context of comparing design solutions emerging from the RPD model and the decision ladder.

Taking all of the above into consideration, this thesis found substantial evidence for the existence of RPD decision-making during challenging airway management situations. Therefore, when designing for situations with similar characteristics the findings advocate considering RPD in the design process. Still, the RPD could not account for a few aspects of cognitive work as they occurred in anaesthesia. Therefore, an extension to the existing RPD model was proposed. Furthermore, the complementary use of other decision-making representations, such as the decision ladder, was discussed.

### 9.3.2 Contribution to knowledge and methods

This PhD research also offered contributions to knowledge and methodology. Firstly, I have not only applied, but also extended the DCD framework in a safety critical domain. The research program demonstrated how to integrate the study of cognitive pathways and human factors enablers and barriers in the DCD process and the development of decision support design concepts. I have further triangulated different qualitative research methods (e.g. the CDM and focus groups) and clinician perspectives (anaesthetic nurses, junior and senior anaesthetists) to identify suitable decision support design concepts. While triangulation of interviews and focus groups is common in healthcare (Valdez, McGuire, & Rivera, 2017), there is a paucity of Human Factors research that used method and source triangulation for the purpose of developing tools, technologies and work space design in healthcare (Papautsky et al., 2015).

Moreover, this study was the first one that applied and extended the DCD framework in the domain of anaesthesia. This has not been done previously. Thereby, this PhD offered methodological contributions regarding how best to examine decision making of anaesthesia teams in critical incidents. I found that while field observations were not fruitful due to the low number of incidents in clinical practice, they were necessary to understand the complexity of the anaesthetic practice. The combination of CDM interviews and scenario-based focus group discussions were most valuable to identify the most critical decisions and identify decision support concepts. Due to the 'low frequency, high acuity' nature of critical incidents in anaesthesia, research activities based on scenarios and past incidents were the most effective to discuss challenges and potential solutions.

Nevertheless, using scenarios and past incidents presented methodological challenges. For instance, past incidents are retrospective, rely on long-term memory and are susceptible to hindsight bias. However, since participants in this research could choose the incidents they wanted to discuss, they chose high acuity cases they could remember clearly. This minimised the risk of memory loss as much as possible. Furthermore, during the CDM interviews much emphasis was placed on discussing key decisions and underlying thought processes at specific time points of the critical incident. This encouraged participants to put themselves back in the situation at the particular point in time. While a degree of hindsight biases cannot be avoided, the way the CDM was structured limited its extent as much as possible. Scenarios rely on the participant's imagination to put themselves in a particular clinical situation. Occasionally, participants drifted away from discussing what they think they would actually do to general discussions on what you 'should' do, a common behaviour discussed by Crandall et al (2006, p. 81). It required some effort to turn the participant's focus back to the goal of the discussion, especially in the focus group discussions.

Finally, this research program demonstrated that including knowledge sources with different clinical backgrounds and experience in the research (i.e. anaesthetic nurses, senior anaesthetists and junior anaesthetists) was necessary to obtain an adequate representation of the key decisions and the requirements for decision support from different perspectives. While it was not explicitly distinguished between decision requirements from anaesthetic nurses and anaesthetists, having both perspective was necessary to approach completeness in the key decisions required to successfully solve airway challenges. Likewise, the focus groups discussions with anaesthetic registrars were important to get the perspective of less experienced clinicians on potential decision support design concepts.

In conclusion, this research program identified a successful research plan to examine key decisions and their requirements of anaesthesia teams during challenging airway management situations. Thereby, this research provided an example that will hopefully be adopted in other areas to further improve clinical practice.

### 9.3.3 Contribution to clinical practice: the developed decision support tool

Given the paucity of Human Factors applications to the design of decision support in anaesthesia, this study addressed a practical gap in clinical practice. The practical contribution of this PhD is the designed decision support tool – the airway equipment tray. The concept of standardizing airway equipment emerged from the knowledge elicitation of experienced anaesthesia providers (observations, interviews, follow up surveys) and junior anaesthetists (focus groups). The airway equipment was then co-designed with a small sample of anaesthesia providers. Thereby, this PhD research program was the first one in anaesthesia that filled the existing gap between the study of critical decisions under naturalistic conditions and the design of suitable decision support.

The organised airway equipment tray is a decision support tool that is embedded in the physical environment. While an organised airway equipment tray has not previously been developed to assist with challenging airway management situations during the operative period, the need for equipment standardisation and availability has been discussed in other areas of anaesthesia. For instance, in chapter 2 the development of dump kits in pre-hospital care and difficult airway trolleys was discussed. The need to standardize difficult airway equipment has also been recommended for anaesthetists working in rural areas (Eley, Lloyd, Scott & Greenland, 2008). However, to date, these artefacts lack a Human

Factors approach leading the design process. The airway equipment tray designed as part of this research program is unique because it was developed based on a human-centred design process with the people that will be using the artefact in clinical practice.

#### *9.3.3.1 Support of decision-making and work flow - a HFE perspective*

The key characteristic of the airway equipment tray is the standardized and visible presentation of airway equipment. Thereby, the goal is to support key decisions related to preparation and transitioning between airway techniques. While presenting the airway equipment in a standardized manner, there is still a degree of flexibility on where to put certain equipment and the number of back-ups participants prefer to prepare. The tray also does not dictate a certain approach on how to solve the airway management challenge in order to provide flexibility for the context-sensitivity of airway management (Hung & Murphy, 2010) and room for individual preferences on how to handle challenges Cuvelier, Falzon, Granry, Moll, & Orliaguet, 2012).

The design of the physical environment including accessibility of airway equipment is essential in clinical environments. The physical environment acts as an important mediator for team communication. In other words, the physical environment shapes cognitive and collaborative work (Xiao, 2005). This is the central tenet of distributed cognition (Hutchins, 1995). By offering an organised layout, the airway equipment tray aims to support team situational awareness (Salmon et al., 2008). By having a layout of the airway equipment that is consistent across cases and known by members of the medical team, it is suggested that the tray will assist medical teams in keeping track of the progress of the situation and support familiarity of equipment set up in time-pressured situations (Chrimes et al., 2018). This is especially relevant because the composition of anaesthesia teams constantly changes and therefore, there is variability in how equipment is prepared by care providers with differing experience and preferences.

In contrast, clinicians dislike clinical decision support that is inflexible, dictates a certain clinical approach and distracts from the clinical work (Kilsdonk et al, 2017). Due to the inter-individual variability in healthcare, (cognitive) activities in healthcare need to be flexible to account for this variability. The inter-individual variability is a unique characteristic of healthcare that is not frequently presented in other industries. Consequently, the need for flexibility and context-sensitivity needs to be taken into account in particular when designing cognitive support for healthcare (Lintern & Motavalli, 2018). The designed decision support tool also considers the work flow of airway management: rather than providing a distraction to the clinical work like current cognitive aids and checklists requiring clinicians to step away from their work to engage with the intervention, the airway equipment tray is embedded in the work flow of airway management. It supports the natural workflow by guiding through the natural action sequence of airway management activities.

Compared to other approaches aiming to support decision-making in anaesthesia and healthcare in general, the design of this airway equipment tray is unique. Similar to the design of ecological interfaces, with any healthcare design it is important to not merely design rule-based. A rule-based design may work for certain scenarios, but especially in complex environments such as healthcare it is brittle because the context constantly changes (Flach et al., 2017; Lintern & Motavalli, 2018). There is nothing wrong with a generalised rule of ‘if you reached this point and the current technique is not working, a transition needs to happen’. However, it is impossible to develop a comprehensive rule-set for a complex problem such as airway management challenges. The airway equipment tray has shielded itself from the danger of being rule-based due to its flexibility and non-sequential design. The airway equipment tray aims to offer more visibility in when this point is reached, due to the lay-out of equipment and the separation between used and non-used equipment. However, due to its flexibility, it does not support the decision on which technique to transition to. This is dependent on the practitioners’ experience and personal preferences.

Indeed, organisation of the physical environment is only one aspect of the complex multi-layered system that affects decision-making in anaesthesia. While the aim of the airway equipment tray is to support the recognition of adequate actions for the present situation, it does not support the technical skills and the ‘readiness’ of clinicians to initiate transitions that may be less frequently performed. In this sense, fixation errors as occurring in the case of Elaine Bromiley (Bromiley, 2009) require a multi-faceted systems approach (Watterson et al, 2014). In order to be effective, other system elements such as airway management crises training are necessary to effectively support challenging airway management. Training supports the acquisition of technical skills of rarely performed actions as well as the recognition of unfolding crises (Watterson, 2014).

#### 9.3.3.2 Support of expert versus novice performance

As discussed previously, the use of the designed decision support intervention relies on the expertise of the clinicians using it, and does not act as a replacement for expertise. This has been discussed in the context of emergency cognitive aids in anaesthesia (Marshall, 2017). Clinicians require the knowledge to decide which technique most adequately matches the situation at hand; thus a pattern-matching process that lies at the heart of recognition-primed decision-making. The designed airway equipment tray highlights the options (i.e. available equipment) and thereby aims to support recognition of satisficing actions. However, when it comes to the preparation of airway equipment the tray will likely support junior nurses to prepare required airway equipment if there was insufficient communication beforehand.

## 9.4 Evaluation of the decision-centred design framework

The DCD framework guided the process of this research program and supported the translation of research findings into design concepts. The process of identifying the initial decision requirements to the design of the decision support prototype was a challenging journey requiring iteration and continuous adaptation. For example, a few of the initial design ideas we discussed in the publication in chapter 4 were not followed through. This was mostly due to the development of further insights from the continued data collection. Based on this experience, the triangulation of multiple research methods was extremely beneficial in shaping design ideas.

While the DCD process is sequential in theory, we found that the phases were not as easily defined in practice. Although the general process of the DCD was useful for the guidance of research activities, the five overarching DCD phases are similar to other human-centred design approaches (Militello & Klein, 2013). The proposed uniqueness of DCD is the focus on the critical decisions made by experienced subject-matter-experts in challenging, time pressured situations. The associated CDM aligned well with this focus and was beneficial to identify decision requirements from experienced subject-matter-experts. Although, Lintern (2010) proposed that the focus on experts is a matter of emphasis rather than being specifically tied to the DCD framework. According to Lintern (2010), even the RPD model could be used to map decision-making of less experienced people by accentuating the second level of the model.

I experienced some challenges in aligning the CDM probes, the RPD model and the DRT's. It was difficult to decide on a format of the DRT's; firstly, because they were not tied to a particular theoretical model and, secondly, there is much flexibility regarding the structure and content of the columns. In the literature, the structure of DRT's varies and is adapted to the suit the need of the particular research question. While this flexibility was useful on the one hand, it created some ambiguity when identifying the best methodical way of generating the DRT's. This experience is reflected by Lintern's (2010) claim that the DRT is without underpinning theory and does not '*benefit or suffer from the constraints of a theoretical framework'*. This lack of a universal methodical approach stands in contrast with the DL, which serves as both a model and a representation (Lintern, 2010).

Another challenge with the application of the DCD framework was ambiguity on what constitutes a 'difficult decision'. While Klein (2010) provided a generic definition of a decision, this definition was broad and could have applied to many different actions. While this is primarily a methodological concern and it should naturally emerge from the data what the challenging decisions are, a lack of a universal definition made it challenging to be rigorous in the data analysis.

Despite the above discussed challenges, the DCD framework was a useful framework to identify decision requirements and translate these into design concepts. The general phases makes it broadly applicable across domains, which at the same requires much domain expertise from the leading researcher to concretise its methods for the specific field. In other words, much emphasis should be placed on the domain familiarisation as well as the preparation phase to develop cognitive probes that elicit knowledge relevant to the challenges experienced in the domain.

## 9.5 Limitations of the research program

This research program has some methodological limitations. Several of these limitations related to the specific studies and were already addressed in the individual chapters. This section will focus on limitations related to the broader research program and those not yet discussed as part of the previous chapters. The main limitation is that the methods undertaken, while falling under CSE, still had an individualistic focus. While the DCD framework and associated methods such as the CDM were useful to identify key decisions, their requirements and environmental cues, they did not scale up to a true system approach. In other words, there is a tension between the individualistic RPD model and a holistic sociotechnical system engineering design approach to design.

Schraagen (2017) has previously recognised that NDM approaches are primarily focused on the cognitive level. He suggested adding methods to existing NDM approaches that focus on the 'transaction' level, a system level above the knowledge level that is studied by macro cognitive approaches. The transaction level approach is congruent with the concept of distributed cognition (Hutchins, 1995) and the distributed situation awareness approach (Fioratou et al,  2010; Stanton et al., 2006). The transaction level describes all objects and people (i.e. agents) and their relations within a particular environment as a network. One method to study the transaction level is social network analysis (Wasserman & Faust, 1994). In the medical domain, network analysis has, for example, been applied to study communication patterns of cardiac surgery teams (Schraagen, 2011). For this thesis, social network analysis would have been useful to complement the decision requirements analysis to study the importance of other agents in the clinical environment from a 'true system level' and not merely from the point of view of the interviewees (Schraagen, 2017). This would have (1) de-emphasized the relevance of the clinicians in the system and emphasized the importance of other system agents in the exchange of knowledge and cues and (2) added an element of 'objectivism' to the research, which currently has solely relied on the perspectives of the interviewees. From this 'transaction' level, it would have also been easier to study the resilience of anaesthesia teams on a system level by studying how the whole system gracefully extends during challenges (Woods, 2015).

In terms of a broader systems perspective, in hindsight it would have been beneficial to integrate some methods from CWA. Starting out with a work-domain analysis would have been useful to identify the boundaries that constrain the purpose and overall functioning of anaesthesia (G. Lintern, 2009). This could have identified how other anaesthesia activities, such as pain management and drug administration, affect (i.e. constrain and conflict with) airway management. Finally, descriptive system models such as the artichoke model (Bogner, 2007) or the more detailed Systems Engineering Initiative for Patient Safety (SEIPS) model (Holden et al., 2013) would have been frameworks to examine broader system factors affecting the decision-making processes in challenging airway management (i.e. on the organisational or governmental level). Still, these models are mainly descriptive and broad; and would have not necessarily been beneficial to identify specific decision support design solutions.

Nevertheless, while the DCD approach undertaken in this research program focused on individualistic decisions, we were still able study how the wider system affected these decisions; albeit from the perspective of clinicians. While this may have not scaled-up to analysing airway management challenges from a true systems level, it provided sufficient information to identify system design solutions. However, in hindsight I do realise that at points these systems design solutions may have not flown entirely naturally from the theories underlying the CTA methods undertaken.

Another limitation of the undertaken DCD framework was that the main focus on key decisions. Other macro-cognitive functions and supporting processes were not equally considered (Klein et al., 2003). While macro cognitive functions such as situation assessment and planning in relation to decision-making were discussed, the DRT's and identified decision support design interventions were specifically related to the key decisions. While this was the original goal of decision-centred design, the focus of the NDM paradigm expanded to the study and support of other macro-cognitive functions and processes such as sense-making, coordination and uncertainty management (G. Klein & Wright, 2016). To reflect this inclusion of other macro-cognitive activities, decision requirements tables have been more broadly described as cognitive requirements tables (Militello et al., 2016). In conclusion, by concentrating on identifying key decision in our data, this research may have potentially missed some important insights about other macro-cognitive functions.

While this is not explicitly a limitation of the research program or DCD framework, I would approach the decision selection process as done in this thesis differently in the future. Due to the explorative nature of this research, our initial focus on key decisions was broad and thus needed to be refined at a later stage. For future research applying the DCD framework I would recommend a narrower focus on a small number of difficult decisions or other macro-cognitive functions emerging from the data, rather than identifying all critical decision points to begin with. This would have refined the research in its earlier stages.

Finally, so far this research does not contain an evaluation component including quantitative outcome measures. The evaluation of the newly designed tool is an essential aspect of the DCD process. Especially in healthcare, the evaluation of newly designed prototypes is essential before its integration into clinical practice (U.S. Department of Health and Human Services, 2016; Zborowsky & Bunker-Hellmich, 2010). The evaluation element of this research program is not conducted as part of this PhD research due to time constraints. However, it will be part of post-doctoral research and an evaluation framework is discussed in detail in the next section. As previously discussed in chapter 2, the scope and main goal of this PhD thesis was the knowledge elicitation and study of decision-making processes of anaesthesia teams for the purpose of identifying a decision support tool. Emphasis was placed on the early stages of the DCD process because a research driven Human Factors approach as performed in this study has not yet been applied to decision support design in anaesthesia. Also, the design process up to this point has not been iterative and feedback on the first version of the prototype has not yet been obtained from subject-matter experts. In the next section, future research to finalise the prototype as well as an evaluation framework including outcome measures will be outlined.

## 9.6 Future research

In terms of fulfilling the DCD process of this research program, another design iteration will be performed as part of post-doctoral research to refine the prototype before it will then be evaluated in both simulation and clinical practice. The current version of the airway equipment tray prototype will be shown to subject-matter-experts in order to obtain their feedback on the initial design.

Subject-matter-experts with varying experiences and clinical backgrounds were interviewed as part of the scenario-based co-design process discussed in chapter 8. Participants were in strong agreement regarding the design requirements of the airway equipment tray. However, the present study took place under laboratory conditions and, therefore, could not account for the complexity and variability of clinical environments in the real world. It is expected that the design of the equipment tray will be further modified once it has been evaluated in a realistic simulation or clinical setting.  After final improvements have been made, the final DCD phase will then concern the usability evaluation of the airway equipment tray (discussed in section 9.6.1 below).

From a broader system perspective, future research also needs to address the implementation process of the new artefact within the healthcare system (Edmondson, Bohmer, & Pisano, 2001). This concerns the deployment of the airway equipment tray within the anaesthetic environment. For instance, this concerns training needs, potential changes to clinical procedures using the airway tray or change in management. A detailed discussion of the deployment of the airway equipment tray from a broader system perspective is beyond the scope of this thesis.

### 9.6.1 Evaluation framework

The evaluation of the airway equipment tray will be accomplished by applying usability evaluation methods. Usability Engineering describes a variety of methods to assess the usability of an interactive system with experts and end users. Especially in safety critical environments such as healthcare, usability evaluation is critical before systems are integrated into clinical practice (Jaspers, 2009). The FDA acknowledges Usability Engineering as an important aspect of medical device development and recommends its integration to manufacturers (U.S. Department of Health and Human Services, 2016).

Methods from Usability Engineering are the underlying foundation of Human Centred-Design, although the DCD framework does not specify particular methods of evaluation. DCD broadly acknowledges the need to ‘test whether the system supports [the] user' (Crandall et al., 2006), and more specifically if the system supports 'cognitive performance indicators' such as situation assessment, cue prominence and flexibility (Militello & Klein, 2013). To align with the goal of DCD to support decision-making in challenging situations, evaluations are typically scenario-based, context-specific and involve cognitive challenges identified in previous phases (Militello & Klein, 2013).

#### *9.6.1.1* Usability evaluation study: Follow-on work

The proposed evaluation study for the airway equipment tray developed in this research program is a scenario-based simulated use evaluation. In order to identify if performance with the airway equipment tray differs to what is currently used, participants will complete a scenario with both the new airway cart design and a currently used airway cart design (within-subjects design). A comparison with an existing healthcare system is a common approach to identify superiority of the newly designed intervention (Lin et al., 1998; Schnittker, Schmettow, Verhoeven & Schraagen., 2016). Two different airway emergency scenarios will be created that will require the participants to perform the key activities related to the key decisions aimed to be supported by the design intervention: preparation, grasping and passing airway equipment to assist transitioning between techniques and suggesting/prompting certain airway equipment when the current technique does not work. Participants will be randomly allocated to (1) order of using new airway cart or currently used airway cart and (2) the scenario they will complete with each of the two carts.

Participants will evaluate the airway equipment cart by completing two airway management activities with both airway carts (preparation and retrieval of airway equipment). In order to prevent carryover effects, four patient scenarios will be created. Two of them will require the set-up and preparation of the airway cart for a routine adult surgery, and two will involve a difficult airway management scenario where transitions between airway techniques are required to manage the airway successfully. The scenarios covering similar activities will be unique with differing clinical contexts, but will require a similar set up and retrieval of equipment to make a comparison possible. Outcome measures will be related to the selected key decisions and concern:

- Time and completeness of airway equipment preparation
- Time and completeness of offering and retrieving airway equipment
- Effectiveness and time of identifying missing airway equipment
- General perceived usability using the SUS (Bangor, Kortum, & Miller, 2008; Brooke, 1996)
- Evaluation questionnaire and interview to obtain feedback on potential areas of improvement

While evaluation is the last phase in the DCD framework, it is part of the iterative design cycle and therefore tightly related to the previous prototyping phase (Militello & Klein, 2013). Possibly, a few usability problems will be detected through the evaluation process. These problems will be modified in the airway tray prototype before it will be go through another round of usability evaluation. Following the evaluation of the prototype and modifications made based on that first evaluation, another evaluation study should following testing the improved airway equipment tray under more realistic conditions. The evaluation should occur in more realistic, simulated airway management emergencies. Practically, it could be evaluated in the ANZCA EMAC courses, which involve challenging airway emergency scenarios in advanced patient simulation. Ethics approval for the evaluation study has been obtained for one tertiary urban hospital in Melbourne. The production of the airway equipment tray for this evaluation study is currently in progress.

### 9.6.2 Integration of decision support intervention into clinical practice

If both evaluation studies identified enhanced performance with airway equipment tray, the next logical step is the evaluation in the clinical setting. According to the FDA (2016), validating a tool in the clinical practice will result in different performance outcomes because the sample size will be larger and use will be more flexible than under simulated use testing. Optimally, the use of the airway tray should be validated using a combination of observations such as shadowing (Quinlan, 2008) and self-reports. Other studies have used self-reports only (Zhang et al., 2017). Following a training sessions, clinicians in this study had the choice of using the newly designed intervention or an existing intervention. At the end of their shift, they were asked to fill in usability evaluation questionnaires such as the SUS. While this approach would rely on self-reports and would not involve performance measurement, it is low-cost, flexible to clinicians and efficient to administer. If the evaluation of the airway equipment tray in the clinical setting was successful and its deployment from a broader system perspective has been investigated, the decision support tool can be integrated into the clinical practice.

## 9.7 Closing remarks

The healthcare industry still has a long way to go with respect to using the study of naturalistic decision-making to inform the design of complex sociotechnical healthcare environments (Catchpole & Alfred, 2018). The present research program addressed this gap by employing a Human Factors Engineering approach to inform the design of a system element to support anaesthesia providers during challenging airway management situations. The insights gained from this research highlighted that undertaking an NDM-style approach is necessary to understand how clinicians make decisions in complex, time-pressured situations and identify suitable decision support design solutions. The consideration of ‘work-as-done’ decision-making processes and requirements of clinicians interacting with the design intervention as performed in the present research will hopefully contribute to a shift in how healthcare design of complex sociotechnical environments is practiced in the future.

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# 11 Appendices

## 11.1 Appendix 1

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Editorial

Editorial

# Safe anaesthetic care: further improvements require a focus on resilience

Anaesthesia has been described as a 'model for patient safety'.[1] In recent years, the significant risks that accompany administration of anaesthesia have been mitigated by developments in practices and technologies, commonly seen as a benchmark for other areas of health. Studies of anaesthesia-related mortality show that the mortality rate related to anaesthesia is approximately one in 58 000, and even lower in healthy patients.[2] It has become increasingly difficult to investigate specific hazards of anaesthesia because of the rarity of these events, requiring large nationwide research efforts. One such audit was the Fourth National Audit Project (NAP4) of the Royal College of Anaesthetists and the Difficult Airway Society. The NAP4 project found that patient harm from airway management during anaesthesia occurs rarely, with 46 reported events of major airway management complications during anaesthesia per million general anaesthetics, and a mortality rate of 5.6 per million general anaesthetics (1:180 000).[3] Even if the numbers of instances were underreported by a factor of four as suggested, the numbers of adverse events are still very low. Despite the safety of anaesthesia, however, the NAP4 report claims there is still 'room for improvement'.

Anaesthesia shares two key characteristics of other high-reliability organizations; a preoccupation with safety and a goal of 'zero harm'. The challenge for anaesthetists in this current era of safety is to find the next step that will reduce harm even further at a time when the number of adverse events to learn from is shrinking. Rather than concentrating on the reduction of harm (i.e. focusing on things that 'went wrong'), another way of approaching safety is to determine why things went well. This approach of strengthening safe practices is termed 'resilience'. Resilience describes the property of being flexible, robust, and elastic.[4] In high-reliability organizations, this translates to an ability to 'respond to sudden, unanticipated demands for performance and then return to normal operating condition quickly and with a minimum decrement in performance'.[5] We believe that human factors research focusing on resilient behaviours of practitioners is required to improve the high-standard quality of anaesthetic care further.

The interdisciplinary domain of human factors refers to the study of interrelations between humans, technology, and their environment, and has been successfully applied to improve standards of health care.[6] Within traditional human factors research, safety is associated with the absence or reduction of errors that may induce patient harm. Reason's Swiss cheese model[7] is one that is well established within this view of safety and frequently used in order to describe risk prevention. The model explains accidents by lined up holes (i.e. 'safety gaps') in the multiple defensive layers of a system. These occur from the combination of latent conditions ('resident pathogens' within the system) and active failures ('unsafe acts' by practitioners). Within this model, investigative tools such as 'root cause analyses' aim to identify these holes and thereby support the development of safety measures that fill them or mitigate their effects. Some causal factors of failures by clinicians at the 'sharp end' are frequently identified that are assumed to have caused patient harm; personal performance-modifying factors, such as time pressure and tiredness, or cognitive factors, such as inadequate situational awareness and flawed decision making, are commonly cited.[8 9] The solution to these cognitive and personal performance problems is often limited to further education to prevent similar situations occurring in the future.[10] The effectiveness of education to improve non-technical skills has been tested using behavioural rating scales, such as the Anaesthetists' Non-Technical Skills scoring system (ANTS).[11 12] There is still much to learn about error prevention, and traditional human factors research has greatly contributed to the high safety standards that have been reached within the anaesthetic domain.[1] The limitation of this approach, however, is that quality and safety improvement has mainly become a retrospective activity, focusing on what went wrong. This approach is known to be susceptible to hindsight and outcome biases and insensitive to the potential side-effects caused by preventing the initial error.[13]

A more recent alternative is to view safety as a 'dynamic non-event'; dynamic because it is 'preserved by timely [adjustments of the anaesthetic practitioner], and non-event because successful outcomes rarely call attention to themselves'.[7] Hence, the anaesthetist is the central source of keeping safety within acceptable boundaries. Few human factors studies in anaesthesia have used such a 'resilience-based' approach. Cuvelier and Falzon[14] investigated how anaesthetists anticipate situations that may disturb routine working conditions. They found that anaesthetists consider potential scenarios before selecting suitable techniques for each of these scenarios. Preferences in techniques varied widely among anaesthetists; for instance, in a simulated paediatric situation involving syndactyly in a 2-yr-old infant, six anaesthetic practitioners would strictly exclude intubation by laryngoscopy as an option, whereas 12 would include it. Here, anaesthetists base their decisions on reflection of their own and team resources and adaption of these collaborative resources to the specific situation. This shows that 'safe' performance cannot be achieved solely by regulation and standardization but is based on resilience-building self-assessments on an individual level. Anaesthetic teams also show resilient behaviours when coping with unforeseen events.[15] Anaesthetic teams differed in strategies to 'recover' and 'control' a situation involving a moved tracheal tube that disrupted oxygen supply. Some teams initially communicated in order to gain a shared understanding and identify the problem, and consequently, oxygenated and re-intubated. Other teams were more 'cautious',[15] and firstly recovered the situation by manual oxygenation before communicating on how to proceed. Opposed to the former, these teams also called other staff for help. Cuvelier and Falzon's study demonstrates that: (i) the anaesthetic practitioners′ resilience is fundamental in maintaining the patient's safety; and (ii) anaesthetic teams differ in the strategies they use to create resilience. Both teams succeeded in keeping the safety of the patient within acceptable boundaries, although their approaches to safety differed. In contrast, the traditional human factors approach would rather focus on whether behavioural and cognitive deficiencies had contributed to potential patient harm, such as failing to call for help or to communicate effectively before taking action.[14] With the traditional view, safety is a binary construct depending on identifying performance that is 'inadequate' and 'erroneous' compared with rules and established guidelines, whereas the assessment of safety from a resilience view depends on the conditions of the situation and the involved trade-offs in decision making.[15]

Examining how anaesthetic practitioners create safety therefore offers a valuable contributory pathway for future research to complement the traditional 'error counting' approach. In terms of the Swiss cheese model, the resilient anaesthetic practitioners at the 'sharp end' of operations keep a large number of holes undetected. Only a few holes reach attention eventually, by means of incidents that are reported. By focusing on how anaesthetic practitioners bridge the majority of gaps, more feasible information can be obtained about what makes their daily performance successful. As suggested by Moloney,[16] the day-to-day responsibilities of anaesthetic practitioners in patient care may be better represented by a 'Parmesan Cheese Model'; during their daily work, anaesthetists frequently encounter adverse events that may take 'shavings' from the quantum of safety. These shavings are important regardless of how thin they may be, because they erode the safety margins that we work within. In Moloney's model, the anaesthetist is fundamental in keeping emerging disruptions (i.e. 'shavings') within an acceptable safety boundary. Resilient strategies help to identify where and when they occur and attempt to mitigate their effects. A focus on resilience ensures that safety is not overestimated, which is a risk when the emphasis is primarily placed on occasional, noticeable incidents.

The predominant view of safety as a 'dynamic non-event' actively maintained by the anaesthetic practitioner naturally presumes that safety requires resilience. Resilient behaviours are ubiquitous in the anaesthetic domain, although resilience-based research is not yet widespread. The human factors domain offers suitable research methods for uncovering practitioners' resilient work by observing how anaesthetic practitioners do their daily work and how they successfully manage potentially harmful situations.[4] Future safety research in anaesthesia should identify behaviours that safe, resilient practitioners use so that they can be distributed and embedded into clinical practice guidelines. By systematically building in resilience, we can ensure that new safe practices become widespread.

## Declaration of interest

None declared.

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*R. Schnittker[1*] and S.D. Marshall[2,3]*
*[1]Monash Injury Research Institute, Monash University, Building 70, 21 Alliance Lane, Clayton Campus, Clayton, VIC 3800, Australia*
*[2]Department of Anaesthesia and Perioperative Medicine, Monash University, Melbourne, VIC 3800, Australia*
*[3]Monash Simulation Centre, Monash Health, 823-865 Centre Road, East Bentleigh, Melbourne, VIC 3165, Australia*
*[*]Corresponding author. E-mail: raphaela.schnittker@monash.edu*

## 11.2 Appendix 2

### Decision requirements tables of CDM interviews

Below the decision requirements tables for each interview are listed. For brevity, only key decisions that were selected to be included in chapter 5 are shown (this explains the numbering on the left, e.g. in interview 2, only the fifth decision has been included).

**Interview 1 - Anaesthetist**

| No | Decisions | Challenges | Critical cues | Critical expertise | Design/support ideas (embodied in environment) | DT | Nature of challenge | OP |
|---|---|---|---|---|---|---|---|---|
| 2 | Transition from failed awake fiberoptic intubation to face mask ventilation | The patient unexpectedly stopped breathing while doing an awake fiberoptic intubation and needed to be oxygenated quickly | Pulse oximeter (can't remember exactly) | Knowing that you have to go back to face mask if patient stops breathing<br><br>Knowing what to do if that fails; being aware that it could fail<br><br>Noticing the signs of stopped breathing | - Pulse oximeter worked well in supporting the transition to face mask<br>- Have back up equipment directly available/accessible and delivered by support staff | Prototype | Unexpected but well known | Intra |
| 3 | Transition from failed face mask to laryngoscopy | Patient could not be ventilated with a face mask and needs a definite airway for ICU | Patient is still blue,<br>No movement in the chest | Knowing that intubation usually solves the problem as a definite airway<br><br>Not fixating on trying to face mask ventilate if it's impossible | - Planning tools used for training and simply designed to be used in the emergency that indicate transitions as reminders (visible to the whole team)<br><br>- Have different airways readily and visibly available so they can be grabbed easily/it is not forgotten they are available | Prototype | Unexpected but well-known | Intra |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **4** | Transition from failed laryngoscopy to surgical airway | The patient needs to be oxygenated and laryngoscopy and face mask failed previously. There is time pressure. The anaesthetist is not experienced | Patient is still blue, no movement in the chest<br><br>The surgeon is available who is skilled in doing surgical airways | Knowing that a surgical airway is the last resort to solve an upper airway problem definitely and stable for ICU<br><br>Knowing that, alternatively, a laryngeal mask could have been tried first to buy time<br><br>Knowing about the skills of available staff/know your own limitations | - Easily accessible surgical airway pack<br>- More training to improve technical skills of doing a surgical airway<br>- Support decision to do surgical airway under time pressure if person cannot be woken up and all other supraglottic airways failed → training with planning tools<br>- Ideally, an ENT surgeon should be on call to help out with emergency surgical airways | Prototype | Unexpected and rarely done (but well known from theory) | Intra |
| **5** | Additional attempt laryngoscopy after failure of surgical airway | Surgical airway went wrong (surgeon cut herself) and the airway was still not secured. Time pressure. Laryngoscopy was previously tried by the registrars and failed | The surgeon cut herself and cannot perform a surgical airway; patient is still de-saturated | Knowing not to persist on a strategy if it failed before and move on<br><br>Knowing that, alternatively, a laryngeal mask could have been tried first to buy time | - Easily access equipment and have equipment readily available<br>- Trigger by the team to use other equipment in response to non-improving oxygen saturations | Prototype | Unexpected but well-known | Intra |

## Interview 2 - Anaesthetist

| No | Decisions | Challenges | Critical cues | Critical expertise | Design/support ideas | DT | Nature of challenge | OP |
|---|---|---|---|---|---|---|---|---|
| **5** | Use adjunct or manoeuvre to facilitate face mask ventilation (secondary decision) | Similar | Similar | Knowing that the current technique does not work and it has to be moved on to another technique | Have adjuncts visibly available in the environment to the anaesthesia team to trigger their use<br><br>Encourage anaesthetic nurse to offer pieces of equipment to the anaesthetist | Prototype | Unexpected but well-known | Intra |

## Interview 3 - Anaesthetist

| No | Decisions | Challenges | Critical cues | Critical expertise | Design/support ideas | DT | Nature of challenge | OP |
|---|---|---|---|---|---|---|---|---|
| **3** | Use adjunct or manoeuvre to facilitate face mask ventilation (secondary decision, part of direct laryngoscopy) | Guy was difficult to bag and mask because of weight and airway anatomy | No pressure in the bag and circuit, chest did not move up and down as expected, | Know alternative strategies to use when bag mask does not work<br><br>Know not to persist on strategies that don't work but move on and do something different | Have adjuncts visibly available in the environment to trigger their use<br><br>Team triggers use of adjuncts; have adjuncts readily available and offer them (e.g. through re-designing the anaesthetic trolley) | Prototype | Unexpected but well-known | Intra |
| **4** | Transition from failed direct laryngoscopy to asleep fiberoptic intubation | Patient was impossible to intubate with a direct laryngoscopy but urgently needed surgery | Impossible to insert laryngoscopy because head did not move and teeth disarranged, bottom jaw did not open much | Knowing these cues indicate an impossible laryngoscopy<br><br>Don't persist on trying laryngoscopy if it is impossible, but move on to other strategies | -<br><br>Planning tools used for training and simply designed to be used to indicate | Prototype | Unexpected but well-known | Intra |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Oxygen saturation was fine with the bag mask and guerdal | Make sure oxygen saturation is adequate before doing an asleep technique | transitions as reminders<br><br>Reminder of achieving 'Green zone' of oxygenation | | | |

**Interview 4 - Anaesthetist**

| No | Decisions | Challenges | Critical cues | Critical expertise | Design/support ideas | DT | Nature of challenge | OP |
|---|---|---|---|---|---|---|---|---|
| **4** | Additional attempt at laryngoscopy as the primary airway technique (use bougie to facilitate tracheal intubation) | Patient was difficult to intubate | Participant was observing colleague struggling getting the tube in | Knowing to not persist on the same strategy but use an alternative strategy to optimize intubation attempt<br><br>Being aware of adequate oxygenation of the patient while having a repeated attempt | Provide additional equipment visibly to the anaesthesia team to promote not forget using it; get it offered by the team<br><br>Planning tools used for training and simply designed to be used that indicate transitions as reminders | Prototype | Unexpected but well-known | Intra |
| **5** | Transition from failed laryngoscope to face mask | Additional attempt at laryngoscopy went wrong and it was decided to go back to a safe point where no harm could occur to the patient | Observing colleague having struggle inserting the tube | If something fails, go back to a point of safety and do not persist with trying to intubate<br><br>Per default, go back to face mask or to a point where things are fine and then make another | Provide face-mask visibly and accessible near the anaesthesia team<br><br>Prompting by anaesthetic nurse to go back to face mask after a certain amount of attempts/time has passed → define trigger point (pulse oximeter?) | Prototype | Unexpected but well-known | Intra |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | decision. Bag mask ventilation = green zone and always go back there. | Planning tools used for training and simply designed to be used that indicate transitions as reminders | | | |

**Interview 5 – Anaesthetic nurse**

| No | Decisions | Challenges | Critical cues | Critical expertise | Design/support ideas | DT | Nature of challenge | OP |
|---|---|---|---|---|---|---|---|---|
| **3** | Planning/Preparation – Having equipment readily available* | A potential difficult patient needs to be intubated | Anaesthetist communicates to the nurse that the patient might be difficult, which triggers preparation | Knowing what could possibly go wrong in the process and have equipment ready to be used for plan A,B,C | Support planning procedure by a standardized equipment trolley that acts as a cognitive aid for the inclusion and visibility of equipment | Prototype | Planning | Pre |

*Note: Planning was an essential activity for anaesthetic nurses and was therefore included in the DRT's

**Interview 6 - Anaesthetist**

| No | Decisions | Challenges | Critical cues | Critical expertise | Design/support ideas | DT | Nature of challenge | OP |
|---|---|---|---|---|---|---|---|---|
| **3** | Transition from failed gas induction to asleep tracheostomy | The gas induction of the patient failed because they lost the patients' airway as soon as they were trying to lay here down<br><br>Patient was very sick and the medical condition would not have permitted a | The bag was moving less and less, which means her entidal volumes were dropping. | Knowing how to identify dropping volumes (go a bit blue, hear pulse oximeter tone, numbers start to drop, bag stops moving)<br><br>Knowing to transit between techniques when entidal volumes drop | Have an ENT surgeon easily accessible to help with the emergency<br><br>Have the surgical kit readily available and easy to use. | Deliberate<br><br>(quick deliberation if sitting up or laying down) | Expected | Intra |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | laryngoscopy or waking up the patient | | Knowing that if it would have been an elective case the patient could have been woken up instead of doing a tracheostomy<br><br>Knowing the skills of how to perform a tracheostomy/make a plan for this type of medical condition<br><br>Good communication with the ENT surgeon and nursing staff | More practical training to perform tracheostomies. | | | |

## 11.3 Appendix 3

**Supplementary materials – Manuscript draft submitted to Journal of Cognitive Engineering and Decision Making (chapter 7)**

# Supplementary materials

*Edited Narrative 3 (anesthesiologist)*

While working his own case, **A** heard the emergency buzzer from the adjacent operating theatre. After ensuring conditions were stable, he handed his own **P** to his **AN** and requested that surgery would not proceed until he returned so that he could respond. On entering the adjacent theatre, he saw that **P** had low oxygen saturations and was not exhaling carbon dioxide. **A2** was attempting ventilation with a bag mask, but that was not working. There was considerable time pressure. **A** assisted **A2** with the face mask ventilation. One inserted a nasopharyngeal airway and held the mask with two hands while the other squeezed the bag to optimize the mask seal and hence ventilation. The capnography showed rising carbon dioxide levels. **P** showed chest movement and the oxygen levels rose.

The situation could be controlled, which relieved the time pressure. **A** noticed blood around **P**'s airway, which indicated damage to the airway before he arrived. **A** discussed the situation with **A2** for a couple of minutes, finding that **A2** had attempted video laryngoscopy first but failed, and then transitioned to a normal laryngoscopy and failed with that as well. These two attempts had caused some airway trauma, which made the subsequent face mask ventilation harder because the airway became bloody.

Because he was a second responder, **A** asked **A2** what options there were to handle the **P**'s airway. They spent the next couple of minutes negotiating the plan. **A** recommended that the option of waking the **P** should not be forgotten. They discussed if this was a viable option and what else they could do. **A** proposed that they could either wake **P** and abort surgery or secure the airway by a different mechanism. **A2** preferred a different airway approach. **A** agreed, but because he did not want more repeated attempts at airway management, they agreed on one more attempt before resorting to waking **P**.

Because **P** already had some airway trauma and the laryngoscope is a quite sharp device, they agreed to attempt intubation with a fiberoptic scope, which is a softer device. They further decided to use a laryngeal mask as a stop-gap measure to be hands free as they prepared for the fiberoptic intubation. The plan was then to put the fiberoptic scope through the laryngeal mask to intubate the **P**. After placing the laryngeal mask, they called for the difficult airway trolley, explained everything to **AN** and requested a second **AN** to assist. **A** and **A2** ensured that all in the room understood the plan. One **AN** was to track the time and call a halt if they spend more than ten minutes trying to manage the airway. They inserted the fiberoptic scope (camera) to check that the airway was not too damaged. They decided to proceed because the airway did not look too swollen. They inserted the tube with the assistance of the fiberoptic scope and then removed the laryngeal mask and finished the intubation. They called the Intensive Care Unit to request that they can leave this tube in after the **P** was transferred to them, to avoid risk of damage to the airway. Because of that, **P** would be left asleep for 24 hours with the tube until the airway settled down.

*Table 1*. Decision Requirements Table, narrative 3, anesthesiologist

| | *Incident* | *Critical Information* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **A** & **A2** agree to attempt intubation with a fiber-optic scope and that if this attempt at fibreoptic intubation fails, they will wake **P** and abort the surgery | Time pressure; oxygen saturations, exhaled carbon dioxide, chest movement, pulse oximetry; blood around **P**'s airway; **A** aware of previous failed attempts at intubation; surgery was not an emergency so aborting it would have been acceptable | **Recognize Typicality; P** already has airway trauma from previous intubation attempts **Plausible Goals;** balance need for surgery versus risk of further damage to **P**'s airway | **Training;** difficult case experience & training, & discussions of difficult cases such as in morbidity & mortality meetings |

*Table 2*. Decision Ladder Table, narrative 3, anesthesiologist

| | *Description* | *Process* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **A** hears emergency buzzer | Observe | | |
| 2 | Ensures own **P** is okay and can be handled without him for a while; moves to other theatre | Develop Plan<br>Evaluate Plan<br>Execute | | |
| 3 | **A** checks capnography & pulse oximeter & observes **A2** trying to ventilate with face mask | Observe | | |
| 4 | **A2** ventilating unsuccessfully & there is time pressure | Interpret | | |
| 5 | **A** advises **A2** he is not ventilating | Execute | | |
| 6 | Assists anaesthetist with face mask ventilation with two hands & a nasopharyngeal airway | Execute | | |
| 7 | Capnograph & pulse oximeter coming up, chest moving | Observe | | |
| 8 | Face mask ventilation successful, situation can be controlled, there is less time pressure | Interpret | | |
| 9 | Gathers information from **A2**, notices blood around airway | Observe | | |
| 10 | **A** realises airway was damaged before he arrived | Interpret | | |
| 11 | **A** & **A2** discuss options; try once more to secure **P**'s airway with softer procedure, or else wake **P** | Identify & Compare Options | Aware of acceptable outcomes | **Technology**: Decision support for comparing options & for assessing trade-offs associated with pursuing different goals |
| 12 | **A2** prefers to try again; **A** agrees but does not want repeated attempts | Select Preferred Outcome | | |
| 13 | If next attempt fails, they will wake **P** | Evaluate Plan | | |
| 14 | Attempt fibreoptic intubation with laryngeal mask | Develop Plan | | |
| 15 | Fibreoptic intubation is a softer approach; should be more effective & not too harsh on already damaged airway, laryngeal mask as stop gap measure while preparing equipment | Evaluate Plan | | |
| 16 | Insert laryngeal mask, order difficult airway trolley, explain everything to **AN**, request second **AN**, announce plan to the whole team, ask **AN** to track time to avoid fixation | Develop Plan | | |
| 17 | Airway should not be too swollen to continue with intubation, check | Evaluate Plan | | |

| | | |
|---|---|---|
| | airway with fibreoptic scope before proceeding with intubation | |
| 18 | Insert fibreoptic scope | Execute |
| 19 | Airway does not look too swollen, it should be okay to continue with fibreoptic intubation | Interpret |
| 20 | Proceed with fibreoptic intubation & removal of laryngeal mask | Execute |
| 21 | Because of damage to P's airway from earlier intubation attempts, removal of tube may cause further damage | Anticipate |
| 22 | Call ICU to ask for **P** to be kept asleep with tube in until airway has settled (24hrs) | Develop<br>Plan<br>Execute |

*Edited Narrative 4 (anesthesiologist)*

While walking through the recovery unit, **A** heard stridor coming from one of the beds, a **P** in her late 70s struggling to breathe. The oxygen saturation monitor had fallen off, but she looked hypoxic and she had tachycardia as shown by the monitors. **A** immediately took **P** into theatre where theatre staff came to help. **A** contacted an Ear-Nose-Throat surgeon for help, but while waiting attempted to ventilate the **P** with a bag mask. This was partially successful. He could still hear the stridor, which indicates that some air is going in and out of **P**'s lungs. Because **P** was combative, **A** used some anaesthetic gases additional to the oxygen to keep her both calm and asleep. The situation improved at first, but deteriorated after a little, as shown by the bag moving less and less. Although **A** applied some positive pressure, the breathing functions of the **P** could not be supported anymore. The oxygen saturation levels dropped further. **A** used a laryngoscope to see if he could insert a breathing tube into the **P**'s airway. However, he could not see any landmarks of the pharynx to help guide the tube in the correct position.

He declared a 'can't intubate, can't ventilate' situation. He attempted a laryngeal mask airway as a rescue, and thought it fitted well. However, when he connected the laryngeal mask to the bag, he could not squeeze the bag, which indicated that he could not get any oxygen into the **P**. He attempted another laryngeal mask airway with a different sized mask. Simultaneously, he told the nurses to ready then surgical airway kit. While he was waiting for that, he looked again with the laryngoscope. **A** was very stressed and the time pressure was extreme. **A** performed a surgical airway with a needle puncture as a temporary solution until the Ear-Nose-Throat surgeon arrived to perform a tracheostomy. The surgical airway was partially successful because the oxygen saturations did not drop further, although neither did they improve significantly. **A** has never done a surgical airway with a needle before. At this point, the Ear-Nose-Throat surgeon arrived. The Ear-Nose-Throat surgeon then performed a successful tracheostomy.

*Table 3.* Decision Requirements Table, narrative 4, anesthesiologist

| | *Incident* | *Critical Information* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **A** discovers **P** in distress. | **A** hears stridor from **P** behind curtain; **P** showing low oxygen saturations, tachycardia, blue skin colour | **Recognize Typicality; P's** condition is critical; **P** needs immediate intervention to support breathing. | **Technology, Procedures**; improved systems for monitoring **P**s in recovery |
| 2 | **A** worked through a series of different methods to ventilate **P** finally succeeding partially with a surgical airway. | **A** was unable to establish in advance that some of the methods he attempted would not work for this patient | **Recognize Typicality, Mental Simulation;** being able to judge what methods are likely to work with this type of patient | **Technology**; systems that can enhance situational assessment as it applies to evaluating patients for ventilation methods **Training**; difficult case experience & training (observation of experienced **A**'s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, simulations of difficult cases) with emphasis on assessing situational suitability of intubation method and on mentally simulating different intubation methods for different **P** conditions |
| 3 | Open surgical airway (while waiting for Ear-Nose-Throat surgeon) | **A** has never done a surgical airway with a needle before. | **Typical Action;** perform surgical airway with needle | **Training;** simulation training on technical skills to perform a surgical airway |

*Table 4.* Decision Ladder Table, Narrative 4, Anesthesiologist

| | *Description* | *Process* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **A** hears stridor behind curtain | Observe | **A** hears stridor from **P** behind curtain; **P** needs immediate intervention to support breathing. | **Technology, Procedures**; improved systems for monitoring **P**s in recovery |
| 2 | **A** checks behind curtain | Execute | | |
| 3 | **P**, just out of surgery, blue skin colour, struggling to breathe, high heart rate | Observe | | |
| 4 | **P** looks hypoxic, has tachycardia | Interpret | | |
| 5 | **A** transfers **P** to operating theatre, contacts ENT surgeon | Execute | | |
| 6 | **A** ventilates **P** with face mask | Execute | **A** unable to establish in advance which method would work with this **P** | **Technology**; systems that can enhance situational assessment as it applies to evaluating patients for ventilation methods<br>**Training**; difficult case experience & training (observation of experienced **A**'s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, simulations of difficult cases) with emphasis on assessing situational suitability of intubation method |
| 7 | Face mask ventilation partially successful | Interpret | | |
| 8 | **P** combative | Observe | | |
| 9 | Use anaesthetic gases to keep **P** calm & asleep | Develop<br>Plan<br>Execute | | |
| 10 | Bag is moving less & less in **A**'s hand | Observe | | |
| 11 | **A** applies positive pressure | Execute | | |
| 12 | Bag movement does not improve | Observe | | |
| 13 | Can no longer support **P**'s breathing this way | Interpret | | |
| 14 | **P**'s oxygen levels continue to fall | Observe | | |
| 15 | **A** attempts to insert a breathing tube into **P**'s airway with the aid of a laryngoscope | Develop<br>Plan<br>Execute | | |
| 16 | **A** cannot identify landmarks of the pharynx to guide insertion of the tube | Observe | | |
| 17 | **A** declares 'can't intubate, can't oxygenate', attempts to fit laryngeal mask | Execute | | |
| 18 | Bag hard, no movement when connected | Observe | | |
| 19 | No oxygen being delivered to P | Interpret | | |
| 20 | **A** tries different sized laryngeal mask, tells nurses to prepare surgical airway kit | Develop<br>Plan<br>Execute | | |
| 21 | Similar signs as above, bag remains hard | Observe | | |
| 22 | Situation does not improve, **P** still not getting oxygen | Interpret | | |
| 23 | **A** looks again with laryngoscope while waiting for the ENT surgeon | Execute | | |
| 24 | Extreme time pressure, surgeon has not arrived yet | Interpret | | |

| | | | | |
|---|---|---|---|---|
| 25 | Performs surgical airway with needle kit as a temporary solution until surgeon arrives | Develop<br>Plan<br>Execute | **A** not confident with procedure | **Training;** simulation training on technical skills to perform surgical airway |
| 26 | Oxygen saturations stabilized but not yet improving | Observe | | |
| 27 | Surgical airway was partially successful | Interpret | | |
| 28 | ENT surgeon arrives & executes tracheostomy immediately | Execute | | |

*Edited Narrative 5 (anesthesiologist)*

**A** was called to the Emergency Department to see a **P**. He noticed the severity of the situation. **P** had low oxygen saturations that indicated the urgency of treating **P**'s airway. **A** assumed that a surgical airway would be required so he transferred **P** to an operating theatre because it offers more optimal conditions to treat a patient airway due to availability of advanced technology and more experienced staff. He called **A2** for help and called the operating theatre to make sure they were prepared for this difficult case, with extra equipment ready. **P**'s oxygen levels dropped further during transfer to the operating theatre and **P** had a seizure in the lift. Despite the deteriorating situation, **A** decided against intubating **P** in the lift because of the suboptimal conditions. Instead, he and **A2** hurried into theatre pushing **P**'s bed as fast as they could. In theatre, they tried to ventilate the **P** with a bag-mask. **P**'s oxygen levels did not improve. **A** inspected **P**'s pharynx with the laryngoscope and tried to insert a breathing tube. This failed because **P**'s airway was too swollen to insert the tube and **A** could not see any anatomical landmarks to guide tube insertion. **A** declared 'failed intubation and failed ventilation' and proceeded to open a surgical airway with a needle puncture. While preparing the surgical airway, **A** decided attempted insertion of another mask into **P**'s pharynx as a rescue to buy some time. This failed as well. Simultaneously with bag mask ventilation, **A** attempted to open a surgical airway with a needle kit. Due to **P**'s unfavorable anatomy (obesity, short neck), and the fact that he had never done a surgical airway on a **P** like this, the attempt failed. **A2** had a second attempt, which failed as well.  **A2** suggested they call an Intensive Care Unit consultant for help because they are usually more experienced with surgical airways. The Intensive Care Unit consultant arrived and performed the surgical airway successfully using a needle-and-knife technique. The **P** was re-oxygenated and transferred back to the Intensive Care Unit.

*Table 5*. Decision Requirements Table, narrative 5, anesthesiologist

| | *Incident* | *Critical Information* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | First attempt to ventilate **P** failed**, A** switched to another method | **A** was unable to establish in advance that first method he attempted would not work for this **P** | **Recognize Typicality, Mental Simulation;** being able to judge what methods are likely to work with this type of **P** | **Technology;** systems that can enhance situational assessment as it applies to evaluating patients for ventilation methods **Training**; difficult case experience & training (observation of experienced **A**'s handling difficult cases, discussions of difficult cases in morbidity and mortality meetings, simulations of difficult cases) with emphasis on assessing situational suitability of intubation method and on mentally simulating different intubation methods for different **P** conditions |
| 2 | **A's** attempt to open a surgical airway with a needle failed | **P**'s unfavourable anatomy; **A** had never done a surgical airway on a **P** like this. | **Typical Action;** perform surgical airway on all **P** types | **Training;** simulation training on technical skills to perform a surgical airway |

*Table 6*. Decision Ladder Table, narrative 5, anesthesiologist

| | *Description* | *Process* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **A** takes call from Emergency Department about a **P** that has presented with an acute life-threatening condition | Observe | | |
| 2 | **A** observes **P** has low oxygen saturations | Observe | | |
| 3 | Severity of the situation, urgency of treating the **P**s' airway, **A** aware that **P** could die | Interpret Anticipate | | |
| 4 | **P** will need a surgical airway & must be transferred to the operating theatre | Identify Desired Outcome | | |
| 5 | Calls for help, calls operating theatre to ensure they are ready with extra equipment | Develop & Execute Plan | | |
| 6 | Noticed oxygen levels dropping further in lift, **P** had seizure | Observe | Contrast options of treating **P** in lift versus theatre; use theatre for surgical procedure when possible | **Training;** training on mental simulation |
| 7 | Suboptimal conditions in lift to intubate | Interpret | | |
| 8 | Don't intubate in lift but transfer **P** to theatre as fast as possible | Options Analysis | | |
| 9 | Pushes **P** into theatre as fast as possible | Execute | | |
| 10 | Arrived in theatre, **P** worsening (presumably) | Observe | | |
| 11 | Face-mask ventilation | Execute | **A** unable to establish in advance which method would work with this **P** | **Technology;** systems that can enhance situational assessment as it applies to evaluating patients for ventilation methods **Training**; difficult case experience & training (observation of experienced **A**'s handling difficult cases, discussions of difficult cases in morbidity & mortality meetings, simulations of difficult cases) with emphasis on assessing situational suitability of intubation method |
| 12 | Oxygen levels were not improving | Observe | | |
| 13 | Face-mask ventilation unsuccessful | Interpret | | |
| 14 | Attempt laryngoscopy | Execute | | |
| 15 | Airway too swollen, no visible landmarks | Observe | | |
| 16 | Attempt at laryngoscopy unsuccessful | Interpret | | |
| 17 | Declaration of 'failed intubation, failed ventilation' | Execute | | |
| 18 | Prepare for surgical airway, insert laryngeal mask to buy time | Execute | | |

| | | | | |
|---|---|---|---|---|
| 19 | No improvement in oxygen saturations (presumably) | Observe | | |
| 20 | Laryngeal mask failed | Interpret | | |
| 21 | Perform surgical airway with face mask ventilation; Unfavourable landmarks to do a surgical airway | Develop<br>Plan<br>Observe<br>Execute | Ability to perform surgical airway on all patient types | **Training;** simulation training on technical skills for surgical airway |
| 22 | Surgical airway failed, both anaesthetists tried | Interpret | | |
| 23 | Other attending anaesthetist suggests a call to the ICU consultant as they are more skilled with surgical airways | Develop<br>Plan<br>Execute | | |
| 24 | ICU consultant arrived & performed surgical airway with both needle & knife | Execute | | |
| 25 | Oxygen levels improved | Observe | | |

*Edited Narrative 6 (anesthetic nurse)*

A trauma **P** with blood in his brain, a collar, and blood in his airway was admitted to the operating theatre for neuro surgery. Because of the collar and the head injury, this **P** would be difficult to intubate. **A**, **AN**, and other operating staff team members discussed what they are going to do. **A** had seen **P** in the emergency department and knew what he was like. **A** informed **AN** that he would attempt an awake fiberoptic intubation as plan a with video laryngoscopy available as plan b. **AN** prepared everything that was needed by setting up the anaesthetic trolley and getting all necessary equipment for the fiberoptic intubation. She ensured the anaesthetic trolley was stocked with airway equipment, and she also brought in the difficult intubation trolley and the video laryngoscope. She also advised her resource nurse what is happening in case they got into difficulties and they needed another hand. **P** was awake when brought into the operating theatre. **AN** connected **P** to the monitoring system. Other nurses made sure **P** had an IV running and went through the usual checking processes, such as making sure they had consent and the right **P**. Someone used a bag and mask on **P** to support his breathing functions and pre-oxygenate.
**AN** was to make sure that everything 'went according to plan; that they had all the equipment they needed, that **P** was connected to monitoring systems, and that all was ready for the fiberoptic intubation. **P**'s airway was numbed with a nebulizer to prepare him for the fiberoptic intubation. **AN** passed equipment to **A**, who attempted the fiberoptic intubation. **A** was bag-masking and **AN** stood next to him. Another nurse held **P**'s collar in a neutral position. **AN** then handed the fiberoptic scope to **A** who attempted to insert it, which was difficult because the blood interfered with the view. **A** had a few attempts but it didn't work properly. **P**'s oxygen levels started to drop. **A** removed the

tube and returned to face-mask ventilation to re-oxygenate the **P**. **A** then inspected **P**'s airway with the video laryngoscope after **AN** had passed it to him. The view with the video laryngoscope was still not good. **A** returned to face-mask ventilation to re-oxygenate **P**.

At that point **AN** asked **A** if he would like another consultant. **A** agreed and **AN** asked one of the scrub nurses to ask the resource nurse to find a consultant. When he arrived, **A2** (who was more senior than **A**), in agreement with **AN**, tried again with the fiberoptic scope. If this failed, they would wake the **P**. **AN** was thinking about what they could do and what options there were if they could not intubate **P** with the fiberoptic scope this time. They repositioned the table and **A2** then attempt intubation with the fiberoptic scope. **A2** was eventually able to find the landmarks and intubate **P**.

*Table 7.* Decision Requirements Table, narrative 6, anaesthetic nurse

| | *Incident* | *Critical Information* | *Critical Expertise* | *Design Ideas* |
|---|---|---|---|---|
| 1 | **AN** ensured that they had all the equipment they needed, that **P** was connected to monitoring systems, and that all was ready for the fiber-optic intubation | **AN** aware that this could be a difficult intubation | **Recognize Typicality;** skill in proactive contingency planning | **Technology;** a standardized equipment trolley in which the various anaesthetic technologies are readily visible & organized to support planning |

*Table 8*. Decision Ladder Table, narrative 6, anesthetic nurse

| | *Description* | *Process* | *Critical Expertise* | *Design Challenges* |
|---|---|---|---|---|
| 1 | **A** advises **AN** of an arriving trauma **P** who will be potentially difficult to intubate, & advises her of the airway management plan | Observe | | |
| 2 | **AN** understands the plan & the challenge posed by this **P** | Interpret | | |
| 3 | **A** advises **AN** that they will do a fibreoptic intubation as plan A & a video laryngoscopy as plan B | Observe | | |
| 5 | **AN** prepares the fiberoptic intubation & the other equipment to have everything ready for the **P** & lets the resource nurse know about the situation | Develop Plan Execute | Knows what equipment to prepare & how to advise others who may assist | **Technology;** a standardized equipment trolley in which the various anaesthetic technologies are readily visible & organized to support anticipatory planning |
| 6 | **AN** sees **A** struggling to with the fiberoptic intubation & then the video laryngoscopy | Observe | | |
| 7 | **AN** asks **A** if he would like help from another consultant | Develop Plan Execute | Knows that consultants are available & how to access & navigate available human resources for help | **Technology;** a readily accessible information system that shows consultant availability & consultant expertise |
| 8 | **A** agrees; he would like help | Observe | | |
| 9 | **AN** will get help but not leave **P,** will have scrub nurse ask resource nurse to find a consultant | Develop Plan Evaluate Plan Execute | | |
| 10 | **A2** arrives, **AN** listens to **A** & **A2** discuss their plan to attempt fiberoptic intubation again | Observe | | |
| 11 | **AN** aware that there is no backup plan yet if this last attempt at fiberoptic intubation fails | Anticipate | | |
| 12 | **AN** reflects on options if this attempt at fiberoptic intubation fails | Identify Options | | |
| 13 | **AN** observes **A** & **A2** performing fiberoptic intubation again (successfully) | Observe | | |

**Raw narratives**

*Narrative 1 (anesthesiologist)*

The anaesthetist received a call from the surgeon the night before. The surgeon told the anaesthetist that the list of the anaesthetist would be interrupted because there was a sick patient, with a tear in his oesophagus. The anaesthetist was not worried but assumed he had to do an endotracheal intubation. He saw the patient for the first time the next day in the operating theatre. When seeing the patient he realised that next to the serious condition the guy may also be difficult to intubate, because he had terrible lungs. He was also obese and had a fat neck, a full set of teeth, and an 'okay' mouth opening. He could not lay down but had to sit up to be able to breathe sufficiently. This told the anaesthetist he had not much respiratory reserve because of his condition. The anaesthetist decided to give prolonged pre-oxygenation to optimize the patient's lung reserves. He also decided to use a video laryngoscopy because of the patient's difficult looking airway. The anaesthetist prepared and got everything he thought ready and told the anaesthetic nurse that this may be a difficult intubation. The anaesthetist was not too worried because, although the patient was sick, they manage sick people all the time, so he would just do what he would normally do. The anaesthetist ordered some extra equipment and after about four to give minutes of pre-oxygenation he realised there was no more benefit in waiting, so he put the patient off to sleep with propofol. He used a short-acting muscle relaxant because he wanted to get the tube down as quickly as possible. After waiting for about 30 seconds, the anaesthetist had a look with the laryngoscope and he had not a perfect view, but enough to get the tube in. The anaesthetist believed he put the tube through the vocal chords. He then connected the tube to the bag and two signals are critical: it should be possible to squeeze the bag to get oxygen into the lungs, and the monitor should indicate exhaled carbon dioxide as an indicator for successful ventilation. The anaesthetist tried to squeeze the bag, but it was impossible. Thus, no oxygen was going into the patient's lungs and because of that, no carbon dioxide was coming out, and hence no capnograph was visible. The anaesthetist pulled the tube out, and at this stage, the oxygen saturations were very low. He noticed that by hearing the sound of the pulse oximetry and seeing it on the machine. The patient looked terrible. The anaesthetist then attempted to face mask ventilate the patient with a bag mask. It did not work, which was a very stressful experience. The anaesthetist did not see the chest moving up and down. He called for help, got the extra equipment and articulated a surgical airway may need to be done to the surgeon. He articulated 'I can't intubate, I can't face mask ventilate'. Colleagues came running in and he picked a specific colleague to help who he felt was most decisive and competent. The colleague took a laryngeal mask, which has not been tried yet, and the patient came good.

*Narrative 2 (anesthetic nurse)*

The anaesthetic nurse was waiting in the holding bay in front of the operating theatre for the patient to arrive to go into surgery. Everything was prepared, the drugs were out and the airway was selected and they were just waiting for the patient to arrive. After the patient arrived in the holding bay, they commenced the standard checking procedure and IV line connections. The patient had anxiety, which is is why the anaesthetist decided to give her some drugs that would relief the anxiety. After the drugs were given, they noticed the patient got more scared and was gasping for air. This is not an unlikely symptom of someone having a panic attack, however it is unlikely that this happens after the calming medication was given. Thus, they weren't sure what was going on. The anaesthetist, who was in the holding bay with the anaesthetic nurse while it happened, asked the anaesthetic nurse to bring an 'ambul bag' (a big bag and a mask that is best to use for situations where positive airway pressure is needed, such as here) to get oxygen into the patient. They connected everything and the anaesthetist held the mask with two hands holding the mask for a better seal, and the anaesthetic nurse ventilated. They then brought the patient into the operating theatre and connected the patient to the anaesthetic machine. This was done to better control the airway, connect the patient to the anaesthetic circuit and put her to sleep. This was no problem because they could keep ventilating the patient while moving her into the operating theatre, which was only a few steps away.  The anaesthetist said they need help and the anaesthetic nurse pressed the emergency buzzer to get help from a senior anaesthetist. A lot of people came in, and they quickly described the situation to them: that they still don't know what happened, but that they successfully ventilated the patient (which they saw because the chest was rising, there was fog in the mask and they could see a Co2 trace on the anaesthetic machine monitors), and that she has a good mouth opening. The anaesthetist had a look at the airway and decided to proceed with the intubation, which was the initial plan. The anaesthetist then asked if they could give the 'remaining' muscle relaxant from the syringe. That made everyone realise what happened: the anaesthetist confused the anxiety medication with the muscle relaxant, which caused the patient to paralyse and stop breathing. As the situation was under control because they could face mask ventilate successfully, the anaesthetist decided to proceed with the surgery and intubated the patient as planned originally.

*Narrative 3 (anesthesiologist)*

An anaesthetist was busy with his own case when he heard the emergency buzzer coming from the operating theatre next to him. He handed over his own patient after making sure the conditions were stable and the anaesthetic nurse could watch the patient for the period he was away, and the surgeons would not continue the surgery until he was back. He then went over to the operating theatre that required assistance. When he entered the operating theatre, he saw that the anaesthetist in charge was in trouble. The first thing he did was looking at the monitor and saw the missing capnography and the low oxygen saturations. He also saw the anaesthetist in charge trying to ventilate the patient with a bag mask, unsuccessfully. Hence, there was quite a bit of time pressure. He said to the anaesthetist in charge 'you are not ventilating and he agreed. The anaesthetist coming in assisted the other anaesthetist with face mask ventilation. This involved putting a nasopharyngeal airway in and holding the mask with two hands while the other person was squeezing the bag to optimize the mask seal and hence ventilation. They could then see the capnography coming up, the chest movement and then the oxygen levels rising. The anaesthetists were relieved because now the time pressure was reduced and the situation could be controlled. At this point the anaesthetist had actually the opportunity to ask the anaesthetist in charge what happened, and he then also noticed there was some blood around the airway which indicated to the anaesthetist there must have been some damage occurred to the patient's airway before he was coming to help. This conversation took a couple of minutes because the anaesthetist asked about the history of the patient, the procedure and what happened consequently. He found out that the anaesthetist in charge used a video laryngoscopy first and failed with that, and then switched to a normal laryngoscopy and failed as well. Hence he had two attempts before and thereby caused some airway trauma, which made the subsequent face mask ventilation harder because the airway became bloody. Because he was a second responder he then asked the anaesthetist in charge what options there were to handle the patient's airway. They then spend the next couple of minutes negotiating the plan. The anaesthetist recommended that the option of waking up the patient should not be forgotten, and they discussed if this was a viable option and what else they could do. The anaesthetist's proposal was twofold. Initially they could either look at waking up the patient and aborting surgery or keeping the patient asleep and securing the airway by a different mechanism. The preference of the anaesthetist in charge was to go with a different airway approach and the anaesthetist agreed, but he did not want more repeated attempts at airway management. So they agreed that they give one more attempt at securing the airway and if that proves impossible, they wake up the patient. As there was already trauma and the laryngoscopy is a quite sharp device, they wanted an approach that is softer. Therefore, they decided to do the intubation with a fiberoptic scope. They further decided that they put a laryngeal mask down first as a stop-gap measure to be hands free and able to prepare the equipment needed for the fiberoptic intubation. The plan was then to put the fiberoptic scope through the laryngeal mask to intubate the patient. After placing the laryngeal mask, they called for the difficult airway trolley, explained everything to the anaesthetic nurse and also requested a second anaesthetic nurse to help out. The equipment was brought in and everything was prepared. The anaesthetists also announced the plan to everyone in the room, so everyone was aware of what was going to happen. Also, the anaesthetist told the anaesthetic nurse to track the time and if they spend more than ten minutes trying to manage the airway, the anaesthetic nurse should let them know so they can prevent fixating on getting the airway in. They then put the fiberoptic scope in, which has a camera attached, and checked that the airway was not too damaged. They decided to proceed with the procedure because the airway did not look too swollen. They could get the tube in with the fiberoptic scope and then removed the laryngeal mask and finished the intubation. They then called the Intensive Care Unit to discuss with them if they can leave this tube in after the patient is transferred to them, because they did not want to take the risk of taking this tube out any time soon due to the damage that occurred and the difficulties they had with intubation. Because of this, the decisions was also made to leave the patient asleep for 24 hours with the tube until the airway settled down. The Intensive Care staff agreed to leave the same tube in for 24 hours.

*Narrative 4 (anesthesiologist)*

The anaesthetist was walking through the recovery unit and noticed noises of stridor coming from one of the beds. The anaesthetist went to check the patient behind the curtain and saw an old lady that just had a thyroidectomy. It was a lady in her late 70s and she was struggling to breathe. The Oxygen saturation monitor has fallen off, but she looked hypoxic to the anaesthetist because of her blue skin colour. She had tachycardia as shown by the monitors, which means her heart rate was at about 130.  The anaesthetist quickly brought the patient into theatre and anaesthetic nurses and staff came to help. The anaesthetist contacted an Ear-Nose-Throat surgeon for help. In the meantime, the anaesthetist tried to ventilate the patient with a bag mask, which was partially successful. He knew that, because he could still hear the stridor which indicates that some air goes in and out of the patient’s lungs. The patient was combative, and therefore the anaesthetist used some anaesthetic gases additional to the oxygen through the bag mask, to keep her both calm and asleep. The situation improved first, however he could feel the situation worsening after a little while because he felt the bag in his hand moving less and less. The anaesthetist applied some positive pressure, however the breathing functions of the patient could not be supported anymore. The oxygen saturation levels dropped further and then the anaesthetist decided to have a look with the laryngoscope, to see if he could insert a breathing tube into the patient's airway. However, he could not see any landmarks of the pharynx to help guiding the tube in the correct position. Therefore, he declared a 'can't intubate, can't ventilate' situation. He tried a laryngeal mask airway as a rescue, and thought it fitted well. However, when he connected the laryngeal mask to the bag and then tried to squeeze the bag it was impossible. The bag remained hard and did not move, which indicated that he could not get any oxygen into the patient. He then decided to have an additional attempt with another laryngeal mask, which had a different size. Simultaneously, he told the nurses to get the surgical airway kit ready. While he was waiting for that, he had a second look with the laryngoscope just to fill in the time. The anaesthetist was very stressed at this time, and the time pressure was extreme. The anaesthetist performed a surgical airway with a needle puncture as a temporary solution until the Ear-Nose-Throat surgeon would arrive to perform a tracheostomy. The surgical airway was partially successful because the oxygen saturations did not drop further, however did also not improve significantly. The anaesthetist has never done a surgical airway with a needle before. At this point, the Ear-Nose-Throat surgeon arrived. The Ear-Nose-Throat surgeon then performed a tracheostomy, which was successful eventually.

*Narrative 5 (anesthesiologist)*

The anaesthetist got a call from the Emergency Department to see a patient that presented an acute life-threatening condition, impacting his ability to breathe. Once he saw the patient in the Emergency Department, he noticed the severity of the situation and the low oxygen saturations of the patient. That indicated the urgency of treating the patient's airway. The anaesthetist feared the patient could die at any moment. The anaesthetist assumed that, in order to treat the patient's airway definitely, a surgical airway is required eventually. The anaesthetist decided to transfer the patient down to the operating theatre instead of treating the patient in the emergency department. He decided this because the operating theatre presents more optimal conditions to treat a patient's airway due to availability of advanced technology and more experienced staff. After making this decision, he called another anaesthetist for help and called the operating theatre to make sure they are prepared for this difficult case and have extra equipment ready. While transferring the patient down to the operating theatre, the anaesthetist noticed the patient's oxygen levels dropped down further, and further the patient had a seizure in the lift. Despite the situation even worsening, the anaesthetist decided to not intubate the patient in the lift because of the suboptimal conditions. Instead, he and his colleague were running into theatre pushing the bed as fast as they could. In theatre, they tried to ventilate the patient with a bag-mask. This failed, because the oxygen levels were not improving. Therefore, the anaesthetist decided to have a look inside the patient's pharynx with the laryngoscope and tried to insert a breathing tube. This failed too, it was impossible to insert the tube because the airway was too swollen and the anaesthetist could not see any anatomical landmarks to guide the insertion of the tube. The anaesthetist declared 'failed intubation and failed ventilation' and therefore decided to do a surgical airway with a needle puncture. While preparing the surgical airway, the anaesthetist decided to try and insert another mask into the patient's pharynx as a rescue to buy some time. This failed as well. With bag mask ventilation simultaneously, the anaesthetist tried to perform a surgical airway with a needle kit. Due to the unfavourable anatomy of the patient (obesity, short neck), and the fact that he has never done a surgical airway on a patient like this, the surgical airway failed. Another anaesthetist had a second attempt, which failed as well. The other anaesthetist then suggested to call an Intensive Care Unit consultant to help, as they are usually more experienced with surgical airways. The Intensive Care Unit consultant arrived and performed the surgical airway successfully using both needle and knife techniques. The patient was able to be re-oxygenated and transferred to the Intensive Care Unit.

*Narrative 6 (anesthetic nurse)*

The anaesthetic nurse heard about a trauma patient that would come down to the operating theatre for neuro surgery. She heard the patient had a blood in his brain, a collar and blood in his airway. Therefore, they knew beforehand this patient would be difficult to intubate, because patients with collars are difficult to intubate and the patient is quite sick with a head injury. The anaesthetic nurse and other operating staff team members had a discussion with the anaesthetist on what they are going to do. The anaesthetist had seen the patient before in the emergency department and therefore knew what the patient was like. The anaesthetist informed the anaesthetic nurse that he decided to do an awake fiberoptic intubation as plan a, and also have the video laryngoscopy handy as plan b. The anaesthetic nurse then prepared everything that was needed, set up the intubation trolley and got all the equipment for the fiberoptic intubation. She made sure that the anaesthetic trolley was stocked with airway equipment, and she also brought the difficult intubation trolley and the video laryngoscope. She also told her resource nurse about what is happening, just in case they get into difficulties and they need another hand. The patient was quickly brought into the operating theatre. The patient was awake, but wasn't quite with it because his head injury and some relaxants that were given him before. The anaesthetic nurse connected the patient to the monitoring, other nurses made sure he had an IV running, etc. Then the usual checking processes happened, such as making sure they had consent and the right patient etc. Someone was bag and masking the patient to support his breathing functions and pre-oxygenate, which was successful. The nurses task was to make sure that everything was going according to plan, that they had all the equipment they needed and connect the patient to monitoring and monitor (e.g. ECG and blood pressure), and prepare the fiberoptic intubation. The patient was then prepared for the fiberoptic intubation, the airway was numbed with a nebuliser. The anaesthetic nurse passed the equipment, which was ready to go on her little trolley next to her, to the anaesthetist, who had the first attempt at fiberoptic intubation. The nurse had her own anaesthetic trolley next to her with the standard airway equipment, and then there was also the difficult airway trolley that had the fiberoptic intubation ready to go on there. The anaesthetist was bag-masking and the anasthetic nurse stood next to him. Another nurse held the collar of the patient in a neutral position. The anaesthetic nurse then passed over the fiberoptic scope and the anaesthetist had an attempt at inserting it. This was difficult because the view was not good because of the blood. The anaesthetist had a few goes at getting it in, but it didn't work properly. The oxygen levels of the patient started to drop a little bit. They then took out the tube and went back to face-mask ventilation to re-oxygenate the patient. The anaesthetist then decided to have a look with the video laryngoscope. The anaesthetic nurse passed over the equipment to the anaesthetist. The view with the video laryngoscopy was still not good and they thus again went back face-mask ventilation to re-oxygenate again. At that point the anaesthetic nurse asked the anaesthetist if he would like another consultant there. The anaesthetist agreed and the anaesthetic nurse asked one of the scrub nurses to go to the resource nurse who finds another consultant. When the second anaesthetist was there (who was more senior than the anaesthetist currently working on the patient), in agreement with the anaesthetic nurse he decided to go back to plan A and have one more try with the fiberoptic scope. The plan was that if this would not be successful, they would wake up the patient. The anaesthetic nurse was thinking about what they could do and what options there were if they were not able to intubate the patient with the fiberoptic scope this time. They repositioned the table and the senior anaesthetist then had another attempt at intubation with the fiberoptic scope. He was able to find the landmarks eventually, and intubate successfully.

## 11.4 Appendix 4

**Coding of design requirements and Human Factors principles**

**Participant 1 – Anaesthetic nurse**

| **Interview notes** | **Design requirements/user needs for airway cart** | **Associated Human Factors design principles** (adapted from Nielsen, 1994 and Shneiderman, 1998 in Zhang et al, 2003); Nielsen (1994). |
|---|---|---|
| - Supports idea of improving airway trolleys | - | - |
| - Puts immediate stuff they need on the top shelf (e.g. tube size, size mac blade, stuff she most likely needs). On bottom shelf she has back up airway devices like guedals, back up LMA's, back up blades, etc that she not as likely will use but could potentially need). | Separation of primary and back up equipment | ***Minimalist*** |
| - Everyone sets up space differently; some put a lot on it and others don't. Some nurses put guedal on the top for example but nurse doesn't find herself often using them so she keeps them on bottom shelf. Some nurses will have monitoring devices on top as well that are put on once the patient is asleep. Give flexibility but yet standardise a bit | Flexibility and standardisation trade-off | ***Flexibility and efficiency of use*** |
| - Participant doesn't like the clutter, it's not imperative to the airway so participant puts it on the bottom. That's personal preference | Separation of primary and back up equipment | ***Minimalist*** |
| - Some standardisation would be beneficial, especially in cases where something goes wrong. Everyone sets up their trolley differently so you don't always know where to find things. | Flexibility and standardisation trade-off | ***Flexibility and efficiency of use*** |
| - Sometimes you come in in the morning and the person the day before set up their trolley differently, and when you are in a rush and just put on things and then look for equipment later because | Flexibility and standardisation trade-off | ***Flexibility and efficiency of use; Categorisation, consistency and standardization*** |

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| | person doesn't know where they put it. If there would be some sort of standardised way, you could just walk in, and even in a rush, you would still know exactly where to find things. It's that emergency management where you can just go in without having to think | Layout, Categorisation & Visibility | ***Categorisation, consistency and standardization*** |
| - | Bougie taped on the side of the trolley so she can easily rip it open and take it out as necessary | Layout, categorisation & visibility | ***Consistency and standardisation; Recognition rather than recall;*** |
| - | Guedal sort of in back corner at the top because she probably doesn't need it, but may. | Layout, categorisation & visibility | ***Categorisation, Consistency and standardisation; Recognition rather than recall*** |
| - | If LMA back up airway she goes a size larger rather than smaller | - | - |
| - | Ideally lays everything out on the trolley | Layout, categorisation & visibility | ***Visibility; Categorisation; Consistency and standardisation; Recognition rather than recall*** |
| - | Nasapharyngeal airways usually in anaesthetic machine which is easy to access (and usually when using them it is not a massive emergency). Anaesthetist and nurses know that nasapharyngeal airways are in the anaesthetic machine, but anaesthetists often pull open every single draw and can't find them and then the anaesthetic nurse tells them they are in draw 2 | Proximity and accessibility of airway equipment | ***Proximity Compatibility Principle; Recognition rather than recall*** |
| - | Nurse knows that LMA is at the bottom shelf at all times because that's a habit she learned since she started in anaesthetics. But if another nurse doesn't have the habit she may not see that it's there, but they would know where in the room to find one | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardisation; Recognition rather than recall*** |
| - | If she says equipment is laid out like this, she means that she stacks the equipment in the kidney dish in that order (more or less), to deal with space constraints. She does that also to separate contaminated equipment from the other equipment and the trolley | Separate contamination area | *Hygiene requirement* |
| | | Space to grasp equipment versus general space constraints | *Space requirement* |

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| - Has two little dental cups and they sit on the top of the trolley and they have tapes, tegaderms, ecg dots and the other one has guedals etc. A lot of people keep them underneath because some of the equipment is not imperative on the airway | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardization*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Has guedals standing up so she can see the colour, has only the one she thinks she needs on the top and rest on the bottom, to reduce the clutter | Layout, Categorisation & Visibility | ***Visibility; Categorisation, Consistency & standardisation*** |
| | Separation of primary and back up equipment | ***Minimalize*** |
| - Likes idea of laying equipment down, definitely aids recognition and preparation and makes it much easier, especially if you are in an emergency situation | Layout, categorisation & visibility | ***Recognition rather than recall; Categorisation, Consistency and standardisation; visibility*** |
| - Operating theatre is not the best, especially in emergencies, it gets really crowded | Space to grasp equipment versus general space constraints | *Space requirement* |
| - Ideally has trolley right next to her so she can grab things while assisting with one hand. But that's not always possible- sometimes she has her trolley behind her or somewhere else, depending on how many people are in there and what equipment is in the room | Space to grasp equipment versus general space constraints | *Space requirement* |
| | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardization*** |
| - In these stressful situations, when you have to rifle around in a kidney dish, it's not always the best thing. Whereas if equipment could be laid out step by step you could just put your hand put on it and recognise it rather than tapping around blindly | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardization; Recognition (tactile) rather than recall*** |
| | Space to grasp equipment versus general space constraints | *Space requirement* |

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| - In cardiac they have a double lumen trolley and they do lay everything out, and have a bigger trolley, cardiac theatres are a lot bigger | - | - |
| - Would really like a bigger trolley and lay things out, even if it is only slightly bigger, and not be using kidney dishes. | Layout, Categorisation & Visibility | ***Categorisation, Consistency & Standardisation; Visibility*** |
| | Space to grasp equipment versus general space constraints | *Space requirement* |
| - Expanding tray on the trolley like an expanding table is not a bad idea, concern is, does the stuff stay on it as set up and doesn't move? Laryngoscopes can break easily and equipment needs to be sterile so can't fall down, so there has to be a way to secure it on the shelf if they move | Equipment shouldn't move or easily fall off trolley | *Physical environment requirement* |
| - Only has one guedal on the top (the one in the right size, always has it on top) because it just simplifies, especially when the airway cart is behind her and she can't see. | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardisation*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| | Separation of primary and back up equipment | ***Minimalist*** |
| - Didn't have an airway trolley at the other hospital (just a green tray) at all which was very impractical. Usually sat on the anaesthetic machine or on the patient. Likes that at the Alfred there is an airway trolley with a dedicated space | - | - |
| - While she is not looking at the bottom shelf, it is ingrained to her that the next option is LMA if they can't get the tube in and they can't bag mask, and LMA is always at the bottom. 'It's not really a visual cue, but it's just to know what we do'. It's second nature to ask them if they want an LMA, she is not waiting for them to ask but she asks | - | - |
| - Always checks in the morning that she has a pro seal LMA in the stock trolley | - | - |

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| - Templates and laying out would help definitely help in preparing. Especially when you are tired you look at the trolley 100 times and think you have everything you need and then they bring the patient in and you realise you don't have all of it | Layout, Categorisation & Visibility | ***Recognition rather than recall; Visibility; Categorisation, Consistency and Standardisation*** |
| - Templates better than a checklist, hates checklists | - | - |
| - *'[Surgical checklist] hardly ever gets done […]. And I think a lot of them have just memorised the questions on there anyway… […] they are just going through the motions'. But we look at charts, we look at screens, we look at writing all day…the last thing we want is another checklist. A visual aid like this where it's just 'put that on there, put that on there, you've got everything', rather than having to read through a list and going 'yep yep yep I have got all those, oh, I'll go and get that in a second', but then you get distracted by something else […] whereas if you are placing things onto a map that is actually showing you what you need, you are gonna be a lot more alerted to the fact that something is missing…whereas with checklists, you can just run through it and you could be totally on autopilot [thinking] 'yeah I've got it all', but actually not got it all'.* | Layout, Categorisation & Visibility | ***Recognition rather than recall; Visibility; Categorisation, Consistency and Standardisation Matching system and real world*** |
| - You need flexibility but in some instances, there are people who put way too much on the trolley and they need to be reined in and so a template surface would be really good at doing that | Standardisation and flexibility trade-off | ***Categorisation, Consistency and standardisation*** |
| - In an emergency you cannot focus on your task if you are total cluttered in and you can't find anything. '*If I have my trolley I want to be able to find things, without having to look for them. They need to be there in front of me, not hidden underneath,…*' | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardisation*** |
| | Flexibility and standardisation trade-off | ***Categorisation, Consistency and standardisation*** |
| - Has bair hugger on bottom shelf underneath back up equipment | - | - |
| - Doesn't worry about extubation equipment because there are extra things she doesn't need on her trolley during induction or maintenance | - | - |
| - Anaesthetists often toss aside the mask and nurse has to find it for extubation | Layout, Categorisation & Visibility | ***Categorisation, Consistency and standardisation*** |

| | | |
|---|---|---|
| - Usually takes only her kidney dish to extubate the patient because she doesn't need much | - | - |
| - Is concerned about equipment getting stuck or tangled if it stands up or close together | Layout, Categorisation & Visibility | ***Categorisation, Consistency & Standardisation; Visibility*** |
| | Space to grasp equipment versus general space constraints | *Space requirements* |
| - Really likes the idea of flat laying equipment because it would make life a whole lot easier compared to a kidney dish where everything can be stuck together | Layout, Categorisation & Visibility | ***Categorisation, Consistency & Standardisation; Visibility*** |
| - Likes the idea of grooves, would put grooves for two sizes of tubes | | |
| - If guedals can all be stand up in a pocket or something and she can see the colour, nurse would actually like having all of them on the top. That way she could grab one easily without looking too | Layout, Categorisation & Visibility | ***Visibility, Recognition rather than recall, Categorisation, Consistency & standardisation*** |
| - You could have a groove for each piece of airway equipment with a metal barrier that holds equipment in place, even if you don't use particular equipment and don't have it in the groove. You can adapt it for the case | Flexibility and standardisation trade-off | ***Flexibility and efficiency of use*** |
| - If standardized she would probably have two sizes on top. Only reason because she only has one size on top and one at the bottom is because the anaesthetist tells her what size he wants | Layout, Categorisation & Visibility | ***Categorisation, Consistency & standardisation*** |
| - Doesn't need additional colours because it may get confusing, outlines of equipment are enough | - | - |
| - Would like the surgical airway kit to be more obvious/coloured | - | - |
| - If person wouldn't have secure airway she would hit emergency buzzer and ask if they want the difficult airway trolley or surgical airway kit | - | - |
| - Would put dirty equipment back into groove if it didn't work because she does not want to write it off, because sometimes you try again with the same equipment | - | - |

| | | |
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| - Thinks anaesthetists don't look at trolley but they just 'go off' the vortex in their head. 'Ah intubation doesn't work, so I go back to face mask'… | - | - |
| - Airway trolley is anaesthetic nurses domain, they support anaesthetist through the process of airway management, so it's up to the nurses to have all the equipment available | - | - |
| - Grooves would help to guide prep and make sure equipment does not get tangled | Layout, Categorisation & Visibility | ***Categorisation, Consistency & standardisation Visibility, Recognition rather than recall*** |
| | Space to grasp equipment versus general space constraints | *Space requirement* |
| - HATES checklists, has to fill in checklists every day and does not like it. Really likes idea of silhouettes that just tell her where to put things and what she needs. Much easier than another checklist! Sometimes need to grab stuff without looking so it would be great to improve current way of doing things | Layout, Categorisation & Visibility | ***Categorisation, Consistency & standardisation; Visibility; Match between system and world*** |
| - If doing the grooves provide additional once for different sizes, although normally she wouldn't put different sizes on top shelf to avoid unnecessary equipment. But could be left empty if not needed | | |
| - Silhouettes would be great for set up and handover since everyone does it different, some standardisation would be good to immediately see what the other person has and what may be needed additionally. | Layout, Categorisation & Visibility | ***Visibility; Categorisation, Consistency & standardisation*** |
| | Standardisation and flexibility trade off | ***Categorisation, Consistency & standardisation Recognition rather than recall*** |
| - Older nurses hate change and are set in their ways | - | - |

**Photo 1.1**. Top shelf with most important equipment (only necessary equipment is on top, no back up guedals etc).

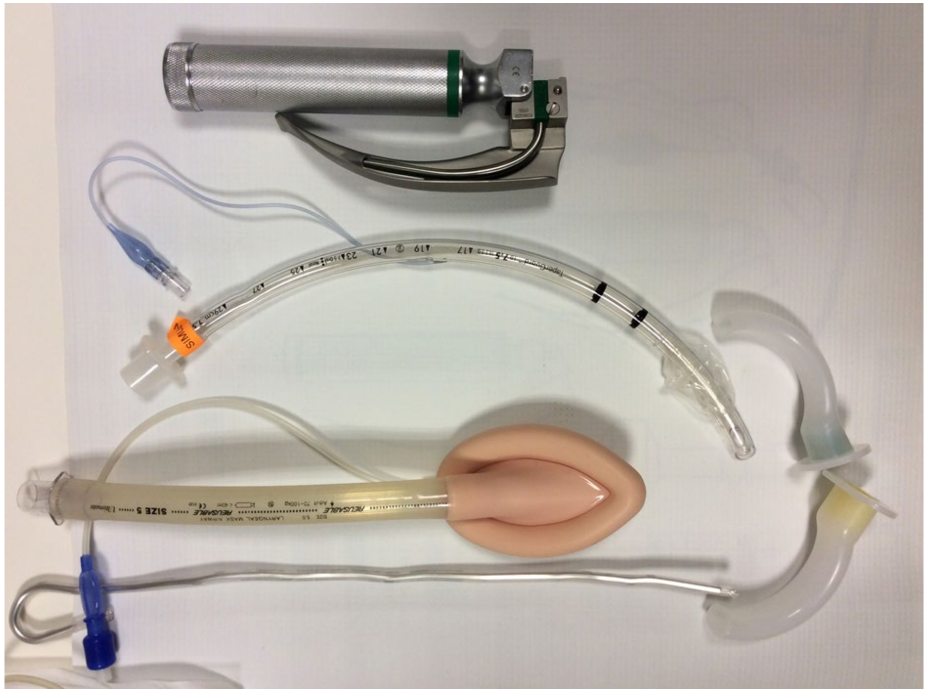

**Photo 1.2**. Set up of back up equipment (separated by primary equipment, sitting bottom shelf)

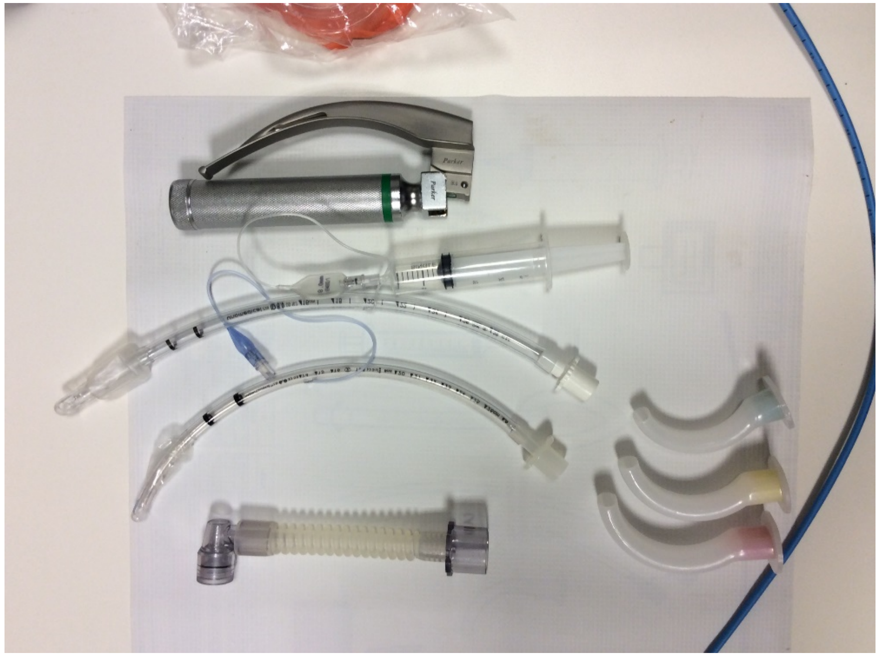

**Photo 1.3**. Separating equipment if designing grooves were equipment sits on the trolley

**Participant 2 – Anaesthetist**

| **Design requirements/user needs for airway cart** | **Design requirements/user needs for airway cart** | **Associated Human Factors design principles** (adapted from Nielsen, 1994 and Shneiderman, 1998 in Zhang et al, 2003); Nielsen (1994). |
|---|---|---|
| - Problem: Every hospital has a different cart and most of the staff are VMO's so moving between hospitals a lot. Trolleys are differently set up within hospitals too, depending on where you go (e.g. ED and ICU is different than theatre). This is very confusing and it's probably hard for the registrars as well because there is no standardisation of the equipment. | Standardisation and flexibility trade off | ***Categorisation, Consistency & standardisation*** |

| | | |
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| This was about the difficult airway trolley, but also true about routine equipment. | | |
| - Standard airway equipment set up is pretty variable. Sometimes you ask for a piece of equipment and the nursing staff does not necessarily know. | Layout, Categorisation and visibility | ***Categorisation, Consistency & standardisation*** |
| - There needs to be staff training on how to use equipment and when they designed the difficult airway trolley, they designed it in a way that the commonly used equipment is at the top, and the less commonly used equipment at the bottom (CICO equipment such as surgical airways) | Layout, Categorisation and visibility | ***Categorisation, Consistency & standardisation*** |
| | Separation of primary and back up equipment | ***Minimize*** |
| - Funding is a big issue | - | - |
| - Self-contained trolley are the best, if everything is there in one spot it makes it cognitively easy | Proximity and accessibility of airway equipment | ***Proximity Compatibility Principle; Recognition rather than recall*** |
| - There are two difficult airway trolleys at the moment, unlikely that two get used at the same time but as a back-up there are two. It is put on a whiteboard where the difficult airway trolley was moved to. | - | - |
| - For routine cases, anaesthetic nurses have a stainless steel trolley with two levels, the top has a kidney dish usually with the laryngoscope. The guedals are usually kept on the anaesthetic machine so not on that trolley, the bougie also often on anaesthetic trolley. It depends, often the anaesthetic nurse asks before beginning of the case what airway equipment you would like and they have to scrounge between a few different places to assemble the equipment. During the case they already get ready for the next case so it's all ready for the next patient. | | - |
| - Making sure that there are two functional laryngoscope blades | - | - |
| - Face mask is on anaesthetic circuit so wouldn't be out on the trolley. | - | - |

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|---|---|---|
| - Have a stylet ready to go in the tube because case is emergency so you would need to do RSI | - | - |
| - Bougie there in case it's difficult, all fairly standard | - | - |
| - Tends to divide equipment up because it's easier to grab something if there is a bit more space and the trolley itself is fairly confined | Separation of primary and back up equipment | ***Minimize*** |
| | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| - Laryngoscope is put into kidney dish to avoid contamination of other equipment with patient's saliva so that goes into a separate section | Separate contamination area | ***Hygiene requirement*** |
| - Tends to put adjuncts in the bottom so if you run into difficulties you can grab them quickly. | Separation of primary and back up equipment | ***Minimize*** |
| | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility*** |
| | **Proximity and accessibility of airway equipment** | ***Proximity Compatibility principle*** |
| - Would usually put second tube at the bottom, but likes to have a back-up at the top anyway in case something goes wrong, good from a safety point of view although probably uncommon. Sometimes having a smaller tube is also advantageous | Standardisation and flexibility trade off | ***Flexibility and efficiency of use*** |
| | Layout, Categorisation and Visibility | ***Categorisation, consistency and standardisation*** |
| - Tape bougie on the side of trolley so it's quickly accessible and maintains the visibility of it | Layout, Categorisation and Visibility | ***Visibility*** |

| | | |
|---|---|---|
| - Arranged set up likes this probably useful for novices because they may forget a step, so actually mapping the equipment out is good. In the emergency they have these dump kits and the advantage of that is that it's very easy to roll out the equipment and makes it less likely to forget something especially in a hurry and when you need a variety of tools the people may not be know what these tools are. The dump kits gives you that mental reminder 'oh I don't have the bougie, oh I don't have my LMA'. | Layout, Categorisation and Visibility | ***Recognition rather than recall; Categorisation, consistency and standardisation*** |
| - Often spoiled in theatre as equipment is around, just not in the one location but if patient is getting worse the planning becomes even more important so it's good to have that formal cognitive aid (that's also true for the ward or other areas) | Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation*** |
| - Would help anaesthetic nurses with transitions because you could go along a certain sequence compared to when everything is in the kidney dish and you're trying to find what you need. If laid out they are easier to grab | Layout, categorisation and visibility | ***Visibility; Categorisation, Consistency and standardisation*** |
| | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| - Not open the equipment to not waste equipment | Account for equipment that is still in package (to avoid waste) | ***General requirement*** |
| - Would personally prefer to have a big surface because it is easier to visualise what's in front of you, harder to look on multiple levels to find things. But trolley's they have at the moment are small so that's not feasible. But it would be feasible in the ICU and ED because their trolleys are wider | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| | Layout, categorisation and visibility | ***Visibility; Categorisation, Consistency and standardisation*** |
| - Idea: have a pre-folded line or section where people can extend or leave it simple as they please (some people like one big surface, others like the separation), people can adjust it to their work place | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |

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| - Colour coding helpful with guedals. Guedals may be helpful standing up to see colours. Putting them together helps to grab the right size fairly easily | Layout, categorisation and visibility | ***Categorisation, Consistency and standardisation*** |
| - Different manufacterers use different colours for guedals etc, so if you go to a different hospital it may not be exactly the same | - | - |
| - Likes to only have one guedal on top because it gives clarity and if there are too many things they can fall off | Separation of primary and back up equipment | ***Minimize*** |
| - Needs to be wiped down easily, if paper based can be thrown out but that's not environmentally friendly. Flat plastic work too. It just needs to be able to be cleaned easily because everything that went into the patient's mouth will be contaminated with saliva and you don't want other equipment to be contaminated or the workspace. So, whatever goes on the surface should stay on there. Plastic or laminated surface would work | Needs to be cleaned easily | ***Hygiene requirement*** |
| - Where to put equipment that has been used and doesn't work? People get panicked in that situation so they just throw equipment back on the surface. See's that with trainees when you come in and they are having trouble, everything is completely disordered because they are so focused on their one task that they are not really aware of their work space. So worry is that everything is thrown everywhere. And then the issue is you don't know what is clean what is dirty and when you come in as a second responder | Separate contamination area | ***Hygiene requirement*** |
| - Kidney dish concept works because it separates dirty from clean, but it does not lay out equipment but rather has it in one pile | Separate contamination area | ***Hygiene requirement*** |
| - The problem with that is it's not laid out in orderly manner anymore and you're moving stuff around. Grooves work but how do you clean surface between cases then as well? | TBD | |
| - Sometimes you reuse equipment that failed before so surface needs to account for that as well | TBD | |
| - Colour coding very helpful for equipment. Can get confusing with already exisiting colour codings (e.g. for guedal) but you could do a simply colour coding (e.g. common versus uncommon equipment). This gives second responder a quick cue where person is up to as well. | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| - Problem is that this is individual choice though (what is common, what is uncommon)? Some people are comfortable with only one laryngoscope for example | - | - |

| | | |
|---|---|---|
| - If intubation doesn't work and you go to laryngeal mask, he would then call for difficult intubation trolley and focus is then on **oxygenating rather than intubating** | - | - |
| - Would put guedals on second draw as back up, because you know the equipment is there but avoid confusion with too much equipment on the top shelf. Plus you want to allow space for people to grab things as well. | Separation of primary and back up equipment | ***Minimize*** |
| | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| - Depending on the patient, sometimes you need several sizes | - | - |
| - Put ridge in middle between contaminated and clean equipment so they can't roll into each other and stops equipment from moving, but it needs to be easy to clean. Solid divider might be easier than grooves. But grooves/slots may still work if they are not too deep | Separate contamination area | ***Hygiene requirement*** |
| | Needs to be cleaned easily | ***Hygiene requirement*** |
| | Equipment shouldn't move or easily fall off trolley | ***Physical environment requirement*** |
| - Grooves may be hard because equipment often stays in wrap, so it's not wasted. Simple divider may work here | Account for equipment that is still in package (to avoid waste) | ***General requirement*** |
| - Laying equipment out like this will make it easier because you can progress in a methodical order. Also, as a second responder this makes it much easier because you can see what has been tried already. | Layout, categorisation and visibility | ***Visibility; recognition rather than recall; categorisation, consistency and standardisation*** |
| - Call for help cue on second tray would help, visible to the whole team, even technicians etc. Although may be problem if seen too late (i.e. help needed earlier). | - | - |
| - Communication with anaesthetist can suffer under stress so assist with that | - | - |
| - Laid out equipment useful in situations where you haven't had time to discuss plan with anaesthetist first. Time consuming part is finding the equipment so that would help | Layout, categorisation and visibility | ***Visibility; recognition rather than recall*** |

| | | |
|---|---|---|
| - Participant doesn't understand why manufacturer does not put all equipment in one bag which you can just open and you know everything is there. Problem is all equipment comes from different manufacturers and it would be wasteful. Although, in other areas in the ICU for example they do have a box with all equipment in there that is needed for a particular procedure, for example central lines. It is assembled by assistants but it's all there, even though different pieces are coming from different manufacturers. It would be nice if something like this would exist for airway management. | Proximity and accessibility of airway equipment | ***Proximity compatibility principle*** |
| - Set up of equipment is variable for every case, so need to account for that. But linear set up according to plans is quite useful. Although, divided in quadrants would work really well too where you have equipment in every corner to account for flexibility for every case. This would be helpful because it's then up to them in what order they are grabbing the equipment compared to left-right/bottom-down which is what people would usually do. | Layout, categorisation and visibility<br>Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation***<br>***User control and freedom*** |
| - Good thing about the vortex is that it is not prescriptive and people can choose themselves where to go in and where to go out. Dividing it into quadrants thus makes sense because they can get in anywhere in the sequence/they are not committed to a path. | Layout, categorisation and visibility<br>Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation***<br>***User control and freedom*** |
| - Trick is to not too many areas, maybe four areas/quadrants. | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| - Dividers with sections and pictures/silhouettes of airway management would be helpful to aid for preparation. | Layout, categorisation and visibility | ***Visibility*** |
| - Separation with kidney dish or area dedicated for contaminated equipment is important | Separate contamination area | ***Hygiene requirement*** |
| - Thinks nurses will be compliant with this if it is easy to implement, you will just run into problems if things become complex and people don't see the utility…but especially for the junior nurses would get a maximum benefit out of it. And there are many junior staff here so that would be useful. Because they can be task focused and then forget the back-up devices. | Simple rather than complex design | ***Simplicity, system matching the real world*** |
| - Often looks on trolley and asks and nurse and clinician remind and check each other. | - | - |

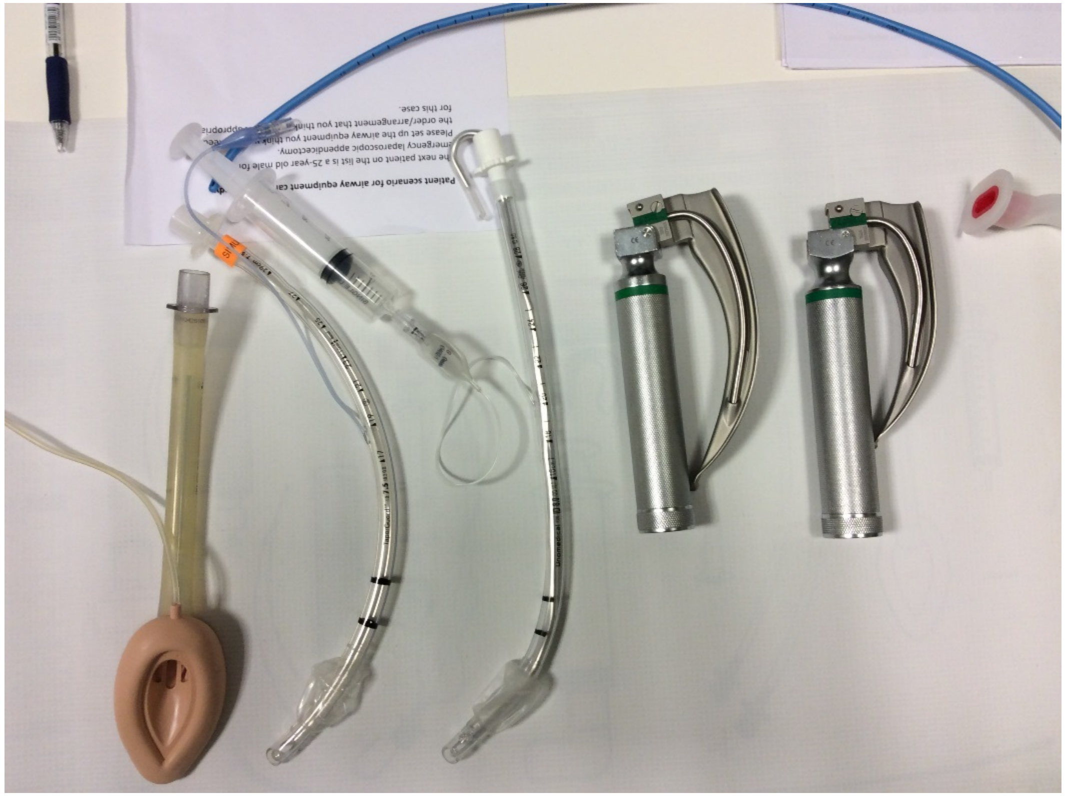

**Photo 2.1**. Arrangement of equipment if there would be no separation for primary and back up equipment

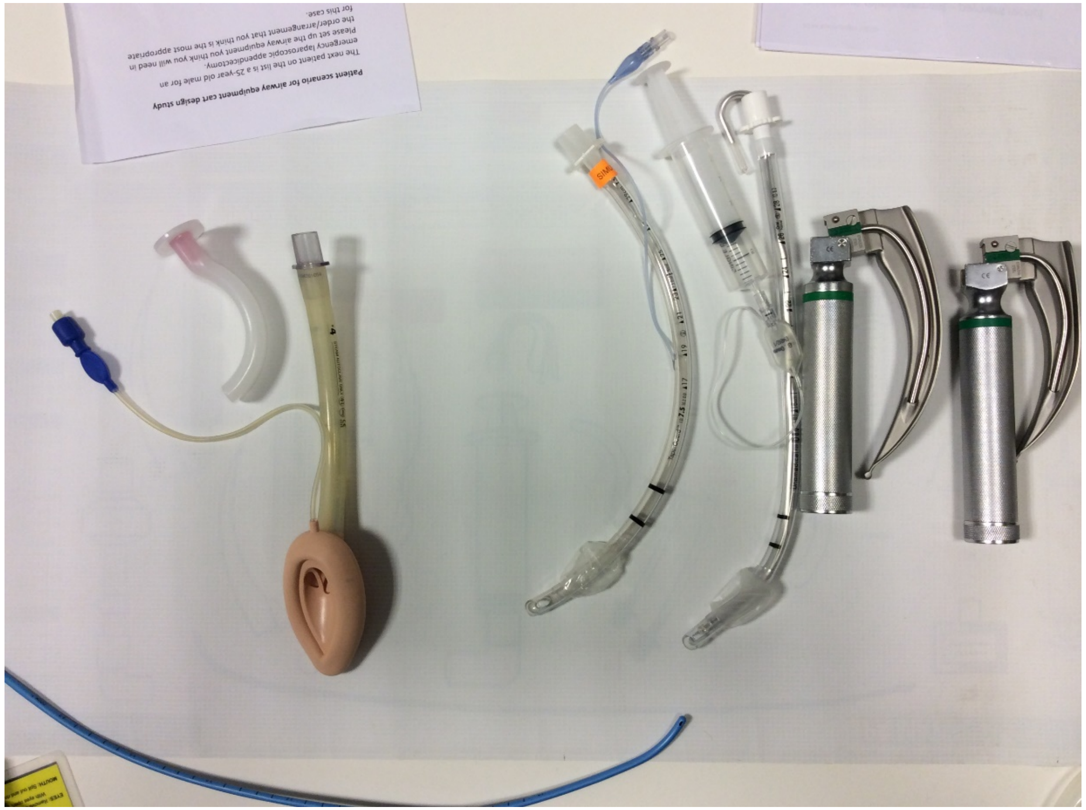

**Photo 2.2**. Equipment if there would be a separation (left would be back up, i.e. the bottom), right would be primary

**Participant 3 – Anaesthetic nurse**

| Design requirements/user needs for airway cart | Design requirements/user needs for airway cart | Associated Human Factors design principles (adapted from Nielsen, 1994 and |
|---|---|---|

| | | |
|---|---|---|
| | | Shneiderman, 1998 in Zhang et al, 2003); Nielsen (1994). |
| - Dedicated airway trolley good idea because at the moment there is only one draw in [the anaesthetic] trolley dedicated to airway stuff and that's the third draw down and it is so cramped that if you are trying to find something especially in a hurry it's almost impossible, you have to pull out like 50 things to get what you're looking for | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility*** |
| - Trolley you take to the patient is a lot better because you can set it up in your own way, you know where everything is and you don't have to look for things and I can just reach my arm out and grab a guedal and can just reach whatever I need. Although a lot of times people move that trolley while you try and concentrate on the airway and then it gets a bit of a mess sometimes | Flexibility and standardisation trade off<br>Layout, categorisation and visibility<br>Proximity and accessibility of airway equipment | ***Flexibility and efficiency of use***<br>***Categorisation, consistency and standardisation, visibility***<br>***Accessibility requirement*** |
| - Set up: Guedals in the right back corner of it, then I would have in the left hand left corner I have lubricants, extension and all that sort of stuff that may be needed, and then I have the dirty kidney dish with the laryngoscope either size 3 or 4 depending on if they are male or female, the tube and the syringe and then underneath the trolley I have space LMA's and a tube size down so if we run into trouble we have LMA's ready to go | Layout, categorisation and visibility<br>Separation of primary and back up equipment | ***Categorisation, consistency and standardisation, visibility***<br>***Minimize*** |
| - Like the separation because underneath is the stuff you are only going to use if the first line fails, it's kind of like first and second line. I know that it's under there and you can see it and it just makes it easier because a lot of the time you are holding the mask while you are trying to get something so it's easier to have it right there | Separation of primary and back up equipment | ***Minimize*** |
| - Guedals are in sort of 'take away' container, puts the one he needs standing up in the front so he can see colour and yellow one behind (?). Also avoids equipment rolling off | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation, visibility*** |
| - Kidney dish is really important to have because equipment used shouldn't contaminate other equipment and you can also | Separate contamination area | ***Hygiene requirement*** |

| | | |
|---|---|---|
| just carry the kidney dish if you need it, for example if the cart is behind you, you can just grab it. Thus, sometimes you can't even see the trolley because it's behind you | | |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Because there is space limitations it also can't be too big | Space to grasp equipment versus general space constraints. | ***Space requirement*** |
| - Participant is a bit 'ocd' so has everything in order so he can just grab immediately what he needs without even looking | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility*** |
| - Therefore also only wants absolute necessary equipment on top of trolley | Separation of primary and back up equipment | ***Minimize*** |
| - Equipment preparation based on own experience, looks at patient list beforehand | Flexibility and standardisation trade-off | ***Standardisation to support low experience*** |
| - Anaesthetist usually only tells you what they want once the patient is wheeling in, so you need to have it there already | Proximity and accessibility of airway equipment | ***Accessibility requirement*** |
| - It would be beneficial to improve the design of the trolleys because at the moment there is no regulated way of doing things, especially when you take over from someone they have just everything and you don't even need and you try to find a guedal and there is just so much stuff | Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation*** |
| | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility*** |
| - People get everything out on the trolley and participant doesn't like it because especially in a hurry and you need something quickly you gotta be able to just look and grab it | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| | Separation of primary and back up equipment | ***Minimize*** |
| - At the moment the airway trolley is not dedicated to airway really, everyone wants to use the trolley (scrub nurses) and they sort of 'fight' over it and most of the time during the case the airway equipment is moved away and scrub nurses use it. | Accessibility and proximity of airway equipment | ***Proximity compatibility principle*** |

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| Once you finished with induction scrub nurses often dismantle the trolley and put your stuff somewhere else, which isn't great. You don't really need it after you induced the patient, but when it comes to extubation you need it again and you don't know where anything is | | |
| - Thus, a dedicated airway trolley would be really helpful and something build in so we don't have to use denture cups | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| - It would be helpful to have draws attached to the airway trolley which everything you need, i.e. separate draws for LMA's and tubes because at the moment everything is cramped into one draw in the anaesthetic trolley so if you need something extra you need to pull out 50 other things first to find what you are looking for | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| - Problem: no funding to buy trolleys (few hundred dollars per trolley) | - | - |
| - Plastic tray on top could help that could be moved away because equipment keeps together because participants had moments where equipment wasn't kept together | Proximity and accessibility of airway equipment | ***Accessibility requirement; accessibility compatibility principle*** |
| - If unexpected difficult intubation and they could bag mask he would run and get the difficult intubation trolley which lays out the steps from top to bottom which really helps because it guides which draw to open to get out the CMac etc. | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| - Thinks the steps etc not necessary for routine airway equipment because it's too much, you don't need that | - | - |
| - If you would have grooves on the plastic surface it would help because it wouldn't dictate what people have to do, they just use what's in front of them and they can set it up in their own but at the same time it would still keep the uniformity between everyone | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility*** |
| | Standardisation and flexibility trade off | ***Categorisation, consistency and standardisation*** |
| - Could make an extra groove for equipment that only a few people would put at the top and they could still decide if they want to fill it (participants idea) | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |

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| - You definitely need a space for the dirty equipment because of saliva and blood: clean and dirty area | Separate contamination area | ***Hygiene requirement*** |
| - In a stressful situation you just want to chuck the equipment (that didn't work) behind you and forget about it. | TBD | - |
| - Alert to call for help on the surface may be helpful: not many people call for help, only if you can't bag mask | - | - |
| - Likes colour coding | - | - |
| - Although there is not too much equipment needed, participant likes idea of templates for novices and juniors to visually remind them what they need in each case. Especially when you just have one after the other, for preparation but also as a visual cue. A lot of people get caught out for not having the back-up equipment there, for example the bougie. We have a high turnaround with new staff | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility; recognition rather than recall*** |
| - Reckons you can just lay equipment on top of the templates, which would be helpful. After more probing participant said it would be useful to have grooves in the shape of the equipment to prevent equipment from moving and falling off the trolley | Layout, categorisation and visibility | ***Visibility, recognition rather than recall*** |
| | Equipment shouldn't move or easily fall off trolley | ***Physical environment requirement*** |
| - Because a lot of people know the equipment but they don't know why people are asking for it, they just know it's there. So it would be helpful to have some extra notes on the surface such as 'can't ventilate' that would be helpful for the new staff. Although problem with too much information on the surface | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; recognition rather than recall*** |
| - Has not heard of vortex or used it, but after explaining it he said that's kind of like the difficult intubation trolley organisation | - | - |
| - He thinks difficult intubation trolley is useful if staff understands why certain steps are actually needed on the trolley, not only the steps themselves | - | - |
| - In terms of categorisation he would always have equipment that belongs together very close together, for example intubation equipment are close together in the dish, and the | Layout, categorisation and visibility | ***Proximity compatibility principle; categorisation, consistency and standardisation*** |

| | | |
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| guedals are always together etc., bougie always taped to the side. Separate groove for back up face mask on bottom and one for LMA's. Would actually only have two LMA's | Separation primary and back up equipment | ***Minimize*** |
| - Wouldn't have nasopharyngeal airways out, they are in the anaesthetic trolley. He would have them out for extubating in case they are extubating deep. For the extubation he wouldn't set up the surface again but only take the bougie, and the face mask. | - | - |
| - Improvement of airway trolley would be helpful for visual reminder to replace equipment and see a spot is empty, thus for preparation mainly. Also having a visual cue of what the next step is to transition, for example seeing the guedal then. | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility; recognition-rather than recall*** |
| - A lot of people just take the kidney dish next to the patient and don't even take the trolley with one guedal in it and the intubation equipment. | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Thus most people like to minimalize but have back up equipment visibly available | Separation of primary and back up equipment | ***Minimize*** |
| | Layout, categorisation and visibility | ***Visibility*** |
| - Separates equipment in corners, participant likes to keep things as separated as possible, but everyone does it differently. He likes it in the corner so when he can't see the trolley he can just reach around and grab it. A lot of people just chuck it all together in the back and have the dirty stuff in the front. It just gets too much! | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| - A lot of people don't do it linear or in any order or separated, as long as everything is on the top, that's how they do it. Participant thinks separation could help them because a lot of the time it's the same and nurses get flusted and because there is no order and no control so people start freaking out and they don't know where to look and they start getting yelled at and it's just this vicious cycle, like a big snowball effect. | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| | Separation of primary and back up equipment | ***Minimize*** |
| - Most things go wrong after hours when there is no support | - | - |

| | | |
|---|---|---|
| - And people are tired during shift work and then it gets to a point where you need stuff to just be procedural, where you don’t have to think about it. And that set up would help. Minimize and in the order of what you are going to need and you know that doesn’t matter what you need and which theatre you are going to go it’s there already. Things you need the most, and back up equipment. And there is not too much standard airway equipment. You can swap pieces of equipment for different surgeries. | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation, recognition rather than recall*** |
| | Proximity and accessibility of airway equipment | ***Accessibility requirement*** |
| - Thinks it’s a good idea to uniform it a bit more, especially for handover and it takes you a little while to know where everything is and that trolley could help to make it easier. ‘You just need to able to go in, know what’s going on, and get out […]’. Would help second responders to know what person is up to, especially in those emergency situations where there are two anaesthetists talking to different people, but we are all using the same trolley. Thus having it separated and clear would help very much | Layout, categorisation and visibility | ***Categorisation, consistency and standardisation; visibility*** |
| - Says it would be good to have registrars on board too to get their views | - | - |

**Photo 3.1.** Left side bottom shelf (back up), right side top with bougie taped to the side and intubation equipment in dirty kidney dish.

**Participant 4 – Anaesthetist**

| | **Design requirements/user needs for airway cart** | **Associated Human Factors design principles** (adapted from Nielsen, 1994 and Shneiderman, 1998 in Zhang et al, 2003); Nielsen (1994). |
|---|---|---|
| - Standardizing layouts is helpful, particularly in emergencies and make sure things aren’t missed | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation; visibility; recognition rather than recall.*** |
| - Difficult thing is how to do it as their have their special way of doing it and they don’t like to be told how to do it in a different way | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Standardisation of equipment is not a foreign concept and you could use knowledge and ideas of people to incorporate | - | - |

| | | |
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| - Doesn't need guedals and LMA's but would like to know it's there just in case there is difficulty with ventilating | Layout, categorisation and standardisation | ***Visibility*** |
| - Set up depends on where anaesthetic nurse stands, tailored to the nurse | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Puts things unlikely to be used in bottom draw | Separation primary and back up equipment | ***Minimize*** |
| - Leaves things in plastic wrap | Account for equipment that is still in package (to avoid waste) | ***General requirement*** |
| - Plan A: What I am expecting to use, Plan B: different sizes and introducer, plan c: rescue techniques if things get out of control. Sort of three categories | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Thinks trolley needs to be a bit higher for nurses, especially bottom shelf. Would put back up equipment there because she would know that equipment is nearby/within the trolley | Proximity and accessibility of airway equipment | ***Accessibility requirement*** |
| - Wouldn't put everything on the top because it is big and the trolley gets crowded | Separation primary and back up equipment | ***Minimize*** |
| | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| - Happy with sections because it may be easier to find what I want, rather than getting everything 'in my face'…similar idea to the difficult airway trolley | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Likes to tape the bougie on the side so it cannot fall off and it can be opened quickly when it's still in wrap | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation; visibility*** |

| | | |
|---|---|---|
| - Puts equipment in sequential order, makes sense to her but its' more important for the anaesthetic nurses than for her. It doesn't really matter to her how it is laid out as long it is all there and there is some sort of checklist. Probably likes back-ups on the bottom stuff because she finds it easier if there is less (i.e. have two trays), but it depends more on the nurses what they like. | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation; visibility*** |
| | Separation primary and back up equipment | ***Minimize*** |
| - Likes idea of kidney dish where used equipment gets put in | Separate contamination area | ***Hygiene requirement*** |
| - Needs sticky tape etc. too | - | - |
| - Trusts anaesthetic nurse in terms of set up, nurses are often proactive. Usually scans that there is back-ups but is not too diligent with the checks, gets complacent with nurses because it works so well most of the time | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Standardizing a bit more would be useful for completeness of preparation | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Many other places don't have airway trolleys, they just put equipment on the anaesthetic machine or on top of the patient | - | - |
| - Trolley is helpful though because it is a preserved place for airway equipment, but many operating theatres are small and often there isn't much space | Accessibility and proximity of airway equipment | ***Proximity compatibility principle*** |
| | Space to grasp equipment versus general space constraints | ***Space requirement*** |
| - Likes ideas of sections on the tray | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - It would be good to have the masks grouped together and LMA's etc., but there is the issue with separating contaminated and clean equipment, but depends if you got them out of the packet or not | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| | Account for equipment that is still | ***General requirement*** |

| | | |
|---|---|---|
| | in package (to avoid waste) | |
| | Separate contamination area | ***Hygiene requirement*** |
| - Separate area for contaminated equipment would be good | ***Separate contamination area*** | Hygiene requirement |
| - It would help to see what you have already tried and didn't work to move on, but sometimes you move back and forward but you would still know which was plan a and which was plan b when you put it somewhere else | TBD | TBD |
| - Other hospitals use bowls which is good because it prevents equipment from falling, bowl is good for contamination | Equipment shouldn't move or easily fall off trolley | ***Physical environment requirement*** |
| - Does not pay too much attention to the airway cart | - | - |
| - Standard lay out like a shadow board would be useful, but not for every case because some cases are more complex than others | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Having a lay out almost forces a check, because it's a visual cue and it's much easier than a checklist. Likes the idea of using that, putting everything down in the beginning of the day and then put it aside and set up for the particular case | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation; recognition rather than recall, visibility*** |
| - Would find it useful for herself for preparation and check, not necessarily for during the case because it is mostly up to anaesthetic nurses to know where things are. But it would be useful to know for the confidence. Nurses who are experienced get onto things pretty quickly so not sure if it would be needed to improve | - | - |

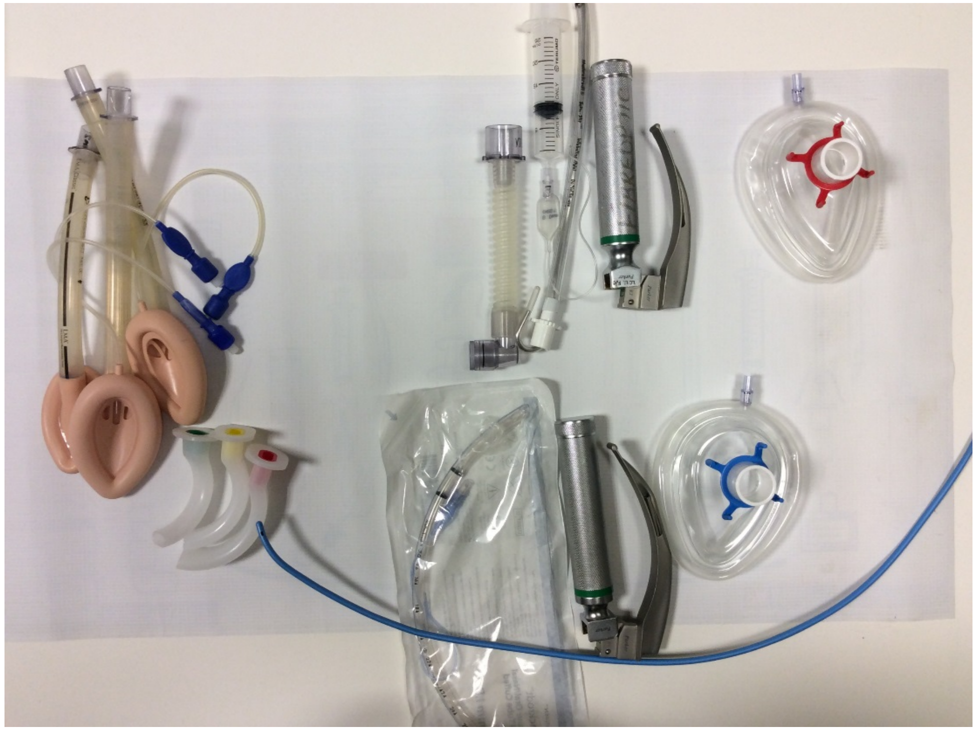

**Photo 4.1**. Left rescue on bottom shelf, top first line approach, bottom second line approach

**Participant 5 – Anaesthetic nurse**

| | **Design requirements/user needs for airway cart** | **Associated Human Factors design principles** (adapted from Nielsen, 1994 and |
|---|---|---|

| | | |
|---|---|---|
| | | Shneiderman, 1998 in Zhang et al, 2003); Nielsen (1994). |
| - ‘I always set up in order, just in case I gotta run out, they crash, you have to relief me, I have got it all in order’ | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation; visibility*** |
| - Always look at male/female and kg’s and then potentially swaps sizes on the go | - | - |
| - Nasopharyngeal always in second draw in anaesthetic machine, but wouldn’t put them out. | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| | Separation of primary and back up equipment | ***Minimize*** |
| - Underneath on the bottom three plastic dishes with the guedals, different tapes, eye ointment, trackie tape etc. | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| | Separation of primary and back up equipment | ***Minimize*** |
| - Always puts guedals up to see colours. Right guedal at the top shelf | Layout, categorisation and standardisation | ***Visibility*** |
| - Wouldn’t use the stillet unless it’s a flexible tube or anaesthetist asked for it | - | - |
| - Bougie always on the side on the trolley | Layout, categorisation and standardisation | ***Visibility*** |
| | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Alfred Centre does not have this trolley, so if something goes wrong I have to leave anaesthetist to go to anaesthetic machine to grab stuff. So at least with this trolley I have one hand so I can reach the trolley and grab it. ‘*I can’t survive without it, you can’t leave’* | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| | Flexibility and standardisation trade off | ***Flexible and efficiency of use*** |
| - Anaesthetist can’t look up, he is occupied with the airway, so can’t see whatever you put in his hand | - | - |
| - Likes that stuff is in anaesthetic machine because it’s close to you, but definitely would like it to have in the airway trolley but needs a different trolley | Accessibility and proximity of airway equipment (strongly prefers own trolley) | ***Accessibility requirement*** |

| | | |
|---|---|---|
| - Anaesthetist may need to go down sizes so you need to know where equipment is | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation; visibility*** |
| - So in the Alfred Centre they have to cluster all the equipment around the patient because they don't have a trolley. | - | - |
| - So I have everything on my trolley so I don't have to leave him | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Has LMA's in the bottom shelf (second shelf) for the whole day if something goes wrong | Accessibility and proximity of airway equipment (accessibility of back up equipment) | ***Accessibility requirement*** |
| - Always separates | Separation of primary and back up equipment | ***Minimize*** |
| - Sometimes cases are moved between theatres and another case comes in and then he can just swap sizes, so that's not too hard 'my common sense does this, within 30 seconds', or if patient is bigger or smaller than expected. Therefore it's helpful to have everything in one place | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Always set it up organised because person coming in to help sees immediately what they are up to and can take over, even a junior | Layout, categorisation and standardisation | ***Visibility*** |
| - Doesn't know how other people work because you work autonomously but you would think 99.9% does it like this because you have to | - | - |
| - If you don't have a trolley, like in the Alfred centre, you need to put it all together but he always gets himself a trolley anyway. And if you have to switch it's really hard to see for the other person what equipment they got if it's all put together | Layout, categorisation and standardisation | ***Visibility*** |
| - It would be great to have all the equipment in one trolley, and have the second shelf as a draw because it is a fair way away to get to the anaesthetic machine to get stuff with all the cables and tubes and the patient in the way and you can't walk around because you just don't have the time | Proximity and accessibility of airway equipment | ***Proximity compatibility principle, accessibility requirement*** |

| | | |
|---|---|---|
| - You don't know how people get taught because everyone does it different, and sometimes a reasonably junior teaches a junior so they may not get the best strategies | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| | Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation*** |
| - Is positive about the idea of templates/slots as a baseline and reminder/visual cue, it's already done like this in the emergency and its great having it all laid out as the patient rolls in. | Layout, categorisation and standardisation | ***Visibility*** |
| - Likes the idea of a plastic tray with the slots to organise equipment. | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - You still want the nurse to analyse though and don't want the nurse to become a 'template nurse' but that's experience | Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation*** |
| - Laying out equipment in order really important for transitions | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Puts guedal in back because it's not needed most of the time, but it's still there | Proximity and accessibility of airway equipment (having everything in the same space; accessibility of back ups) | ***Accessibility requirement*** |
| | Separation of primary and back up equipment | ***Minimize*** |
| - You have lots of things to trip over in operating theatre, which is why he sets it all up and have it all in one place | Proximity and accessibility of airway equipment | - |
| - He always sets up his trolley first thing in the morning and he literally cannot look at it and knows where everything is | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Other people have set up in similar way when he came in as a second responder, 'you would be mad not to' | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Knows what equipment patient need because of experience, juniors need to be more directed. Juniors hopefully prepare like that too because it is quite common sense | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |

| | | |
|---|---|---|
| - Prepares equipment at 7:30 in the morning religiously, so always knows where everything is, knows when he grabs in the back on the bottom shelf there is the fifth LMA | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Junior nurses not as anticipatory, it's experience | - | - |
| - Set up would help especially junior nurses to have equipment sequential, it's no good to having that stuff all over the shop | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Doesn't think it's good when there is a lot variability, not for junior nurses. | Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation*** |
| - '*Some people have all of this stuff in their yellow kidney dish, which would send me to drink. Because I don't know what you've got in there, it's a mess.*' | Layout, categorisation and standardisation | ***Visibility; categorisation, consistency and standardisation*** |
| - Participant has only laryngoscope in the kidney dish because it is passed back to him dirty, puts dirty mask in there too. Kidney dish is really important, wouldn't put equipment back on the trolley | Separate contamination area | ***Hygiene requirement*** |
| - During the case top becomes dirty area, puts all dirty in the kidney dish on the left. So, there isn't much left on the trolley because most of it is on the patient. | Separate contamination area | ***Hygiene requirement*** |
| - Has all equipment back up ready in the glass cabinet for the next cases. | - | - |
| - Would like a reminder to call for help on the template in red or something in the corner on the right hand side | Reminder to call for help | - |
| - Always earmarks bell, surgical airway kit and powerpoints in different theatres | - | - |
| - Thinks new set up would be helpful for less experienced nurses to prevent forgetting items | Layout, categorisation and standardisation | ***Recognition rather than recall; Categorisation, consistency and standardisation*** |
| - ICU and ED have all their equipment there and they have a 'crash cart' | - | - |
| - Likes colour coding in general, like the paediatric trolleys which is colour coded according to weight but nothing like that in mains. He finds that very helpful and it's set up sequentially like he does it too. | - | - |

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| - Wants visibility on the bottom shelf and he can see bottom shelf with his left eye | Layout, categorisation and standardisation | ***Visibility*** |
| - Always looks what he has to replace after the case | - | - |
| - Would like all the equipment in the airway cart but would need to have four tiers, you wouldn't have to walk over to the anaesthetic machine. | Proximity and accessibility of airway equipment | - |
| - Why aren't trolleys improved?: 'We need more research, we need people like you to innovate these trolleys'. | - | - |
| - Junior nurses wouldn't know what's in all the draws. | Layout, categorisation and standardisation | ***Visibility; recognition rather than recall*** |

**Photo 5.1.** Right side is first approach, left side is bottom shelf with dishes and LMA's

**Participant 6 – Anaesthetist**

| | **Design requirements/user needs for airway cart** | **Associated Human Factors design principles** (adapted from Nielsen, 1994 and Shneiderman, 1998 in Zhang et al, 2003); Nielsen (1994). |
|---|---|---|
| - Doesn't like airway trolley as it stands, always had equipment on the anaesthetic machine reachable to him, important if you need it in a hurry, especially the laryngoscope. He wants to be able to just grab them quickly without asking someone to hand them over | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Finds it annoying that the nurse has the laryngoscope | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Depends who he is working with, but he prefers to have the basics (laryngoscope, LMA, tube, guedal) on the anaesthetic machine just in case | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Some people consider it as wasteful but it would simplify things if you need help with a patient, you don't need to reach over to get the trolley or get the nurse bring it to you | | - |
| - Impacts work flow more than decision-making | - | - |
| - Comes from a different era, where things were different, nurses less involved. Nowadays, nurse claims ownership of the airway trolley and airway equipment is moved to the trolley from the anaesthetic machine, which makes it hard to access equipment in a hurry as the anaesthetist due to the set up in the operating theatre (trolley behind anaesthetic nurse which stands on 45 angle to anaesthetist, with | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |

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| anaesthetic machine between them). So if you want something in a hurry or if something goes wrong in the middle of the case (i.e. LMA dislodges) and the nurse is doing something else or is on a tea break, it's quite cumbersome because you need to walk around the machine to access it. It doesn't happen very often but it isn't readily accessible to the anaesthetist. It would be readily accessible on the anaesthetic machine | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Location of airway trolley could be changed according to participant (but never is) | - | - |
| - Theatre is cramped for access anyway, because it has a video tower in it that isn't moved as well (left to anaesthetist) | Space to grasp equipment versus general space constraints | ***Physical environment requirement*** |
| - Puts equipment on the anaesthetic machine himself (has a 'friendly fight' with the nurse): laryngoscopes, tube and LMA | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Has second tube open in a packet | | - |
| - Equipment could routinely be put on anaesthetic machine, but they are taken off and put on the trolley because otherwise you would be duplicating a lot of the equipment. There is equipment shortage with the laryngoscopes hence you can't duplicate. You have two laryngoscopes usually in case one fails | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| | Flexibility and standardisation trade off | ***Flexibility and efficiency of use*** |
| - Reaching over the airway trolley also increases risk of equipment falling on the ground. | Equipment shouldn't move or easily fall off trolley | ***Physical environment requirement*** |
| - Spare equipment is often in a packet and ripping that open takes time | - | - |
| - Problem with nurses, you get assigned by the roster and you don't know who you will work with and you may be working with a junior nurse who does not have much experience. There is also a high turnover. And you don't want to have the junior nurse there when 'all the wheels fall off' | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |

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|---|---|---|
| - The design of the airway trolley could support junior anaesthetic nurses: you just need to have a few things on the top, the ones that are commonly used; packaging hard to open and in a crisis you don't have the time or nurse not familiar with the packaging. | Layout, categorisation and standardisation<br>Separate primary and back up equipment | ***Categorisation, consistency and standardisation***<br>***Minimize*** |
| - You gotta plan for the lowest common denominator when it comes to nurses, it's a teaching hospital; same thing for anaesthetic registrars | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Some of the anaesthetic nurses are fantastic; almost as good as the registrars, they know what you need and they'll get it and they anticipate what the situation will be like, but if the nurse is junior, or they are on the tea break, you have to use the circulating nurse who may not be very familiar with the equipment | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Main problem that trolley is not readily accessible. It does not sit on the anaesthetic machine because it gets in the way of the monitoring screen, and the anaesthetic record is on the other side (right side), patient monitoring on the left plus arm that takes cables and it's not easy to push them out of the way | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Could use surface of anaesthetists machine if it was bigger, and then you got the screens intruding on the space | - | - |
| - Different machines have different sized working spaces which makes it tricky. Usually there is an overhead tray on it as well with stuff on top. Participant sometimes put equipment on top of the anaesthetic machine but that's not feasible for small people | - | - |
| - Depending on the design of the machine you may be able to build a lazy susan that you can swing in and out, first for the anaesthetic nurse, then to the anaesthetist | *Design suggestion* | - |
| - Nobody really thinks about the problem if problems occur later on in the case, only during the start. | - | - |
| - You have spare tubes etc. stored in the bottom draws in the drug trolley, and it's an issue that the stock does not | - | - |

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| checked and re-stocked because you run out sometimes. Incredibly important task of anaesthetic nurses | | |
| - There are different locations where the airway equipment can get stored: airway cart, anaesthetic machine, drug trolley. Again, there is no consistency, especially between hospitals. Often there is no room for the airway gear next to cables etc. | Layout, categorisation and standardisation<br>Accessibility and proximity of airway equipment | ***Categorisation, consistency and standardisation***<br>***Accessibility requirement*** |
| - Extra draws mean extra cost. Participant would like some consistency. Not everyone is working full time here, there are quite a few VMO's that only work once a week at the Alfred and then work at other hospitals where anaesthetic machines are different. There is no consistency in buying policies for the public hospitals, you buy based on cost and past experience. | - | - |
| - Participant would like an airway trolley (rather than airway equipment on anaesthetic machine) that is readily accessible and that is there if you needed it later on. Currently it's too far away and it takes longer to get equipment and communicate with nurse who may not have much experience | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Patient's arm can be in the way, cables etc. and there is not lots of free space, pretty cramped | - | - |
| - Participant would like to see what's on/in the trolley, he never really knows what's in the draw (in airway trolley). Participant tries to check trolley before he starts but he doesn't always do that | Layout, categorisation and standardisation | ***Visibility*** |
| - Likes idea of swing out shelf for airway equipment, but is difficult in terms of space under anaesthetic machine. Bair hugger is also a problem and can't sit close to surgeons because they don't like it | *Design suggestion for airway equipment cart* | - |
| - Nurse always stands on right hand side to anaesthetist, although that doesn't make sense to anaesthetist since it doesn't accommodate left handed people. There is no reason nurse couldn't work from the left hand side and leave the trolley there, you could move video tower. | - | - |

| | | |
|---|---|---|
| - If you keep the trolley, participant would like to see some basic equipment on the top of the anaesthetic machine, 'just so you have some get out of jail equipment' (tube, LMA, laryngoscopes, couple of airways) | Accessibility and proximity of airway equipment (for both anaesthetists and anaesthetic nurses) | ***Accessibility requirement*** |
| - Doesn't know if nurses are opposed to it or if they haven't considered it. Everyone is legalistically minded, everyone is worried about getting sued when something goes wrong. Therefore there may be a resistance to change unless it's all been protolised. | - | - |
| - Participant talks about how recently he had to change the LMA because it wasn't fitting properly and he had to get another one from the draw (airway trolley) and open it and it all takes time when you want things to happen quickly. Patients can desaturate quickly. | - | - |
| - Participant not sure what nurse keeps on top of the trolley at the moment, there is no standardised top of trolley | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Opening a guedal airway actually takes quite a long time, you can't just 'pop it through'. You don't want to open it already in case you don't need that piece of equipment, because then you have to throw it out | - | - |
| - 'Nobody wants to be associated with a disaster', everyone feels guilty afterwards. | - | - |
| - We need to consider where the surface needs to be, if we need to leave it where it is | - | - |
| - There is no provision for left handed anaesthetists, they just have to 'suck it up' | - | - |
| - If participant would have it his way, he would be happy to have trolley on the other side (left side) and the tube in front of the patient so anaesthetist can pick it up. And nurse leave the trolley there, just in case you wanted it again | - | - |
| - Video towers are often in the way and are put in the back. '*Theatre design is hopeless. It is designed by people who never work in theatres'.* You have got to accommodate the work floor space you have got | - | - |

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| - Still happy about the tray that is accessible to both anaesthetic nurse and anaesthetist, doesn't like the idea of searching through the draws which is distracting from the task and it doesn't work. Also doesn't believe that every anaesthetist checks the content of the draws before they start. He tries but doesn't do it every time. It should always be stocked but lists overrun and in the end of the day the nurses should be stocking it for the morning, but that doesn't always happen. | *Design suggestion* | - |
| - In terms of equipment on surface: mask on the circuit and the valve down, likes two laryngoscopes (3 and 4) | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Likes to look at length of guedal airways not colours, has one of them out and the other ones in the package | Layout, categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| | Separate primary and back up equipment | ***Minimize*** |
| - Put bougie on the side just in case, taped on the side | Layout, categorisation and standardisation | ***Visibility*** |
| - Has a spare tube in the package at least on top of the machine (weather the nurse likes it or not) in case they drop the other one | Accessibility and proximity of airway equipment (accessibility of back up equipment) | ***Accessibility requirement*** |
| - You always have back-ups in the stock draw too | Accessibility and proximity of airway equipment (accessibility of back up equipment) | ***Accessibility requirement*** |
| - Likes most equipment on top, because you can see what's there, doesn't necessarily need separation of top and bottom. 'That's what I want to see…and I can say to the nurse: I want that'. Experience of nurses varies and you don't always have the most experienced one. 'Sometimes you got to make provisions for worst case scenario' (in terms of experiences) | Layout, categorisation and standardisation | ***Visibility; categorisation, consistency and standardisation*** |
| - Would like pretty much the same equipment on the anaesthetic machine. | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |
| - Some sort of slot or template would be reasonable to guide preparation of surface; could make some sort of | Layout, categorisation and standardisation | ***Recognition rather than recall; visibility;*** |

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| autoclavable. The other option would be to have a description on the side that guides people | | ***categorisation, consistency and categorisation*** |
| - Problem with equipment rolling off. The surface of the current trolley has a 'fence', but equipment can still roll through it. It doesn't happen too often though, where it happens is when the trolley itself is moved when someone else needs it and the trolley trips over a cable on the floor. That needs protection, or it in an area where it has unimpeded access between trolley, nurse and anaesthetist. It could be on the left hand side or between the head of the patient and the anaesthetic machine (but that limits accessibility to right arm, and the bair hugger comes in too as well as the pipe) | Equipment shouldn't move or easily fall off trolley | ***Physical environment requirement*** |
| - If you could put it on top of anaesthetic machine that would be ideal, but nurse cannot reach it (on the very top), unless it would be a swing shelf or put it on the anaesthetic surface (if deep enough; and there are different anaesthetic machines with different surfaces). There are issues with the left hand side too. Maybe the trolley needs to stay where it is. Different theatres are set up differently too depending on surgery | - | - |
| - If you could have a tray, like a tea tray that you can lift wherever you want to (start on anaesthetic machine then move it out of the way, or the other way round) that could work. | *Design suggestion for airway cart tray* | - |
| - Needs to fit on top of airway cart and also on top of the anaesthetic machine (can't be too deep). Tray can't interfere with access to the controls. You can then divide the surface into areas | Size requirement airway surface | ***General requirement*** |
| - It has to be something simple that people can agree too. | - | - |
| - Nurses are often very short staffed and don't turn up and then you have to work with what you've got and then you want to have something easy | Layout, Categorisation and standardisation | ***Categorisation, consistency and standardisation*** |
| - Standardisation will help, but it's different. '*Different strokes for different folks'* | Flexibility and standardisation trade off | ***Categorisation, consistency and standardisation;*** |

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| | | ***flexibility and efficiency of use*** |
| - Other people have problems with the current airway cart too, but we had to adapt to it | - | - |
| - He comes from an era where it was much simpler, less equipment etc. | - | - |
| - Needs space for contaminated equipment | - | - |
| - Maybe you can negotiate that right arm isn't that important (and most of the time its next to the side anyway) and you can put the trolley there, still much better than how it is done currently, which is not accessible. The trolley has to probably stay on the side for right handed anaesthetists but you need to access it and right arm is of secondary importance. You need to standardise the top and have it there and keep it there (between patient head and anaesthetic machine). | - | - |
| - Again, sometimes you need something from the trolley and the nurse can't help you and then you need to walk around and it all takes time. | Accessibility and proximity of airway equipment | ***Accessibility requirement*** |

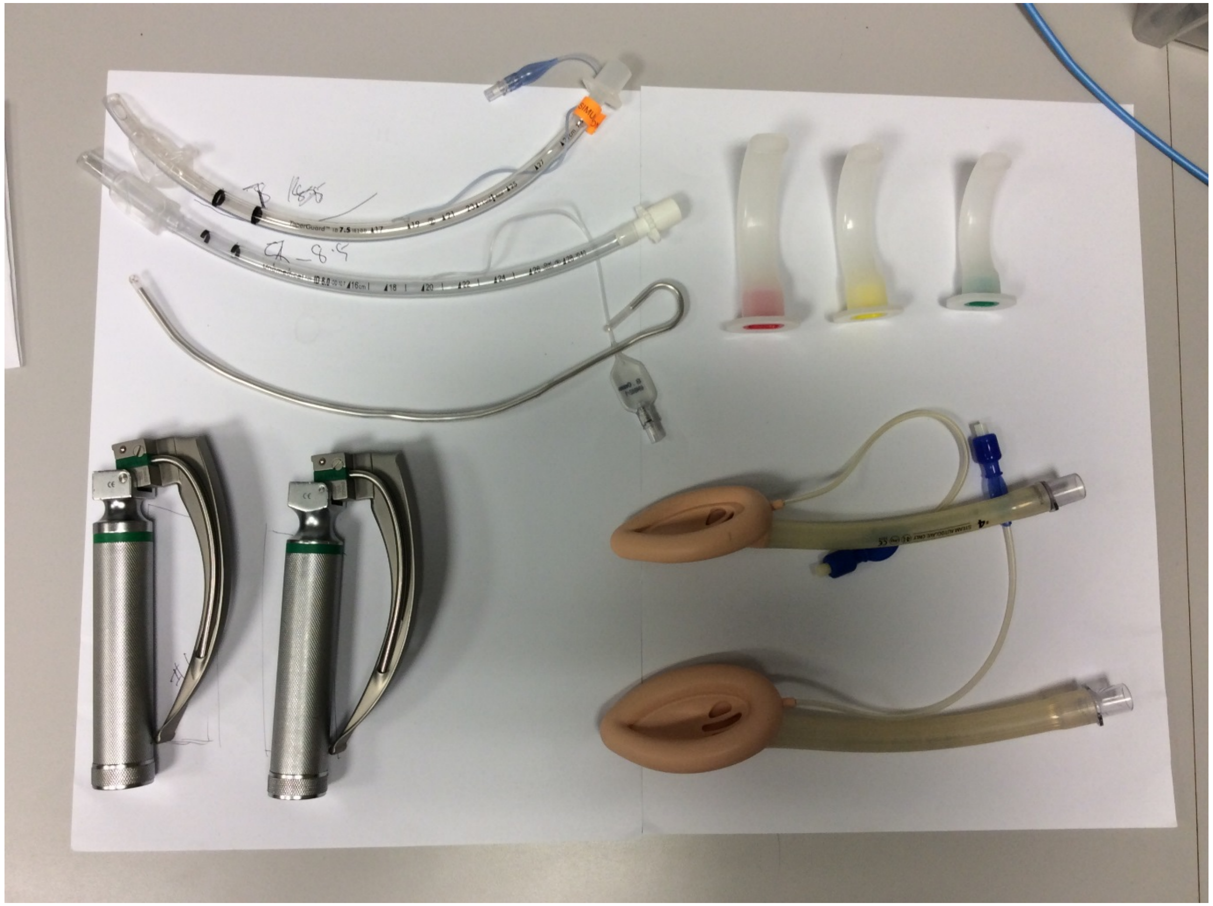

**Photo 6.1**. Set up of the top shelf

## 11.5 Appendix 5

### Detailed description of design requirements for airway equipment tray

Below, the detailed description of the design requirements for the airway equipment tray are presented. The description format was adapted from the Situated Cognitive Engineering approach (Neerincx & Lindenberg, 2008)

#### 1. Surface dedicated for airway equipment

| ***REQUIREMENT 1*** | **Surface dedicated for airway equipment** |
|---|---|
| ***Supports decision or function*** | **Preparation and retrieval of airway equipment** |
| ***Description*** | Participants discussed the need of having an area in the operating theatre that is dedicated for airway equipment. Current airway cart used is not dedicated to airway equipment and used for other purposes during surgery (airway equipment is moved elsewhere, no consistency). Ideally an improved version would be a cart with a few different draws but in general a surface that keeps airway equipment together and accessible is desired. It will be moved around due to the nature of the anaesthetic environment so it needs to be 'foolproof' for that (see requirement 5). Also, it was discussed that the current airway cart is currently mainly accessible by the anaesthetic nurse. An airway surface that is readily accessible by both anaesthetist and nurse is desired. |
| ***Evidence*** | - Airway cart design study interviews<br>- Proximity and accessibility (HF principle); proximity compatibility principle |
| ***Realisation*** | - Plastic surface for airway equipment that can be flexibly moved and put on a variety of flat surfaces (including the patient), and thus be accessible by both anaesthetic nurse and anaesthetists and does not get in the way of other technology |

| | |
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| | - Size: can't be much bigger than current airway cart used or other surfaces such as the anaesthetic machine (see requirement 7). Surface cannot interfere with access to controls<br>- Clear plastic surface that can be wiped down with disinfection fluid (i.e. does not need to be autoclavable necessarily unless going to be used in a sterile field such as intubation of neonate (EXIT procedure) or trachesteomy |
| ***Constraints*** | The development of a full airway cart with draws will be restricted by funding, thus an airway surface that is flexible and can be put on different surfaces if needed presents a feasible alternative. |

**2. Separation of primary and back up equipment**

| **REQUIREMENT 2** | **Separation of primary and back up equipment** |
|---|---|
| ***Supports decision or function*** | Preparation and retrieval of airway equipment |
| ***Description*** | Participants would like to be able to separate equipment according to priority. Primary airway equipment should be able to be at the top, whereas back up airway equipment should be able to be stored on a second shelf, separate from the primary airway equipment. Most participants prefer this because it minimalizes clutter,confusion and it also makes it easier to grab equipment if there is a bit more space (see requirement 6). Back up equipment still needs to be in arm reach, easy to grab and ideally be visible to participants as a visual cue and reminder. |
| ***Evidence*** | - Airway cart design study interviews<br>- HF principle 'minimalize' |
| ***Realisation*** | - Surface that has two separated areas for primary (top) and back up (bottom). I.e. a plastic tray that can be put on top of airway cart so equipment can be put on top and underneath |

| | |
|---|---|
| | - Clear plastic so the underneath is visible |
| ***Constraints*** | Provide flexibility in how equipment can be separated (or not separated) according to individual preferences |

**3. Layout, categorisation and visibility**

| **REQUIREMENT 3** | **Layout, categorisation and visibility** |
|---|---|
| ***Supports decision or function*** | Preparation and retrieval of equipment |
| ***Description*** | Participants categorised their equipment according to the plan and grouped pieces of equipment together according to the method. For example, equipment pieces related to intubation (laryngoscope, endotracheal tube, connector) where always grouped together. Primary airway devices where put in the front, where-as adjuncts like to be used in the back or on the side (e.g. guedels and boogie's). Space for lubricants, tape etc. is required too (which was not included in the study). |
| ***Evidence*** | - Interviews airway cart design study<br>- HF principle 'Consistency and standardisation', 'Recognition rather than recall', 'Visibility', 'system matches real world' |
| ***Realisation*** | - Airway equipment is laid out on airway surface to increase visibility of available and already used equipment (visibility)<br>- Sections for each airway method that are clearly separated (categorisation)<br>- Sections divided in quarters and not sequentially to avoid prescribing a particular sequence (flexibility)<br>- Section for each airway method has (vague) shape of airway method and black and white sketch of airway to aid preparation (black and white clear sticker |

| | |
|---|---|
| | placed on bottom of groove from the outside). (recognition rather than recall, system matches real world)<br>- Standardised set up will assist grasping equipment even if airway cart is behind nurse |
| | ***pecific set up requirements for surface (based on interview study and equipment layout activity):***<br>- Section for Guedels makes them stand up in order according to their size so that their colour can be seen (visibility, recognition rather than recall). Guedal section in the back of the surface<br>- One section for laryngoscope(s), tube(s), syringe and connector<br>- One section for LMA's (in the back)<br>- Other back corner space for lubricant, tape, eye ointment, extensions etc (but can be put under surface too)<br>- Bougie is always taped to the side of the cart (or the airway surface) as this is done in the same way by virtually everyone |
| ***Constraints/challenges*** | - While offering a more standardised lay out, still provide some flexibility as to how equipment is laid out as this differs according to surgery, patient and clinician's preferences<br>- Airway equipment is often not opened and left in package (as sometimes it may not be needed). Sections need to be big enough to accommodate the airway equipment in the packages; thus provide option to leave equipment pieces unopened in packaging |

4. **Flexibility and standardisation trade-off**

| **REQUIREMENT 4** | **Flexibility and standardisation trade-off** |
| --- | --- |
| ***Supports decision or function*** | Preparation and retrieval of airway equipment |
| ***Description*** | Clinicians need to be able to flexibly adjust what they want on the bottom or top shelf of their trolley, because everyone has individual preferences. Some like more equipment at the top, whereas others choose to minimalize. Still, especially for handover, some standardisation should be given to make handovers easier and support clinicians in recognising what the person in charge has been up to. |
| ***Evidence*** | - Interviews airway cart design study<br>- HF principle 'User control and freedom', 'Flexibility and efficiency' |
| ***Realisation*** | - Airway surface that has a degree of flexibility on how it can be prepared, i.e. if back up equipment is put on the top or bottom. Furthermore, it shouldn't force equipment groups to be prepared in a certain sequence as this can differ per surgery, patient and individual preferences |
| ***Constraints*** | Trade-off between providing flexibility but yet standardise to support uniformity |

5. **Proximity and accessibility of airway equipment**

| **REQUIREMENT 6** | **Proximity and accessibility of airway equipment** |
| --- | --- |
| ***Supports decision or function*** | General work flow, accessing airway equipment quickly and easily |
| ***Description*** | Ideally, all airway equipment should be in the same space so they don't have to move between airway cart and anaesthetic machine. Currently, some pieces of equipment are stored in the anaesthetic machine (extremely cramped and it takes some time to |

| | |
|---|---|
| | find what you need- which is not optimal especially in a hurry), others are in the stock cabinet and the most immediate equipment on the airway cart, prepared by the anaesthetic nurse. It would be handy if the airway cart would have some additional draws under the two shelves where all airway equipment can be stored. |
| ***Evidence*** | - Airway cart interviews |
| ***Realisation*** | Provide airway carts with more draws, although this would not be part of the airway surface itself but the whole cart. |
| ***Constraints/Challenges*** | Departmental funding is limited and may constrain the purchase of new airway carts to accommodate this requirement Therefore, a plastic surface but no full airway cart will be designed. The plastic surface needs to have the flexibility of being placed on any surface and moved between them, or even into another room to aid preparation. Ideally, two trays per theatre – one active for current patient, one ready to be set up for next patient |

**6. Airway equipment shouldn't move or easily fall off trolley (Physical environment requirement)**

| **REQUIREMENT 5** | **Airway equipment needs to be held in place** |
|---|---|
| ***Supports decision or function*** | General work flow |
| ***Description*** | Airway equipment is fairly light and can easily fall off the cart when the cart is moved (which often occurs). |
| ***Evidence*** | - Airway cart design study<br>- Knowledge of the nature of the anaesthetic environment through observation |
| ***Realisation*** | - Grooves/indented areas that hold airway equipment in place |

| | |
|---|---|
| | - Have a 'fence', i.e. slightly elevated on the outside to make sure equipment cannot fall off |
| ***Constraints/Challenges*** | Grooves/indented areas need to be able to be easily cleaned between cases; therefore it should not have acute angles |

**7. Space to grasp equipment versus general space constraints**

| **REQUIREMENT 7** | **Space to grasp equipment versus general space constraints** |
|---|---|
| ***Supports decision or function*** | General work flow, such as passing equipment to anaesthetists (especially in a hurry) |
| ***Description*** | There needs to be sufficient space between pieces of equipment to provide some space to grab equipment better and make sure equipment is not too cramped. This is especially important when the trolley is not in eye sight (which often occurs, especially in cases where lots of other equipment is required and the airway cart has to be moved behind the nurses) |
| ***Evidence*** | Interviews airway cart design study |
| ***Realisation*** | - Make surface slightly bigger than the current airway cart surface (this is possible when it sits on top)<br>- Separate primary and back up equipment and provide some constraints in how much equipment can be put on the top (see requirement 2) |
| ***Constraints/Challenges*** | There are major space constraints in the operating theatre and the new airway surface cannot be much bigger than the surface of the current airway cart (can overlap on the sides a bit) |

**8. Airway surface easy to move**

| **REQUIREMENT 8** | **Airway surface easy to move** |
|---|---|
| ***Supports decision or function*** | Retrieval of equipment |
| ***Description*** | Participants mentioned that their airway equipment cart is frequently used for other purposes once the patient has been induced. Other clinicians in the room often put other equipment on the cart and put the airway equipment elsewhere, which can be frustrating especially when it comes to extubation where some equipment is needed but previously organised equipment is now scattered elsewhere. Another problem discussed was access; anaesthetists standing at the head of the patient are not able to easily access the airway cart themselves which is usually next or behind the anaesthetic nurses. |
| ***Evidence*** | - Airway cart design study<br>- Amenable to work-as-done not work-as-designed |
| ***Realisation*** | - An airway cart surface that could be easily moved to a different location at all times<br>- Plastic tray is light and sits on top of airway cart with handles to easily transport to a different location, for example on top of the anaesthetic machine or even the patient |
| ***Constraints/Challenges*** | - Sizing must fit to airway cart (and preferably anaesthetic machine). Anaesthetic machine and airway cart type may differ (in the long term, at least) thus sizes may change. The same airway cart has been used at the Alfred for years, though. |

General and hygiene requirements

**9. Airway equipment surface easy to clean (hygiene requirement)**

| **REQUIREMENT 9** | **Airway equipment surface easy to clean** |
|---|---|
| ***Supports decision or function*** | General work flow and hygiene requirements |
| ***Description*** | Participants need surface that is easy and quickly to clean. Equipment on the airway cart needs to be changed quickly for consecutive cases and it needs to be easy to wipe it off between cases |
| ***Evidence*** | - Airway cart design interviews |
| ***Constraints/Challenges*** | Presumably still harder to clean than a flat surface |
| ***Realisation*** | Plastic surface can be easily wiped off and indentations aren't very deep, so they should still be able to be cleaned easily |

**10. Separate contamination area (hygiene requirement)**

| **REQUIREMENT 10** | **Separate contamination area** |
|---|---|
| ***Supports decision or function*** | Cleaning and tracking what has been used already (i.e. transitioning between techniques) |
| ***Description*** | Separate clean from dirty equipment so clean equipment does not get contaminated with used equipment. This is important to potentially save clean equipment that wasn't used for the next patient. This is currently done by having a kidney dish on the side. |
| ***Evidence*** | - Interviews airway cart design study |
| ***Realisation*** | Have a separated indented area that is preserved for contaminated (used) equipment |

| | |
|---|---|
| ***Constraints/Challenges*** | Limited space on surface, potential confusion if used equipment is re-used? |

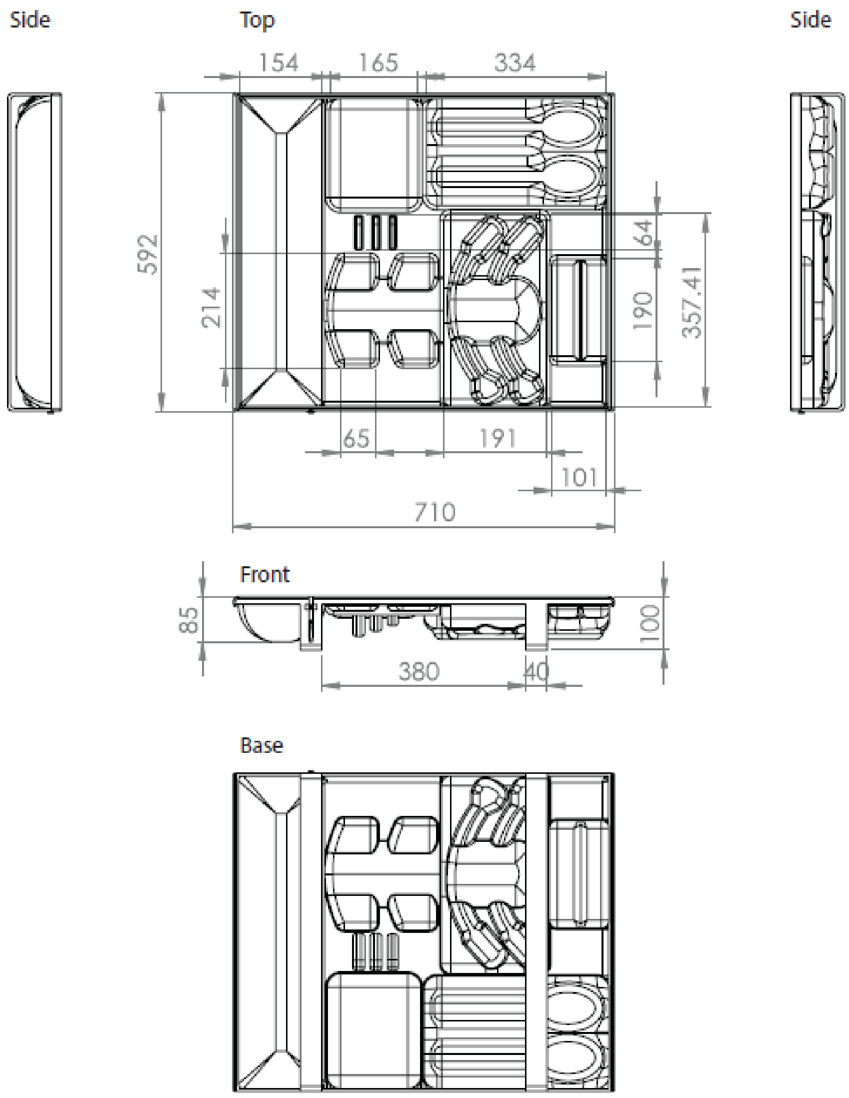
**11. Account for equipment that is still in package to avoid waste (general requirement)**

| **REQUIREMENT 11** | **Account for equipment that is still in package** |
|---|---|
| ***Supports decision or function*** | Waste management |
| ***Description*** | As most of the airway equipment is single-use Participants mentioned that they frequently leave equipment in the package if it is not used for sure (i.e. back up equipment). |
| ***Evidence*** | - Interviews airway cart design study |
| ***Realisation*** | Leave grooves big enough to accommodate packaged equipment |
| ***Constraints/Challenges*** | Participant mentioned that package of certain equipment (guedal airways specifically) are hard to open in a hurry; package not designed user friendly to assist with opening (e.g. pre-folded lines or arrows to indicate where to open). |

## 11.6 Appendix 6

**Airway equipment tray dimensions and renderings**

### Dimension drawing




All measurments are in mm