Abstract

The Schema World Action Research Method (SWARM) has previously been used as a means to explore the underlying decision-making processes involved in retrospective incident reports. The approach has been fruitful in capturing all interacting processes involved in managing incidents. This paper proposes that SWARM may also be used prospectively within the early phases of the design lifecycle for new behavioural-based intervention strategies. Six pilot interviews were conducted to explore pilots' perceptual cycle processing when faced with a suspected engine oil leak. The aim was to explore whether there may be any deficiencies within current practise and explore ways in which pilots may be better supported in dealing with abnormal system parameters such as this. A number of design recommendations are proposed for a new avionic system capable of supporting and guiding pilots through the decision making process.

Key words: Aviation; Decision making; perceptual cycle model; schema world action research method

Introduction

Despite inherent personality differences between pilots (Wang & Zhang, 2020), commercial aviation is a highly regulated and proceduralised environment meaning that, for every predicted eventuality, the flight crew is equipped with standardised procedures to follow (Green, 1990), engrained within extensive training regimes. It can therefore be described as a ‘rule-based’ activity (Sanderson & Harwood, 1988). However, despite this extensive training, Shappell and Wiegmann, (1996) argue that approximately 60-80% of all aviation incidents and accidents could be attributed, at least in part, to human error. Human error on the flight deck is therefore, unsurprisingly, considered to be one of the principle threats to flight safety (Civil Aviation Authority, 2008; Green, 1990; Weigmann & Shappell, 1997). Whilst it is important to acknowledge that overall, people do not deliberately set out to make mistakes (Dekker, 2006; Woods et al. 2010), humans are inherently fallible. Despite the best efforts of designers and safety practitioners, human error remains an unavoidable reality within socio-technical systems including aviation (Fedota & Parasuraman, 2009). Furthermore, the potential for human error appears to be an inevitable by-product of managing complex systems, including an aircraft cockpit (Woods et al. 2010). It is therefore important to understand how pilots make decisions as it provides a means to identify ‘how’ and, potentially more importantly, ‘why’ things go wrong. This gives rise to the possibility of identifying ways in which pilots can be aided in the future, via the potential use of altered training regimes or technological aids.

The processes underpinning decision-making are typically explored in a reactive manner, that is to say research explores why accidents occur or, explore why operators make mistakes, after an event has taken place. However, it can be argued that models of decision making may also be used proactively. Models of decision making can be useful when applied early on in the design and development of new flight deck technology in order to provide a more descriptive and complete account of what pilots actually do, or have done in the past (Dillon, 1998). There are numerous models of natural decision making (NDM) within the literature. Considerable debate remains over how decision making processing can be best conceptualised and presented (Jenkins et al. 2010). Lipshitz (1993) identified nine different models of NDM. This included the most popular, the Recognition-Primed Decision Model (RPDM; Klein, 1986). The RPDM model argues that decisions are based upon the recognition of critical information and utilisation of prior knowledge (Klein 1989; 1998). When people need to make a decision, they quickly match the situation to previous patterns that they have learned (Klein, 2008). This process enables the decision maker to recognise whether the situation is typical or familiar (Klein, 1989). If the situation assessed can be matched to a prior event (experienced or trained), the decision maker is able to utilise their previous experiences in dealing with the situation. Kahneman (2011) argues that this culminates in fast, instinctive and emotional responses. According to Naikar (2010), the RPDM proposes that decision makers will evaluate each individual option until a satisfactory option is found. This mental simulation allows the decision maker to evaluate the adequacy of the proposed action. The exploration of alternatives stops when the operator reaches a satisfactory option, the action of satisficing (Klein, 1998). Yet, this does not mean it is always the most suitable option and inexperienced operators may need to reject several options before selecting an action (Klein et al. 1989; Naikar, 2010). This approach has been useful in understanding decision making across a variety of domains including Rail (Stanton & Walker, 2011) and Truck drivers (Salmon et al, 2013).

Yet, critique of the RPDM states that interactions to the decision making are solely within the individuals cognitive processing and the model does not capture the moderating effect of the environmental interactions (Plant & Stanton, 2014). Furthermore, RPDM does not fully capture the connection between the decision and the external environment, which is vital in order to understand why a decision was made at the time (Dekker, 2006). Excessive focus is placed on the decision as processed in the mind of the individual (Plant & Stanton, 2014; 2016). In this respect, the Perceptual Cycle Model (PCM; Neisser, 1976) is thought to give a better account of how decisions are made relative to the psychological processing of the individual and the environmental context surrounding it (Plant & Stanton, 2014; 2016). For this research, the aspects of the environment that influence the decision making were crucial in understanding how the pilot may be better supported by their surroundings to make enhanced decisions.

A schema is an organised pattern of thoughts and/or behaviours that help organise our knowledge of the world (Neisser, 1976). Schemas therefore provide a template in which we formulate mental representations of the world that can be used to guide future behaviour (Chalmers, 2003; Plant & Stanton, 2012). According to the literature, there are five defining features of a schema; meaningful organisation, embedded with other schema, change dynamically as information is received, reorganised based upon incoming data and they are gestalt mental representations (Anderson, 1977; Norman, 1981). Schema Theory provides a valuable explanation for how we interact with the world (Stanton & Walker, 2011). The PCM (Neisser, 1976) offers a visual representation of how 'schema' is embedded in a reciprocal, cyclical relationship between an individual and their environment. In this manner, it identifies that the schema that are based on the training and experience of the individual determine the actions that the individual will perform in a set scenario. Yet, it also dictates that present information in the world can assist in constructing the schema. This is in agreement with others who support the notion of sensemaking, whereby situation specific beliefs are thought to be activated by contextual factors that guide behaviour when generic belief networks require additional support (Baber et al, 2015; Attfield & Baber, 2017). Therefore the PCM suggests a way to understand how environmental sampling, combined with pre-existing biases can influence and guide behaviour; but also how subsequent information within the environemnt determines how an individual perceives and gains understanding within specific situations,. The PCM process is represented in Figure 1.

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The PCM places emphasis on understanding the processes involved in decision making, rather than focussing entirely upon decision output. Rather than focusing soley on the decision making within the head of an individual, it places the individual and their schema within the wider decision-making environment. It therefore supports the notion that congition is distributed across the wider system within which it is occurring (Hutchins, 1995; 2000; Stanton et al, 2009) To that end, it does not fall victim to criticism of other approaches that are deemed reductionist in their account of only the individual level of analysis (Reason, 2000). Incorporating the role of the wider system surrounding the decision-making process allows for a greater understanding in how decision making can be supported within the environment that it is conducted (Stanton et al, 2009; Plant & Stanton, 2012). This is important to this area of study because it enables us to see where and how pilots may be better supported throughout the decision making process. This paper was interested in understanding airline pilot decision making in relation to suspected engine oil leak in order to see if any further information may be able to assist the pilot in managing the event. The PCM was proposed as an effective tool for gaining a full representation of all factors impacting on the decision from the training that pilots receive, the information that they are presented within in the cockpit as well as the actions that they take.

Understanding perceptual cycle processing can however be extremely complex (Plant & Stanton, 2013). One approach to reducing this inherent difficulty is to use the Schema World Action Research Method (SWARM; Plant & Stanton, 2016). SWARM is an interview-based method designed specifically for aeronautical decision making, originally developed to elicit information about perceptual cycle processes. Its development aimed to capture the interaction between internal schemata and external world information in order to fully inform the development of the perceptual cycle process (Plant & Stanton, 2016). The method was developed and validated through interview data from airline pilots (Plant & Stanton, 2016).

SWARM facilitates the collection of data from Subject Matter Experts in relation to the three categories of the PCM; schema, action and world. Each of these has sub-types. Schema is comprised of six sub-types (direct past experience, trained past experience, vicarious past experience, declarative schema, analogical schema, insufficient schema. Action has 11 sub-types (Aviate, navigate, communicate, system interaction, system monitoring, environment monitoring, concurrent diagnostics, decision action, situation assessment, non-action, standard operating procedures). The world subtype also has 11 sub-types (Natural environmental conditions, technological conditions, communicated information, location, artefacts, display indications, operational context, aircraft status, severity of problem, physical cues, absent information). Within each of these sub-types are further interview prompts that draw out wide reaching information from subjects to capture the complete processing surrounding the decision making. The full repository of 95 prompts can be found in Plant and Stanton (2016), although the authors recommend not using all of these prompts but reviewing them to determine those relevant to the analysis required. SWARM was the first attempt to develop a methodology that could facilitate the collection of data and practically apply it to the PCM (Neisser, 1976). Previously, the PCM has been used to explore systemic decision-making processes in retrospective analysis of incidents or accidents (Banks et al. 2018; Plant & Stanton, 2012; Stanton & Walker, 2011). However, the authors propose that by using SWARM, the PCM may also be used prospectively during the early phases of the design lifecycle, meaning it may be used to generate data that can inform design requirements for future flight deck technologies.

Displays within commercial airline cockpits have remained largely unchanged for a number of decades (Harris, 2011). This stagnation remains despite it being universally recognised that new sensor-based technology could be used to provide flight crews with more information about aircraft status, potentially offering flight crew more information which could be used to inform safety critical decisions (Salas et al., 2010; Harris & Stanton, 2010). Green (1990) stated that aircraft equipment can be more closely tailored to human requirements and so it makes sense to explore and highlight possible deficiencies in current procedures and displays on the flight deck. This is because it has long been established that there is a connection between the information that is available to an operator and the subsequent quality of their decisions (Jenkins et al. 2010; 2016). Thus, within this paper, we seek to explore the underlying mechanisms of pilot decision making in abnormal operating scenarios using the PCM (Neisser, 1976) and SWARM (Plant & Stanton, 2016) to provide insight into the possible deficiencies within current flight deck architecture and propose how pilots may be better supported through access to timely, accurate information from new avionic systems.

Method

Participants

Six commercial airline pilots were recruited to take part in this study (2 female, 4 male), aged between 26 and 35 years (*M* = 30.17, *SD* = 3.02). All participants were qualified fixed wing ATPL or CPL pilots with an average 3692 hours flight experience (*SD* = 570.39) and had held their licences for an average 8.08 years (*SD* = 1.59). Interviews lasted for approximately 1.5 hours and participants were reimbursed for travel and time spent participating in the study. The study was ethically approved by the university Ethical Research Governance Office (ERGO).

Procedure

Participants were first introduced to the aims of the research before being asked to give informed consent to take part. The participants were then presented with a hypothetical scenario relating to a suspected aircraft engine oil leak. This stated the following:

An incomplete maintenance action has resulted in an oil leak in the aircraft engine. You are in cruise.

The rationale behind focusing on an engine oil leak scenario is that despite being rare, they can have serious repercussions on flight operators, maintenance teams and passengers when handled inappropriately (Australian Transport Safety Bureau; ATSB, 2012; 2017; Parnell et al. in press). In addition, the presentation of engine system parameters has remained largely unchanged for a number of decades with analogue displays simply being replaced by digital equivalents (Harris, 2011). This means that in current practise, pilots only become aware of abnormal system parameters when threshold limits have been met via their on-board alerting systems. At the point of notification, pilots have few options available to them and they must either throttle back, or shut down the engine completely, in order to prevent the engines from reaching oil starvation (ATSB, 2012; 2017). Engine shutdowns in particular have significant implications for the flight operator both in terms of economics and safety so there is great value, both from operations and economic perspectives, in exploring how such situations can be prevented (Parnell et al. in press). The limited options available to pilots within this scenario was also ideal for the explorative nature of the current work.

Schema World Action Research Method

Following the presentation of the scenario, participants were invited to take part in a semi-structured interview using exemplar prompts from the SWARM repository. To get their initial thoughts on the scenario and their response they were asked to give a brief initial overview of their thoughts in relation towards the scenario, prompted by two questions:

1. Currently, how would you be informed of an oil leak in an engine?
2. How would you respond to it?

While these questions were not part of the SWARM interview prompts, they allowed the participants to speak openly about their perception of the scenario as well as ask any further details from the researchers. After this the SWARM prompts began.

A down selected set of SWARM prompts were selected from the original 95 as suggested by Plant and Stanton (2016), not all are relevant to all events so down selection allows the interview to be more efficient. Plant & Stanton, (2016) state that preferably this would use the top five subtypes for each PCM category. The SWARM prompts were reviewed by Human Factors experts to determine which would be relevant to the scenarios presented in the study which is in line with the guidance. A total of 37 of the SWARM prompts were selected for the interview. Example relevant prompts included "What would you be looking at on the technological system during the scenario?"; "Would you require information from others?" and "What information would you use to assess the severity of the problem?". Participants were asked to speak open and honestly and in as much depth as possible. This enabled a full account of their anticipated response to the scenario, capturing their schema representations, information they would access from the world and the actions they would be taking.

Data Analysis

All interviews were audio recorded and subsequently transcribed by the researchers. Transcripts were then reviewed by the researchers. The comments from the interviews were coded to the Schema, Action or World feature of the PCM. As the method utilised the SWARM methology the application of the reports to the PCM model was straightforward, as the relevant prompts related to the relevant PCM category, see Plant & Stanton (2013; 2016) for further details on this process. The process of mapping the interview reports on to the PCMs was conducted in an iterative manner until the researchers were satisfied that the mapped decision making process accurately reflected the interview data. The data was used to develop an amalgamated representation of the pilots' PCM for the given scenarios. As the pilots are highly trained and the proceedures that they conduct on the flight deck are heavily standardised and regulated, the reports were largly similar. The generated PCM containing the combined responses of the pilots was then reviewed by an independent subject matter expert, with over 10 years flight experience and a strong background within the Human Factors discipline to ensure accuracy.

Generating Design requirements

The second part of the interview asked participants to consider how a future engine monitoring assistant (EMA) system may influence their responses to the previous scenario. Here the updated scenario stated the following:

"An incomplete maintenance action has resulted in an oil leak. An automated system detects a non-normal change in system parameters and notifies you of a non-critical oil leak i.e. sufficient levels to complete flight to intended destination safely"

Participants were again asked key SWARM prompts of relevance to generate data that could also be used to inform the development of a PCM that could inform how participants thought a future system could assist them. From the PCMs and the transcriptions the researchers reviewed how the pilots could be further supported with their decision making to inform design recommendations. Importantly, participants were not given specific details of how this system may work, rather they were asked to determine how they may want it to work and what utility it may have.

Results and Discussion

The interviews generated extensive accounts of how trained and experienced airline pilots would respond to the hypothetical scenario of an engine oil leak. Pilots undergo stringent training on a regular basis and they have a set of standard operating procedures that dictates how they respond to engine events such as the engine oil leak. The reports that pilots gave therefore followed similar decision making processes and could be aggregated in one PCM. This was also the approach used by Plant & Stanton (2014) who aggregated data from 20 pilots into one composite PCM, demonstrating that the model can account for all decision making data. Due to applying the SWARM, the accounts were comprised of information that detailed the components that inform the PCM. This included the comprising element of the participants schema, including any previous experience of an event, their trained experience and knowledge of oil leakage. The world information captured all available information in the environment, including the visual presentation of information in the cockpit and communicated information from relevant others. They also detailed all relevant actions that they would take in their response to this event. Through application of the SWARM interviews to the PCM the information could be easily categorised into the three PCM components.

PCM of current processing in response to an aircraft engine oil leak

The final amalgamated PCM of current practise is presented in Figure 2 and outlines the perceptual cycle processes of a pilot when they are subjected to dealing with a suspected engine oil leak. Information available in the 'world' acts as the impetus for diagnosis and option generation. In order to first diagnose and understand the problem presented to them, pilots would attend to any warning messages on the Electronic centralised aircraft monitor (ECAM) system, also sometimes referred to by some manufacturers as the Engine Indicating and Crew Alerting System (EICAS). This system provides data to pilots on the status of a variety of aircraft systems, as well as providing warnings and alerts when parameters reach unusual levels. These warnings are colour-coded to differentiate their urgency for attention and action by the pilot. Participants reported that when receiving an ECAM/EICAS message in this scenario they would seek to validate it by checking the most appropriate system parameters, in this case oil pressure, oil quantity and oil temperature. All of these artefacts are available in the 'world' via the Engine Display. Appraisal of these dials would enable the pilots to determine whether the warning is genuine or spurious. Particularly on older aircraft, sensors are vulnerable to exhibiting false indications and therefore the presence of a single abnormal reading may not be a valid indication of failure (Flight Safety Foundation, 2001). Thus, in order to confirm a genuine failure, flight crews must inspect multiple sources of information. Five participants suggested they might also seek assistance from the cabin crew in terms of performing a visual inspection of the engines. This would provide an opportunity to gather more 'world' based information that would be used to trigger relevant 'schema', previous experience in dealing with available information. This process shows how information in the 'world', that is the presence of a master warning, can go on to trigger relevant ‘schema’. For example the presence of the master warning suggests something is seriously wrong, leading to subsequent ‘action’ which includes checking affected engine system parameters. Further detail is given in Figure 2.

When it came to making a decision, all six pilots spoke about the utilisation of the ‘DODAR’ decision aid (Diagnose, Options, Decision, Assign task, Review) or variations of such, for example, T-DODAR (Time, Diagnose, Options, Decision, Assign task, Review) in order to help them systematically reach a decision (Walters, 2002). The variation in the DODAR come about due to airline specific guidelines, yet each uses a similar tool to guide the pilots decision making. Each element of the tool details key requirements and the order dictactes the order the requirements should be fulfilled. ‘Diagnosis’ is the requirement to gather as much information as possible to determine and confirm the problem. ‘Options’ required the pilot(s) to consider all possible alternatives relating to all possible actions. ‘Decide’ requires the pilot(s) to come to the most appropriate selection of action(s). Once the decision is made, they must then ‘Assign tasks’ to allocate tasks between the pilot flying and pilot monitoring. The ‘Review’ aspect then denotes that the resulting consequences and emerging situation should be continuously reviewed to ensure the desired outcome is achieved. It was evident from the interviews that the DODAR aid was central to the decision making process. The detail they gave regarding the DODAR decision aid linked into the SWARM interviews to allow participants to discuss the factors that guided their decisions and the resulting actions.

INSERT FIGURE 2 HERE

PCM of future proposed processing in response to an aircraft engine oil leak

In scenario 2, all six pilots recognised that an early warning from an EMA system would indicate that minimum thresholds had not yet been met. For example, one pilot stated, *"Time is everything in an aircraft, with failures, with everything. It buys you time so you can sit, think, discuss with the company, come up with a plan and have a bit more time before it is critical." (Participant 2)*. Participants stated that they would still utilise the DODAR decision making tool. This is an airline regulated decision tool that pilots must use to guide their decision making and therefore it would still be applied when the EMA is present. In this scenario, the flight crew would begin monitoring and trending oil in order to rule out the potential for spurious sensor readings as soon as the assistant system alerted them to a possible issue. With engine parameters continuing to show an abnormal downward trend, the flight crew would use their prior experience (both through operational activities and training) to determine that an oil leak was indeed occurring. In terms of a pilots PCM, Figure 3 demonstrates that information in the world (i.e., the system triggers alert in relation to the oil system) can trigger underlying schemata (i.e., EMA provides an advisory warning that may be wrong and therefore requires further investigation), which then goes on to influence action (i.e., monitor and trend oil system parameters to confirm what the problem may be). Importantly, the majority of the PCM remains similar to that presented in Figure 1 (i.e., pilots would utilise the same information in the world which would go on to trigger the same underlying schema). As one pilot stated; *"I would do the same checks. I would have a look for myself…" (Participant 4)*. However, this is likely to be a product of the strict training a pilot goes through. For example; *"…I think that is something that pilots always do. We have to check, check and double check" (Participant 1)*. With this in mind, it is mainly the 'Action' phase of the PCM that changes as a result of EMA implementation which is what we would expect.

INSERT FIGURE 3 HERE

Whilst in the first scenario (current practise), pilots would choose to shut down the engine, the general consensus amongst the pilots for the second scenario (with the EMA) would be to accept the information provided by the pilot decision aid and therefore execute the operational limitation. Pilots would then re-evaluate whether they would still be able to reach their destination, based upon their monitoring and trending of oil quantities. A key difference between the current processes in Figure 2 and anticipated processes in Figure 3 are that pilots are better informed with the future system on the remaining level of oil and if they can reach their destination. Pilots suggested that if they could receive more up-to-date information regarding the oil level in the case of a leak then there would be less ambiguity and therefore, they could make more informed decisions about shutting the engine down. Importantly, pilots did not think that the addition of an EMA would slow down a pilots response to an incident. Instead, the provision of an early warning would enable pilot responses to be more considered. The process of diagnosis, the options that are available, the allocation of tasks and key decision points remain very similar.

Design Recommendations

Once an understanding of pilots actions had been collected using the SWARM technique and subsequently mapped using PCM, it was possible to use this information to generate design concepts that would enable easier access to appropriate information, and therefore reduce the likelihood of the suspected oil leak having a significant impact on flight operations. Table 1 lists a number of possible design recommendations that could be implemented on the flight deck that may reduce the requirement for, and number of, in-flight engine shutdowns as a result of abnormal engine system parameters. These recommendations are based upon providing the flight crew with reliable and accurate data relating to the on-going status of engine system parameters using the EMA.

INSERT TABLE 1 ABOUT HERE

As suggested in Table 1, an additional potential benefit relating to the diagnosis of oil leaks is supporting pilots in choosing an appropriate route diversion and an appropriate airfield for landing. Diversions are typically less of a problem for short haul operators, operating in heavily populated and serviced locations, such as Europe and the United States, whereby maintenance bases are easily accessible. Yet, it is important to remember that choosing an appropriate, non-maintenance landing site is based upon multiple factors. These include environmental factors, for example local terrain and typography, local weather, runway length, type of approach and air traffic, aircraft status, including remaining fuel, weight of aircraft and type of aircraft, and commercial factors such as location of maintenance, costs associated with displaced passengers and crew, availability of alternative accommodation and transport options for passengers. Thus, deciding where to divert is not always an easy and straightforward decision. Novel flight deck technology may be of value within this circumstance to assist pilots in determining the best diversion alternative. For instance, Table 1 suggests that appropriate diversion airports, be this due to aircraft type and weight or company preference, could be automatically highlighted on a new display and updated in real time based upon specific contextual requirements and location, reducing pilots workload when dealing with an abnormal flight scenario.

Future Avionic Systems

In current practise, flight crews typically only become aware of abnormal engine oil system parameters once thresholds for triggering the alerting systems have been met. This is because although instructed to monitor oil level, pilots struggle to interpret abnormal oil behaviour. Technological developments have led to new sensor based technologies within aircraft engines that may be able to provide more accurate and timely information to pilots. This Engine Monitoring Assistant would allow for a more complete understanding of both the current status of the engine as well as projected status. By identifying oil leaks earlier than currently possible and pre-empting potential oil leaks based on trending data, it may be possible to prevent the need to perform in-flight engine shutdowns. This is advantageous for airlines as it would increase the likelihood the aircraft would be able to reach a maintenance base and thus reducing the subsequent disruption caused by the leak. Earlier warning systems would allow pilots to make better, more informed decision, or at minimum less disruptive decisions. This is because they would have greater time in which to consider appropriate actions. In this paper, a number of possible design recommendations that serve to support the pilots in the decision making process have been identified, all compiled following interviews using the SWARM technique. The theoretical underpinnings of the PCM, upon which SWARM is based, provides a contemporary approach to generate novel design ideas for future technology.

Given the severity of the scenario under discussion (i.e. master warning rather than master caution), all participants reported that the current appropriate action following the warning notification would be to shut down the affected engine and land as soon as possible, including completing any necessary diversion. The decision to perform an engine shut down utilises previous knowledge of mandatory training and guidance available within the aircraft’s Quick Reference Handbook (QRH). The primary aim of an engine shutdown would be to protect the engine from entering a state that could lead to catastrophic failure, as a consequence of oil starvation, which could cause irreparable damage to the engine and may risk damage to the rest of the aircraft. However, it is known from previous incidents and accidents that flight crews are not always able to elicit the correct information from their instruments or state cues provided from the airframe itself, for example the presence of significant vibration. A key example of pilots' inability to elicit complete and correct understanding within recent years was the Kegworth air disaster. On January 8, 1989, a Boeing 737-400 bound for Belfast experienced a detached fan blade in No.1 engine (left) (Air Accident Investigation Branch, 1990). This led to the significant airframe vibration and fluctuations on No.1 engine parameters. Smoke and fumes also entered the cabin. A decision was made to divert to East Midlands Airport. However, the crew mistakenly believed No.2 engine (right), and not No1. engine (left), was the damaged engine and proceeded to throttle it back. Airframe vibration reduced which reinforced the crew that their action had been appropriate to deal with the current emergency, as such they proceeded further to shut down the engine (Plant & Stanton, 2012). No.1 engine, which was significantly damaged, appeared to operate normally following the reduction in vibration and the crew's shut down of No2. engine. However, during the flights descent to East Midlands Airport, the damaged No.1 engine suffered complete failure causing the aircraft to crash approximately 2nm from the runway, and onto the busy M1 motorway. Out of 118 passengers, 47 died and 74 suffered serious injury.

Furthermore, a recommendation to provide pilots with real time and accurate information regarding engine status was made by the National Transportation Safety Board (NTSB; 2010) following the 2009, "Miracle on the Hudson" whereby US Airways Flight 1549 that was forced to land on the Hudson River following a dual engine bird strike which caused a loss of thrust in both engines (Marra et al. 2009). Whilst oil leaks are considered to be less safety critical than catastrophic Foreign Object Debris (FOD) strikes, such as in the case of flight 1549, oil leaks and the potential for oil starvation represents a scenario in which additional data relating to the status of the engine would be particularly beneficial. Using the two PCMs detailed up, the design insights in Table 1 provide options for how such a system may be implemented.

Evaluation

SWARM can be seen as a similar methodological approach to the Critical Decision Method (CDM) (Klein, Calderwood & MacGregor, 1989), in that it relies on verbal reports to elicit understanding. As a consequence, similar to CDM, one of the main limitations of SWARM is the reliance on verbal reports (Klein et al. 1989; Stanton et al. 2005) to represent the cognitive processing of the decision maker. There are known issues with memory alteration and decay when data is collected this way (Klein & Armstrong, 2005; Plant & Stanton, 2016). The interviews were conducted in a class-room type envrionment where there were no cues to the cockpit. If the studies were conducted within the cockpit it is true that the pilots may have had more cues to assist them in reporting their decision making process. This should be reviewed in future work. The interviews were based on a hypothetical scenario that the pilots may not have directly experienced in the real world. They did, however, report experience in the simulator of similar events that would trigger the same standardised responses that they reported in response to the oil leak scenario. It is oftern the case that pilots are trained not to respond to the cause of an engine failure, but the resulting impact that it has on the aircraft functionality. This was why the pilots were able to give detailed accounts of the procedures they would conduct to diagnose and contain the scenario. The standardised procedures facilitated the amalgamated PCM representation from SWARM interviews. The validation of the models by an independent subject matter expert also credits the robustness of the PCMs.

Conclusion

The main purpose of this paper was to explore the potential utility of using the SWARM interview technique to elicit value within the product development lifecycle. Using an engine oil leak as an exemplar scenario, the interviews sought to provide insight into the current procedures pilots must undertake, their thought processes and the sources of information that pilots access when dealing with such a scenario. Not only did SWARM enable the production of a perceptual cycle model for this process but the SWARM technique also enabled researchers to generate insight into how pilot decision making can be better supported in such events. In addition to this the same approach was used to determine how pilots may want to be assisted in the future and from this key design recommendations were generated. This represents a much more proactive approach to technology, and specifically cockpit display, design that engages end-users in the design process at a much earlier stage of the design lifecycle than is typical. Such engagement can lead to designs which are more suitable for implementation and installation within a cockpit environment and can more directly address end user needs. While the focus within this work was on aviation, it is possible that similar approaches can be taken in other domains to facilite early engagement of users in the design process. This includes areas such as rail and road where the PCM has already been shown to be effective.

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Figures and Captions

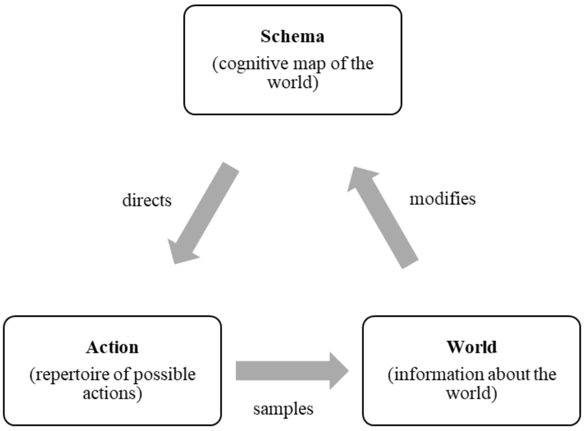

Figure 1. Perceptual Cycle Model (adapted from Neisser, 1976).

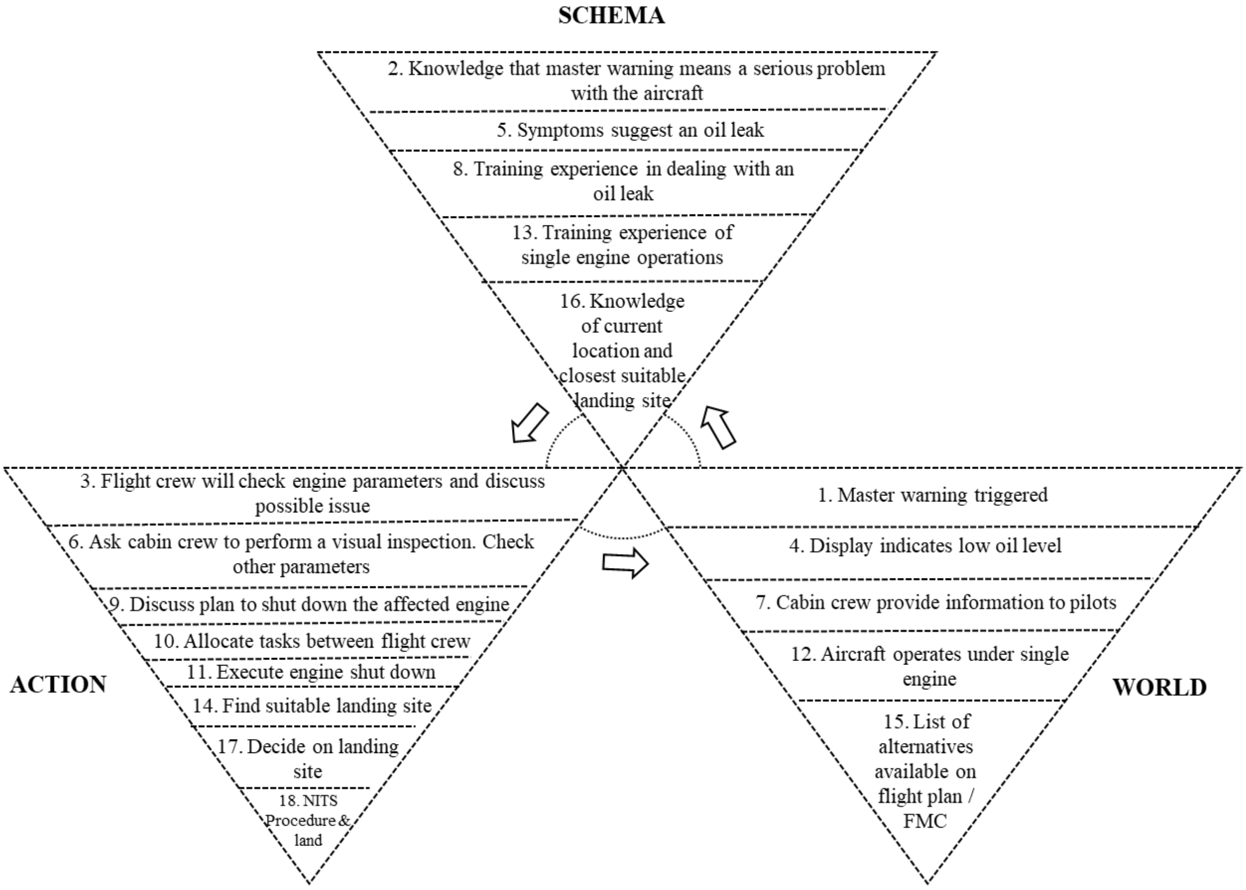

Figure 2. Amalgamated PCM of pilots' current approach to dealing with an engine oil leak

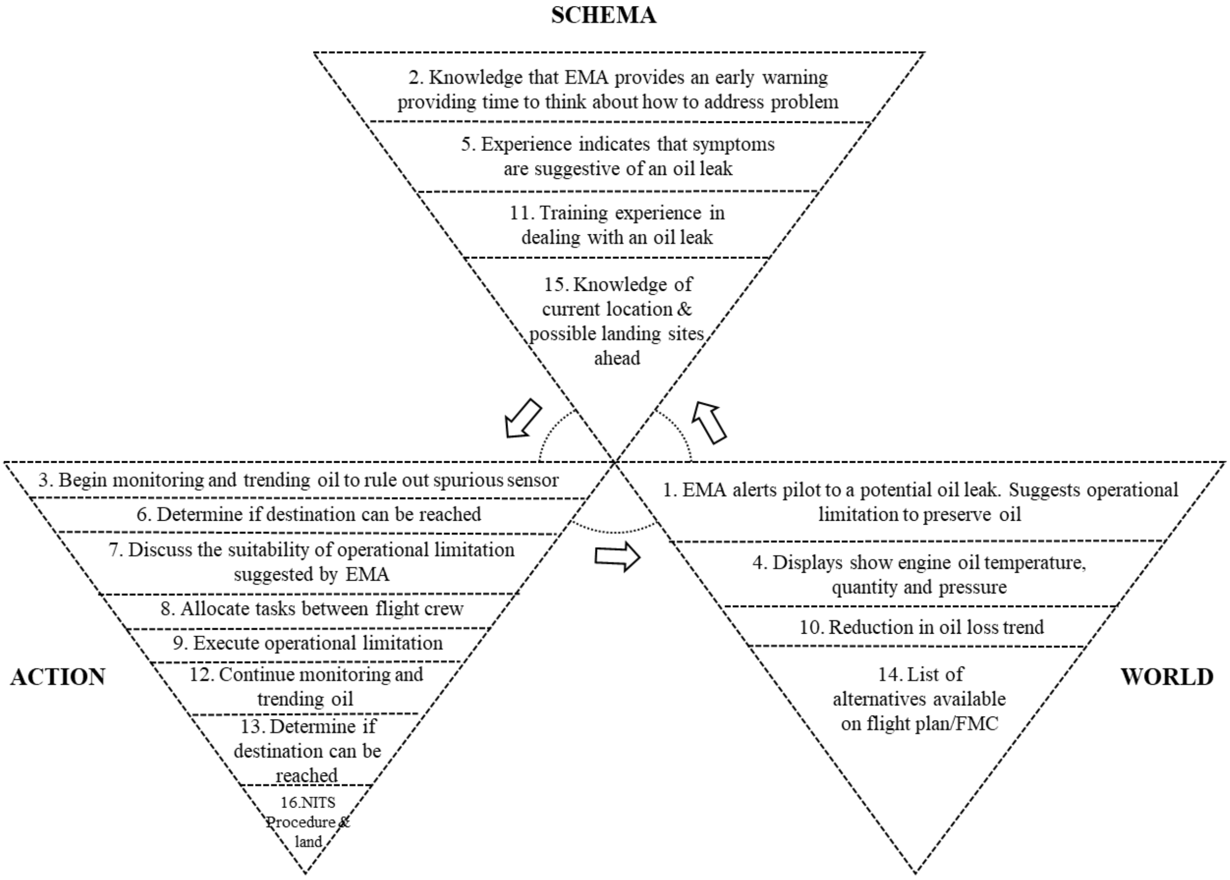

Figure 3. Amalgamated PCM of pilots’ future proposed approach to dealing with an engine oil leak with an automated system assistance

Table and Caption

Table 1. Design recommendations for the flight deck instrumentation

Current practise	***Possible deficiencies in performance***	***Design recommendations***
Pilots to deliberately check system displays and begin trending oil	Subtle leaks difficult to detect using current displays	Provide a graphical representation of oil trend data over time. Enables subtle abnormalities to be highlighted earlier.
Determine how much time is left before engine reaches starvation by trending oil	Requires potentially complex estimations to be carried out by pilots in addition to standard flight tasks.	Automatically present estimated time left to reach starvation based on flight parameters.
Determine most appropriate strategy based on available information	Pilots may select sub-optimal strategy as they lack all available information or find it difficult to access information due to increase in workload as a consequence of the leak.	Provide indication of preferred action but present various options
Follow relevant checklist from Quick Reference Handbook	Time lag associated with finding relevant checklist within Quick Reference Handbook	Automatically present relevant checklist for chosen action
Review information and check that any action has yielded the desired response	Difficult to maintain a detailed and accurate understanding of oil trend levels, especially when considering standard oil dynamics.	Enable flight crew to review historic data and provide them with a projection of future engine state

	Pilots may neglect monitoring of healthy engine to focus on defective engine.	Present data on healthy engine so that regular monitoring can be performed
Check diversion airports on the flight plan	Cost-benefit analysis of alternative airports based on commercial pressures may result in suboptimal choice.	Automatically display most appropriate diversion airports based on aircraft type and other situational requirements