Expert Decision-Making in Naturalistic Environments: A Summary of Research

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ABSTRACT

Effective and efficient decision-making in the Australian Army is integral to successful performance. Therefore, understanding the decision-making process is a research priority. In order to conduct such research, a summation of previous knowledge addressing the decision-making process and the climate within which it is embedded, is important. This report provides a theoretical platform on which to ground future research. It focuses on topics such as: decision theories, previous experience and expert functioning, levels of expertise, teamwork and naturalistic decision-making and decision error. The interrelations between these concepts are discussed, and recommendations for future research are given. Future research would be expected to inform the development of advanced decision support tools, and superior training techniques.

RELEASE LIMITATION

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Executive Summary

The importance of decision-making in the military has provoked much research interest. As a result a large amount of relevant research directly linked with command decision-making exists. It is the aim of this report to summarise and comment on this body of literature, specifically in regard to future research with the Australian Army. The report has been divided into five main sections. These are: decision theories, previous experience and expert functioning, levels of expertise, teamwork and naturalistic decision-making, and decision error.

Firstly, it is important to understand the ever-growing field of decision-making research. Decision research, as a field of Psychology, dates back to the middle of the 20th century. Classical decision theory (Edwards, 1954) and the rational choice model (Janis & Mann, 1977) are examples of widely cited research that has focused on decision-making as an analytical-cognitive process. A new school of thought, called naturalistic decision-making (NDM) has emerged, which is thought to more adequately explain decision-making in emergency situations. Within the field of NDM, the attention of researchers has been focused on how experts make decisions in real life emergency situations.

Secondly, Commanders in the military can all claim to have a certain amount of experience in their field. Therefore, understanding the concept of expertise is also important. Research on novice-expert differences has revealed that there are likely to be certain cognitive and perceptual skills that experts have developed in order to improve their decision-making. One method of generating a greater understanding of expert/ novice differences is by drawing on literature from the field of cognitive skill development. Expertise in this sense can be considered to be similar to any other cognitive skill. It is acquired through quality practice. Therefore, researchers must understand the continuum with which they are working, when talking about "novices" in comparison with "experts".

In addition, the environment within which a Commander is immersed is important. The team surrounding the Commander must be taken into account. In order to do this it is important to understand how teams function. Social psychologists have identified both social and structural characteristics that are commonly observed in groups of people working together. These include: cohesiveness, socialisation, team norms, roles and communication networks. Recent team research has focused on the importance of shared mental models (SMM) in effective teams. SMM guide how team members interact, and also facilitate decision-making in teams. Also, recently it has been suggested that for research and modelling purposes a "team mind" can be established as analogous to the mind of one person. This offers a range of implications for future research and design.

Finally, it is important to be able to discriminate successful and unsuccessful decisions in any study of decision-making. It would be expected that the more experience a person had, the more successful they would be at decision-making. However this has been found to be incorrect. It seems that decision error can be attributed to any of: individual, organisational, or social factors. Developing an overall understanding of how decision error may occur in team environments, such as a headquarters (HQ) team, should aid in modelling such decision-making situations.

In summary the above factors have been identified as important areas for researchers to consider when analysing decision-making in military HQ. Interrelations between the aforementioned concepts are discussed, and recommendations for future research are given.

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Taryn Elliott completed a Bachelor of Arts with Honours in Psychology in 2000. She joined DSTO in November 2000, working in the HSI discipline. She was tasked to the Human Factors battlefield command support system (BCSS) evaluation task. Specifically her role was to research human factors issues, such as decision modelling, decision error, and human biases in decision-making. She has presented work at various national conferences, such as the Land Warfare Conference (2001), and the Australasian Social Psychology Conference (2002). She is currently studying towards a PhD at Adelaide University, undertaking research in the field of naturalistic decision-making.

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1. Setting the Scene

On January 22nd 1991, during the Gulf War, an eight-man SAS[1] team known as Bravo-Two-Zero were sent on a mission behind enemy lines. Their mission was to remain concealed near the main supply route in Western Iraq for 14 days. During this time they would be expected to sever Iraqi fibre-optic cables, and report on the movement of scud missile launchers. However, due to resource limitations, they were given suboptimal equipment. They also received vague intelligence reports. This was apparent when they arrived at their drop off point to find it only about 200 meters from an Iraqi anti-aircraft stronghold. This had not been reported by Intelligence. Because this information was crucial to the success of the mission, the group attempted to contact their base via radio and inform them of the new situation. It was at this time that they realised that they had no contact with base. It was later discovered they had been given the wrong radio frequencies. The group then made the decision to sit out until a liaison arrived in 24 hours. Unfortunately, that was too long a wait. They were spotted by an Iraqi goat herder, and from then a malady of errors began its course. The team were separated. They were confronted with intermittent enemy contact, and were completely unsupported by the larger organisation. Over the next three days, three of the eight died, and four were captured. Only one man made his way back across the Syrian border. This planning error resulted in one of the most costly patrols in SAS history.
(David, 1997)

An anecdote such as this indicates the importance of planning and decision-making in such circumstances. To fail on such an occasion is to perish. Therefore the stakes are high, and the priority for researchers to understand the decision-making process in such circumstances is paramount. This report aims to investigate current understandings of expert decision-making in naturalistic environments, such as the one described in the preceding anecdote. This report sets out the relevant background information required to begin to understand the field of naturalistic decision-making (NDM). It also describes how expertise is understood within this field, and how an expert will commonly function as a part of a team. Finally, this report identifies important areas for future research within the NDM domain.

2. Overview of Issues

Due to the large amount of relevant research directly linked with command decision-making, the author feels it is important to provide an overview of the relevant points at this stage. This brief summary establishes the focal areas to be covered more substantially in the following review.

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[1] Note this is the UK SAS, not the Australian SAS.

Decision research as a field of Psychology dates back to the middle of the 20th century. Classical decision theory (Edwards, 1954) and the rational choice model (Janis & Mann, 1977) are examples of widely cited research that has focused on decision-making as an analytical-cognitive process. Although classical decision theory has proved useful in describing decision-making in a number of situations, it seems that when: timeframes are short, there is substantial uncertainty and the stakes are high, an alternative theory is needed. In response to this, a new school of thought has emerged called naturalistic decision-making (Klein, Calderwood, & Clinton-Cirocco, 1986). The NDM approach aims to investigate decision-making in naturalistic environments where uncertainty, time pressure and high stakes are key variables. This theory has been applied to domains such as fire fighting, defence operations, and emergency medicine. Within the field of NDM, the attention of researchers has been focused on how experts in real-life situations make decisions.

The study of expertise is not limited to NDM theory. There is evidence indicating that, even in ancient times, Socrates and Descartes took it for granted that "understanding a domain means holding a theory of that domain" (Dreyfus, 1997). A particular challenge in the study of "expertise" is to provide an adequate definition for this term. To date, it seems that an accepted definition of an expert in the literature is held as being a person with 10 or more years experience in their chosen domain (Klein, 1997).

Understanding how an expert functions is thought to be the key to duplicating expert performance via training. Obviously this is still an important goal in the field of NDM. The understanding of cognitive and perceptual skills that experts may have developed to improve their decision-making has been improved as a result of studies comparing experts with novices (Glaser, 1987).

One method of generating a greater understanding of expert-novice differences is by seeking to understand cognitive skill development. Expertise in this sense can be considered to be similar to any other cognitive skill. It is acquired through quality practice. Therefore, researchers must understand the continuum they are working with when talking about "novices" in comparison with "experts". Investigating cognitive skill development also provides an opportunity to understand how expertise develops, and such an understanding may aid in the design of training systems.

Due to the complexity of NDM domains, experts will often work in teams to accomplish goals. Therefore, in order to understand how a particular expert functions it is important to consider the wider team context in which they are immersed. This requires a review of the group and teamwork literature in order to identify how teams function. A number of teamwork theories exist and these are outlined in the report.

In any study of decision-making, it is important to be able to discriminate successful and unsuccessful decisions. It would be expected that the more experience a person had, the more successful they would be at decision-making. "Expert error" seems like an oxymoron, but evidence has shown that, despite extensive domain experience, errors can

still occur (NTSB, 1994). Researchers have traditionally attempted to understand error by searching for a breakdown in expert cognitive processing. However, there has recently been a change in direction, whereby error is not thought of as caused by a breakdown in expert processing, but by a poor system in which the expert is immersed (Reason, 1990; Woods, Johannesen, Cook, & Sarter, 1994). Therefore, the relation between context and expert decision-making has been identified as an important area for future research (Lewandowsky & Kirsner, 2000; Orasanu, Martin & Davidson, 2001; Schliemann & Carraher, 1993). Some notable work that has already been done on the effect of the context on decision-making is in the field of decision biases in relation to decision error (Plous, 1993). It is also suggested that there may be social and organisational considerations that contribute to team decision error. Examples of these are false consensus effect, groupthink, group polarisation, and group escalation of commitment (Jones & Roelofsma, 2000). Developing an overall understanding of how decision error may occur in team environments, such as a headquarters (HQ) team, should aid in modelling such decision-making situations.

These main concepts will now be discussed in more detail.

3. Decision Theories

Decision-making is an important cognitive process that occurs frequently in everyday human functioning. Decision-making has been defined by Yates (2001) as the process that leads to the commitment to an action, the aim of which is to produce satisfying outcomes. There have been a number of models created to explain this decision-making process. Preceding the development of the field of NDM, there was a rich tradition of research and formulation of analytical decision-making models. For the purpose of the current summary, prescriptive and descriptive models of analytical decision-making are first described. Following this an explanation and critique of models within the field of NDM will be presented

3.1 Prescriptive (Analytical) Decision-making

Edwards (1954) introduced the classical concept of prescriptive, analytical decision-making to the field of Psychology. This is a prescriptive decision-making theory that can be used to investigate everyday decision-making processes. The theory suggests that people should collect and analyse information, eventually selecting an optimal solution from a range of alternatives. This should be done by evaluating the advantages and disadvantages of each possible outcome and then choosing the one most appropriate to achieve the desired outcome goal. This decision is regarded as optimal (McDaniel, 1993).

This form of decision-making research essentially investigates the quality of the decision made by comparing it with the outcome predicted by a normative statistical model. In

doing so, this theory draws upon such methods as expected utility theory and Bayesian analysis. Possible decision outcomes can be presented statistically as probability estimates for expected outcomes. Relevant research has relied on laboratory experiments to determine how the optimal decision should be reached instead of studying how people actually make decisions. This approach has also examined how real-life decision-making outcomes differ from the optimal solution (Brehmer, Jungermann, Lourens & Sevon, 1985).

It has been argued that this theory of decision-making has weaknesses when applied to real-life decision-making (Beach & Lipshitz, 1997). In particular, it has been suggested that in an NDM situation this model of decision-making does not adequately describe the decision process (Klein, 1989). Some obvious problems within the NDM environment that cannot be catered for in this model are that the time frames in real-life situations may be short, and hence evaluation of pros and cons associated with a variety of options is often not possible. In fact, recent research by Klein, Calderwood and Clinton-Cirrocco (1997) has found that, in contrast with the classical decision-making models, on average fire-fighters only focus on one or two options before making decisions. Also, in NDM environments quality of information is usually ambiguous, so that past experience and the ability to interpret information is important. Thus the adequacy of classical decision theory to explain decision-making in an NDM environment is questionable.

3.2 Descriptive (Analytical) Decision-making

Following the failure of classical decision theory to describe many decision-making events adequately, a number of descriptive decision theories arose (Plous, 1993). One of these is the rational choice model of decision-making (Janis & Mann, 1977). This model provides an analytical approach for understanding decision-making, based on the researchers' observations. The seven process criteria specified by the rational choice model are:

1. A wide range of objectives are identified.
2. A broad spectrum of alternatives are produced.
3. The advantages and disadvantages of each alternative are assessed.
4. A search for new information relevant to each alternative is undertaken.
5. New information is incorporated into the analysis of the alternatives.
6. The advantages and disadvantages are revised.
7. Detailed provisions are made when implementing the chosen decision.

Janis and Mann (1977) argued that this model would be the only way that individuals under pressure could make good decisions. One pressure that was discussed by Janis and Mann (1977) was time pressure, which is of particular interest because it is commonly a characteristic of NDM environments. Associated with time pressure, Janis and Mann (1977) discussed how errors could occur due to people being in a "hypervigilant" state[2]. Hypervigilance was associated with a heightened level of emotion, and it was suggested that this high level of emotion may be sustained for minutes and even hours after the

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[2] This was described as an aroused psychological state triggered by time pressure.

decision had been made. Janis and Mann (1977) indicated that people in a "hypervigilant state" become preoccupied with the losses that may occur due to their time pressured decision-making. They also suggested that decision-makers will be indiscriminately open to all information available, being unable to discriminate relevant from irrelevant. This suggestion does not take into account the experience drawn on by expert decision-makers, and information searching strategies suggested by Klein (1998). However it does highlight the possible association between time pressure and increased levels of emotion.

To date, the role played by emotion in decision-making has not been given adequate attention in the NDM literature. Recent research in the field of neuropsychology suggests that emotions may play a profound role in decision-making (Lawrence & Nohira, 2002, cited in Masters & Mcshane, 2003). It has been suggested that the brain's emotional centres actually receive signals before they reach the cognitive centres of the brain. The emotional centres will process input more quickly and tag this with emotional responses. Following this, the stimuli are transported to the cognitive centre where they will be processed more logically. Thus emotion seems to be inextricably linked with decision-making. However, these ideas remain largely speculative and there is as yet little direct evidence for them.

In sum, the rational choice model seems to describe some decision events and Janis and Mann (1977) have highlighted emotion as a potential influence on decision-making. Rational choice reasoning currently seems to provide the template for the Military Appreciation Process[3] (MAP, see Australian Army, 2004). However researchers have suggested that much human decision-making does not follow the rational choice model (eg. Beach & Lipshitz, 1997). In particular, the finding that decision-makers do not usually compare a wide range of alternatives compels researchers to look more broadly at the decision-making process. For example, in an Army situation there may be only one solution generated. Also, there may be inadequate time to search for new information relevant to possible alternatives, and to incorporate this into the evaluation. Instead it has been suggested that the past experience of the decision-maker is vital in this context (Klein, 1998).

Other descriptive analytical theories have also been suggested as explanations for decision-making. Deviations from the outcomes predicted by traditional analytic decision models have illustrated that biases are present in human decision-making. From this, the decision bias and heuristic paradigm emerged (Plous, 1993). Researchers in this field attempt to describe the heuristics that human decision-makers tend to use in order to reduce cognitive load. A summary of some of the popular decision bias theories is provided in Table 1.

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[3] The Military Appreciation Process is a series of steps taught to Officers to apply to planning/ decision-making scenarios.

Table 1. Description of decision theories based on heuristics

Decision Theory	Description
Satisficing (Simon, 1956)	To choose a decision option that satisfies your most important needs. Not necessarily the optimal path.
Prospect theory (Kahneman & Tversky, 1979)	To evaluate alternatives in relation to a reference point. Within this theory it has been found that, in relation to that point, perceived losses are weighted more strongly than gains.
The certainty effect (Allais, 1953)	Where alternatives reduce potential risks by the same amount, the alternative that reduces risk to zero is favoured.
Pseudocertainty (Tversky & Kahneman, 1981)	When an alternative appears to reduce the risk to zero, it is more popular.
Regret theory (Bell, 1982; Dunning & Parpal, 1989;Loomes & Sugden, 1982)	This rests on two assumptions. Firstly, that many people experience regret and rejoicing, and secondly, that we take this into account when we make a decision. Therefore, similar to prospect theory, we try to minimise losses (regret). This, however, does not hold for all decision cases.
Multi-attribute choice (Einhorn & Hogarth, 1981)	Where the alternatives attributes are weighted and one attribute can be traded off for another more important one.
Non-compensatory strategies (Hogarth, 1987)	Similar to multi-attribute choice, but choices are made beforehand on the value of the attributes, and trade offs do not occur.
The more important dimension (Slovic, 1975)	When people are faced with an equal choice they will choose the alternative that rates highest on the "most important dimension".

Firstly, the structure of the studies used to reveal these biases has been criticised as being biased to producing certain results (see Lopes, 1991). Secondly, the theories do not account for uncertain information and they have not been tested in NDM environments. Klein (1998) suggests that several studies found that decision biases are reduced if the study includes contextual factors, and that decision biases do not occur in experienced decision-makers working in natural settings (Christensen-Szalanski & Beach, 1984; Fraser, Smith & Smith, 1992; Gigerenzer, 1987; Shanteau, 1992; Smith & Kida, 1991). It seems that, particularly in situations characterised by time pressure, uncertainty, complexity and high stakes, analytical decision models fail to provide adequate answers (Salas, Bowers & Cannon Bowers, 1995).

Overall, these theories have offered some valuable explanations for observable phenomena, but each has fallen short of providing a theory for decision-making applicable to naturalistic situations (where there are often multiple goals, uncertainty, and time pressure; Fishchoff, 1988). Other descriptive analytical theories have also been suggested as explanations for decision-making. These theories have been largely based on biases found in decision-making (Plous, 1993). They attempt to describe the heuristics that human decision-makers tend to use in order to reduce cognitive load. Overall, these theories have offered some valuable explanations for observable phenomena, but each has fallen short of providing a theory for decision-making applicable to naturalistic situations (where there are often multiple goals, uncertainty, and time pressure). They tend to rely on analytical principles, do not account for uncertain information and have not been tested in NDM environments.

Analytical models of decision-making are based on a set of assumptions that decision-making is mechanistic, and based on probability (Noakes, in press). However, evidence suggests that humans do not consistently use probability-based assumptions (Allias & Hagan, 1979; Beach, 1966; DuCharme, 1970; Edwards, 1968; Kahneman & Tversky, 1973; Savage, 1954). It has been suggested that needing to evaluate such a large number of alternatives in a short period of time is impractical in naturalistic situations (Kaempf & Militello, 1991). In fact usually only one option is considered (Klein et. al, 1989). Also, because of the dynamic environment, continual evaluation and judgement of the environment is required. This is in contrast to a singular moment of choice assumed by these models. Work by Janis and Mann (1977) has successfully brought to researchers' attention the potential role of emotion in decision-making, and this needs to be further explored in an NDM context. Finally, naturalistic environments usually require expert decision-makers, whose experience facilitates their decision-making. This fact is not adequately explained by analytical decision theories. Thus, in naturalistic circumstances, there are grounds for querying the adequacy of analytical decision models.

Moreover, Ebbensen & Konecni (1980) have argued that the external validity of decision-making research that relies on laboratory experiments (such as many of the analytical decision-making models) is minimal. It may be that biases found in the laboratory are simply caused by participants not understanding the task (Fischkoff, 1988). Application of these theories to other environments, and real-world decision-makers, still needs to be achieved. Therefore these theories still require extension, in order to describe decision-making adequately in a military context.

3.2.1 Summarising Analytical Decision-making

In summary, analytical decision-making theories, such as classical decision-making theory, are based on evaluating options and are used to select statistically optimal solutions. However, research has shown that humans do not always behave in this way. As a consequence, a number of descriptive decision theories were developed in an attempt to account for some of the biases observed in decision-making. While these theories provided descriptions of certain observable phenomena, they still tend to rely on evaluation of

options in the decision-making process. It has been suggested that in naturalistic environments, constraints such as time pressure, high-stakes and uncertainty create an environment where the evaluation of options is not possible.

3.3 Descriptive Naturalistic Decision-Making Theories

In response to the inadequacy of analytical decision-making theories to explain decision-making in many real-world decision-making environments, researchers shifted their focus to explore the unique aspects of these environments They were termed naturalistic environments, and included domains such as military, firefighting and other emergency response organisations. These kinds of environments have been defined by Omodei and Wearing (1995) as incorporating the following conditions:

- *Dynamicity* – This refers to the continual complexity of the environment. NDM involves a series of decisions, rather than a single moment of choice as described in traditional decision-making theory (Brehmer, 1990). In this environment, each decision made affects each consequent decision.

- *Uncertainty* – The quality of available information about a situation is often questionable.

- *Distribution of tasks* – This is required because of the complexity of the situation. There is too much information for an individual decision-maker to cope with, so the decision task is distributed among several contributors

3.3.1 Naturalistic Decision-Making Definition

The search for a more appropriate model of decision-making under these conditions has seen the development of NDM theory (Cannon-Bowers, Salas & Pruitt, 1996). Zsambok (1997) defines NDM as:

> …*how experienced people, working as individuals or groups in dynamic, uncertain, and often fast paced environments, identify and assess their situation, make decisions and take actions whose consequences are meaningful to them and to the larger organisation in which they operate (p. 5).*

In other words, NDM research investigates how people use experience to make decisions in naturalistic environments (eg. under time pressure, shifting conditions, unclear goals, degraded information and within team interactions). A common theme in NDM research is the role of expertise in decision-making.

Obviously, the environment described presents a specific set of conditions to be considered when attempting to make decisions. It is also understood that this kind of environment is not unique to the Army; similar environmental demands will be required of fire-fighters, workers in emergency medicine, and air traffic controllers among others.

As foreshadowed above, decision-making within real-world environments has been described as naturalistic decision-making (Cannon-Bowers, Salas & Pruitt, 1996). In other words, NDM research investigates how people use experience to make decisions in naturalistic environments (eg. under time pressure, shifting conditions, with unclear goals, degraded information and within team interactions). Consistent with this definition, research has aimed to identify appropriate models of decision-making to be applied to this context. Ideas that have been put forward include: image theory (Beach & Mitchell, 1987), the RPDM model (Klein, et. al, 1989), and mental models and schema theory of decision-making (Lipshitz & Shaul, 1997). These will now be critically considered.

3.3.2 Image Theory

Image theory is an example of a descriptive model of decision-making that has been applied successfully in some real-world settings (auditing decisions; Beach & Fredrickson, 1987, cited in Beach & Mitchell, 1987). In contrast to traditional decision models that tend to regard information as the only determinant for decision-making, image theory posits that other factors should be considered. It focuses on an individual's values and goals in combination with current information. It also posits that previous experience is important for decision-making. This idea is supported by other research (eg. Klein, 1998).

Image theory holds that the decision-maker should possess three "decision-related images", and these should act to constrain the decisions that can be made. These images are described as:

- *Value image* - This image contains the decision-maker's principles; his/her assumptions about how things should be. When participating in a group the decision-maker can participate effectively by using the organisation's values when making decisions (Beach, Smith, Lundell & Mitchell, 1988).

- *Trajectory image* - This image contains the goals of the decision-maker or the larger organisation within which s/he functions.

- *Strategic image* - This image contains the strategies and plans that have been adopted to accomplish the goals. Each plan is abstract; a sequence of potential activities to work towards eventual goal attainment. Potential plans tend to come from past experience.

Along with these images a decision-maker will have goals that will represent the desired outcome. Combination of the goals and the values is required for the production of a plan. During the decision-making process it is suggested that a compatibility test occurs in the decision-maker's mind to examine the goodness-of-fit between the potential goals and plans, and the values. Decision-making therefore requires accepting or rejecting goals and plans according to suitability and then profitability. In this way it is still incorporating an analytical approach to decision-making.

Because goals and plans are linked in memory, it is often the case that once a goal has been identified, an immediate plan of action can be applied. The link between goal and action is called a "policy", and the process is referred to as "framing the decision". It involves probing memory with information from the current situation. If there is a similar contextual memory to the current situation, the situation is recognised, and an appropriate course of action already stored can be modified and executed. A major part of the decision-making process is monitoring the courses of action that have been decided upon.

It has been suggested by Beach et al. (1988) that this theory could be applied to decision-making in naturalistic environments. However, the theory seems quite difficult to validate, and at this time has not been applied successfully to a NDM environment. A number of studies have aimed to test aspects of the theory. For example, laboratory research has supported the ideas of compatibility and profitability tests during decision-making (Nicholas-Hoppe & Beach, 1987; Payne, 1976). Also, Dunegan (1995) has found that when perceptions of a project's current and target images were more similar decision-makers tended to continue with that project. Finally, the model has been applied in the real world to situations such as organisational decision-making, decision-making for married couples and also auditing decisions (Mitchell, Rediker & Beach, 1986; Beach & Morrison, 1987; Beach & Fredrickson, 1987, cited in Beach & Mitchell, 1987). Thus there has been some support for this theory, but further research is required in order to validate the theory and to test empirically whether it adequately describes decision-making in naturalistic environments. Application to other environments, and real-world decision-makers, still needs to be achieved. Moreover the model does not integrate emotion into the decision-making explanation.

3.3.3 The Recognition Primed Decision-making Model

A well-cited model of decision-making, actually developed from observations in naturalistic environments, is the Recognition Primed Decision-making (RPD) model (Klein et al., 1986). The model was based on interviews and observations of fire ground commanders working in difficult and challenging circumstances (Klein et al., 1986). It was anticipated that, under complex circumstances involving time pressures, the Commanders would make limited comparisons between possible outcomes. However, the early research revealed that they were making no comparisons at all. In fact, 80% of decisions made in this task were made in less than one minute. From this, Klein et al. (1986) identified the following issues:

- The Commanders drew on their previous experience to recognise a typical action to take.
- They did not have to find an optimal solution, merely a workable one.
- Once they had arrived at a suitable course of action, they would mentally simulate it first, to check that it would work.

Consequently, Klein et al. (1986) developed the RPD model. The RPD model posits that experienced decision-makers:

- Usually consider a workable option and do not need to generate a large set of alternatives.
- Generate and evaluate options one at a time, instead of comparing the advantages and disadvantages of all options.
- Evaluate an option by imagining the outcome, and by finding ways to avoid problems that may arise from its implementation.
- Focus on assessing the situation and looking for familiar cues.
- Emphasise acting quickly and not prolonging analysis.

The RPD model describes how people make decisions without comparing outcomes (see Figure 1). The decision-maker initially assesses the situation, looking for familiar patterns or prototypes. This allows him/her to know which goals make sense, what relevant cues to expect and what action should be appropriate. A series of options is then generated. The first solution may not be optimal, but it will usually be workable.

This model also shows that action can be taken quickly, which is important in crisis management (Klein, 1997). The RPD model has been applied to various NDM settings and accepted by a number of research groups as providing a viable description of cognitive processes underlying NDM (Kaempf, Wolf, Thordsen, & Klein, 1996; Mosier, 1991; Pascual & Henderson, 1997). The RPD model has been found to describe decision-making in domains such as fireground command, wildland fire incident command teams, US Army armoured division personnel (Klein, 1989), battle planning (Thordsen, Galushka, Young & Klein, 1987), critical care nursing (Crandall & Calderwood, 1989), and chess tournament play (Calderwood, Klein & Crandell, 1988).

To understand the differences between the environments associated with the RPD model and rational choice model it is useful to contrast the environments in which they are applicable (see Figure 2).

At a cognitive level it has been suggested that the RPD model incorporates two cognitive processes. These are:

- Situation assessment (which is used to generate a course of action)
- Mental simulation (which is used to evaluate a course of action)
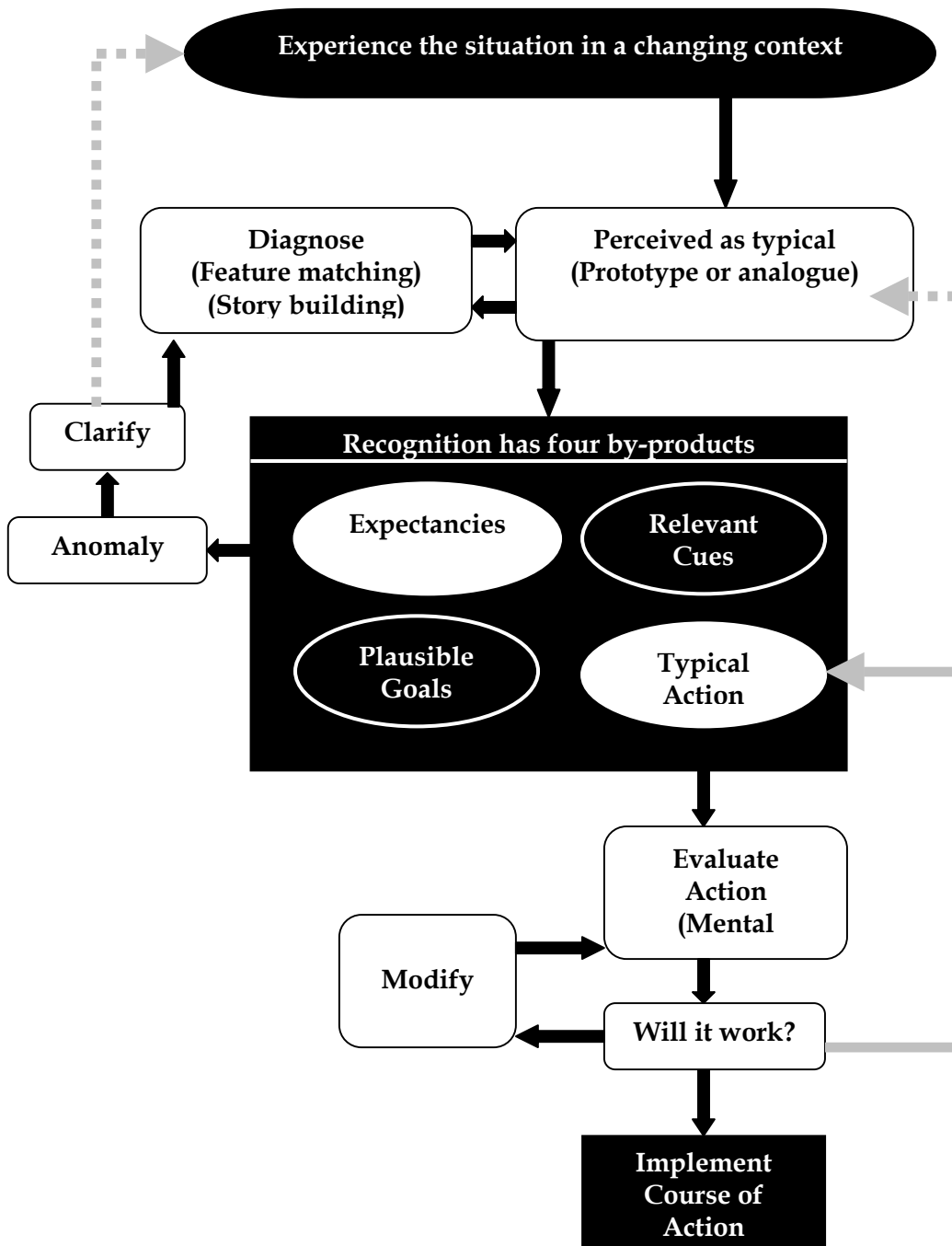
Figure 1. The RPD Model (adapted from Klein, 1998)
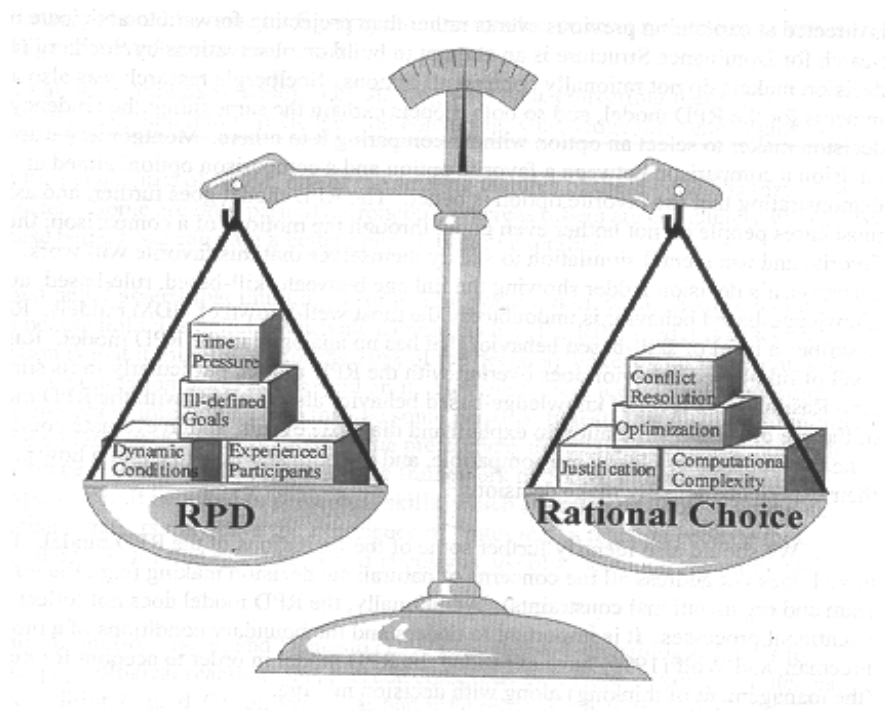
Figure 2. Comparing the RPD Model with Classical Decision-Making (Klein, 1993a).

3.3.4 Situation Assessment and Situation Awareness

Situation assessment is the process by which a decision-maker gathers information pertaining to the current decision problem. Situation assessment occurs initially in the RPD model, and often results in the recognition of a situation from past experience. The rest of the decision-making process depends on correct judgement of the situation.

It has been argued that in real-world situations it is uncommon to be making decisions in a static environment (Klein, 1998). Thus, in contrast with the singular moments of choice, as described in analytical decision-making models, NDM often requires a series of decisions that are interdependent. Therefore, instead of relying on static information, the decision-maker must constantly monitor the changing environment to inform his/her decision-making. This will be changing spontaneously, as well as changing because of each decision made. Thus, NDM requires continual situation assessment. Continual assessment produces situation awareness (SA)[4].

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[4] Situation awareness is defined as "…the perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status into the near future" (Endsley, 1988, p. 97).

Different methods have been suggested as explanations for how decision-makers arrive at SA. George, Kaempf, Klein, Thorsden and Wolf (1996) found that military officers identified the following methods of arriving at SA:

1. 87% of participants used a feature matching strategy. This is where the decision-maker sees the situation as familiar, and arrives at situation awareness through a series of recognised cues.

2. 12% of participants used story generation. When the environment does not provide enough information to be recognised as familiar, the decision-maker constructs a story to explain the information and to arrive at greater situation awareness.

3. Only 1% of cases did not fit into either of these main categories.

Due to the inclusion of SA in the RPD model, a theoretical explanation is offered for the mechanisms by which naturalistic decision-makers can collect and make sense of dynamic information. Thus, in contrast to analytical decision models, it enables the RPD model to be usefully applied to describe decision-making in dynamic, fast paced situations.

Research in the field has identified applications of SA research to be in the areas of training and the development of technology and policy.

3.3.5 Mental Models and the Role of Mental Simulation

3.3.5.1 The Schema and Mental Models in RPD Theory of Expertise

Lipshitz and Shaul (1997) argued that the RPD model oversimplified the processes occurring in NDM. They suggested that this was evidenced in the failure of the model to provide adequate explanations their research finding, which is now outlined. Their study focused on the differences between experts and novices in decision-making in a sea-combat simulation. Lipshitz and Shaul (1997) found that:

- Experts collect more information on the situation before they make a decision because they know what questions to ask.
- Experts engage in a more efficient information search because they know what information to keep track of.
- Experts read the situation more accurately because they are able to identify the difference between relevant and surplus information.
- Experts make fewer bad decisions related to reading the situation correctly.
- Experts communicate more frequently and elaborately with friendly units.
- Experts are more likely to consider other people's perspectives when making their decisions.

Lipshitz and Shaul (1997) found that Klein's RPD model accounted for most of these observations. However, it could not account for experts collecting more information than novices on the situation before they make a decision. As described, the RPD model specifies those conditions under which a decision-maker would collect additional

information. These are: when the decision-maker does not recognise the situation (thus cannot establish goals); if expectancies are violated; or the expert's mentally simulated course of action fails.

If Lipshitz and Shaul (1997) are correct however, and experts always collect more information than novices, it could be inferred that in comparison with novices:

- Experts require more information to identify goals.
- Experts expectations are more likely to be violated.
- Experts engage in mental simulation more often.

According to the RPD model, the third implication is accurate and empirically supported (Calderwood, Crandall & Klein, 1987). However the first two inferences contradict the idea of experts being efficient decision-makers.

Lipshitz and Shaul (1997) suggested that in order for the RPD model to more adequately explain these findings, it should be modified to include schema and mental models. This would account for experts collecting more information, and conducting more effective searching. Figure 3 represents the revised model. The inclusion of these ideas offers an explanation of how an expert evaluates a course of action.

In order to facilitate rapid judgement the expert's stored schema[5] is retrieved from memory. A schema helps determine what we attend to, what we perceive, and what we remember and infer. Schema also help to specify what information is missing and where it can be found. Thus, from Figure 2, continual schema guided situation assessment enables the expert to recognize familiar patterns. The inclusion of schema in a description of expert decision-making explains why experts may seek more information, but because their information seeking is guided, actions can still be taken quickly, which is important in crisis management (Klein, 1997). This may also explain why decision-making can seem intuitive to the decision-maker.

Situation assessment results in a mental representation of the problem at hand. Essentially it is a "hypothetical construct, which refers to the operator's ideas about a system and what it is controlling" (Mogford, 1990, p. 4). Thus, based on current information and previous knowledge and experience the decision-maker forms a mental model of the current situation. Following this the mental model forms the lenses through which the decision-maker views the problem. It helps to shape goal building, and determine expectations formed (Wickens, 1984). It acts as a mental representation of the perceived situation, and facilitates consequent judgements and decisions. Mental models based on good situation awareness also allow decision-makers to project the environment's status into the future (Artman, 1998; Brehmer, 1990). This is referred to as mental simulation. This process is depicted in a model adapted from Endsley (1995) in Figure 4.

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[5] A schema is described by Vaughan and Hogg (1995) as " a cognitive structure that represents knowledge about a concept or type of stimulus, including its attributes and the relations among those attributes." (p. 31).

RPD Model	The Schema and Mental Models in RPD Model

Experience the situation in a changing context

Experience the situation in a changing context

Perceived as typical (Prototype or analogue)

Cognitive Display (Situation awareness) *Cues recognised*	Schema activated which guides information collection. *Expectancies formed*

Recognition has four by-products

Expectancies **Relevant Cues**

Plausible Goals **Typical Action**

Mental Model *Goals/plans*	A *typical action* repertoire is retrieved from memory according to recognition of mental model

Implement Course of Action

Decision is made

Implement Course of Action

A course of action is implemented

Figure 3. Lipshitz and Shaul's (1997) proposed adaptation of the RPD model

MENTAL MODEL

directs selection of model

(IDEAL STATE) **GOALS**

directs change based on situation model

match of plan projections to desired goals directs selections

(PROJECTED STATE) **PLANS**

directs action

match of desired plan to existing scripts

(OUTCOME) **SCRIPTS**

actions devised through projection when no scripts exist

directs selection and revision of system model

directs comprehension projection & expectations

ACTIONS

(SITUATIONAL MODEL) **SITUATION AWARENESS**

directs attention to key features

perception

ENVIRONMENT

Figure 4. The role of mental models in processing current situational information (adapted from Endsley, 1995)

3.3.5.2 How Previous Experience is Stored in Memory

From Section 3.3.5.1 it seems apparent that previous experience is an integral part of the recent NDM models. A cognitive model, proposed by Noble (1993), represents how previously solved problems are stored in memory. These are termed "reference problems". Each reference problem can be broken down into three constituent features (See Table 2).

Table 2. A description of the features described in Noble's (1993) model of how experience is stored in memory

Question Answered	Memory Features	Description of Feature
What?	**Objective features**	This aspect of the memory characterizes the problem and its objectives. It is concerned with concrete features (specific observable events or objects).
How?	**Action features**	These identify the steps that are involved in solving the problem. These are abstract features that help generalise the problem type and solution method.
Where?	**Environmental features**	These comprise cues that were present in the past problem scenario. These are environmental cues that may indicate a similar or related problem.

This model therefore identifies three levels of abstraction in memory storage of memory. Using this model, previously experienced problems can be compared, at conceptually different levels of memory, with the current problem. From these cognitive comparisons, a problem solution that is likely to work may emerge (see Figure 5).
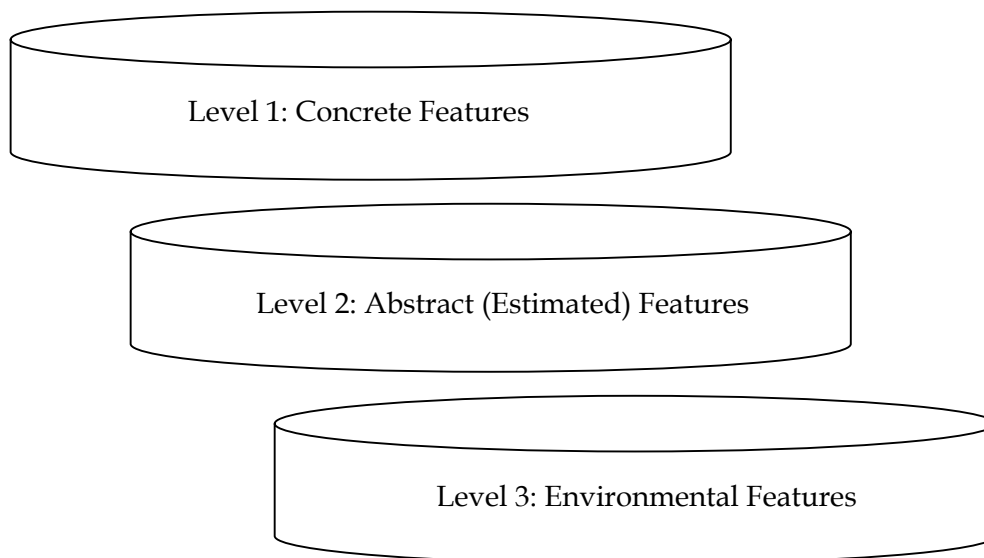
Level 1: Concrete Features

Level 2: Abstract (Estimated) Features

Level 3: Environmental Features

Figure 5. A cognitive model of memory for past problem scenarios (Noble, 1993)

During situation assessment, the reference problems that match the current situation are activated. The "problem solutions associated with those in memory become candidate actions" (Noble, 1993, p. 305). This is in accordance with NDM being proceduralised; meaning that decision-making is directly linked to action and the conditions of its applicability (Means, Salas, Crandell & Jacobs, 1993; Rasmussen, 1983).

Frequently, a decision-maker is forced to make a decision on the basis of incomplete information. In such circumstances, the abstract level of memory facilitates decision-making. Noble (1993) concluded that in such instances cognition may involve the use of sophisticated information processing on general world knowledge. This cognitive model allows recognition-based solutions of new problems that resemble but are not necessarily identical to those previously experienced (Cohen, Freeman & Wolf, 1996).

Studies that support these assumptions include George et al., (1996) who found that military officers who had an awareness of the situation were able to recognise actions appropriate for the current situation from published procedures, and past experiences. Also, Lipshitz (1989) found that Israeli army officers seemed to make decisions by matching situations to an associated action. Means et al. (1993) have also confirmed that the nature of a person's experience, and consequently the patterns recognised, affect the decisions they make.

Thus far the concepts of SA and mental models have seemed to provide good descriptions of the processes believed to be employed by naturalistic decision-makers, but validating this experimentally has proven difficult. Although it is arguable that at present they offer the best available explanation of NDM behaviour, these models still require further elaboration and validation.

3.3.6 Summarising Descriptive Decision-making Theories

In summary, descriptive decision theories have tried to describe how people in the real world actually make decisions. Researchers have recognised that environments such as the military, fire fighting, and emergency services present a specific set of conditions relevant to the generation of appropriate decision theories. These environments have been described as naturalistic environments. Naturalistic environments are complex and dynamic, with time pressure, high stakes, and uncertainty. It has been recognised that these specific conditions require a new theory of decision-making, which has been termed naturalistic decision-making. Within the relatively new field of NDM several decision-making models have been presented as alternatives to analytical models. One example is image theory. This has been widely cited as a model for many organisational type decisions, but is difficult to validate and has not been successfully applied to domains such as the military. Application to other environments, and real-world decision-makers, still needs to be achieved. The most commonly cited model proposed to describe decision-making in naturalistic environments is the RPD model. This has been adapted to include schema and mental models, and has formed the platform for recent NDM research. In addition to this model, Noble (1993) has created a cognitive model of how experience is

stored in memory for use in NDM. This model describes how previous experience feeds into decision-making, and how incomplete information is handled. Overall, these models still require further elaboration and validation, but they do offer important theoretical ideas such as: situation awareness, the use of previous experience, schema and mental models.

4. Previous Experience and Expert Functioning

4.1 Defining Expertise

A critical component of decision-making in naturalistic settings is specialised domain knowledge, which is a product of experience. Despite its inextricable link with the RPD model, expertise has not been adequately defined (Shanteau, 1992). There seems to be a lack of agreement within the literature, with definitions varying from study to study (Shanteau, 1992). Many studies use hours of experience as an indicator (Klein & Calderwood, 1986; Klein et al., 1986). A repertoire of 10 years experience is generally accepted to qualify a person as an expert (Klein & Calderwood, 1986). However, it is not only length of experience that is important; quality of experience should also be considered. For example, Klein et al. (1986) found that for firefighters, 10 years on-the-job experience was not as valuable for skill development as one year in a decaying inner city. Shanteau (1992) suggests that in order to define expertise we need to procure the assistance of those in the field to identify people who have the necessary skills and abilities to perform at the highest level within their specialised domain.

Because of the difficulty in accurately defining expertise, research has tended to focus on the comparison of experts and novices in decision-making. Thus, an understanding of expertise is mediated by novice performance.

To provide an overview of research in this area, Glaser and Chi (1988) reviewed the literature and extracted a list of themes that have become commonly associated with expert performance.

- Expertise is domain specific.
- Experts see patterns.
- Experts are faster and make fewer errors.
- Experts have superior memory in their domain (environmental cues are an aid to recall).
- Experts see and represent a problem at a deeper level.
- Experts spend more time trying to understand a problem but have a more efficient path to solving it.
- Experts have strong self-monitoring skills.
- Experts have refined perceptual abilities.

4.2 Linking Expertise with Naturalistic Decision-making

Experience has been recognised as important in many instances. For example, in a summary of the great military blunders throughout history, David (1997) noted that a "typical handicap seems to be a lack of command experience. Naivety tends to promote vacillation and overcaution, resulting in lost opportunities and ultimately disaster" (p. 1). In this case, the application of expert knowledge to NDM is targeted as the factor differentiating between good and poor decision outcomes. In reality the relationship may not be quite as clear. It is likely that external factors also mediate decision outcomes (Woods, Johannesen, Cook, & Sarter, 1993). However it has been shown repeatedly that experts tend to have different perceptual and cognitive mechanisms in comparison with novices, which facilitate their decision-making (eg. Klein & Hoffman, 1993; Randel, Pugh & Reed, 1996). These will be elaborated.

NDM theory suggests that experts draw on previous experience to make sense of current situations. They rely on familiar stimulus cues in order to predict the success of a decision solution. It has been suggested that, with experience, people learn which cues to attend to, and what information to filter out (George et al., 1996.). Therefore it would be expected that a broader range of experience would provide more recognitional cues upon which the decision-maker may draw when making time-pressured decisions. There has been extensive research on the types of cognitive and perceptual skills that are linked to expert performance. On the other hand, the substance of the experience that experts have acquired has been left largely unexplored. For example, the context of the experience and the mode of acquisition (eg. Direct experience, knowledge gained from lessons, informal communication etc) have not been investigated. This presents limitations in defining expertise and thus impacts on the usefulness of the RPD model for training.

4.3 Perceptual-Cognitive Aspects of Expertise

There has been debate in the literature over whether experts actually use different, more refined higher-level skills (such as methods of problem solving), or whether the expert/novice distinction is perceptual. Means and Gott (1988) suggested that expert and less expert decision-makers apply the same rules but to a different content. Beach and Lipshitz (1997) extended this idea by stating that decision-making events require decision-makers to use their existing knowledge of the context to facilitate both their situation assessment and subsequent decision-making. According to the RPD model, it seems that both perceptual and cognitive skills distinguish expert decision-makers from novices. These skills will be discussed in terms of their contribution to the RPD model.

4.3.1 Expert Information Representation

Klein and Hoffman (1993) argued that experts use their knowledge in order to gain a perceptual advantage. They stated that "expertise is a function of the knowledge base itself, and that as people develop richer knowledge bases they are able to represent

problems in more powerful ways"(p. 208). In other words, experts are able to see what is "invisible" to novices, such as situation typicality, the ability to see distinctions and to identify antecedents and consequences. Therefore the knowledge one accumulates is not as important as how one sees the world (Hutton & Klein, 1999). This perceptual advantage of experts is linked to a number of specialized techniques believed to be employed by experts. These are described below.

4.3.1.1 Attend to Relevant Information

Experts establish situation awareness by relying on familiar stimulus cues. It has been suggested that, with experience, people learn which cues to attend to, and what information to filter out[6] (George et al., 1996). This allows experts to process relevant information more quickly, and not to experience cognitive overload. Due to their ability to filter information, experts are able to take into account more relevant information than a novice is able to (Federico, 1995; Hutton & Klein, 1999). Less expert decision-makers may experience cognitive overload more rapidly because they attend to all information and do not filter irrelevant aspects (Randel et al., 1996).

4.3.1.2 Chunking

The classic study by DeGroot (1965/1978), later replicated by Chase and Simon (1973), compared the performance of chess masters and novices. The researchers were interested in isolating factors that separate an expert from a novice. They found that experts and novices did not differ significantly on memory abilities, depth of planning or other similar areas. Instead, the difference was that the expert players could look at the entire complex chess display and condense it into "meaningful chunks", whereas the novices tried to understand the whole display (Means et al., 1993, p. 310). This ability also seems to be consistent with the idea of schema driven information search.

4.3.1.3 Expert Knowledge Base

Experts have greater domain knowledge than novices. It has been found that their knowledge is also organised differently. Novices will organize representations around surface features, whereas experts will use inferences and principles (Chi & Glaser, 1981). Glaser (1987) suggested that the quality of representation of a particular problem depends on the relations between the structure of a knowledge base and problem solving processes used. The decision-maker constructs a mental model[7] on the basis of domain-related knowledge, and how this knowledge is organized. Therefore, the content and organization of domain knowledge determines the coherence of the representation. This would then determine the quality of decision being made. This idea is consistent with the idea of mental models within the RPD model.

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[6] Refer to section 3.3.5.1, which outlines the inclusion of schema in the RPD model.
[7] Refer to section 3.3.5.1, which outlines the inclusion of mental models in the RPD model.

4.3.1.4 *Pattern Matching*

Experts can see typicality by using pattern-matching techniques. When experiencing an event, information about that event is stored in memory. When looking at a current event, patterns can be recognised as similar to those previously stored. Simon & Gilmartin (1973) estimated that chess masters store 10,000-100,000 patterns in their memory. Chi, Hutchinson and Robin (1988) also supported this view. They studied children who were dinosaur "experts" and "novices". These children were presented with a series of dinosaur pictures and asked to identify whether or not it was a dinosaur. It was found that the "novices" failed to judge typicality. This idea is consistent with Noble's (1993) model of knowledge storage. It has also been discussed as being a critical tool for generating a typical course of action through situation recognition (Klein, 1998).

4.3.2 Cognitive Strategies

4.3.2.1 *Problem Solving Method*

It has been suggested by some researchers that experts and novices do not differ in their ability to use particular problem solving methods or decision rules, but rather in how they use their domain knowledge within this process (Means et al., 1993; Drillings & Serfaty, 1997; Chi & Glaser, 1981). Studies that have supported this idea include Chi and Glaser (1981), who found that both novices and experts can use both bottom up[8] and top down[9] reasoning strategies. In contrast Mullin (1989) found that experts use bottom up rather than top down processes. The type of information the participants were supplied with may explain the contradictory nature of these findings. In the study by Mullin (1989) novices may have been forced to use only using top down processing because of their limited knowledge base in the field. Thus, it seems that, although strategies do not determine expertise, it may be that people make use of different strategies to complement and take advantage of their declarative knowledge, perceptual and cognitive knowledge and other aspects of their experience base (Klein, 1993a, 1993b).

4.3.2.2 *Mental Simulation*

Experts are also better at dealing with problems that have not been previously encountered. This can be explained by understanding their method of progressive deepening or mental simulation. Once an option is considered, experts will use mental simulation to work it through at a deeper level, looking for pitfalls and opportunities. Mental simulation allows experts to project the environment's status into the future (Artman, 1998). This suggests that experts and novices may have the same problem

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[8] <u>Bottom-up processing</u>- Based on the situation, particular solution methods seem appropriate. Individuals work through the problem and generate expected outcomes. This type of processing is automatic and does not require metacognition.

[9] <u>Top-down processing</u>- the context guides the cognitive processes needed to determine whether problem expectations are being met. This type of processing is high level, slow and requires active commitment and cognitive capacity.

solving strategies available, but experts can use them more effectively because of their superior knowledge base and perceptual advantage. They are able to categorise problems according to their large repertoire of knowledge-based schema, and then apply basic problem solving techniques.

Thus there has been a range of skills associated with expert decision-making performance, and these have been successfully incorporated into the RPD model. Further research still needs to be done in order to produce an adequate definition for expertise that can be applied in the future development of expert training systems. For example it is important to clarify exactly what is encompassed within the terms like *previous experience* or *specialised domain knowledge*, because these are not yet clearly definable.

4.4 Summarising Expertise in Naturalistic Decision Making

Expertise is inextricably linked with the concept of NDM (Klein, 1998). Research has tended to focus on the comparison of experts and novices in decision-making. Thus, an understanding of expertise is typically mediated by novice performance. A review of research on expertise outlined that number of facets of expertise were common across domains (Glaser & Chi, 1988). However, to date an adequate definition of expertise has not been generated. This needs to be addressed in future research. Researchers have also debated whether expertise is due to the development of specialised perceptual or cognitive skills. As has been shown, the current RPD model successfully incorporates both types of skills in its description of decision-making. However, it still remains problematic as to the exact nature of expertise, and future research is required. Establishing a good understanding of this at the cognitive level allows for more intuitive interface design for expert decision-makers, because specific information requirements, and appropriate modes of representation can be ascertained.

5. Levels of Expertise

Research has tended to focus on expert/novice comparisons, mainly due to the lack of a clear definition of expertise within the literature. One method of generating a greater understanding of expert/ novice differences is by seeking to understand cognitive skill development.

Expertise in decision-making can be considered as a skill that can be developed. Skills can be broken down into two categories: cognitive and motor skills. Expert decision-making in NDM fits into the first category, but realistically decision outcomes also often rely on motor skills. As classified by Sabol and Wisher (2001) military tasks comprise three components:

- *Knowledge*- based on recall of domain specific information. This depends on experience.

- *Decision*- depends on cognitive processing of the domain-specific information.

- *Execution*- refers to the perceptual motor requirements of a task, for example, target acquisition and tracking.

Therefore, expert decision-making outcomes are dependent on these three things. NDM theory tends to consider both the knowledge of the decision-maker and the decision process within the RPD model, but does not include the decision execution. The literature indicates that there is a link between cognitive skill (knowledge and decision) and performance (motor skill; Welford, 1968). One could make a great decision, but implement it poorly, and the performance outcome would therefore be poor. In a setting such as a military HQ, because the quality of a decision is generally determined by the quality of the decision outcome, it needs to be recognised that this is not only dependent on the key decision-maker. Instead consideration should also be given to the quality of the communication between team members, and the quality of motor skills involved in task execution and other contextual factors.

For the purpose of this section, developing expertise in NDM will be treated as synonymous with cognitive skill development. From a literature review it seems that there is overlap between skill development and more recent articles on development of expertise in NDM. However, it is noted that development of cognitive skills does not necessarily equate to good decision outcomes, as other factors may impact on this.

5.1 Development of Expertise: Skill Acquisition

As expertise increases, individuals use tacit knowledge, and perceive the world through categories. This is referred to as the proceduralisation of declarative knowledge (Means et al., 1993). The understanding of how a skill is developed requires an understanding of how it is committed to memory. Welford (1968) outlined the basic principles involved in learning a skill (see Figure 6):

1. Understanding the task (material must be perceived and comprehended).

2. Material held in short term memory (STM) until there is time for more permanent registration to take place.

3. A memory trace will be established. This must be resilient to subsequent activities interference.

4. The memory trace must endure till time of recall.

5. Recognition of an appropriate situation in which to use information must occur.

6. Material must be recovered correctly ("tip of the tongue" phenomena).

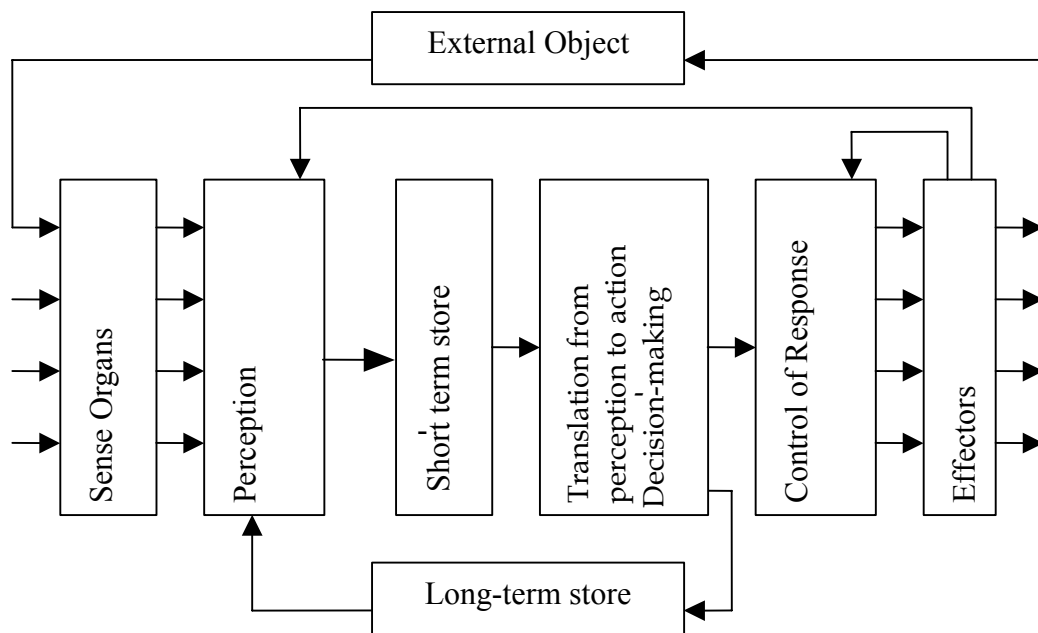7. Recalled material should be used to produce a communicable response.

Figure 6. The storage of experience in memory (adapted from Welford, 1956)

In order for a skill to be learnt, all of these stages must take place, and problems occurring at any of these stages can hinder the process.

Once the basic process of skill acquisition is understood, it can then be applied to a given domain (e.g. Military). With experience, performance of skills has been noted to change. Different stages of skill have been identified (Anderson, 1991; Fitts and Potter 1967; cited in Shanteau, 1992). These are: cognitive stage *(*fact is committed to memory via rehearsal), associative stage (links are made between facts), automatic stage (links are smooth and continuous and less conscious attention is needed to perform the skill).

These stages are similar to those proposed by Rassmussen (1983), who describes the development of expertise by breaking it down into three different phases:

1) *Knowledge-based behaviour* - Requires conscious attention that involves a higher level of cognitive processing or thought than does rule based control. "Know-how" and control rules are not available. The relevant knowledge that the decision-maker does have still needs to be proceduralised. Multiple courses of action are often developed and tested against the goal.

2) *Rule based-behaviour* – Behaviour is directed by a sub routine or procedure that consists of a series of rules. It is goal oriented. The decision-maker is aware that alternative actions are possible to reach the goal and that a choice amongst them can be made.

3) *Skill-based behaviour* – Not requiring conscious attention. Attuned to feedback and easily adjustable.

Probably the most cited model of expert performance is that by Dreyfus (1972). This model provides five stages that describe the development of expertise: novice, advanced beginner, competent, proficient, and expert. As someone develops expertise and moves through the stages outlined they will progress in much the same way as described by Rassmussen (1983). The progression through these skill sets begins with variable awkward performance and continues to a point where decisions become intuitive, and responses more immediate and logical to the decision-maker (Fitts & Potter 1967; cited in Shanteau, 1992).

As one passes through these stages outlined by Dreyfus (1972), skill development is occurring in more than one area. Glaser (1987) isolates the four skill areas that develop as one acquires expertise (see Table 3).

Table 3. Key areas of change as expertise in NDM is attained (Glaser, 1987)

Skill Area	Type of Development
Performance	Variable, awkward performance becomes consistent, accurate, complete and relatively fast.
Judgement	Individual acts and judgements are integrated into overall strategies.
Perception	Perceptual learning occurs so that a focus on isolated variables shifts to the perception of complex patterns.
Locus of control	Increased self-reliance and the ability to form new strategies when required.

As can be seen, as a person develops their cognitive skill (such as decision-making), processing becomes more effective and efficient. As one reaches expertise, often cognitive processing is not occurring at a conscious level. The term 'intuition' has been quite popular in recent literature to describe this type of fluid information processing and decision-making (see Klein, 2003).

This information on cognitive skill development is important when studying decision-makers as it provides an understanding of how they are using and developing their skills as they perform decision-making. It also gives us another means of distinguishing differences between expert and novice decision-makers for input to training technologies.

5.2 Summarising Development of Expertise

In summary, understanding the development of expertise is essential in order to more fully comprehend the expert/novice continuum. Developing expertise in NDM can be seen as synonymous with acquiring a cognitive skill. By considering literature on skill

development, and the role of memory, we are able to understand how general cognitive principles can apply to understanding expert performance. Skill acquisition can initially be explored at a cognitive level. The process of learning and storage of skills in long-term memory represents a basic platform on which to base further understanding of expertise (summarised by Welford [1968]). From there, we are able to describe how expertise develops as experience in a domain increases. The development of expertise has been described in stages by Anderson (1991), Dreyfus (1972), and Rasmussen (1983). These models describe decision skills as beginning as variable and awkward and progressing to a point where decisions become intuitive, and responses more immediate and logical to the decision-maker. The skills that are developed during the translation from novice to expert, have been broken down into four skill areas (Glaser, 1987). These are performance, judgement, perception and locus of control. This information is important for improved understanding of the distinction between expert and novice decision-makers, and also to input into future training technologies.

6. Teamwork and Naturalistic Decision Making

Many organisations require teams of decision-makers in order to handle the complexity of the tasks performed. This is certainly the case with the Australian Army, where HQ teams are established in order to achieve complex planning and decision-making duties. Within this team, the commander is ultimately responsible for the decisions made, but the team guides the decision-making process. Therefore, it is important to understand how teams can impact on the commander's decision-making process.

6.1 Group or Team?

In the psychological literature there has been debate surrounding the difference between teams and groups. *Group* has been used as a much more broad descriptor than *team*. Johnson and Johnson (1987) define a group as " two or more individuals in face-to-face interaction, each aware of his or her group membership, each aware of the others who belong to the group, and each aware of their positive interdependence as they strive to achieve mutual goals" (p. 8). It has been argued that a team is more structured, in that each member has a role and works interdependently toward a common meaningful goal (Morgan, Glickman, Woodard, Blaiwes & Salas, 1986). Teams require co-ordination, which results in simultaneity or sequencing in order to coordinate their efforts (Brannick & Prince, 1997). Teams also tend to have a history and a future, where groups will often be formed and disbanded to achieve a specific short-term task. Paris, Salas and Cannon-Bowers (2000) identify other characteristics that delineate teams from small groups as: multiple sources of information, task interdependencies, co-ordination amongst members, common and valued goals, specialized member roles and responsibilities, task relevant knowledge, intensive communication, and adaptive strategies to help respond to change.

If we are to take the definition one step further and look at differences between group decision-making and team decision-making, we can focus on task instead of simply structure. It has been suggested that in groups the decision-making is the task, whereas for teams the decision-making leads to the task (Jones & Roelofsma, 2000). Looking at command and control teams in particular, such as an Army HQ team, we must realise that they participate in both conditions. This makes the use of this element of the definition rather unhelpful.

It is fair to conclude from this summary that a team is a kind of a group. Therefore, some of the same principles apply, and some research on groups could be equally applicable to a team setting. The reverse however is not true.

6.2 Group Properties and Performance

Any group of people working together over a period of time have been found to have some basic social properties. These are:

- **Cohesiveness –** This is colloquially known as team spirit or morale. It is believed to be the psychological process that transforms many individuals into a group (Vaughan & Hogg, 1995). Operationalising the concept has been difficult, but it seems to be related to interpersonal attraction, increased conformity, improved inter-group communication, and liking.
- **Socialisation** - This can be defined as the "dynamic relationship between the group and its members that describes the passage of its members through a group in terms of commitment and changing roles" (Vaughan & Hogg, 1995).
- **Norms** - These are shared beliefs about the appropriate behaviour for a member of the group. They provide a frame of reference for group members to choose appropriate behaviour for themselves, and evaluate the behaviour of others.

These same properties should be found in a HQ team in the Australian Army, because they are an aggregate of people that work together on a day-to-day basis. Therefore, these group properties would be exhibited.

Two structural properties that are commonly identified in groups are:

- **Roles** - These represent the division of labour in a group.
- **Communication network** - This can be defined as a set of rules that govern appropriate communication between group members.

It seems that these properties are also both consistent with the Australian Army. Firstly, in the Army, roles are explicitly stated (eg. S3, S2), and also a communication network seems to be present which is influenced by the Army rank system.

Aside from understanding properties exhibited by groups, research has also focused on the effect of a group on performance outcomes. Research has found that the mere presence

of others is arousing. This presence acts to facilitate well-learned responses or to impede novel tasks, or poorly learnt skills (drive theory; Zajonc, 1965). Since then it has been suggested that it may not be the presence of others that affects performance, but our understanding of social rewards and punishments (Cottrell, 1972).

Another phenomenon observed in groups is transactive memory. An advantage of working in a group is that groups tend to remember more information than the best individual in that group (Clark & Stephenson, 1989). The term transactive memory refers to a theory developed by Wegner, Erber and Raymond (1991) which suggests that groups develop a shared system for encoding knowledge, where each individual is only responsible for part of what the group needs to know. Each member understands who is responsible for each memory domain.

6.3 Research on Teams

Since the 1950s, team research has regularly evolved. There are eight categories into which theories of teamwork have developed over the last half-century. These are: social-psychological approach, socio-technical approach, ecological approach, human resource approach, technological approach, lifestyle approach, functional (taxonomic) approach, and the integrative approach (for a summary see Paris et al., 2000).

In addition, researchers have worked to identify factors that are internal and external to individuals that may affect team decision-making. Critical skills or traits that may be related to effective teamwork were summarised by Cannon-Bowers, Tannenbaum, Salas and Volpe (1995) and Salas and Cannon-Bowers (2000) into three main categories. These were: cognitions, skills and attitudes. Ideas contained within these three broad areas are summarised in Table 4.

Table 4. A summary of research on critical components of teamwork (Salas & Cannon-Bowers, 2000)

Characteristic	Ideas Encompassed
Cognitions	Cue-strategy associations, task specific team-mate characteristics, shared task models, team mission, objectives, norms, resources, task sequencing, accurate task models, problem models, team role interaction patterns, teamwork skills, boundary spanning roles and team orientations.
Skills	Adaptability, shared situation awareness, mutual performance modelling, motivating team members, team leadership, mission analysis, communication, decision making, assertiveness, inter-personal co-ordination, and conflict resolution.
Attitudes	Motivation, collective efficacy, shared vision, team cohesion, mutual trust, collective orientation, and importance of teamwork.

Aside from this, it is important to be aware of the external variables that can potentially contribute to team performance outcomes. Table 5 shows how these have been summarized by Morgeson, Aiman-Smith and Campion (1997) and Meister (1985).

Table 5. Description of variables that may influence team performance (For examples see Appendix A)

Factor(s)	Description
Contextual Factors	Variables that pertain to the environment in which the team activity is embedded.
Structural Factors	Variables impinging primarily from sources external to the team, but may include some internal to the team (eg. team organisation).
Team Design Factors	Variables inherent to the team itself; the way in which it is designed.
Process Factors	Variables inherent to the team itself; the way in which it functions.
Contingency Factors	Variables impinging from sources internal and external to the team.

6.4 Teams and Shared Mental Models

In the last decade, a substantial amount of team research has focused on the concept of shared mental models (SMM). Researchers agree that teams tend to develop SMM (Cannon-Bowers, Salas & Milanovich, 1999). These can essentially be described as knowledge structures or cognitive representations that are shared between team members, and are used to organise information, understand events and make predictions and decisions (Rouse & Morris, 1986). They allow for a similar understanding of the situation amongst team members, and guide how team members will interact (Gentner & Stevens, 1983). Shared mental models have also been used to explain the co-ordinated performance of teams (Stout, Cannon-Bowers, Salas & Milanovich, 2000). In particular, it has been suggested that an SMM can lead to the use of more proactive communication. This, in turn, has been linked to effective performance. For example it was found that effective teams tend to provide information without prompting and provide information in advance (Stout et al. 2000).

It has been suggested that a number of characteristics can contribute to the development of SMM. For example, teams that engage in effective planning before a mission (task) appear to develop better SMM than those that do not (Stout, Cannon-Bowers & Salas, 1996). Following from this, teams that planned more effectively were also found to perform better under periods of increased workload (Stout et al., 2000).

Klein and Thorsden (1990) put forward the idea of the "team mind". Essentially taking the idea of shared mental models a step further, they propose that a team can be looked at as analogous to the mind of one person. This in turn infers that:

- Cognitive processes are linked to behaviour
- The team has limited attentional resources
- Sometimes important knowledge in the team mind is not retrieved
- The team mind depends on meta cognition
- The team mind is affected by motivation
- A team must learn to co-ordinate its actions
- Teams can draw inferences (by recognising patterns in information held by various team members)

This model infers that literature related to individual decision-making will also be applicable to understanding team decision-making. However, within this idea it is still unclear as to how the "team mind" works.

6.5 Summarising Teamwork and Naturalistic Decision Making

Because teams are often integral to NDM performance it is important to understand decision-making in the context of a team. Despite the lack of consensus in the literature on defining groups and teams, it is believed that a team is a type of group in which each member has a role and works interdependently toward a common meaningful goal. This definition is appropriate to military HQ teams. Social psychological research has identified both social and structural characteristics common to groups of people working together. These include: cohesiveness, socialisation, team norms, roles and communication networks. Many theories have been developed to describe team functioning. These fall into eight main categories and are summarised by Paris, Salas and Cannon-Bowers (2000). Factors internal and external to the individuals have been identified as being predictive of effective teamwork. Internal factors have been identified as: cognitions, skills and attitudes. External factors are: contextual factors, structural factors, team design factors, process factors, and contingency factors. Recent research has focused on the importance of SMM in effective teams. SMM guide how team members interact, and also facilitate decision-making in teams. Finally, Klein and Thorsden (1990) have suggested that for research and modelling purposes a "team mind" can be established as analogous to the mind of one person. This offers a range of implications for future research and design.

7. Decision Error

Decision error is one of the eventual observable NDM outcomes that research attempts to reduce. Ultimately, if NDM always produced optimal outcomes, there would be less need to research its intricacies. However, as illustrated at the beginning of this report, catastrophic errors can and do occur.

There are inherent problems in defining what constitutes a good decision. It has been suggested that a good decision can be defined as one that maximises expected utility (Edwards, Kiss, Majone, & Toda, 1984). However, this definition is open to interpretation. In contrast to this, one could focus on defining what constitutes a decision error. Reason (1990) defined decision error as any decision that fails to achieve the outcome originally intended. This definition allows for decisions to either be correct or incorrect. However, in reality it seems that even if a decision matches up with expectations there are still varying degrees of success ("decision quality"). However measuring "decision quality" seems problematic. It is particularly difficult to measure the decision quality of military commanders because there are so few observable outcomes that are not also affected by factors other than the decision made. Currently, researchers are still attempting to develop valid methods with which to explore decision quality. To date many methods have assumed that what experts' do is "proficient" decision-making. This assumption may not be entirely appropriate however, because, even experts have been reported to make mistakes (Dixon, 1976; Orasanu, Dimukes, & Fischer, 1993; Orasanu, Martin & Davidson, 2001). Therefore, in a study of expertise it is important to recognise this factor and attempt to establish an understanding of how and why these decision errors occur. It can be argued that if we can develop a good understanding of what causes decision errors, and implement appropriate aids and interventions, we should be able to significantly decrease decision-making error.

7.1 Explanations for Decision Error

Klein (1998) broadly defines three main categories of decision error.

- Lack of experience of the decision-maker.
- Lack of information (this impacts on developing a good situation awareness).
- Poor mental simulation (where decision-makers would notice the signs of a problem, but explain them away.)

Two of these factors are associated with the cognition of the decision-maker (lack of experience, poor mental simulation) and the third is an external factor (lack of information).

Consistent with Klein's (1998) analysis, there have been two schools of thought explaining decision error. The first one locates the error as occurring within the cognitive processing of the decision-maker. The second locates the cause of error external to the decision-maker,

and looks at the context surrounding the decision. It is likely, however, that there is an interrelationship between context and cognition that contributes to NDM error.

7.1.1 Context

The context surrounding naturalistic decision-making is seen as increasingly important (Lewandowsky & Kirsner, 2000; Orasanu, Martin and Davidson, 2001; Schliemann & Carraher, 1993). Woods, Johannesen, Cook and Sarter (1993) suggest that instead of focusing on an individual's internal cognitions, if attention is given to the available information, the goals pursued and the level of experience, it becomes easier to remove blame from the decision-maker and investigate the poor situation.

Orasanu, Martin and Davidson (2001) investigated cognitive and contextual factors in aviation error. They suggested that experts could make errors in their decision-making in one of two processes:

- Developing situation awareness
- Selecting an appropriate action

They found from analysing aviation accident reports that four contextual factors seemed to be influencing expert error. They were:

- Ambiguity
- Dynamic Risk
- Organisational and Social Pressures
- Stress (working memory capacity [Hockey, 1979])

These four areas of error fit into different types of contextual frames.

- ***Relational Context*** – *This refers to the relational networks, and collaborative processes between individuals. It also takes into account the mood and morale created by these interactions. Importantly, it includes analysis of communication (both implicit and explicit), and the resulting shared understanding. Therefore, three sub-components could be:*
  - o Relational networks
  - o Communication (implicit/explicit)
  - o Morale/ Mood

This is where "organisational and social pressures" as a predictive category for error would fit in (Orasanu et al., 2001).

- ***Physical Context*** – *This refers to the physical environment in which decision-makers find themselves. This environment can have elements that are dynamic, and others that are constant. For example, for an emergency doctor, the space s/he occupies remains relatively constant. However, the equipment being used by the staff with whom s/he is working and the patients s/he is treating are dynamic. The dynamic environment often contains cues that*

trigger expert schema and decision-making. This concept of physical context then could be divided into two sub-components:
- o Stable environment (relatively unchanging)
- o Dynamic environment (constantly changing)
  - • Specific cues (triggers for expert schema)

This dynamic environment would create ambiguous information at times feeding into decision-making. Thus, as mentioned by Orasanu et al. (2001), ambiguity, resulting from a dynamic environment is predictive of error.

- • ***Emotional Context*** *– This refers to the human emotions entwined in the scenario that could affect perception, and/or performance. This could refer to:*
  - o Stress and anxiety levels
  - o Personality factors (associated with individuals)
  - o Emotion triggering events (such as death)

Stress, as described by Orasanu et al. (2001), would fit in this area.

- • ***Temporal Context*** *– This refers to the time frames in which the event is situated. The length of time taken for a decision to be made or the available time for that decision to be made would fall into this category. Sub-components would be:*
  - o Time of day
  - o Length of event

Risk changing over time (dynamic risk; Orasanu, Martin & Davidson, 2001) would be an artifact of the temporal and physical contexts interrelating.

7.1.2 Where Context Meets Cognition

Hutchins (1996) believes that, "boundaries between individuals and context should be softened… The apparent necessity for drawing such a boundary is in part a side effect of the attempt to deal with the individual as an isolated unit of cognitive analysis, without first locating the individual in a culturally constructed world." (p. 287-288). It may be that in order to understand NDM error more fully, both context and cognition need to be examined.

In classical decision research, a number of decision biases have been identified that cannot be explained by the theory, and that produce outcomes that would deviate from expectations. For example, Kahneman, Slovic and Tversky (1982) show that decision-makers usually use "cognitive shortcuts" that produce answers with less cognitive effort, but there is greater risk of error. These are referred to as heuristics. These same biases may relate to NDM. Some examples that may be relevant to the military climate are:

- • Cognitive dissonance theory (Festinger, 1957)
- • Memory and hindsight biases
- • Context dependence

Festinger (1957) proposed the theory of cognitive dissonance, based on observing typical human behaviour of selective perception. People experience cognitive dissonance when they hold two thoughts that are contradictory or incompatible. He proposed that, whenever possible people attempt to reduce dissonance (an aversive condition). In essence, this explains why people often change their behaviour to match their beliefs, or vice versa. In a military environment an officer may justify a decision s/he has made and ignore the evidence of risks (Dixon, 1976). There are instances of both pre-decisional and post-decisional effects of cognitive dissonance.

- An example of pre-decisional dissonance was documented by Kantola, Syme and Campbell (1984). They found that when people who were reported as using large amounts of electricity were confronted with the reminder of an earlier conservation endorsement they had made, they tended to cut their consumption significantly.
- An example of post decisional dissonance is presented by Frenkel and Doob (1976). After examining a federal election they found that when comparing respondents attitudes before and after the voting process, voters were more likely to believe that their candidate was the best one and had the best chance to win after they had voted.

Further biases that are relevant to the military context are memory and hindsight biases. A critical fact that cannot be ignored when thinking about the role of previous experience in formulating mental models is that memory is not always an accurate storage of past information. As we recall a memory, we also need to reconstruct it mentally (Loftus, 1980; Myers, 1990). Hindsight bias is the "tendency to view what has already happened as relatively inevitable and obvious" (Plous, 1993, p. 35). Therefore, the idea of drawing upon memory to feed previous experiences into current decision-making is fraught with problems. It is possible that in the process of recalling previous experience Commanders could overestimate how obvious a particular course of action was in the past. Hence, this could affect future decisions.

Psychological research has also demonstrated that context in a most basic sense influences judgement. Three such biases due to information presentation are:

- **The Primacy Effect**
  Characteristics presented early in information gathering influence impressions more than those gathered later (Asch, 1946).

- **The Recency Effect**
  When people are able to remember the most recent piece of information more clearly than the initial one, it will tend to influence their impressions most (Miller & Campbell, 1959). Recency effects are a function of recall. In a military domain, primacy effects may be more common than recency effects because decisions are immediately linked to information gathering (Hoch, 1984)

- **Halo Effects**
  The halo effect illustrates that people's reactions to stimuli are context dependent (Plous, 1993). It has been found that when people rate others on various attributes the ratings are often correlated (Thorndike, 1920; Cooper, 1981; Feldman, 1986; Landy & Sigall, 1974). Therefore, impressions formed about a stimulus can be based on beliefs associated with a particular attribute. For example, if a certain member of the HQ staff was thought of as radical, less attention may be placed on his input to the planning/ decision-making.

Other decision heuristics that may be applicable to decision-making in the military are:
- o Representativeness
- o The Law of Small Numbers
- o The Hot Hand
- o Neglecting base rates
- o Nonregressive prediction
- o Clinical vs Actual Prediction
- o Availability
- o Confirmation

A more detailed discussion of these can be found in Plous (1993). It is important in establishing an understanding of expertise in NDM to be aware of these heuristics and biases that would potentially affect decision-making in a military context.

Recent research in an NDM setting has supported the idea that cognition and context are important to consider together to begin to understand decision error (Lewandowsky & Kirsner, 2000; Johnson-Laird, 1999).

7.1.3 Recent Research on Context and Cognition in an NDM Environment

Two ideas that have recently been suggested to explain certain decision errors in an NDM environment are:

- Knowledge partitioning
- Falsity

These will be discussed in turn.

It has been argued in the literature that expertise is domain specific and inflexible. One example of this is provided by Frensch and Sternberg (1989) who studied expert and novice bridge players. They found that when the rules of bridge were changed, there was no significant difference in performance between expert and novice groups. The "expert skills" of the bridge players were of no advantage when the rules were changed. This illustrates the importance of understanding the limits of the domain in which one holds expertise.

The integrated nature of expertise within a defined domain is echoed throughout the field (Glaser, 1996). Berdard and Chi (1992) write that "experts have more stronger links among concepts, suggesting there is a greater degree of connectedness and cross referencing, and the pattern of connections and cross referencing can result in a better structure" (p. 136). However, the 'within-domain' integrated nature of expertise is questioned by Lewandowsky and Kirsner (2000). They found that when performance was compared across different contexts, but in the same domain (identical physical conditions), the predictions that were made were completely opposing. They go on to suggest that expertise may "comprise separate, and sometimes even mutually exclusive components of knowledge"(p. 295).

The testing tool used by Lewandowsky and Kirsner (2000) was a bushfire computer simulation prediction task. The experiments manipulated context within this tool (experts familiar with situations). The metrics taken were: how accurate expert predictions were, physical model compared with expert's model, and how do experts cognitively evaluated combined effects of determinant variables (eg. wind and slope). The outcome was that experts were identified from novices not by their use of strategy (for example wind dominance over slope) but their context specificity of performance.

In response to these findings, Lewandowsky and Kirsner (2000) have proposed that experts store information pertaining to separate areas of their experience in different "packages". It is suggested that each package is integrated internally, but integration between packages proves difficult. This independence across packages could cause the inconsistencies and mistakes that have been observed in expert performance. The access to these knowledge packages is guided by the problem context. From this, it is speculated that partitioning could be avoided if training instructions or diagrams foster integration of predictors (eg. wind speed and slope for a fire fighting context).

This finding is comparable with those found by Schliemann and Carraher (1993). In this study, two mathematically identical problems were given to expert cooks. They were:

- If 2 kg of rice cost 5 cruzeiros, how much do you have to pay for 3 kg?
- To make a cake with 2 cups of flour you need 5 spoonfuls of water. How many spoonfuls do you need for 3 cups of flour?

Both problems are relevant to their domain of expertise. Interestingly though, in the pricing context accuracy of response equated to 90%. In regards to the recipe, accuracy was dramatically lower at 20%. Schliemann and Carraher (1993) explained this in terms of the kinds of cognitive methods the cooks might generally employ in such situations. In the pricing context, calculation of an accurate answer would be required by social convention. However in regard to the recipe measurements expert cooks might generally use estimations in order to generate solutions. This result also emphasises the use of different ways to solve a problem in different contexts within the same domain. It is reasoned that in both cases described expert errors could be explained by applying a compartmental view of expert information storage and retrieval.

The second example of a recent explanation for decision error is falsity. Johnson-Laird (1999) has pointed out the cognitive differences when dealing with either true or false situations. Johnson-Laird (1999) draws on the concept of mental models. When people reason they draw on their mental models, which act like a truth table. Because these are held in working memory, the adequacy of these is limited by the capacity of working memory. This suffices for straightforward problems, but when one has to deal with complex, false information, humans tend to not give answers based on a complete set of logic. When we are told a piece of information is false it becomes difficult to generate all the other possibilities for what the true piece of information might be and hold them all in working memory. Experimental research has been carried out to demonstrate this theory. For example, the problem below was presented to a group of Princeton University students. They were told that only one of the following statements about a hand of cards was true:

- There is a king in the hand, or an ace, or both.
- There is a queen in the hand or an ace, or both.
- There is a Jack in the hand, or a ten or both.
- Is it possible there is an ace in the hand?

From this 99% of the students answered incorrectly. Counter intuitively, the answer is "no". At first glance it may appear that there can be an ace because there is an ace in the first two statements. However, if there was an ace then it would follow that the first two statements would be true and it was explicitly stated in the problem formulation that only one of the statements could be true. Therefore, neither of the first two options can be exclusively true. Johnson-Laird (1999) explains that when we are told a piece of information is false it becomes difficult to generate all the other possibilities for what the true piece of information might be and hold them all in working memory. Therefore, Johnson-Laird (1999) suggests humans simply ignore the falsity in order to process the information more easily (for a summary of falsity see Butavicius & Galanis, in press).

7.1.4 Teamwork and Decision-Making Error

In many NDM situations a team of individuals are required to assist in decision-making. Thus, a team level understanding of NDM error is also required.

It has been suggested that group decision-making is often inferior to individual decision-making (Brown, 1988). Postmes and Lea (2000) suggest that this can be attributed to:

- Process dysfunctions
- Social dysfunctions

Process dysfunctions arise because of structural characteristics in the group setting that may affect decision-making. Examples could be disproportionate chances to communicate or participate.

Social dysfunctions are caused by "limitations inherent in the structure and form of meetings" (Postmes & Lea, 2000, p. 1253). Examples of these processes are: evaluation apprehension, socialising, conformity pressures, social loafing, domination due to status imbalance, free riding, group think (Steiner, 1972; Stroebe & Diehl, 1994; See Appendix B for definitions).

Jones and Roelofsma (2000) add a third causal factor to this suggestion. They suggest that in terms of decision-making error in teams, there are cognitive triggers, as well as organizational and social causes.

Therefore, any decision made in a military HQ environment should be considered at three levels: cognitive (individual), organisational (team/context) and social (team/context). As individual cognitive biases have already been described, the focus will now be placed on organisational and social triggers for decision error.

7.1.4.1 Organisational Triggers for Decision Error

It is interesting to note that many decision errors that have been subsequently analysed have been attributed to high level management decisions. For example, Bruggink (1985) found that 65% of aircraft accidents analysed had been influenced by policy factors. This makes it obvious that decision-making at a certain level in the military must be looked at in the organizational context in which it occurs.

From the field of organisational psychology phenomena such as: organisational culture, group structure, power structure, role structure and communication structure have been identified as organisational factors that may potentially influence performance outcomes (For a summary see Buchanan & Huczynski, 1997).

One area of research which examines organisational dynamics traditionally associated with military performance is 'Unit Climate Profiling' (UCP; Murphy & Farley, 2000). 'Unit climate' is similar to the construct of 'organisational climate' that is widely used in the organisational psychology literature (e.g., Argyle, 1972; Carey, 1998; Schneider, 1990). Unit climate is made up of several dimensions presumed to be antecedents of individual, team and unit readiness to undertake military duties.

The UCP developed from a conceptual framework (Wild, 1988) that attempted to predict combat effectiveness from postulated readiness indictors. The human components of combat readiness included: aptitudes, combat proficiencies, understanding of the task(s), the motivational environment, performance motivation, command intent and leadership. Using the motivational components of this model, Reeves and Hansen (1989) developed and administered a psychometric instrument, the Human Dimension of Combat Readiness Index – Experimental (HDCRI-X), to a sample of Canadian soldiers. Factor analysis confirmed the existence of eight independent factors, made up of 56 items, which accounted for 53.9% of total variance. The eight dimensions were labelled: morale/

cohesion, leadership skills, ideology[10], professional morale[11], and confidence in leadership at four distinct rank levels. It is noted that the sample size used for this analysis was less than satisfactory (a general recommendation is 10 subjects for each item present in a scale (Tabachnick & Fidell, 2001).

The resultant 56-item HDCRI-X was used by Farley (1995) with Canadian soldiers deployed to Bosnia. During this research, he pragmatically refined the design, analysis and use of the measure and renamed it the 'Unit Climate Profile'. The UCP is essentially a tool for commanders to add to their decision-making 'toolkit'.

The UCP appears to have been useful as a form of input into command decision-making in recent peace support operations (Farley, 2002). However formal research needs to be done to determine whether knowledge of unit climate factors actually affects and improves decision-making. Interestingly, previous research has revealed that command perceptions of climate factors such as morale and confidence in leadership can be at considerable odds with the perceptions of subordinates (Korpi, 1965; Eyres, 1998). Korpi (1965) found that Swedish officers had "very unreliable notions of the opinions in their units" (p. 302) and that officers were generally unaware that their perceptions of subordinate morale might be inaccurate. Indeed, the greater confidence officers expressed in their assessments of issues such as morale, the larger the error in their predictions. More recently, Eyres (1998) found that although officers expressed general satisfaction with the leadership they provided, subordinates reported they were, at best, indifferent to officer leadership.

These findings must be considered in the context of decision-making. If commanders do not accurately perceive or assess prevailing attitudes, norms, and values in a unit's culture and subcultures, or their own impact on subordinate behaviour, then the likely consequences of their decisions may be poorly appreciated. Research on the influence of poor or conflicting perceptions of unit climate factors on decision performance appears warranted.

7.1.4.2 Social Triggers for Decision Error

Explanations of social influences on decision-making draw upon a large field of research, particularly stemming from the field of Social Psychology. Jones and Roelofsma (2000) suggest that some important social/group biases to consider in team decision-making are: false consensus effect, groupthink, group polarisation, and group escalation of commitment.

The false consensus effect is the tendency that people have to overestimate the degree to which their own choices and judgements are similar to others (Ross, Greene & House, 1977). This bias can affect teams in terms of assumptions that may be made when

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[10] Ideology refers to internalised normative beliefs associated with military culture such as the legitimacy of the use of force and commitment to military ethos

[11] Professional morale refers to soldiers' confidence in their military skills and abilities

incomplete information is received upon which to base decisions. Assumptions may be made regarding: members of one's own team, the enemy, other teams or individuals within the organisation. Fischhoff and Johnson (1997) have put forward the notion that false consensus may result from an inaccurate mental model of the group about which one is making an assumption. This bias requires further research within a command and control setting in order to more fully understand how it may factor into decision error.

Groupthink is a mode of thinking where the group's desire to agree overrides their desire to come up with the best decision (Janis, 1972). Groupthink can lead to: incomplete survey of alternatives, consideration of too few objectives, and poor information search (Janis & Mann, 1977). Despite criticisms of the theory (Leana, 1985; McCauley, 1989) it seems to have been accepted universally as a phenomenon worth pursing further in research (Adlag & Riggs Fuller, 1993). Thus far, groupthink in a team context seems not to have been tested. It is therefore important to take this into consideration as a potential team bias.

Polarisation is the tendency for the group members to make decisions that are more extreme than the mean tendency, but in the same direction as that tendency (Lamm, 1988). The two types of polarisation are risky shift (the tendency to choose a course of action more risky than the group norm) and cautious shift (the tendency to choose a course of action more cautious than the group norm). One explanation for this phenomenon takes into account group norms. It is understood that more extreme decisions are made in order to confirm group norms. Little research seems to have been done in a command and control setting on this phenomenon, particularly in terms of the effects of time pressure, high stakes, and uncertainty.

Group escalation of commitment is the tendency of groups to pursue a particular course of action even in light of evidence that it is failing. Obviously, within this bias, the issue of leadership arises. A particular type of group escalation occurs in competitive situations. This can be illustrated by considering a price war between two companies. Each company continues to lower the price of their product until they begin reaping losses from the discounts applied to their products. Rationally, this should end the price war, but as was the case with a price war between American Airlines and Northwest Airlines in 1992, the war continues past this point (Jones & Roelofsma, 2000). Clearly, this presents an area to be considered in future command and control team research. Possible benefits may be produced if one could convince the enemy to escalate his commitment.

As well as social biases that may affect decision outcome, there are several other documented group processes that are deemed likely to impact on team decision quality. An example of this is the process known as "brainstorming". Generating novel ideas is important in a military context. Often this is achieved through a process similar to "brainstorming"(Osborn, 1957). Despite evidence that groups left to brainstorm actually do generate more ideas than the individual members, it has not been found that they are more creative (Diehl & Stroebe, 1987; Mullen, Johnson & Salas, 1991). In fact, it has been established instead that groups where individuals create their own ideas without

interacting, are more creative than those that work as a group (Paulus, Dzindolet, Poletes & Camacho, 1993). The reasons that this might be the case include:

- **Evaluation apprehension** - Group members concerned with making a good impression introduces a degree of self-censorship.
- **Social loafing** - Motivation is lost because the task is collective in nature.
- **Production blocking** - Because individuals have to contend with others generating ideas at the same time they are often stifled creatively.

Numerous conditions for decision error exist both at an individual cognitive level, and also at a team level (social and organizational). These need to be considered in research dealing with the Commander's decision-making within the context of the team.

7.2 Summarising Decision Error

An important aim for NDM research is to reduce the occurrence of decision error. Therefore in order to facilitate this an understanding of possible triggers for decision error is needed. There have been a number of explanations put forward, and most tend to focus on context and its effect on cognition. Contextual causes of decision error fall into four categories: relational context, physical context, emotional context and temporal context. Interestingly, when the effects of context on cognition are examined various types of decision errors have been identified. Typically humans try to simplify cognitive processes. They use heuristics (otherwise known as "rules of thumb") to do this. Decision heuristics can lead to quicker decisions, but they tend to present more risk of error. Several heuristics that have been identified in the literature can be applied to a military setting. Examples are: cognitive dissonance, recency and primacy biases, and halo effects. Biases that have recently received attention in the literature are knowledge partitioning and falsity. Biases do not only operate at an individual level but also in a team setting. These occur as process dysfunctions and social dysfunctions. They include such things as: false consensus effect, groupthink, group polarisation, and group escalation of commitment.

8. Conclusions on Expertise in NDM

8.1 Summary

It seems apparent that the topic of expertise in NDM is an important concept for researchers concerned with military decision-making. At the outset of this report, the aims were given as: to present the relevant background information required to begin to understand the field of NDM, how expertise is understood within this field, and how an expert functions within a team environment. The main topics discussed have been: decision theories, previous experience and expert functioning, levels of expertise, teamwork and naturalistic decision-making, and expert error. These topics are essential in

providing a platform for future research into command decision-making. They isolate concepts that must be understood in order to improve the development of command support tools, and training interventions in the Australian Army.

Firstly, this review looked broadly at the history of decision research. Traditional analytical models have been presented, and critiqued as explanations for decision-making in naturalistic environments because of their reliance on assumptions of probability. Research has found that humans do not always behave in this manner. This, coupled with the understanding that classical decision theories failed to explain decision-making in an environment such as the military, led to the search for alternative models.

The understanding that the military operates in an environment very different to those in which much of the traditional decision-making research was performed, led to the establishment of the NDM theory. This in turn provided a platform for more recent models of decision-making, such as the recognition primed decision-making model and the schema and mental models in RPD theory of expertise. These theories take into account the short time frames, uncertainty, multiple goals, and high stakes associated with the NDM process. From these theories, important ideas that have been introduced are: situation awareness, the use of previous experience, schemata and mental models.

Models that describe NDM emphasise the importance of experience to feed into decision-making. Therefore, understanding how experience affects decision-making is another important area. Much of the research on expertise predates NDM theory, but its principles are still applicable to the emerging field. Glaser and Chi (1988) carried out a review of research on expertise and outlined a number of its facets that were common across domains. Most importantly, it seems that seems that experts use particular cognitive strategies in order to complement their declarative, perceptual and cognitive knowledge. This gains them advantage over their novice counterparts. Thus, investigation into expertise is largely concerned with the encoding and storing of knowledge based on experience. An important cognitive model of how this experience is stored in memory has been proposed by Noble (1993). This model describes how previous experience feeds into decision-making, and how incomplete information is handled. This information is directly applicable to the models previously mentioned, as it provides a deeper understanding of the perceptions and processes undertaken in NDM. Thus its incorporation into a more holistic understanding of expert decision-making is integral.

Expertise underlies NDM, and is based on gaining a repertoire of relevant experiences to feed into situation assessment and decision-making. Understanding the development of expertise looks at how this experience is gained, and describes how the cognitive skills associated with NDM emerge. Welford's (1968) model of the storage of skill in memory has been discussed; as have descriptive models of development of expertise proposed by Anderson (1991), Dreyfus (1972), Fitts and Posner (1967; cited in Shanteau, 1992), and Rasmussen (1983). These models are all similar in that they describe decision skills as beginning as variable and awkward, and progressing to a point where decisions become intuitive, and responses more immediate and logical to the decision-maker. The

differences lie in the division of these continuums into identifiable stages. Dreyfus's (1972) model proposes that five levels of skill competency are identifiable, as one becomes an expert. However distinctions between these stages seem to be less obvious compared with those suggested by Rasmussen (1983). The author suggests that Rasmussen's (1983) model provides a good illustration of expert development based on three levels of skill competency. As NDM expertise is developed, the four types of skills that are developed are: performance, judgement, perception and locus of control (Glaser, 1987). Therefore we can begin to establish a cognitive explanation for expert decision-making, and how this may emerge with repetition (experience). Understanding this feeds directly into developing training methods.

It was noted that for application to the real world, it is important to take into consideration the fact that military decision-makers (especially those working in a HQ environment) are part of a team. Therefore, this context must be understood. Social psychological research has provided several characteristics, both social and structural, common to groups of people working together. These include: cohesiveness, socialisation, team norms, roles and communication networks. Many theories have been developed to describe team functioning. Also, factors internal and external to the individuals have been identified as being predictive of effective teamwork. Internal factors have been identified as: cognitions, skills and attitudes. External factors are: contextual factors, structural factors, team design factors, process factors, and contingency factors. Research on mental models and the "team mind" was also discussed. These concepts are important because they provide theories that account for the implicit communication through NDM. They also provide implications for future research and design with teams.

As outlined at the very beginning of the report, errors in NDM can be quite catastrophic because the stakes are so high. Therefore, an important aim for NDM research is to reduce the occurrence of decision error. In order to facilitate this, an understanding of decision error and its possible triggers is needed. Many explanations have been provided for decision-making error. They mainly focus on the effect of context on cognition. Contextual causes of decision error have been identified as falling into the following areas: relational context, physical context, emotional context and temporal context, and psychological. Psychological context refers to the use of decision heuristics in order to make quicker decisions. Several heuristics can be applied to a military setting. Examples are cognitive dissonance, and biases due to the order of information presentation (eg. primacy effect, recency effect, halo effects). Biases that have recently received attention in the literature are knowledge partitioning and falsity. Understanding team biases is also important. These occur in the form of process dysfunctions and social dysfunctions. They include such things as: false consensus effect, groupthink, group polarisation, and group escalation of commitment. Taking both individual and team biases into consideration in any research on military command decision-making is important.

8.2 Further Research

The success of future research hinges on the ability of researchers to provide more holistic understanding of the command process, and to identify where theories fall short of providing explanations for observable phenomena.

From reviewing the literature, four major areas have been identified as requiring further research in order to create more adequate models of command decision-making. Research in these areas will positively influence decision support tools and training techniques. These areas are:

- **Expertise:** The question of how an expert's cognitive functioning differs from that of a novice has created much interest and debate. It is imperative at this stage to integrate previous research and apply current understandings to real-world command decision situations. Successful research in this area could allow people to be trained to think like experts, possibly without the large time commitment generally associated with becoming an expert. Research needs to focus on the processes surrounding a commander's situation awareness and decision-making strategies. This will assist in the design of appropriate decision-making aids and interfaces.

- **Context:** The influence that context has on a commander's decision-making processes is currently unclear. In order to develop appropriate decision aids, the commander's decision-making processes must be looked at in the context of the environment, the team and the organisation in which s/he works. If this is not achieved, development of an oversimplified model could lead to production of inadequate decision aids.

- **Team Processes:** The diffuse nature of decision-making within a military HQ team makes it difficult to only focus on the individual when researching decision-making. Understanding team processes in an environment such as a military HQ is important. This is especially important in a military setting where the Commander controls the decision-making and the staff facilitate other steps of the process. Currently the importance of the HQ staff in the Commander's decision-making process does not seem to be fully understood. This needs to be addressed. This process should also be compared to other command and control settings, in order to understand the relevance of literature focused on other NDM domains for application to a military setting.

- **Decision Error:** Another essential outcome from the investigation of expertise is to generate an understanding of how expert error fits into NDM in the military. Specifically, in a team context, it is crucial to identify the critical areas in which decision biases may impede decision outcomes. This will also be imperative for the development of appropriate decision aids to facilitate expert decision-making.

8.3 Military Specific Research Issues

When applying research such as this to a military specific environment, a number of factors should also be taken into consideration. These are:

- The hierarchical organisation
- Organisational guidelines/Codes of practice
- Regiments (Corps affiliation)
- Reserve and full-time officers

Because the military operates as a hierarchical organization, and soldiers can be promoted through the ranks as a reward for good performance, it is generally assumed that higher ranked officers will have more experience, and will perform better than their subordinates. The organizational structure of the military has developed over the years to support the requirement to be able to operate in extreme circumstances that create stress and uncertainty. The structure should produce an environment in which stress and workload is shared, and a young soldier can carry out their duties without allowing their emotions, morals, and values to hinder their performance in a battle situation. Realistically, this may not be entirely the case.

Secondly, because the Army operates in a complex environment where decisions need to be made quickly, many standard operating procedures and guidelines that soldiers are expected to follow have been developed. These are expected to automate many of the drills and procedures that are frequently carried out by the soldiers. Consequently, any discussion about decision-making in the military must take this factor into account.

Also, within the Army there are different units (regiments) established to perform different functions. For example, there is a regiment dedicated to using armoured vehicles, an infantry regiment, and an air defence regiment (amongst others). A regiment would typically consist of approximately 700 soldiers. Because of the different functions of the regiments, it is possible that different business processes may be the norm. This is obviously an important issue for consideration.

Lastly, an issue related to performance of experts in naturalistic environments is that of time commitment. It may be the case that experts that commit less time to their field of expertise perform at a different level compared to those who commit more time and gather more practical experience. This is similar in other fields, where there are both part-time and full-time experts who function at various intervals (eg. the CFS vs the fire brigade, army reservists vs full-time army, part-time vs full-time doctors, and first aid staff). This could be the product of a shift from full-time employment as the norm to contract work and part-time positions. It is also a product of the demands involved in many of these organizations. In particular, additional staff or decision-makers are often required during emergency situations. At other times, such a large group is not necessary. In the Australian Army, there are a lot of competing demands on officers' time, and not adequate personnel to handle the work load. Therefore, increasingly the reserve officers

are called upon to complete these tasks. Therefore, despite being less "experienced" they need to be equipped to handle the job just as effectively as full-time officers. This issue cannot be ignored by researchers investigating expertise in NDM.

In summary, there are obvious directions for future research aimed at understanding more clearly how a Commander may use his expertise in a team situation in order to make decisions. If we do not carry out research on the areas outlined: expertise, context, teamwork, and decision error, there may be dangerous gaps in our knowledge of command decision-making. These gaps in knowledge will then translate into sub-standard design of decision support tools, and training procedures. To allude back to the anecdote at the beginning of this report, let us feel secure in the understanding that with further research and understanding of expertise in NDM catastrophic errors such as that described should be dramatically reduced.

9. References

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Appendix A: Factors Affecting Teamwork

(Adapted from Morgeson, Aiman-Smith and Campion, 1997).

Factor(s)	Description	Examples
Contextual Factors	Variables that pertain to the environment in which the team activity is embedded	Culture Climate Training/Education systems Reward systems Information systems
Structural Factors	Variables impinging primarily from sources external to the team, but may include some internal to the team (eg. Team organisation)	Physical environment Organisational arrangements Technological systems
Team Design Factors	Variables inherent to the team itself and the way in which it functions	Work Design Task interdependence Team size/composition Leadership
Process Factors	Variables inherent to the team itself and the way in which it functions	Boundary management Task cohesion Performance norms Communication Team interactions Potency/self efficacy Team spirit
Contingency factors	Variables impinging from sources internal and external to the team	Team application/mission Resource availability Procedural requirements Rules on operation, managing, or decision-making.

Appendix B: Definitions

(Vaughan & Hogg, 1995)

Evaluation apprehension-
The physical presence of members of the same species causes drive because people have learned to be apprehensive about being evaluated.

Socialising-
Dynamic relationship between the group and its members that describes the passage of members through a group in terms of commitment and changing roles.

Conformity pressures-
The pressure to conform to group norms in order to identify with and be accepted by that group.

Social loafing-
A reduction in individual effort when working on a collective task (in which one's outputs are pooled with those of other group members) compared to when working either alone or coactively.

Domination due to status imbalance-
Different group members have a different perceived status in the group. Status usually depends on their consensual prestige and their tendency to initiate ideas and activities that are adopted by the group. High status members tend to dominate idea formation in groups.

Free riding-
When a group member is avoiding costly obligations and group membership and allowing other members to incur the costs.

Group think-
A mode of thinking in highly cohesive groups in which the desire to reach unanimous agreement overrides the motivation to adopt proper rational decision-making procedures.

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19. ABSTRACT
Effective and efficient decision-making in the Australian Army is integral to successful performance. Therefore, understanding the decision-making process is a research priority. In order to conduct such research, a summation of previous knowledge addressing the decision-making process and the climate within which it is embedded, is important. This report provides a theoretical platform on which to ground future research. It focuses on topics such as: decision theories, previous experience and expert functioning, levels of expertise, teamwork and naturalistic decision-making and decision error. The interrelations between these concepts are discussed, and recommendations for future research are given. Future research would be expected to inform the development of advanced decision support tools, and superior training techniques.