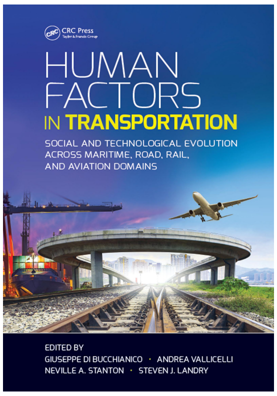

Human Factors in Transportation
Social and Technological Evolution Across Maritime, Road, Rail, and Aviation Domains

Giuseppe Di Bucchianico, Andrea Vallicelli, Neville A. Stanton, Steven J. Landry

Using Neisser's Perceptual Cycle Model to Investigate Aeronautical Decision Making

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Section IV

Aviation Domain

Introduction

A significant amount of human factors work, perhaps disproportionate in terms of size, has been applied to the air transport sector. Similar to the road domain, the air transport sector has undergone rapid expansion in terms of economy, scope, and technological innovation since its inception a little over 100 years ago. Human factors issues have been a constant priority throughout this time, with the focus migrating from manual instrumentation and ergonomic issues to issues surrounding the integration of complex automation in both flight deck and air traffic control systems. The focus of this work has always been to improve the safety of the air transportation system.

Reflecting the general areas of research over the years, the 10 chapters of this section of the book are divided into three main groups: aviation safety (Chapters 20 through 22), air traffic control human factors (Chapters 23 through 26), and aircraft human factors (Chapters 27 through 29). Hopefully, these chapters provide some insight into the types of issues currently being pursued by researchers and engineers.

Steven Landry

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Using Neisser's Perceptual Cycle Model to Investigate Aeronautical Decision Making

Katherine L. Plant and Neville A. Stanton

CONTENTS

20.1 Introduction

20.1.1 Aeronautical Decision Making

Aeronautical decision making is a form of naturalistic decision making (NDM: Klein et al., 1989) in which decision makers have domain expertise and make decisions in contexts that are usually characterized by limited time, goal conflicts, and dynamic conditions. The most popular model in the NDM domain is Klein's (1998) recognition primed decision (RPD) model. In summary, this captures how experts make decisions based on recognition of past experiences that are similar to the current situation. These experiences are used to generate one workable option before considering other options, a process known as satisficing (Klein, 1998). In complex cases, evaluation of the option reveals flaws that require modification or the option is rejected in favor of the next most typical reaction. Klein (1998) highlighted dynamic conditions, that is, the changing situation, as one of the key features of NDM. As new information is received or old information becomes invalid, the situation and goals can be radically transformed. This cyclical nature of decision making is referenced in the RPD model in terms of mental simulation but this is only internal to the decision maker. The cyclical nature of a changing external environment is not fully captured in the RPD model. Similarly, the implementation of the model does not connect the internal process of the decision maker to the external environment in which decisions are made. The explanation provided by the RPD model is primarily one of the decision-making processes occurring in the head of the decision maker (Plant and Stanton, 2014a). However, decision making of any kind, especially in the dynamic conditions that characterize the NDM environment, is a product of the interaction of the processes going on in the head of the decision maker and the conditions in the external environment. As Dekker (2006) argued, in order to truly understand decision making it is essential to account for why the actions and assessments undertaken by an operator made sense to them at the time. What makes sense for a decision maker will be based on internal information in the head and external information in the environment. As such, it is proposed that Neisser's (1976) Perceptual cycle model (PCM) is a more suitable framework to model decision-making processes because it accounts for the cyclical interaction that occurs between an operator and their environment in a way that is not captured by the RPD model.

20.1.2 Perceptual Cycle Model

As illustrated in Figure 20.1, Neisser presented the view that human thought is closely coupled with a person's interaction in the world, both informing each other in a reciprocal, cyclical relationship. World knowledge (schemata) leads to the anticipation of certain types of information (top-down processing); this then directs behavior (action) to seek out certain types of information and provides a way of interpreting that information (bottom-up processing). The environmental experience (world) results in the modification and updating of cognitive schemata and this in turn influences further interaction with the environment. The role of past experience is emphasized in the PCM, as Neisser proposed that schemata are the medium in which the past affects the future, that is, information previously acquired will determine what will be sampled next. The model has been most widely applied as an explanatory framework to understand factors such as situation awareness or decision making from the perspective of individuals operating as part of larger systems. For example, in the aviation domain, Plant and Stanton (2012a) demonstrated how the PCM could explain the actions of the pilot's involved in the Kegworth plane crash. Similarly, this approach has been used in the rail domain (see Stanton and Walker, 2011; Salmon et al., 2013). Whilst the PCM offers an explanatory framework, the account of the decision-making process is at a relatively high level. Neisser (1976) described the three elements of the PCM as being: internal schemata, actions undertaken, and world information, but did not further subcategorize these elements. This chapter presents a more detailed classification scheme in order to gain a fuller understanding of the perceptual cycle that pilots engage during critical incident decision making.

20.2 Method

20.2.1 Data Collection

Twenty helicopter pilots were interviewed using the Critical Decision Method (CDM) (Klein et al., 1989). This is one of the most commonly used cognitive task analysis (CTA)

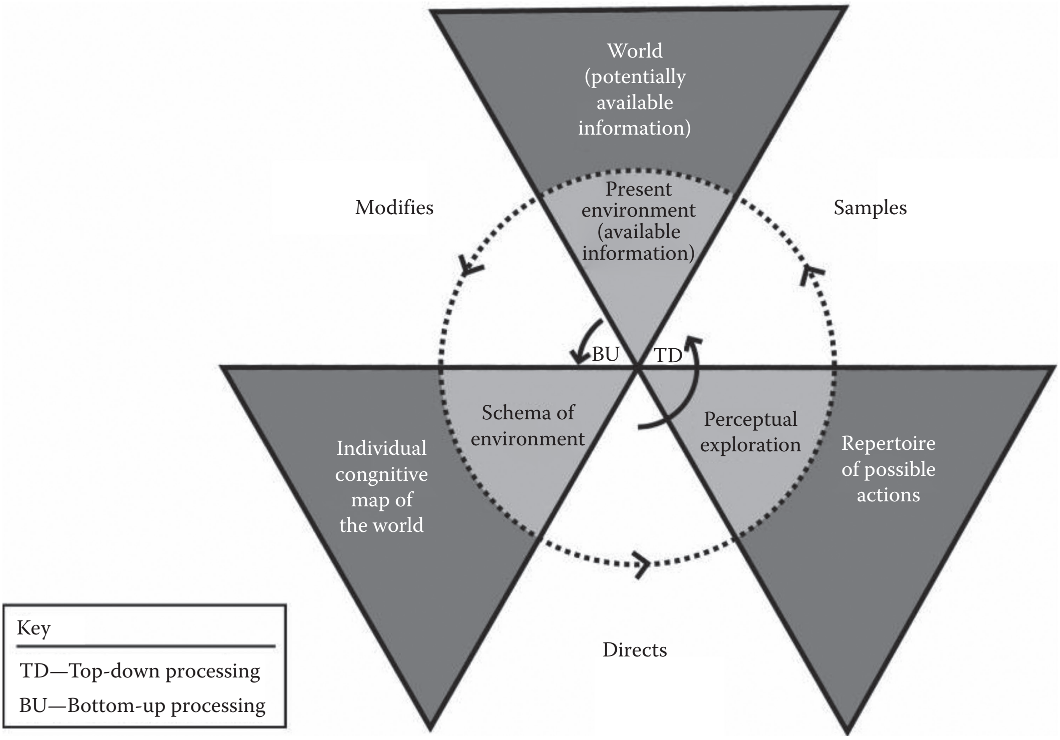

FIGURE 20.1
The Perceptual Cycle Model. (Adapted from Neisser, U. 1976. *Cognition and Reality*. W.H. Freemand and Co., San Francisco.)

methods and achieves knowledge elicitation through the use of cognitive probes as a tool for reflecting on strategies and reasons for decisions during nonroutine situations. The CDM procedure involves participants describing a critical incident they were involved with, defining a timeline of events and answering the deepening probes. The deepening probes cover factors including goals, experience, decisions, options, and information. A more detailed description of the procedure can be found in the associated literature (see Klein and Armstrong, 2005; Plant and Stanton, 2013; Stanton et al., 2013).

The 20 pilots that participated in the study were recruited through an advertisement placed on the British Helicopter Association website and via word-of-mouth. The sample consisted of 19 males and 1 female. Twenty five percent of the sample was aged between 31 and 40 years, 40% were aged between 41 and 50 years, and 35% were aged between 51 and 60 years. The pilots were all relatively experienced; flying hours ranged from 1150 to 13,000 (mean = 5942, SD = 3304, median = 5000). The pilots were employed in a variety of occupations including search and rescue, military, personal passenger transport, North Sea transport, and as test pilots. This study was granted ethical permission by the University of Southampton Research Ethics Committee.

Each pilot was interviewed at their place of work and was asked to think of a critical incident they had been involved with, which was defined as being a nonroutine or unexpected event that was highly challenging and involved a high workload in which they were the primary decision maker. Each participant provided a high-level overview of the incident and structured a timeline of events. After the incident description/timeline construction phase, the cognitive probes were asked in relation to the decision making during the incident. The interviews were audio recorded and later transcribed.

20.2.2 Data Analysis

20.2.2.1 Data Treatment

The 20 CDM interviews produced data about critical incidents that were amalgamated across the 20 interviews. The data from each interview were structured into six generic phases of incident that have been previously identified in similar data (Plant and Stanton, 2012b). The six phases were (including percentage of data in each phase): (1) pre-incident (9%), (2) onset of problem (23%), (3) immediate actions (24%), (4) decision making (24%), (5) subsequent actions (15%), and (6) incident containment (5%). In accordance with the guidelines on qualitative data analysis, the text was chunked into meaningful segments of approximately one sentence or less in length. This resulted in 904 text segments across the 20 interviews. The data analysis techniques undertaken here are based on the principles of thematic analysis which is a method for identifying, analyzing, and reporting patterns (themes) within data (Braun and Clarke, 2006). This approach offers a flexible and useful research tool that can provide a detailed account of complex data. The data were subjected to both deductive and inductive thematic analysis.

20.2.2.2 Deductive Thematic Analysis

Deductive thematic analysis was initially used to classify the data. In this process themes or patterns in the data are generated from existing theory (Boyatzis, 1998). In accordance with the broader research question of exploring decision-making processes from the perspective of the perceptual cycle, the PCM was used as the theoretical underpinning for the deductive thematic analysis. As such, three themes were defined as: schema (statements relating to the use of prior knowledge and knowing things because of experience or expectations), actions (statements of doing an action or discussing potential actions that could be taken), and world information (statements relating to potential or actually available information in the world including physical things, conditions, or states of being). Interested readers are directed to Plant and Stanton (2013), which describes the development of the coding scheme in more detail. The focus of this chapter is not to look at these themes in any detail because this has been done previously (see Plant and Stanton, 2012a, 2013, 2014b) but rather to explore themes within these high-level categories via inductive thematic analysis.

20.2.2.3 Inductive Thematic Analysis

Inductive thematic analysis was undertaken on the data in each of three high-level categories of schema, action, and world in order to uncover more detailed themes within this data. Inductive thematic analysis is the process by which the data are used to generate themes (Patton, 1990). In its purest form inductive analysis is a process of coding data without trying to fit it into a preexisting coding frame (Braun and Clarke, 2006). However, the data in this study were already classified into the three PCM codes and this therefore had some bearing on the nature of the themes generated in the inductive analysis process. The constant comparison technique was employed whereby each text segment was compared with previous items to see whether the same or a different phenomenon was described. The taxonomy was developed through an iterative process of review and refinement using the opinions and expertise of colleagues in the research group. The process of inductive analysis resulted in the identification of six schema subtypes, 11 action subtypes, and 11 world subtypes. These are presented in the PCM taxonomy in Appendix.

20.2.2.4 Relationship and Frequency Analysis

This research sought to explore the relationships between different elements of the perceptual cycle. To do this, for each CDM interview, each code was collated into a frequency table that captured "from-to" links between the different categories as they appeared in the coded transcripts. For example, a text segment coded as "action_decision action" (from), followed by a segment coded as "world_standard operating procedure" (to) were recorded in the frequency matrix. This was summed across the 20 interviews to create an amalgamated frequency count for each of the six phases and across the data set as a whole. This frequency count analysis was subjected to network analysis using the Agna™ software. This is a social network analysis (SNA) tool but is becoming an increasingly popular method for general network analysis. It provides a range of different metrics for analyzing networks and interested readers are directed to other texts for comprehensive descriptions of available metrics, including Houghton et al. (2006), Baber et al. (2013), and Stanton (2014).

Specifically, the metric of sociometric status (SMS) was of interest to define key information elements related to critical decision making. Sociometric status refers to the relative importance of a node (concept) within a network as its calculation is based on the connectedness (i.e., number of connections to other nodes) of a particular information element. The argument is that concepts with high sociometric status values represent key concepts as they are highly connected to other concepts within the critical decision-making network (Stanton, 2014). Here, the concepts (i.e., PCM subcategories) with a sociometric status value above the mean plus one standard deviation for the network were identified as primary concepts, those with a value higher than the mean but lower than the mean plus one standard deviation were identified as secondary concepts and those with a value lower than the mean were identified as tertiary concepts.

20.2.2.5 Reliability Analysis

It has previously been demonstrated that the original PCM coding scheme based on the three primary elements of schema, action, and world generated high levels of inter-rater (86%) and intra-rater (83%) reliability over a 4-week period (Plant and Stanton, 2013). To assess reliability, three additional coders were judged by the standard set by the expert coder in a blind condition, that is, raters were unaware of the expert's coding decisions. Reliability scores were calculated based on percentage agreement, that is, number of agreements divided by the number of times the coding was possible, multiplied by 100. This was in accordance with the literature that has suggested this is the most suitable way to calculate reliability scores with data of this nature (Boyatzis, 1998). There is general consensus that 80% agreement is the threshold for acceptable agreement (see Plant and Stanton, 2013) and this is used as the benchmark here for assessing reliability. The coders were presented with 200 text segments (10 from each interview) which represented 22% of the data. The text segments were selected using a random number generator. This randomly generated 10 numbers within the range of total number of text segments for each interview. Additionally, the original expert coder re-coded the 200 selected text segments. This occurred 13 months after the original coding had taken place. The results of the reliability assessment are presented in Table 20.1, all fall above the 80% threshold for agreement.

TABLE 20.1
Average Percentage Agreement from the Reliability Assessment of the PCM Taxonomy

	Inter-Rater Analysis (%)	Intra-Rater (%)
Schema subcategories	87	88
Action subcategories	84	82
World subcategories	82	88
Total (averaged across the three categories)	81	86

20.3 Results

Table 20.2 presents the primary, secondary, and tertiary concepts for the whole process of dealing with a critical incident (i.e., not phase of incident specific). These are listed in order of importance (highest to lowest) based on the sociometric status values. The sociometric status analysis was also conducted on each of the six phases of flight, these are described in relation to the primary and secondary concepts:

- *Pre-incident*: In this phase the pilots set the scene and described the antecedents to the incident. The most relevant concepts in this phase generally came from the world concepts. There were two primary concepts, both subtypes of world, being natural environmental conditions and operational context. Furthermore, location and physical cues were also defined as secondary concepts. Aviate and standard operating procedures were highlighted as the most relevant action concepts and declarative schema was the most important schema concept.

TABLE 20.2
Primary, Secondary, and Tertiary PCM Concepts When Dealing with a Critical Incident

Primary Concepts	Secondary Concepts	Tertiary Concepts
Aviate (A)	Operational context (W)	Standard operating procedure (A)
Decision action (A)	Physical cue (W)	Absent information (W)
Location (W)	Direct past experience (S)	Technological conditions (W)
Natural environment (W)	Trained past experience (S)	Insufficient schema (S)
Display indication (W)	Declarative schema (S)	Aircraft status (W)
	System monitoring (A)	System management (A)
	Communicate (A)	Concurrent diagnostics (A)
	Situation assessment (A)	Nonaction (A)
		Communicated information (W)
		Environment monitoring (A)
		Artifacts (W)
		Problem severity (W)
		Vicarious past experience (S)
		Navigate (A)
		Analogical schema (S)

Note: Letters depict whether the concept belongs to schema (S), action (A), or world (W) categories of the PCM.

- *Onset of problem phase*: This phase was characterized by the primary concept of physical cue. Technological conditions and display indication follow as the second and third most relevant world concepts. In this phase the most relevant action concept and third most relevant overall concept were aviate, the act of flying the aircraft. Other important action concepts included systems monitoring, concurrent diagnostics, and systems management. The most relevant schema concepts were direct past experience, trained past experience, and insufficient schema.
- *Immediate actions phase*: There were no primary concepts in this phase, but the most important concept was display indication (world concept) followed by trained past experience (schema concept). Action subtypes generally dominated this phase, with seven of the 14 secondary concepts coming from the action category, including aviation, systems monitoring, concurrent diagnostics, decision action, communicate, situation assessment, and standard operating procedures.
- *Decision-making phase*: In this phase, unsurprisingly, decision action was the primary concept. The remaining secondary concepts were evenly spread around the three elements of the PCM, with four world concepts (location, aircraft status, absent information, and display indication), four action concepts (situation assessment, communication, aviate, and standard operating procedure), and three schema concepts (direct past experience, trained past experience, and declarative schema).
- *Subsequent actions*: There are no primary concepts in this phase, but the top five most relevant secondary concepts are aviate, decision action, declarative schema, communicate, and display indication.
- *Incident containment*: In this phase, again, there are no primary concepts and only action and world subtypes appear as secondary concepts. Including in the action category; aviate, systems management, and communicate and in the world category; location, operational context, and aircraft status. Eleven of the 28 concepts do not feature in this phase of the incident, given that only 5% of the data are represented in this phase.

The primary and secondary PCM concepts were modeled into a network (see Figure 20.2). The links between each concept represent the directional flow of information and the strength of the links was informed by the Agna™ network data, the thicker the line, the stronger the link is between the concepts.

20.4 Discussion

Decision making can be one of the determining factors regarding whether or not normal situations turn into incidents, and incidents turn into accidents. Decision making in complex sociotechnical systems needs to be viewed through the lens of distributed cognition and the PCM achieves this by acknowledging the interaction between internal cognitive schemata held by the decision makers and the external environment in which decisions are made. However, the high level of description provided by the PCM has meant that only a limited level of detail is gained about the core areas of the model. This research applied a detailed PCM taxonomy to critical decision-making data and then analyzed the results using the SNA metric of SMS in order to determine the relative importance of PCM concepts during ACDM.

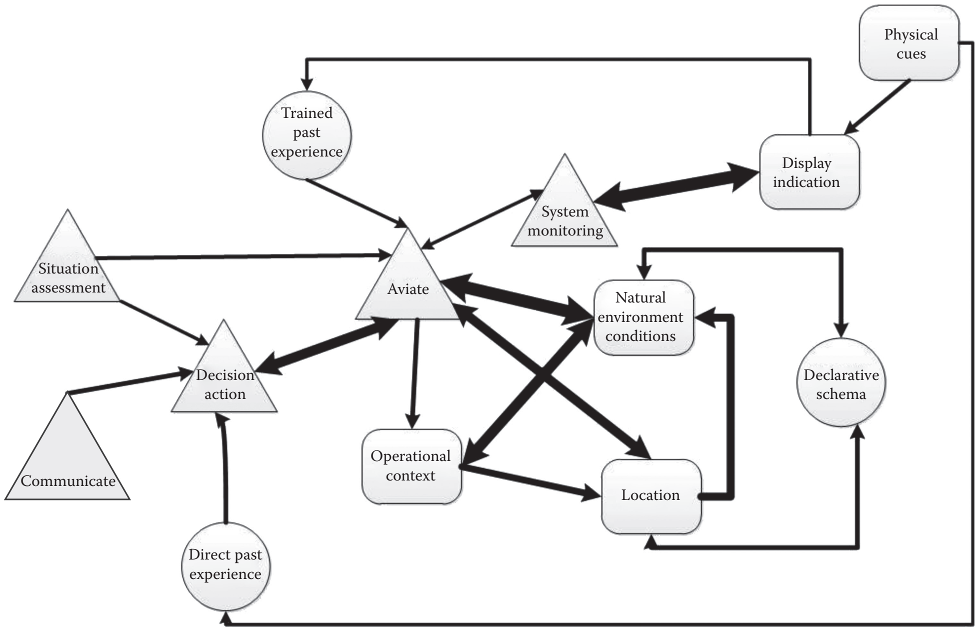

FIGURE 20.2
Network model of aeronautical critical decision making.

20.4.1 Summary of Results

The PCM taxonomy was developed to gain a more detailed understanding about the process of ACDM from the perspective of the PCM. The analysis discussed is a composite account summed across the 20 interviews and is considered both as a whole and by phase of incident. In both instances the PCM concepts were scored on sociometric status to determine their relative importance (the higher the status, the more important the concept). This resulted in the classification of primary, secondary, and tertiary concepts (only primary and secondary concepts are discussed as these are most pertinent to the ACDM process). The analysis showed that the most important concept for ACDM was the action concept of aviate; highlighted in Figure 20.2 as most of the other concepts are connected to aviate in some way. This is unsurprising given that aviate is the primary task management requirement in the "aviate–navigate–communicate–manage systems" strategy employed by all pilots when dealing with non-normal situations. It is of paramount importance that, regardless of what is happening around them, pilots continue to fly their aircraft. In a study of task management priorities, Schutte and Trujillo (1996) found that participant's prioritized aviate when dealing with non-normal situations. The next most important concept was "decision action." This is to be expected in data collected for decision-making research and increases confidence with the method for collecting decision-based data. The next three most relevant concepts were from the world category: location, natural environmental conditions, and display indications.

The absence of any schema subtypes in the primary concepts suggests that ACDM is predominately driven by bottom-up information processing, that is, the environmental information that is received drives the actions that are undertaken. This is supported by the ACDM model (Figure 20.2), which shows the strongest links between aviate and the world concepts of location and natural environment. This information processing strategy is akin to what Rasmussen (1983) described as skill-based behavior (SBB). SBB is the smooth, automatic, and execution of highly practiced physical actions. At this level of behavior world information and the pattern recognition, this induces maps directly onto physical actions. This develops through extensive training where operators acquire cued response patterns suited for specific situations and is therefore characteristic of expert performance. Rasmussen (1983) also described rule-based behavior (RBB) and knowledge-based behavior (KBB), the former requiring identification and recall of known rules which are stored in memory and the latter being effortful, conscious processing of unfamiliar situations. Through the process of training and learning, pilots will progress from KBB, through RBB, to SBB in the flight control task (aviating).

The phase specific analysis demonstrated that PCM concepts vary in importance according to phase of incident. For example, the "onset of problem" phase is characterized by the physical cues and technological conditions that generally alerted the pilot to the problem. Aviate is the most relevant action, in line with our previous discussion about the importance of maintaining adequate handling of the aircraft at all times. In the "immediate actions" phase, display indication was the primary concept and the next 11 secondary concepts were subtypes of the schema and action categories. This suggests that this phase was characterized by top-down information processing which is supported by the importance of trained past experience and direct past experience as secondary concepts. Insufficient schema also features as a secondary concept which was apparent when pilots talked about insufficient background knowledge to deal with the problem that was presented. It is unsurprising that in the "decision-making" phase decision action is the primary concept. Secondary concepts include a variety of all three subtypes as text segments in this phase related to the actions undertaken once the primary decision was made (e.g., situation assessment, communicate, and aviate) and how these actions were influenced by the world information (e.g., location, aircraft status, and absent information) and stored knowledge (e.g., direct past experience, trained past experience, and declarative schema).

20.4.2 Evaluation

The role of the perceptual cycle in Aeronautical Critical Decision Making (ACDM) has been previously identified (Plant and Stanton, 2012a, 2013, 2014a,b), but from this work the finer detail of the interactions was able to be explored. The results make intuitive sense, insomuch that concepts have the most relevance in the phases where they would expect to be found and are less relevant in phases where they are not expected. For example, decision action is the primary concept in the decision-making phase, whereas severity of problem and concurrent diagnostics do not feature in the pre-incident phase (because the incident had not happened yet). For exploratory studies, intuitive sense is important because it points toward the appropriateness of the data collection and analysis methods. The relative importance of concepts was objectively determined by the sociometric analysis function in Agna™ which suggests that the classification method employed with the PCM taxonomy was appropriate for gaining an increased understanding about ACDM.

A fundamental component of the PCM are schemata, these are akin to internal mental templates and therefore cannot be directly measured but only inferred through the manifestation of observable behavior or recalled information. As presented here, contemporary approaches for eliciting schema-based data and inferring perceptual cycle processes generally pair data collection methods such as interviews with qualitative data analysis including network modeling or thematic analysis. This is a form of CTA as they are approaches that determine the cognitive elements (i.e., mental processes and skills) required for task performance and the changes that occur as skills develop. The CDM is one of the most popular CTA methods. However, the CDM focuses on eliciting knowledge for behaviors classed as recognition-primed decisions (RPD), that is, decisions for which alternative actions are derived from the recognition of critical information and prior knowledge. The RPD model is the most popular and enduring model in the NDM domain. However, we have previously argued that it does not go far enough at acknowledging the interaction between schemata and environmental information and the modifying effect each can have on the other (Plant and Stanton, 2014a). Rather, the RPD model tends to focus on the decision-making processes that occur in the mind of the decision maker. However, this is only achieved at a generic level with questions such as "did your experience influence the decisions that you made?" The findings presented here suggest that schema data are not being captured as well as action and world data and therefore alternative methods are required that are more suited to extracting the three elements of the PCM.

20.4.3 Future Applications and Research

The potential exists to utilize the PCM taxonomy in any qualitative data analysis including data collected from interviews, communication transcripts, or verbal protocols. Stanton and Salmon (2009) stated that a valid taxonomy can be used either proactively to anticipate potential situations or retrospectively to classify and analyze situations after they have occurred. Both applications have associated practical implications, for example, in the identification of areas that may benefit from decision-making training or redesigning interfaces to facilitate the provision of information in the external environment. Salmon et al. (2012) argued that the use of taxonomies facilitates the aggregation of data across multiple cases, this is consistent with Fleishman and Quaintance's (1984) assertion that taxonomy development allows for the establishment of a base for conducting and reporting research studies to facilitate their comparison.

A comprehensive taxonomy should enable attributes that distinguish a category member from the general population to fall into a meaningful pattern, given knowledge of relevant literature, for example, contrasting expert and novice perspectives. With perceptual cycle processing, it is likely that experts would rely on schemata to select relevant environmental cues and therefore be more selective than novices in the information they attend to. Inexperienced and experienced pilots are known to have different accident types, the former being associated with loss of control accidents due to a lack of basic handling skills and the latter being associated with more cognitively-driven accidents, such as complacency (Civil Aviation Authority, 1997). Using the PCM taxonomy to highlight where and how differences in decision-making manifest between different demographic groups will increase its external validity and provide useful information about ACDM.

20.5 Conclusion

The PCM views decision making through the lens of distributed cognition, providing a process-orientated approach for understanding how internally held mental schemata interact with information perceived in the external environment to produce actions and behaviors. This study has demonstrated that different elements of the perceptual cycle differ in their importance depending on the phase of dealing with a critical incident. Understanding what information is utilized, when it is utilized, and how this interacts with actions undertaken is taking a step toward being able to develop decision-centered training aids, design solutions, or procedural strategies based on the principles of perceptual cycle information processing.

Acknowledgment

The authors thank the pilots who gave their time to participate in the interviews.

Appendix: PCM Taxonomy

Schema Subtype	Description	Examples
Vicarious past experience (VPE)	Statements relating to experiencing something in the imagination through the description by another person (e.g., hearing a colleague recall an incident they were involved with) or documentation (e.g., reading about a certain event in an industry magazine or incident/accident report)	*"I knew I had surged the engine…I had heard about surging…I hadn't experienced it but I knew that the engine was surging. It had been described to me, in books. You don't train for it. No one plays you a sound clip, it's more by reading documents I suppose"*
Direct past experience (DPE)	Statements relating to direct personal experience of similar events or situations in the past. This covers events experienced in live, operational contexts as opposed to those experienced through training	*"I have experienced levels of vibration on other aircraft and I know what is normal, what is abnormal, this exceeded it tenfold…"*
Trained past experience (TPE)	Statements relating to knowledge developed by direct personal experience of a specific task, event or situation, experienced within the confines of a training scenario (e.g., ground school training, simulator training, or training sorties)	*"The decision of what to do was in my experience because of training. I had seen this instance before in a simulator"*
Declarative schema (DS)	Statements relating to a schema that manifests as a descriptive knowledge of facts, usually as a product of the world information available	*"I knew it had just come out of maintenance, I was aware it could be a spurious event"*
Analogical schema (AS)	Statements relating to comparisons between things for the purpose of explanation and clarification. Typically these analogies will be structural analogies of physical objects or states of affairs in the world (akin to mental map or mental model)	*"How high am I, how fast am I, can't see a lot so having to make this picture in my head based on the information that I do know"*
Action Subtype	**Description**	**Examples**
Insufficient schema (IS)	Statements relating to inadequate or lacking knowledge, that is, a schema is not developed for a certain situation	*"It didn't fail like they do in training, so I wasn't instantly sure it was an engine failure"*
Aviate (Av)	Statements relating to direct manipulation (handling) of flight controls in order that the aircraft can be flown and safety is maintained	*"I attempted to roll the aircraft level"*

(*Continued*)

Action Subtype	Description	Examples
Navigate (Nav)	Statements relating to the process of accurately ascertaining position and planning and following a route or desired course	*"I followed the coast back"*
Communicate (Comm)	Statements relating to the sharing or exchange of information	*"I transmitted a non-standard mayday call"*
System management (Sys Man)	Statements relating to the processes of making an input into technological systems in order that the interaction or manipulation has an explicit output	*"I put in St. Albans head into the navigation system, so I typed in the three digit code which is St. Albans head"*
System monitoring (Sys Mon)	Statements relating to looking at (observing, checking) displays to gain an understanding of the situation	*"I did a complete scan of all the systems information"*
Environment monitoring (Env Mon)	Statements relating to observing or checking the internal or external physical environment in order to establish the current state-of-affairs	*"I was keeping eyes out for ground contact and searching for visual references"*
Concurrent diagnostic action (Conc Diag)	Statements relating to the process of determining, or attempting to determine, the cause or nature of a problem by examining the available information at the time the incident is occurring	*"We initially started looking for circuit breakers, to look if any had popped"*
Decision action (DA)	Statements relating to a conclusion or resolution that is reached after considering the available information	*"The first decision was to idle back the bad engine, rather than shut it down"*
Situation assessment (Sit Ass)	Statements relating to actions that relate to the evaluation and interpretation of available information	*"Trying to take into account the threats to you and the aircraft, that is, if I precede down a given path what is it likely to result in?"*
Nonaction (Non A)	Statements relating to actions that were not performed, either because the situation did not warrant a particular action or because equipment faults did not allow a particular action to be performed or because the pilot made an error or omission	*"I couldn't read any of the instruments or communicate"*
Standard operating procedure (SOP)	Statements relating to following the prescribed procedure that ought to be routinely followed in a given situation	*"I completed the pre-take off checks"*
World Subtype	**Description**	**Examples**
Natural environmental conditions (NEC)	Statements about natural environmental conditions (e.g., weather, light, temperature, noise)	*"Fortunately it was a clear day, nice sunny day"*
Technological conditions (Tech Cond)	Statements relating to the state of technological artifacts (e.g., with regard to appearance and working order)	*"…engines responded and all other stuff came back on"*
Communicated information (Comm info)	Statements relating to information available to the pilot from other people (e.g., other crew members, ATC, coastguard, etc.)	*"I received the cloud base report from Newquay"*
Location (Loc)	Statements relating to particular places or positions	*"…so now we were over the destination"*
Artifacts (Art)	Statements discussing physical objects, including written information, symbols, diagrams, or equipment	*"I had the flight reference cards"*
Display indications (Dis Ind)	Statements relating to the information elicited from the physical artifacts	*"Only thing identifiable was the high transmission oil temperature"*

(*Continued*)

World Subtype	Description	Examples
Operational context (Op Cont)	Statements relating to the routine functions or activities of the organization (e.g., search and rescue, police search, military training, etc.). This can include statements about the importance of being serviceable for the operational context or crew familiarity with the aircraft and how this effects decision making	*"the aircraft was relatively heavy because we were taking people back to Germany"*
Aircraft status (Air Stat)	Statements relating to the current status of the aircraft's integrity or performance (e.g., how good or bad it is flying, the current configuration of the aircraft, autopilot activation, etc.)	*"the aircraft was flying fine"*
Severity of problem (Prob Sev)	Statements relating to how bad (or otherwise) the critical incident is	*"we weren't in any immediate danger"*
Physical cues (Phys Cue)	Statements relating to external cues that provide information of conditions or states of being (e.g., noises, sounds, vibration, smells)	*"there was a loud bang, coughing and spluttering"*
Absent information (Abs Info)	Statements relating to information that was missing, not present or lacking. Reasons for this may include technical faults with equipment or nonexistent information	*"I didn't have a comprehensive map"*

References

Baber, C., Stanton, N.A., Atkinson, J., McMaster, R., and Houghton, R.J. 2013. Using social network analysis and agent-based modelling to explore information flow using common operational pictures for maritime search and rescue operations. *Ergonomics*, 56(6), 889–905.

Boyatzis, R.E. 1998. *Transforming Qualitative Information: Thematic Analysis and Code Development*. Thousand Oaks, California: Sage.

Braun, V. and Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.

Civil Aviation Authority. 1997. CAP 667: *Review of General Aviation Fatal Accidents 1985–1994*. London: Civil Aviation Authority.

Dekker, S.W.A. 2006. *The Field Guide to Understanding Human Error*. Aldershot: Ashgate.

Fleishman, E.A. and Quaintance, M.K. 1984. *Taxonomies of Human Performance. The Description of Human Tasks.* Academic Press: Orlando, Florida.

Houghton, R.T., Baber, C., McMaster, R., Stanton, N.A., Salmon, P.M., Stewart, R., and Walker, G. 2006. Command and control in emergency services operations: A social network analysis. *Ergonomics*, 49(12–13), 1204–1225.

Klein, G.A. 1998. *Sources of Power: How People Make Decisions*. Cambridge, Massachusetts: MIT Press.

Klein, G.A. and A. Armstrong. 2005. Critical decision method. In *Handbook of Human Factors and Ergonomics Methods*, edited by N. A. Stanton, A. Hedge, K. Brookhuis, E. Salas, and H. Hendrick, pp. 35.1–35.8. Boca Raton, Florida: CRC Press.

Klein, G.A., Calderwood, R., and Macgregor, D. 1989. Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man and Cybernetics*, 19 (3), 462–472.

Neisser, U. 1976. *Cognition and Reality*. San Francisco: W.H. Freemand and Co.

Patton, M.Q. 1990. *Qualitative Evaluation and Research Methods*, 2nd ed. Newbury Park, Newbury Park, California: Sage.

Plant, K.L. and Stanton, N.A. 2012a. Why did the pilots shut down the wrong engine? Explaining errors in context using schema theory and the perceptual cycle model. *Safety Science*, 50, 300–315.

Plant, K.L. and Stanton, N.A. 2012b. "I did something against all regulations": Decision making in critical incidents. In *Proceedings of the 4th International Conference on Applied Human Factors and Ergonomics*, July 21–25, 2012, San Francisco. *Advances in Human Aspects of Aviation*. Landry, S (Ed), 2012 (Conference book). Boca Raton, Florida: CRC Press.

Plant, K.L. and Stanton, N.A. 2013. What's on your mind? Using the perceptual cycle model and critical decision method to understand the decision-making process in the cockpit. *Ergonomics*, 56(8), 1232–1250.

Plant, K.L. and Stanton, N.A. 2014a. All for one and one for all: Representing teams as a collection of individuals and an individual collective using a network perceptual cycle approach. *International Journal of Industrial Ergonomics*, 44, 777–792.

Plant, K.L. and Stanton, N.A. 2014b. The process of processing: Exploring the validity of Neisser's perceptual cycle with accounts from critical decision-making in the cockpit. *Ergonomics*, 58(6), 909–923. Doi: 10.1080/00140139.2014.991765.

Rasmussen, J. 1983. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics*, 13(3), 257–266.

Salmon, P.M., Cornelissen, M., and Trotter, M.J. 2012. Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. *Safety Science*, 50, 1158–1170.

Salmon, P.M., Read, G.J.M., Stanton, N.A., and Lenne, M.G. 2013. The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. *Accident Analysis and Prevention*, 50, 1278–1288.

Schutte, P.C. and Trujillo, A.C. 1996. Flight crew task management in non-normal situations. In: *Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society*, pp. 244–248. Santa Monica, California: HFES.

Stanton, N.A. 2014. Representing distributed cognition in complex systems: How a submarine returns to periscope depth. *Ergonomics*, 57(3), 403–418.

Stanton, N.A. and Salmon, P.M. 2009. Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems. *Safety Science*, 47, 227–237.

Stanton, N.A., Salmon, P.M., Rafferty, L.A., Walker, G.H., Baber, C., and Jenkins, D. 2013. *Human Factor Methods. A Practical Guide for Engineering and Design*, 2nd ed. Aldershot: Ashgate.

Stanton, N.A. and Walker, G.H. 2011. Exploring the psychological factors involved in the Ladbroke Grove rail accident. *Accident Analysis and Prevention*, 43(3), 1117–1127.