Leaps and Shunts: Designing pilot decision aids on the flight deck using Rasmussen's ladders

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ABSTRACT

When designing a new pilot decision aid for the flight deck, it is important to understand 'how' pilots make decisions in abnormal operating scenarios so that we can ensure they are provided with appropriate support. This paper provides a decision ladder analysis of an aircraft engine oil leak using data collected from six commercial airline pilot interviews. Traditionally, decision-making models are used reactively as a means to explore why things go wrong. However, we explore whether these models can also be used prospectively. Our analysis yields a number of possible design implications for the design of a pilot decision aid on the flight deck.

KEYWORDS

Decision Making, Transportation, Aviation, Decision Ladder Template, Design Implications

Introduction

Aeronautical decision-making is a systematic approach used by pilots to determine the most appropriate course of action in response to a specific set of circumstances (Federal Aviation Administration, 1991). However, regardless of domain, there is a long-established connection between the information available to an operator and the quality of their decisions (Jenkins et al. 2010; 2016). In order to ensure safe and effective system control, decision-makers must be supported by having access to timely information that is both accurate and in a format that can be easily understood. However, the displays available to pilots on the flight deck have remained largely unchanged for a number of decades (Harris, 2011). There is much research investigating the use of novel technologies on the flight deck. For instance, the use of touchscreens continues to attract attention (e.g., Coutts et al. 2018; Dodd, 2014; Harris, 2011). In addition, it is recognised that new sensor-based technologies using bespoke algorithms can provide flight crews with much more information about system status (Salas et al., 2010; Harris & Stanton, 2010). The integration of new technology however requires a thorough assessment of current operations to determine whether the interfaces, and therefore information, that are available to the flight crew are sufficient. We have chosen to focus on engine oil leaks, as whilst they are considered to be rare occurrences, they are well publicised within the public domain. For example, on 24th February 2011, Qantas Flight VH-OQG that was travelling from Singapore to London detected an engine oil leak 8 hours into the flight. The crew chose to reduce the thrust on the affected engine and continued to their planned destination (Australian Transport Safety Bureau, 2012). Later on in the same year, Qantas Flight VH-OQC experienced a similar issue on the same route. However, in this situation, the flight crew chose to shut down the engine and divert to Dubai, United Arab Emirates (Australian Transport Safety Bureau, 2012). More recently, the flight crew of Emirates Flight A6-EGA were forced to perform an in-flight engine shut down and divert after receiving a low oil level alert via the Engine-Indicating and Crew-Alerting System (EICAS, Australian Transport Safety Bureau, 2017, also called the Electronic Centralised Aircraft Monitor: ECAM). These case studies have highlighted the need for flight crews to properly understand the severity of the oil leak in order to elicit an appropriate response. We therefore pose the question of 'how' pilots make decisions in otherwise abnormal operating scenarios.

Typically, models of decision-making are used as a means to identify why and how things have gone wrong (i.e., reactively). However, this paper argues that decision models may also be useful in the design and development of new flight deck technology and can therefore be utilised much earlier on in the design process. According to Rasmussen (1997) decision-based research can be divided into the following four categories: normative models that are developed by Subject Matter Experts; the development of decision support tools requiring knowledge-based problem solving; naturalistic decision making (NDM; Klein, 1989) models that describe and explain actual behaviour (e.g., Recognition-Primed Decision Model; Klein, 1989); and cognitive based models (e.g., Hammond et al. 1987). NDM research is context specific (i.e., the models apply to specific times, locations and people observed) (Klein, 2008; Zsambok, 1997) and therefore the paradigm is not necessarily useful in exploring how new technology may impact upon the decision-making process more generally. The Model of Cognitive Control (Rasmussen, 1983) offers an alternative approach as it differentiates between skill-, rule- and knowledge- based behaviour using the representational medium of decision ladders (see Figure 1 for an example).

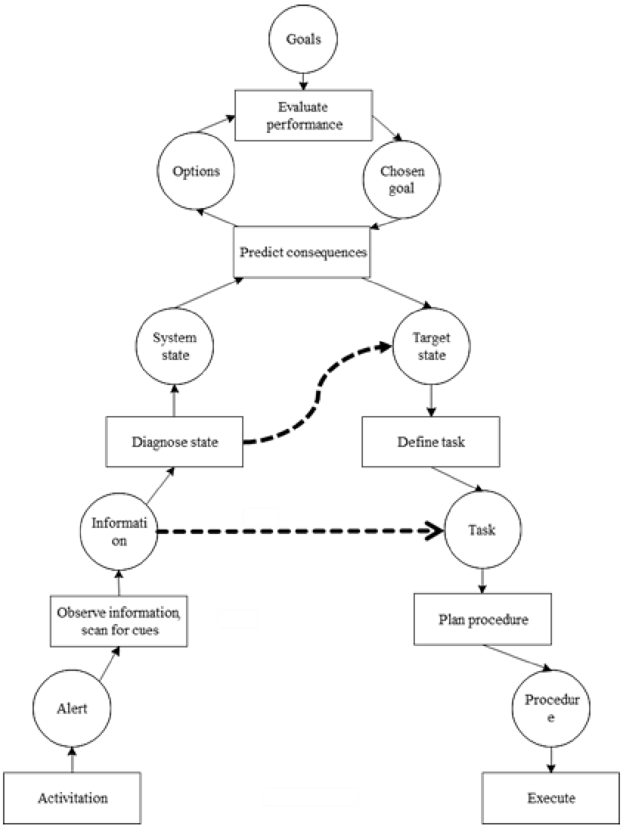

Figure 1: Decision Ladder Template showing two types of shortcut: 'shunts' (box to circle) and 'leaps' (circle to circle).

Decision ladders were originally developed as a reference frame for designers of human-machine systems (Rasmussen, 1974; 1976). This is because they can be used to demonstrate how a particular design may support certain activities. Specifically, decision ladders focus on the entirety of the decision-making process rather than the process of selecting an action from a series of alternatives (Rasmussen, 1974). This means that they can provide insight into the underlying information processing requirements that go on to influence a particular action. Decision ladders consist of rectangular nodes (information processing activities) and circular nodes (state of knowledge)

(McIlroy & Stanton, 2015). The left hand side of the ladder outlines the current situation (i.e., situation assessment; Lintern, 2010) whereas the right hand side represents the planning and execution of a response that will achieve the target system state (McIlroy & Stanton, 2015). Whilst decision ladders are sequentially arranged, in practice, the entry and exit points of the ladder will depend upon the nature of the tasks and the actors that are involved (McIlroy & Stanton, 2015). With this in mind, there are two types of shortcuts available to the decision-maker. Firstly, 'shunts' connect information-processing activities to a resultant state of knowledge (box to circle). Second, 'leaps' connect two states of knowledge (circle to circle).

The decision ladder template may not be deemed as a classical NDM research outputs, but Orasanu & Connolly (1993) identified notable overlaps between the approaches. They state that there are eight factors that are typical of decision making in naturalistic environments: complex environments; competing goals; requirement to balance organisational norms and goals with personal choice; time constraints; multiple stakeholders; ill-structured problems; high stakes; and multiple event-feedback loops. Jenkins et al. (2010) propose that decision ladders therefore offer a compatible approach to compliment the more established NDM techniques.

To date, decision ladders have been used in various contexts including eco-driving (e.g., McIlroy & Stanton, 2015), healthcare (e.g., Ashoori et al. 2014) and intersection design (e.g., Cornelissen et al. 2013). Importantly, decision ladders are not restricted to modelling decision making in familiar situations – they can also be used to explore decision making in unfamiliar or atypical scenarios (Naikar, 2010). In such scenarios, both novice and expert users would be expected to follow the decision ladder in a linear fashion (Mulvihill et al. 2016). Thus, we want to provide insight into the decision-making process of pilots dealing with an engine leak and consider the design implications for new technology going forward. In order to populate the decision ladder template, we used the Schema World Action Research Method (SWARM; Plant & Stanton, 2016).

Method

Whilst SWARM was originally developed as a means to capture information about an individual's perceptual cycle processes (e.g., Neisser, 1976), Plant & Stanton (2017) argue that it should also be viewed as an extension of the original Critical Decision Method (Klein, 1989). SWARM consists of 95 prompts that are structured around the sub-types of the Perceptual Cycle Model (PCM: Neisser, 1976); schema, action, world. However, the original authors of SWARM recognise that it is not always practical to utilise all 95 prompts in a single interview study. Instead, they suggest using a compacted SWARM that is tailored to suit the requirements of the current study. In down-selecting SWARM prompts, Plant & Stanton (2016) suggest that using the top five subtypes from each PCM category is appropriate. In this study, a total of 37 SWARM prompts were selected for inclusion in line with this guidance.

Participants

Six commercial airline pilots were interviewed as part of this study (2 female, 4 male), aged between 26 and 35 (M = 30.17, SD = 3.02). All were currently employed by an airline company with an average 8.08 years (SD = 1.59), 3692 hours (SD = 570.39) experience. Ethical approval was sought and granted from the Ethical Research Governance Office at the University of Southampton (ERGO; reference ID: 40619). It is important to note that data collection ended once it was deemed that data saturation had been reached. Grady (1998) defines saturation as the point in which *"…the researcher begins to hear the same comments again and again… It is then time to stop collecting information and to start analysing what has been collected"* (p.26).

Procedure

Upon receiving informed consent, participants were presented with a hypothetical scenario relating to an engine oil leak. It is important to bear in mind the impracticalities associated with conducting pilot interviews on the actual flight deck. We therefore had to rely heavily on retrospective descriptions, using documentation (e.g., Quick Reference Handbook) and example engine status displays to help facilitate discussions. The scenario was intended to reflect current practice in which flight crews only become aware of an oil leak when minimum thresholds have been met. This goes on to trigger a warning via the EICAS or ECAM system that requires some form of response. Typically, pilots who have been exposed to oil leaks in real world scenarios have either chosen to throttle back or shut down the engine completely (Australian Transport Safety Bureau, 2012; 2017). All interviews were audio recorded and later transcribed.

Analysis

A prototypical decision-ladder, intended to be representative of current practise, was created based upon the amalgamation of interview data. The decision-ladder was continually reviewed and refined by two Human Factors experts until both were satisfied the representation accurately reflected the decision-making process. This was then reviewed by an independent Subject Matter Expert. The final iteration is presented in Figure 2 and outlines the entire sequential pathway. It represents the way in which a pilot may analyse a situation, evaluate and select their goals, and plan and execute a task (Jenkins et al. 2010).

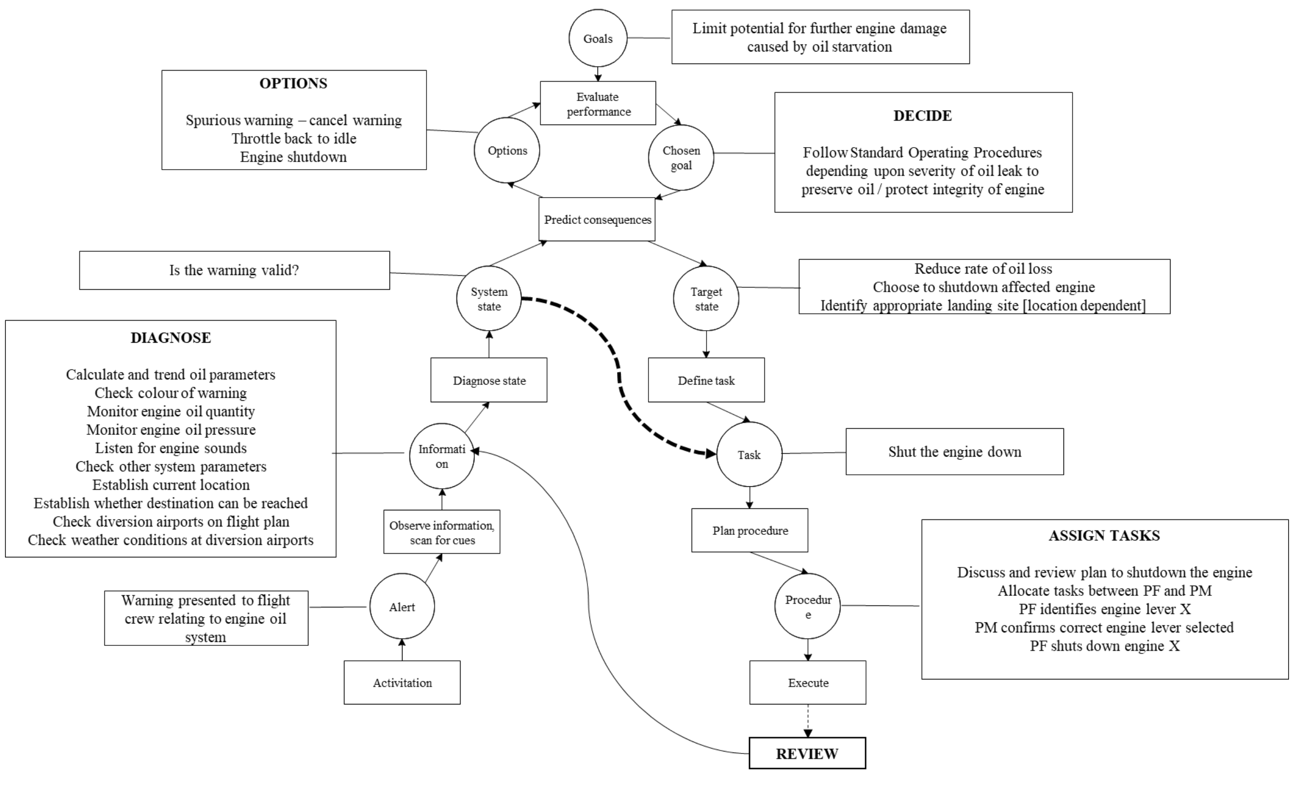

Figure 2: Hypothetical decision ladder of a pilot dealing with a suspected engine oil leak using the DODAR decision tool (notes: dashed line represents a potential ‘shortcut’. Representation based upon current practise)

It was recognised that in an oil leak scenario, the overriding goal would be to preserve the engine and therefore limit the damage that would be caused as a result of oil starvation. In order to do this, pilots would need to verify the validity of the warning trigger utilising information from the environment (e.g., colour of warning, engine status displays, presence of sound, etc.). Pilots would recognise that the ‘target state’ would be to reduce further oil loss by following Standard Operating Procedures (SOPs). These SOPs would enable pilots to plan and execute the appropriate action. In this scenario, all six pilots stated that they would perform an in-flight engine shutdown. However, pilots are exposed to oil leak scenarios during their compulsory simulator training exercises. Thus, it may be possible for pilots to ‘shortcut’ their way through the decision-making process (as represented by the dashed line in Figure 2). In such a scenario, pilots may intrinsically recognise that the cues are indicative of an engine oil leak and may already know that an engine shut down is required. They would then be required to plan for the procedure prior to any action response (i.e., discuss, review and allocate tasks).

Importantly, all six pilots advocated the use of decision mnemonics to help them systematically reach a decision. There are many decision mnemonics available to pilots (e.g., SHOR, Wohl, 1981; FORDEC; Hormann, 1995). However, all six pilots invited to take part in this study discussed the use of DODAR (Diagnose, Options, Decision, Assign task, Review) or T-DODAR (Time, Diagnose, Options, Decision, Assign task, Review; Walters, 2002). Given the importance of these mnemonics, DODAR has been mapped onto the decision ladder template. It also demonstrates that decision-making is not simply about responding to an alert, but also incorporates a ‘review’ stage in which the decision maker must assess whether or not the actions implemented have led to the desired outcome.

However, decision ladder templates offer more than an indication of the shortcuts available to decision makers (Lintern, 2010). They can also be used to exploit design implications based upon the data used to populate them. Figure 3 presents a number of possible design interventions based upon the information provided in the decision ladder. These design interventions may facilitate pilots to move through the decision-making pathway in alternative ways. Three shortcuts have been identified. The first shortcut, ‘alert’ to ‘procedure’, outlines that the warning presented to the flight crew could be enough to trigger a response although this seems like a reactive approach and one that is unlikely to be utilised given that pilots will continue to validate system warnings and seek to gather as much information as possible to inform their decision making. Thus, the second shortcut, ‘information’ to ‘procedure’ seems more plausible. This entails that pilots observe and interpret the information that is being provided to them via the pilot decision aid. This may be enough to trigger a response in which pilots discuss and review their plan of action. The third shortcut that may become available is between ‘options’ and ‘procedure’. A pilot decision aid may be able to assist pilots by identifying a list of possible remedial actions. Equipped with this knowledge, they may feel it appropriate to enact one of these actions. It is also worth noting that additional information provided by new sensor-based technology could lead to subtle, albeit abnormal, changes in oil system parameters are detected earlier than current practise. If these changes can be detected prior to minimum/maximum thresholds being met, it seems unlikely that pilots would choose to shut the engine down. Technological intervention via a decision support tool could therefore also have potential to alter the outcome of the decision-making process.

Conclusion

Currently, flight crews only become aware of an oil system issue when minimum/maximum thresholds have been met. This significantly impacts upon the options available to the flight crew as such occurrences will trigger EICAS/ECAM warnings. This paper identifies a number of possible design interventions that would seek to provide an earlier indication of issues within the engine oil system. No such technology exists on modern day aircraft today. The design interventions presented in this paper offer an indication of how flight crews may be supported in the future. It is therefore important to emphasise to systems architects, engineers and interface designers that decision ladders are not restricted to understanding decision-making but can also be used as a tool to generate novel design ideas.

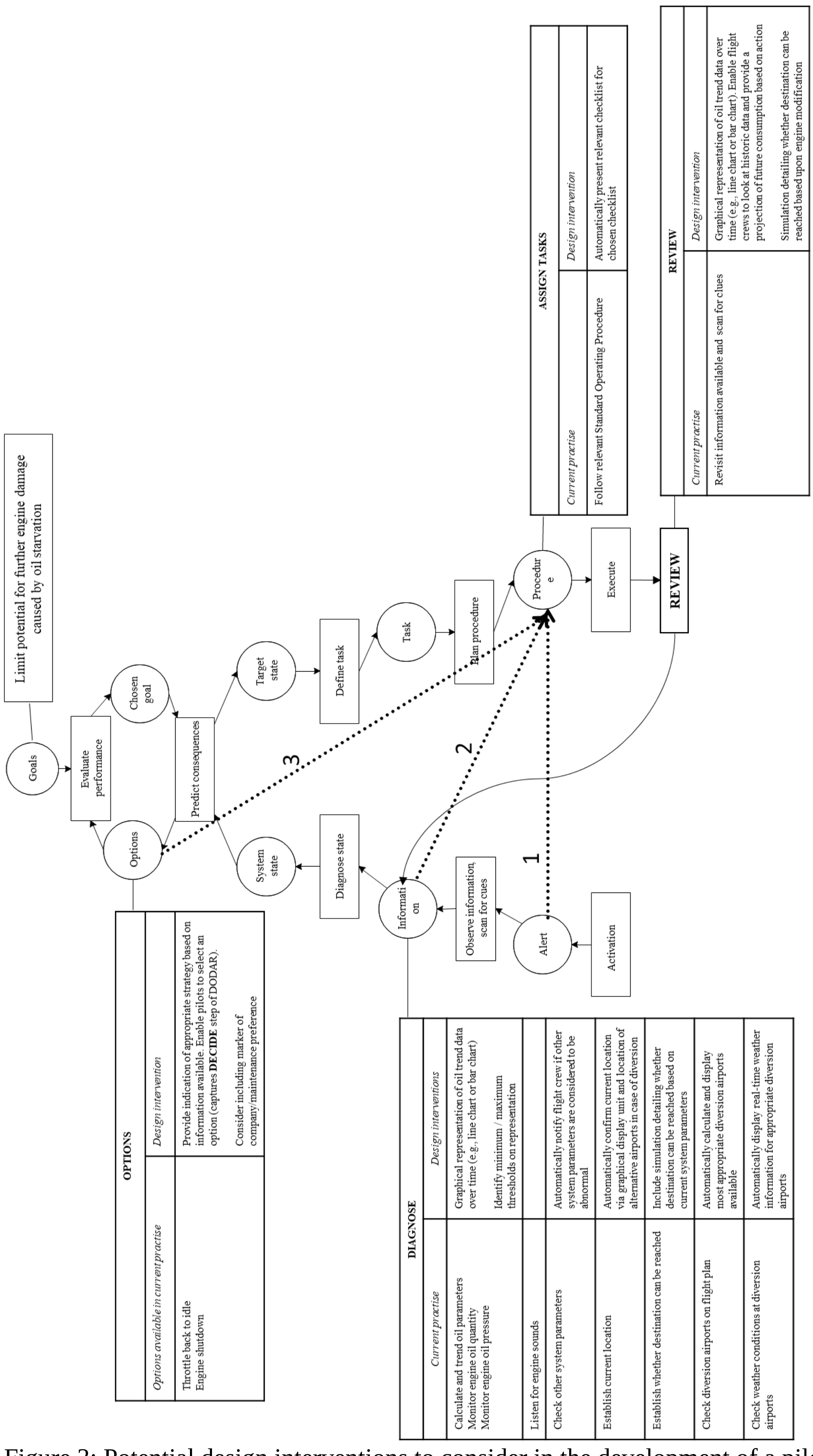

Figure 3: Potential design interventions to consider in the development of a pilot decision aid

These representations can also be utilised early on in the design process to assist in the development and refinement of information requirements (e.g., see Jenkins et al. 2016; Stanton et al. 2017). They provide a template in which end user feedback can be incorporated. Of course, we recognise that there is much debate over how we can conceptualise, analyse and represent the decision-making process (Jenkins et al. 2010). Rasmussen (1986) confirms that “the decision ladder is not a model of the decision process itself, but rather a map useful to represent the structure of such a model” (p. 70). This is because the decision ladder outlines the cognitive states and processes that might be used rather than those actually used (Vicente, 1999). It is important therefore that future work seeks to validate the assumptions of these representations using empirical research methods. Going forward, we should also take the opportunity to explore what other models of decision making can tell us, especially when we consider Naikar (2010) and Plant & Stanton (2016) suggest that a multi-modelling approach can be complementary as different models are likely to capture different elements. Regardless of the approach taken, we are satisfied that this paper provides insight into how systems architects, engineers and interface designers may use models of decision making prospectively to understand the problem space and identify how new technology may assist the human operator in coping with abnormal occurrences on the flight deck.

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