# Using the Decision-Ladder to add a Formative Element to Naturalistic Decision Making Research

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# 1 Executive Summary

## 1.1 Background and reasoning behind the work

This report is submitted under HFI DTC work package 4.6.1, exploring requirements analysis for decision making training. This report is one of a number of reports submitted under the same work package.

The primary reason for the approach developed and described in this report, is in direct response to the complexity of the sociotechnical domains that typify military systems. These complicated, dynamic domains are frequently unpredictable; thus, there is perceived benefit in an approach that models the decision making activity in terms of how actors can proceed through the process rather than how they actually do or should.

It is believed that a more holistic approach is important for the conceptualisation, analysis and study of these domains. Further, it is contended that such an approach is essential in considering the introduction of new combat identification (combat ID) technology and its implications for training and operating procedures.

## 1.2 Specific research question being addressed

The remit of this report is to develop a model of decision making that, like current approaches to Naturalistic Decision Making (NDM), accounts for the relevance of context and expertise. Unlike current NDM approaches, the described approach aims to create a prototypical model that is less constrained to a given time, location and group of actors. This initial report describes such an approach, demonstrating its applicability to military domains. Future work, based upon this approach, is anticipated to investigate the value of the model in investigating decision support systems.

This report considers decision making in-line with theories of macrocognition (Crandall et al, 2006; Klein, 2000; Schraagen et al, 2008). According to Schraagen et al (2008), in contrast to microcognition, which attempts to provide a reductionist, causal-chain account of behaviour, macrocognition seeks to maintain a focus on the phenomena themselves. In short, theories of macrocognition acknowledge that, in complex sociotechnical domains, elements of cognition are inextricably linked; further, the linkage between these elements is neither clear nor static. Thus, to understand decision making in these domains, it should be viewed in its entirety and in the context of a number of other aspects of cognition. This report therefore considers the decision making activity in terms of problem detection, sensemaking, evaluation of competing goals, and the selection of a task.

## 1.3 What was undertaken in the research?

The research involved a detailed examination of contemporary theories on decision making. The report also builds upon work produced for the HFI DTC on Cognitive Work Analysis (CWA). Desk-based research was used to study the implication of decision making for the role of combat ID. A model of decision making for combat ID was then produced in a small table-top study involving a subject matter expert in the field of tank warfare, Lt Col Alan Ellis.

This report presents a prototypical model of decision making that is complimentary to existing NDM techniques. Based upon Rasmussen's decision-ladder, the approach provides a model of how decision making can proceed within a given domain. The report starts by exploring different types of decision making research, addressing the compatibility of the decision-ladder and the recognition-primed decision making model. Based upon the decision-ladder, an approach for capturing formative descriptions of existing decision making processes is presented. The example of land-based combat ID is used to demonstrate this approach. Two new representations are introduced to aid the understanding of these domains and to support the design of decision support tools. The first maps the links between information elements, system states and options. The second, clusters elements in the decision making process in terms of their location in the world. The approach presented is not intended to replace existing decision making analysis techniques, rather, based on similar data collection procedures, its aim is to compliment them with a more formative integrant.

## 1.4 What was discovered?

This report has illustrated the benefits of supplementing NDM approaches with a more formative element. As stated, the use of the decision-ladder has a number of benefits in considering what can happen within in environment, rather than what does, or what should happen. Thus, it provides a description beyond what actually took place at a prescribed time and location with a given actor group. The model has been specifically developed to remain generic, it is actor-independent and can easily be adapted to consider the introduction of additional technology designed to provide decision makers with additional information. The extensions presented provided a deeper understanding of the domain; furthermore, the model provides a template for exploring the potential impact of changes to technology (such as in-tank interfaces or helmet mounted displays), training support, operating procedures, and allocation of function. Thus, informing design and system optimisation decisions.

## 1.5 Main conclusions and recommendations

Whilst the model has been developed specifically for tank-on-tank warfare, it is broadly applicable to all combat ID activities, regardless of platform. Minor changes are expected throughout the model; however, this model forms a solid basis for adaptation to other domains including maritime and air. The tank-warfare model has subsequently been successfully applied to police operations on the 22nd of July 2005 in Stockwell, with only minor modifications (Jenkins et al, in preparation).

The report has identified significant overlaps in the aspirations and origins of the NDM and CWA approaches. The presented approach is intended as an addition to further inform some of the other aspects of decision making research listed by Rasmussen (1997), namely; the development of decision support tools through the modelling of knowledge-based problem solving, and the relationship between the ecology of work and the design of support systems.

In its current guise, this work originates from a theoretical standpoint supported by a small data collection activity. The approach requires further validation, particularly in support of its claims to aid the design of decision support systems. Extensions to this work, including further validation of the model, are presented in a proceeding HFI DTC report (Jenkins et al, 2008).

## 1.6 Military relevance of the work

Combat ID is always a relevant issue for the Ministry of Deference (MOD); a greater understanding of the way decisions are made is therefore of significant benefit. As combat ID technologies become readily available the design and integration of these systems becomes a significant issue. This work forms the basis for the consideration of these systems, presenting a model to consider their impact on current cognitive processes and the implications for operating procedures and training.

## 1.7 Context with other reports

There are a number of other reports conducted for the Ministry of Deference that address similar and compatible subjects.

Watson and Wright (2008) address weapons delivery in a distributed team made up of commanders on the ground, Forward Air Controllers and distributed pilots. The scope of Watson and Wright’s (2008) report is much broader than the topic of this report, covering issues including communication breakdowns and cultural factors. Watson and Wright’s (2008) report is based heavily on observation and interview, they use a series of semi-structured interviews to present a description of what happened in the past in specific naturalistic situations. Based upon collated data collected in the interviews, the approach proposes mitigating responses to known faults with the system. The report does not address the synthesis of these potential mitigating solution, nor does it address second-order effects (such as SOPs allowing aircrew and Forward Air Controllers to challenge decisions). The approach is also limited to issues with the system identified in the limited interview process.

The work of the Integrative Combat Identification Entity Relationship (INCIDER) team (Caseley et al, 2007; Dean et al, 2008) provides a mathematical encounter model of how actors are expected to behave. The model is run on a computer and uses a number of algorithms influenced by variables and random number generators. According to Dean et al (2008):

*“The encounter model process compares new information [generated by the computer program] about the unknown entity (from sensors and information sources) with a representation of preconception (based on a mixture of pre-mission briefing and gut feel). It then iteratively obtains more information by using the different sources available and by moving closer to the unknown entity. This process continues until either a decision is reached, or until a timeout condition is reached, indicating that the decision-*

*maker was unable to declare an identification decision. As with all analysis, the approach taken can only be judged by its utility to inform or its ability to be applied to areas real world concerns"*

Based upon the description provided by Dean et al (2008), it would appear as though the INCDER engagement model relies upon a normative, linear description of how the decision making task is conducted. The model appears to fail to model shortcuts taken in response to perceived threats evident from additional environmental factors. Thus, in its current guise, the simplified model proposed by the INCIDER team has limited applicability to real world problems, Dean et al (2008) identify one of these limitations as of INCIDER as is its inability to deal with many-on-many encounters. Furthermore, while this could be considered the first stage in the process of developing a larger model, the scalability of the model is far from clear-cut. The approach described by the INCIDER team is effectively independent of the environment, as Watson and Wright (2008) point out, the environment is variable from one engagement to the next, due to different rules of engagement and target types. In its current guise the INCIDER model fails to consider a number of key environmental factors that are identified in this report as having the potential to influence a decision maker's response to threat (such as the gun position, the positioning of the potential target, its physical appearance, the formation it is moving in and its location in relation to phase and boundary lines).

Whilst parallels can be drawn between the work described in this report and the work conducted by the INCIDER team, there are a number of mismatches between the approaches. The most significant of these is the conflict in opinion on the suitability of mathematical models to describe complex human behaviour. The findings of this report suggest that the number of information elements with the potential to influence a decision, combined with the variation in individual schema would make it impossible to accurately predict a decision outcome, or response time, in a naturalistic setting. The INCIDER model appears to account for this complexity by the use of an arrogated term 'belief' informed by a decision engine. Whilst the variability in the results of this decision engine could be optimised to closely match aggregate data of natural results, it fails to model idiosyncratic behaviour. Furthermore, there are clear differences in the approaches from a theoretical perspective. In terms of perception, the INCIDER model treats elements of the individual's schema (such as bias and preconception) independently of the environment, mapping them as individual variables that are set prior to the simulations. Conversely, the approach discussed in this paper is rooted by Neisser's (1976) perceptual cycle, which proposes that schema directs perception and in turn, the way in which an individual searches the environment for information. The information collected then modifies the pre-existing schema, completing the ongoing cycle. Thus, individuals are not considered to be passive receivers of information, instead they are directly coupled with their environments, searching them for information to validate their models of the system state. This report agrees with Watson and Wright's (2008) assertion that decision making is a function of the interaction between the environment, other humans in the system, and technologies.

To summarise, the differences between the three approaches can be described by their respective modelling approaches. The INCIDER team present a mathematical model of expected decision making behaviour, whilst Watson and Wright (2008) present a interview-based model of case-specific decision-making events. This report presents a model of what could happen in combat ID decision making. Thus, when placed on a continuum ranging from a theoretical model to a record of observed naturalistic behaviour, this report sits somewhere between the work of the INCIDER team and Watson and Wright. The remit of the approach described in this paper is far less ambitious, the analysis is limited to an event that starts when the decision making team is alerted to a potential target and ends when a decision is made on an appropriate action, either to dismiss the alert, evade the suspected target or engage them.

The approach described in this report is contended to be compatible with Watson and Wright's (2008) report. It is proposed that a refinement of the described model to fit the Close Air Support domain would add further structure to the findings made by Watson and Wright (2008) extending their findings to a context-specific, situation-independent model. As identified by Watson and Wright (2008), this report may also be of interest to those involved with the Fratricide Investigation and Research Environment (FIRE) Study, which addresses the use of synthetic environments to reduce incidences of fratricide.

Whilst clear theoretical differences have been identified between the approach described in this paper and the approach of the INCIDER team, it is contended that both approaches can be used to cross validate the findings of their counterpart. It is contended, that future decisions made based on the INCIDER model related to balance of investment between Situational Awareness (SA), Target Identification (TID) systems, and Tactics, Techniques and Procedures (TTPs; e.g. doctrine and training) would benefit from being considered in more formative models of cognitive behaviour, such as the one proposed in this report.

# 2 Introduction

Decision making is of fundamental importance to almost all human activities; its criticality to the safe and efficient running of complex sociotechnical systems cannot be overstated. For this reason, the topic has received significant interest from human factors researchers and practitioners, globally in all manner of fields. Within, and between these communities there has been substantial debate over the most appropriate means for conceptualising, analysing and representing decision making activity. As with many analyses, the chosen approach is heavily influenced by the context and the type of output sought. Rasmussen (1997) lists decision research as falling under four main categories:

1. Paradigms from normative models developed by Subject Matter Experts (SMEs) to teach novices rational decision strategies

2. The development of decision support tools for situations calling for knowledge-based problem solving

3. Models explaining actual behaviour (Naturalistic Decision Making (NDM; Beach, 1990; Klein, 1989, 1998)

4. Cognitive-based models of decision strategies explaining the relationship between the ecology of work, design of support systems and actual performance

Dependent on the required output, it may be desirable to focus solely on one of the aspects listed above; alternatively, there may be perceived benefit in considering two or more of these aspects in unison.

Within the cognitive ergonomics community, the third type of research in Rasmussen's list, NDM, receives much attention, accountable for dedicated NDM conferences held bi-annually, attracting researchers from around the globe. In his paper summarising NDM, Klein (2008) ascribes the major contribution of NDM as describing how people actually make decisions in real-world settings. Zsambok (1997) offers a more expansive description:

> *"The study of NDM asks 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 the larger organization in which they operate."*
> *(Zsambok, 1997 p5)*

Based upon Klein's (2008) and Zsambok's (1997) descriptions, NDM approaches can be classified as descriptive – they model what actually takes place within an environment. For this reason, the models they produce are context specific. As with the work of Watson and Wright (2008), they apply to the specific time, the location and the people that were observed. The numerous benefits of such an approach are described extensively by the NDM community (Klein et al, 1986; Klein, 2008; Zsambok, 1997; to name but a few) and are widely accepted. There are, however, limitations to such a descriptive approach when attention is turned to some of Rasmussen's (1997) other classes of decision making research; specifically the second and fourth – relating to developing knowledge-based decision support tools and capturing the relationships between ecology and sensemaking.

Cognitive Work Analysis (CWA; Rasmussen et al, 1994; Vicente, 1999) is an approach developed specifically to consider complex dynamic environments. The approach can be classified as formative as its aim is to model the work domain in terms of how activity can proceed, in an attempt to support the development of knowledge or understanding. According to Jenkins et al (2009), the complex sociotechnical systems CWA sets out to model are typically made up of numerous interacting parts, both human and non-human, operating in dynamic, ambiguous and safety critical domains. When compared against the environments NDM has been developed to study, notable overlaps can be observed. Orasanu and Connolly (1993) identified eight factors that typify decision making in naturalistic environments:

- Ill-structured problems;
- Uncertain, dynamic environments;
- Shifting, ill-defined or competing goals;
- Multiple event-feedback loops;
- Time constraints;
- High stakes;
- Multiple players; and
- Organisational norms and goals that must be balanced against the decision maker's personal choice.

In her paper, Naikar (under review) compared a tool from the CWA framework developed to model decision making, the decision-ladder, with one of the most common models applied in NDM studies, the Recognition-Primed Decision (RPD) model. Comparing their origins, Naikar (under review) found that both were motivated by observations of expert decision making in natural settings. It is therefore apparent that the similarities between these approaches, in terms of applicable domains, origins and data collection, are pronounced.

Whilst Naikar (under review) identified differences between the approaches, she summarises her paper by describing them as complementary. One of the fundamental differences she describes between the approaches relates to actor roles. Whereas the RPD model focuses on human decision making, the decision-ladder is not concerned with who carries out the activities that are required in the work domain; for example, whether the activities are carried out by humans or by automation. It is not the case that these aspects of decision making are considered unimportant within the CWA framework, rather that they are considered better dealt with in a later phase of analysis. In-line with some of the earlier discussion, Naikar (under review) also comments on the formative nature of the decision-ladder. Whereas the RPD model focuses on expert decision making in familiar situations, the decision-ladder is concerned with the various behaviours that can occur under different conditions; for instance, when experts are confronted with unfamiliar situations or when novices are engaged in performing certain tasks. Therefore, the RPD model is predominantly concerned with rule-based behaviour. In contrast, the decision-ladder has been developed to accommodate skill-, rule-, and knowledge-based behaviour. According to Schraagen et al (2008), NDM moves decision making from a “normative” description of what decisions should be made, to a descriptive model of what decisions are actually made. The contribution of the decision-ladder is on focusing on the decisions that could be made within a certain situation. It could also be argued that the INCIDER encounter model produces a normative model of what should happen based upon a number of known variables, likewise Watson and Wright’s (2008) approach falls broadly into the category of describing what decisions are actually made.

For these reasons, it is contended that an approach based upon CWA’s decision-ladder could be supplemented to NDM studies and the existing MOD research to provide a domain-specific, activity-independent, knowledge-based description of the decision making process; further it is contended that this would inform the development of decision support systems. The remainder of this report is devoted to describing such an approach.

## 2.1 Control Task Analysis (ConTA)

CWA models a range of different constraints that govern how activity can be conducted within a work domain; a complete description of these phases can be found in Jenkins et al (2009). The second phase of CWA, Control Task Analysis (ConTA), is arguably the most applicable to decision making. The phase identifies what needs to be done, within a system, independently of how or by whom. Rasmussen et al (1994) describe the ConTA phase as both, ‘activity analysis in work domain terms’ and ‘activity analysis in decision making terms’. This report will focus on the elements of the framework that model activity analysis in decision making terms.

### 2.1.1 Activity analysis in decision making terms

The decision-ladder (see Figure 1) was developed by Jens Rasmussen who observed that expert users were relying on rule-based behaviour to conduct familiar tasks. Rasmussen (1974) states that the sequence of steps between the initiating cue and the final manipulation of the system can be identified as the steps a novice must take to carry out the sub task.

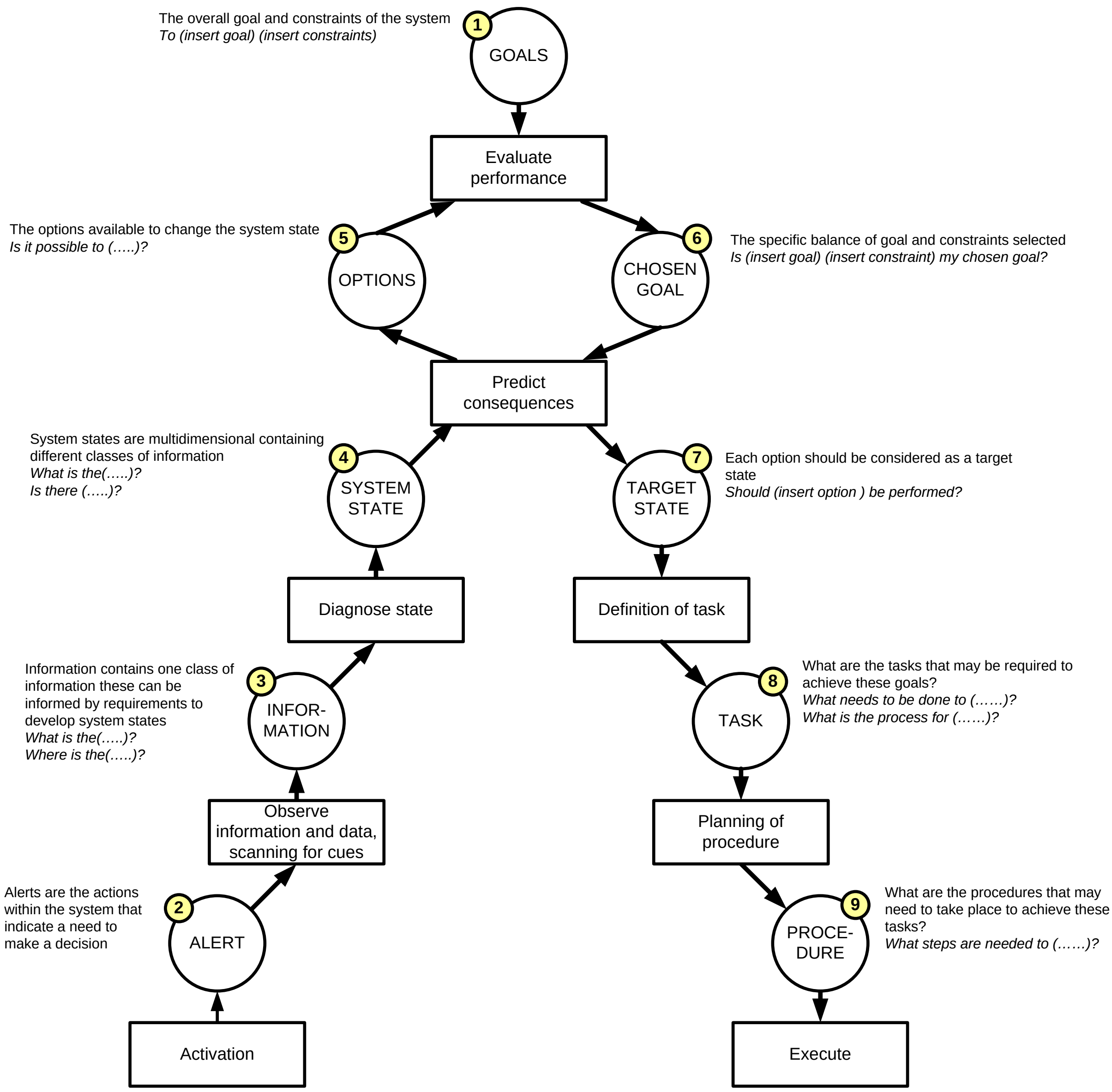


**Figure 1 - Description of decision-ladder (boxes indicate data-processing activities, circles indicate resultant states of knowledge)**

The ladder contains two different types of node: the rectangular boxes represent data-processing activities and the circles represent resultant states of knowledge. According to Vicente (1999), the decision-ladder represents a linear sequence of information processing steps, but is 'bent in-half'. Novice users (to the situation) are expected to follow the decision-ladder in a linear fashion, whereas, expert users are expected to link the two halves by shortcuts. According to Naikar & Pearce (2003), the left side of the decision-ladder represents the observation of the current system state, whereas, the right side of the decision-ladder represents the planning and execution of tasks and procedures to achieve a target system state. Sometimes observing information and diagnosing the current system state immediately signals a procedure to execute. This means that rule-based shortcuts can be shown in the centre of the ladder. On the other hand, effortful, knowledge-based goal evaluation may be required to determine the procedure to execute;

this is represented at the top of the ladder. There are two types of shortcut that can be applied to the ladder; 'shunts' connect an information-processing activity to a state of knowledge (box to circle) and 'leaps' connect two states of knowledge (circle to circle); this is where one state of knowledge can be directly related to another without any further information processing. It is not possible to link straight from a box to a box as this misses out the resultant knowledge state. Cummings & Guerlain (in review) point out that when a shortcut is taken, various information-processing actions are bypassed but the desired results are still achieved. The decision-ladder not only displays these shortcut relationships in information-processing activities, it also highlights those states of knowledge that are bypassed if a shortcut is taken. According to Cummings & Guerlain (in review), the decision-ladder maps, rather than models, the structure of a decision-making process. In the case of systems with computer-based decision support tools, the decision-ladder represents the decision process and states of knowledge that must be addressed by the system whether or not a computer or a human makes the decision.

## 2.2 The domain

Decision making research has long been of significant interest to military circles; as Fernall (2007) points out, decision making research is key to reducing errors, increasing decision quality and speed, particularly in remaining within the enemy's decision cycle. To discuss the presented approach, this report will focus on the decisions required for combat identification (combat ID) in land-based warfare. Specifically, the focus will be on tank crews attempting to identify other armoured vehicles in combat scenarios.

Combat ID is the way in which military personal distinguish friend from foe and non-combatants during operations. The UK Ministry of Defence (cited in Bourne, 2006) defines combat ID as:

> *"the process of combining situational awareness, target identification and specific tactics, techniques and procedures to increase operational effectiveness of weapon systems and reduce the incidence of casualties by friendly fire."*
> *(Bourne, 2006, p1)*

The increasing involvement of the military in coalition operations, demanding interoperability amongst forces, further exasperates the challenge of combat ID. In an attempt to expedite the combat ID process, and reduce occurrences of misidentification, a number of technologies that support combat ID have been developed that have reached maturity in recent years. Generally, these systems function by identifying known friendly units in the area, and they are currently unable to identify positively enemy targets; they can only omit a friend or an unknown response.

The example of a tank-on-tank warfare environment typifies the complex sociotechnical domains that CWA and NDM have been developed to cope with. The environment is uncertain – with adversaries deliberately trying to deceive their opponents, there are often competing goals such as neutralising threats quickly and preventing misidentification of friendly assets. Time is extremely critical – it is essential to identify and engage the enemy before they have time to identify and engage. The system also contains multiple actors both within the tank and between tanks working in high stress life and death situations. Based upon this description, this domain typifies a complex sociotechnical system as well as a NDM environment described by Orasanu and Connolly (1993).

## 2.3 Developing the prototypical model

In an attempt to better understand decision making, the decision-ladder can be used to develop prototypical models of activity. As Rasmussen et al (1994) are keen to communicate, it is important to draw the distinction between typical and prototypical work situations. People tend to describe what they find to be normal, usual ways of doing things, representing an intuitive averaging across cases – typical situations. Conversely, prototypical work situations are developed from actual data from context specific cases. This then forms a set of prototypical activity elements, defined by either the problem to solve or the situation to solve within, which, in varying combinations can serve to characterise the activity within a work system. Thus, unlike the interview technique used by Watson and Wright (2008), which focused on a series of typical situation-dependant descriptions. This approach relies on a structured interview technique to establish a formative situation-independent description.

Figure 2 shows the decision-ladder for a tank crew deciding whether to engage a potential target. The approach used to create this model is based upon descriptions by Rasmussen et al (1994). It builds heavily upon the work of Elix & Naikar (2008); however, the application is markedly different. Whereas Elix & Naikar (2008) discuss the use of the model for first-of-a-kind systems, this report discusses its application to existing systems. As a result, a bottom-up approach is taken for completing the representation as opposed to the top-down approach described by Elix & Naikar (2008).

The information was elicited from an experienced tank commander in a two-phased tabletop process. The first phase of the process was to complete the decision-ladder based upon a typical example supplied by the expert. The second phase of the process was to supplement the typical model with the additional or alternate information elements not captured in the first phase. For example, other possible alerts that could raise the tank crew’s awareness to a potential target, or additional information elements that could inform system states. Thus, converting the typical model, developed in the first phase of the process, into a prototypical one. A systematic process for the data collection is presented below. The numbers in the description of the process correlate to the steps of the decision-ladder shown in Figure 1.

1. The expert was introduced to the decision-ladder model and asked to describe his overall goal in operating the system.

2. The expert was asked to talk the analysts through the process of detecting a potential target and deciding how to respond to it. The expert was guided to start the description by indicating what first drew his attention to the potential target (the alert).

3. The expert was then asked to list the artefacts that he and his crew used to gather information.

4. The expert was asked to explain how he used these information elements to diagnose the current system state.

5. The expert then described the options available to him.

6. The expert then explained how he would balance the competing constraints on his goals.

7. Based upon the goal selected the expert then listed the target states available (his options) and selected the target state he would take.

8. This state was then broken down into a series of tasks.

9. The tasks were then broken down into procedures.

The notes were recorded and then read back to the expert. For each stage of the decision-ladder, the expert was asked to capture all other elements that would be available. This information was used to generate the prototypical model presented in Figure 2. The annotation was structured using the guidance shown in the italic comments in Figure 1.

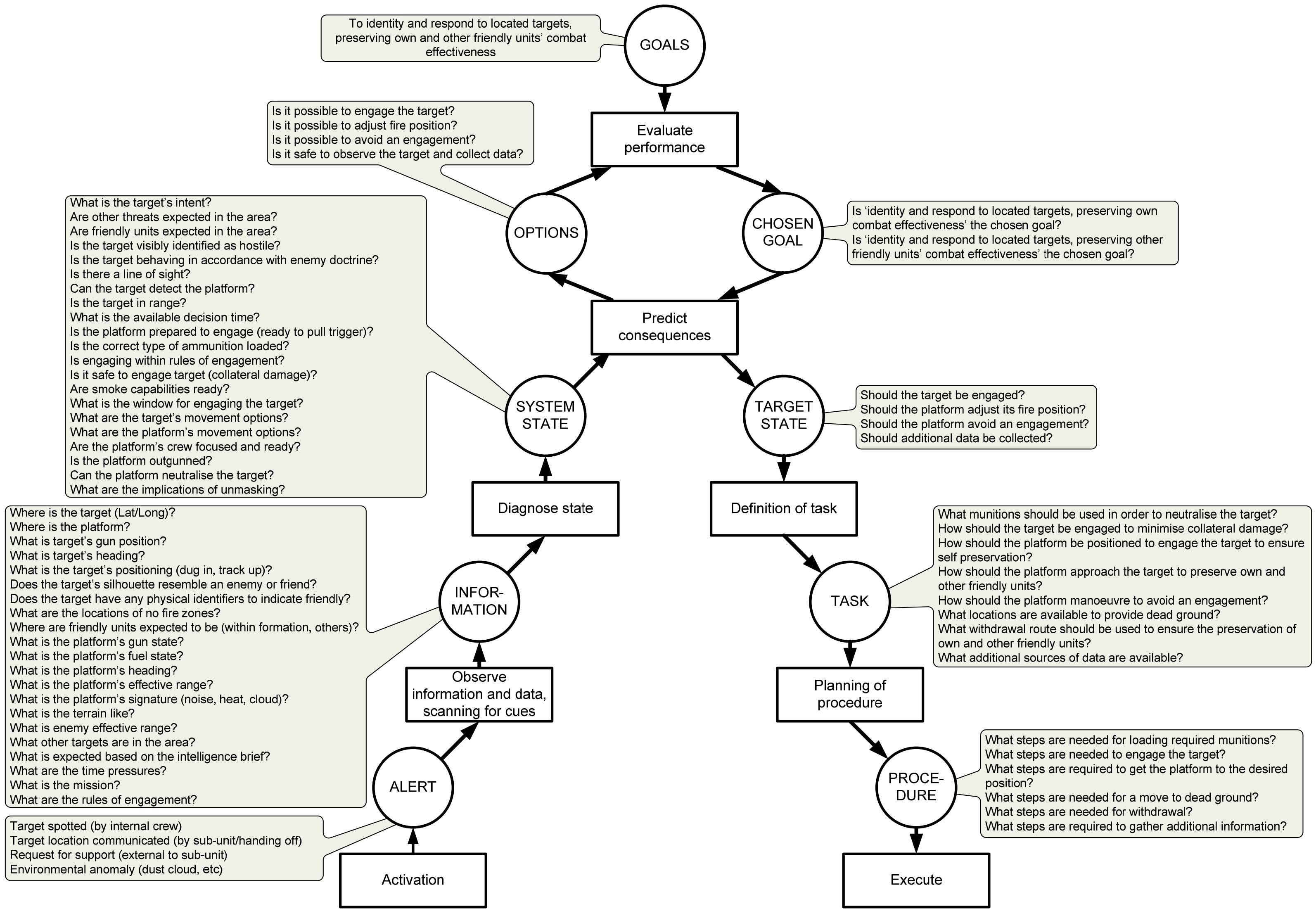


**Figure 2 - Decision-ladder for the perception of potential targets**

### 2.3.1 Stage 1 – Determining the goal

The first stage of the process was to structure the goal of the system – framing the remainder of the data collection exercise. The SME was asked to provide a high order goal along with a number of constraints affecting it; the expert was reassured that the constraints could possibly be in conflict. Based upon Elix & Naikar's (2008) guidance the information was placed in the format "To (insert goal) (insert constraints)". The goal decided upon was 'to identity and respond to located targets', and the constraints included 'preserving own combat effectiveness' as well as the 'combat effectiveness of other friendly units'. As not all detected targets are likely to be hostile, these constraints could be in conflict in certain situations, where an element of risk is placed on one part of the goal to ensure the other. Elix & Naikar (2008) found that activity was usually best characterised by having only one goal per work function. In situations where more than one goal is required, they recommended representing the analysis on multiple decision-ladders.

### 2.3.2 Stage 2 – Alert

The SME was asked to begin the walk-though at the chronological start of the process, basing the discussion on a typical encounter. In the first pass through the model the SME identified the alert as a potential target spotted by the gunner, in the second pass this was generalised to include the entire tank crew. Other possible alerts included, target location communicated (by sub-unit/handing off), request for support (external to sub-unit), and environmental anomalies (dust cloud, etc).

### 2.3.3 Stage 3 – Information

In the first pass of the process, the expert was asked to list the information elements they would use to determine the identity of the potential target. As with the alert stage, the second pass was used to validate this and to add in additional information elements that could be used in the role of identifying the potential target. Examples of information elements include the location of the target and the platform (the term used to represent the expert's tank), the target's heading and gun position, as well as information on the terrain. In situations where the expert started talking about system states, a note was made and the expert was allowed to continue undisturbed.

### 2.3.4 Stage 4 – System state

The system states represent a perceived understanding of the system based upon the interpretation of a number of information elements. For example, the potential target's intent could be informed by fusing a number of the following information elements; the target's location, heading, gun position, and positioning (dug in, track up), combined with an understanding of the terrain. Within Figure 2, these system states are represented as questions. According to Elix & Naikar (2008), the key distinction between an information element and a system state is that system states are formed of more than one quantifiably different elements of information. In short, information elements are processed and fused to form system states.

### 2.3.5 Stage 5 – Options

The options within the ladder can be described as the opportunities for changing the system state in an attempt to satisfy the overall goal. As the italics in Figure 1 show, the points are structured as questions in the form; "is it possible to (…)?" The number and type of options available will be informed by the system state. It is anticipated that in certain situations there may only be one option available to the tank crew. The options listed in Figure 2 include, engage the target, adjust fire position, avoid an engagement, and observe the target and collect data.

### 2.3.6 Stage 6 – Chosen goal

The chosen goal, at any one time, is determined by selecting which of the constraints receives the highest priority. In this case, a decision is required to determine if the goal is to preserve own or other friendly units' combat effectiveness. As Elix & Naikar (2008) make clear, this does not have to be an absolute choice per se; rather, one takes a higher priority than the other does in the given situation.

### 2.3.7 Stage 7 – Target state

The target states mirror the options available; once a particular option is selected, it becomes the target state. In Figure 2, the options are rephrased in the form 'Should (option) take place'.

### 2.3.8 Stage 8 – Task

The listed task questions relate to the tasks required for achieving the target state whilst maintaining the overall goal. For example, determining how to engage the target whilst minimising collateral damage. In this model, the tasks focus on the actions required to either evade the target, engage it, or collect additional data. If the target is recognised as being benign, no further action is required and the decision maker exits the decision making cycle.

### 2.3.9 Stage 9 – Procedure

The procedure lists questions related to the steps required to achieve each of the listed tasks. For example, determining the steps required to get the platform to the desired position.

### 2.3.10 Stage 10 – Validating the model

One way of validating the model, that was employed, is to view the previous and subsequent knowledge states, checking for a linkage between elements used at each level. For example, taking a system state and checking that all the information elements that could inform it exist. Also checking to see if the existence of this system state would provide any additional options.

Whilst the model was generated and validated in a linear process, it is also important to clarify that actors are not expected to move through the decision ladder model in a linear fashion. The available information will strongly influence the path through the ladder and the decision making process that it represents. In certain situations, decision makers are expected to move from an information element such as the appearance of a target, that is clearly identifiable as enemy, to an action to engage. Likewise, if the target is unambiguously identifiable as a friendly unit, the decision maker is likely to exit the decision making process.

# 3 Applications of the model

Elix & Naikar (2008) comment that the decision-ladder approach can be used to design interfaces, crew concepts, training programs, and workspace layouts for future systems that are well tailored to their work demands; however, they are not explicit about how this can be done. This report now turns its attention to providing a description of how the generated prototypical model can be used to inform an understanding of the relationship between the elements in Figure 2, and ultimately the design of decision support systems.

As stated in the introduction, a number of devices have been considered to supplement the process of combat ID within this environment. Fernall (2007) discusses the use of decision support tools (training, software), and how they have been met with limited success. The design of these systems, and the way information is presented to the users, will undoubtedly have a marked effect on human and, in turn, system performance. The task of combat ID involves detecting changes in the environment that mean that action is required of the decision maker; the decision maker is then required to seek information that will allow them to diagnose the current system state. Based upon this perceived system state, the decision maker then evaluates their options, considers their goals and selects a desirable target state. Thus the pertinent information depends on the alert, and the available information elements. Rasmussen et al (1994, p129) highlight the fact that, without a satisfactory understanding of the decision making process, system designers overestimate the amount of information required for action by a specialist who is immersed in the context. Rasmussen et al (1994) also comment that system designers under-estimate the complexity of meaningful displays that are acceptable to such experts actively seeking cues for action.

It is contended that the way information should be displayed to actors can be informed by two key concepts, (1) the relationship between information objects and the system states and, in turn, (2) the way these objects are clustered. As previously stated, the structure that the information is presented in is of fundamental importance; humans are not passive receivers of information. They seek context specific data for diagnosis of the system states, seeking data to confirm or reject models of the current system state in an attempt to reduce the cognitive load and speed up decision time (see Neisser's perceptual cycle model; 1976). By presenting data in a structured format, access to relevant data can be increased. According to Rasmussen et al (1994):

> *"Decision makers can often be overloaded by the presentation of separate data, whereas complexity in itself need not be a problem, provided that meaningful information is presented in a coherent, structured way. Such users are not passively receptive to information input; instead, they actively ask questions of the environment, based on their perception of the context." (Rasmussen et al 1994, 129)*

### 3.1.1 Recording the relationship between information objects and system states

The relationship between information elements and system states is not captured within the decision-ladder model presented in Figure 2; instead, a list of possible information elements and system states is presented. In order to develop a greater understanding of the decision making process, there is much perceived benefit in explicitly linking information objects to system states to identify which information elements can inform which system states. Figure 3 uses a matrix representation to show such a relationship. The system states are listed down the page, to the right the information objects are listed, and to the left the options. The black cells indicate a relationship. Returning to the previous example of informing an understanding of the target's intent, the top line of Figure 3 captures the related information elements; the location, gun position, heading, and positioning (dug in, track up), combined with an understanding of the terrain. An important distinction to make is that Figure 3 is constraint-based; it indicates the elements that *could*, rather than *do* or *should* inform the decision about the system state. Actors are not expected to seek all of these information elements in all situations. The example system state just given is informed by elements existing in the external environment. Other system states, such as 'is the target behaving in accordance with enemy doctrine' can also be informed by other types of information elements. This system state can use the same information elements as the previous example combined with information on the location of other targets (informing formation) as well as information contained in the intelligence brief. The captured relationships between information elements, system states and options remain static independent of specific situation. They therefore have the potential to support knowledge-based reasoning about the environment. These relationships could form the basis of information structure in an interface for a decision support aid. By recording the relationships between these elements, it may also be possible to develop training aids to assist novices in developing accurate system states from a mixture of information elements.

### 3.1.2 Clustering elements within the system

In the tank-warfare environment the decision-maker's data collection opportunities are not limited to what can be observed by the naked eye. The locations of the decision making elements are listed in Figure 4; they are classified as, in the external environment, in the internal environment (inside the tank) or in documentation (such as intelligence briefs, orders, rules of engagement). The recording of this information has implications for the design of the tank system. It provides critical information about the requirements for crewmembers to be observing information elements inside and outside of the tank. Based upon this understanding, decisions can be informed relating to, the allocation of function between the crewmembers, the design of displays within the tank, and the design of helmet mounted displays for units surveying the external environment. It also has the potential to inform operating procedures that encourage commanders to seek additional information from their crew that they do not have direct access to. New systems fitted to tanks frequently display a lot of external environmental information on an internal display screen. With the majority of the required information displayed upon the screen, decision makers may spend relatively less of their time surveying the external environment. If key information elements are missing from the display this may have a negative impact on the decision makers' ability to diagnose a system state and in turn, select an appropriate action. Therefore, the introduction of a system that changes the way a decision maker gathers information on a situation needs to be carefully considered. This issue is not specific to tank warfare, rather it applies to all aspects of combat ID.

## 3.2 Potential applications in other MOD projects

The approach described in this report is contended to be compatible with Watson and Wright's (2008) report addressing weapons delivery in a distributed team made up of commanders on the ground, Forward Air Controllers and distributed pilots. It is proposed that a refinement of the described model to fit the Close Air Support domain would add further structure to the findings made by Watson and Wright (2008), extending their findings to a context-specific, situation-independent model. As identified by Watson and Wright (2008), this report may also be of interest to those involved with the Fratricide Investigation and Research Environment (FIRE) Study which addresses the use of synthetic environments to reduce incidences of fratricide.

Whilst clear theoretical differences (such as the use of mathematical model to describe complex human behaviour) have been identified between the approach described in this paper and the approach of the INCIDER team, it is contended that both approaches can be used to cross validate the findings of their counterpart. It is contended, that future decisions made based on the INCIDER model related to balance of investment between Situational Awareness (SA), Target Identification (TID) systems, and Tactics, Techniques and Procedures (TTPs; e.g. doctrine and training) would benefit from being considered in more formative models of cognitive behaviour, such as the one proposed in this report.

**Options**

| System States | Is it possible to engage the target? | Is it possible to adjust fire position? | Is it possible to avoid an engagement? | Is it safe to observe the target and collect data? |
|---|---|---|---|---|
| What is the target's intent? | | | ■ | ■ |
| Are other threats expected in the area? | | | ■ | ■ |
| Are friendly units expected in the area? | | | | ■ |
| Is the target visibly identified as hostile? | | | | |
| Is the target behaving in accordance with enemy doctrine? | | | | |
| Is there a line of sight? | ■ | ■ | ■ | ■ |
| Can the target detect the platform? | | | ■ | ■ |
| Is the target in range? | ■ | ■ | | ■ |
| What is the available decision time? | | ■ | ■ | ■ |
| Is the platform prepared to engage (ready to pull trigger)? | ■ | | | |
| Is the correct type of ammunition loaded? | ■ | | | |
| Is engaging within rules of engagement? | ■ | | | |
| Is it safe to engage target (collateral damage)? | | | | |
| Are smoke capabilities ready? | | | ■ | |
| What is the window for engaging the target? | | ■ | | ■ |
| What are the target's movement options? | | ■ | ■ | ■ |
| What are the platform's movement options? | | ■ | ■ | |
| Are the platform's crew focused and ready? | ■ | ■ | ■ | |
| Is the platform outgunned? | | | | ■ |
| Can the platform neutralise the target? | ■ | | | |
| What are the implications of unmasking? | ■ | ■ | | |

**Information**

| System States | Where is the target (Lat/Long)? | Where is the platform? | What is target's gun position? | What is target's heading? | What is the target's positioning (dug in, track up)? | Does the target's silhouette resemble an enemy or friend? | Does the target have any physical identifiers to indicate friendly? | What are the locations of no fire zones? | Where are friendly units expected to be (within formation, others)? | What is the platform's gun state? | What is the platform's fuel state? | What is the platform's heading? | What is the platform's effective range? | What is the platform's signature (noise, heat, cloud)? | What is the terrain like? | What is enemy effective range? | What other targets are in the area? | What is expected based on the intelligence brief? | What are the time pressures? | What is the mission? | What are the rules of engagement? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| What is the target's intent? | ■ | | ■ | ■ | ■ | | | | | | | | | | ■ | | | | | | |
| Are other threats expected in the area? | | | | | | | | ■ | | | | | | | | | | ■ | | ■ | |
| Are friendly units expected in the area? | | | | | | | | ■ | ■ | | | | | | | | | ■ | | ■ | |
| Is the target visibly identified as hostile? | | | | | | ■ | ■ | | | | | | | | | | | | | | |
| Is the target behaving in accordance with enemy doctrine? | ■ | | ■ | ■ | ■ | | | | | | | | | | ■ | | ■ | ■ | | | |
| Is there a line of sight? | ■ | ■ | | | ■ | | | | | | | | | | ■ | | | | | | |
| Can the target detect the platform? | ■ | ■ | ■ | | ■ | | | | | | | | | ■ | ■ | | | | | | |
| Is the target in range? | ■ | ■ | | | ■ | | | | | | | | ■ | | ■ | | | | | | |
| What is the available decision time? | ■ | ■ | ■ | ■ | ■ | | | ■ | | ■ | | ■ | ■ | | ■ | ■ | ■ | | ■ | ■ | ■ |
| Is the platform prepared to engage (ready to pull trigger)? | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| Is the correct type of ammunition loaded? | ■ | ■ | | | | | | | ■ | ■ | | | ■ | | ■ | | ■ | ■ | | ■ | ■ |
| Is engaging within rules of engagement? | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | ■ | | | | | | ■ |
| Is it safe to engage target (collateral damage)? | ■ | ■ | | ■ | ■ | | | ■ | | ■ | | | ■ | | ■ | | | ■ | ■ | ■ | ■ |
| Are smoke capabilities ready? | | | | | | | | | | | | | | | | | | | | | |
| What is the window for engaging the target? | ■ | ■ | | ■ | ■ | | | ■ | | ■ | ■ | ■ | | | ■ | | | | ■ | ■ | ■ |
| What are the target's movement options? | ■ | ■ | ■ | ■ | ■ | | | | ■ | | | ■ | | | ■ | ■ | ■ | | | | |
| What are the platform's movement options? | ■ | ■ | ■ | ■ | ■ | | | | ■ | | ■ | ■ | ■ | | ■ | ■ | ■ | | ■ | ■ | |
| Are the platform's crew focused and ready? | | | | | | | | | | | | | | | | | | | | | |
| Is the platform outgunned? | ■ | ■ | | | | | | ■ | | | | | ■ | | | ■ | ■ | | | | |
| Can the platform neutralise the target? | ■ | ■ | | ■ | ■ | | | ■ | | ■ | ■ | | ■ | ■ | ■ | | | | | ■ | ■ |
| What are the implications of unmasking? | ■ | ■ | ■ | ■ | ■ | | | | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |

**Figure 3 - Relationships between system states, information and options (black cells indicate a relationship)**

| | | In the world | | |
|---|---|---|---|---|
| | | External environment | Internal environment | Documentation |
| Alert | Target spotted (by internal crew) | x | x | |
| | Target location communicated (by sub-unit/handing off) | | x | |
| | Request for support (external to sub-unit) | | x | |
| | Environmental anomaly (dust cloud, etc) | x | | |
| Information | Where is the target (Lat/Long)? | x | x | x |
| | Where is the platform? | x | x | |
| | What is target's gun position? | x | | |
| | What is target's heading? | x | | |
| | What is the target's positioning (dug in, track up)? | x | | |
| | Does the target's silhouette resemble an enemy or friend? | x | | |
| | Does the target have any physical identifiers to indicate friendly? | x | x | |
| | What are the locations of no fire zones? | | | x |
| | Where are friendly units expected to be (within formation, others)? | | | x |
| | What is the platform's gun state? | | x | |
| | What is the platform's fuel state? | | x | |
| | What is the platform's heading? | x | x | |
| | What is the platform's effective range? | | | x |
| | What is the platform's signature (noise, heat, cloud)? | x | | x |
| | What is the terrain like? | x | | |
| | What is enemy effective range? | | | x |
| | What other targets are in the area? | x | | x |
| | What is expected based on the intelligence brief? | | | x |
| | What are the time pressures? | | x | x |
| | What is the mission? | | | x |
| | What are the rules of engagement? | | | x |
| System State | What is the target's intent? | x | | x |
| | Are other threats expected in the area? | | | x |
| | Are friendly units expected in the area? | | | x |
| | Is the target visibly identified as hostile? | x | | x |
| | Is the target behaving in accordance with enemy doctrine? | x | | x |
| | Is there a line of sight? | x | | |
| | Can the target detect the platform? | x | | x |
| | Is the target in range? | | x | x |
| | What is the available decision time? | | | x |
| | Is the platform prepared to engage (ready to pull trigger)? | | x | |
| | Is the correct type of ammunition loaded? | | x | |
| | Is engaging within rules of engagement? | | | x |
| | Is it safe to engage target (collateral damage)? | x | | x |
| | Are smoke capabilities ready? | | x | |
| | What is the window for engaging the target? | | | |
| | What are the target's movement options? | x | | |
| | What are the platform's movement options? | x | | |
| | Are the platform's crew focused and ready? | | x | |
| | Is the platform outgunned? | x | | x |
| | Can the platform neutralise the target? | | | x |
| | What are the implications of unmasking? | x | | x |

**Figure 4 - Location of elements in the world**

# 4 Conclusions

This report has discussed the benefit of extending NDM studies beyond the description of what actually took place at a prescribed time and location with a given actor group. The benefits of supplementing this approach with a more formative approach based on CWA have been presented. To illustrate this process, the example of land-based combat ID is discussed and presented using a model of tank warfare. Elix and Naikar's (2008) first-of-a-kind model has been modified to form the basis of the data collection. This approach has then been extended, introducing new representations to capture explicitly the relationships between information elements, system states and options. Further data is also captured by classifying the elements in terms of their location within the environment. The potential benefits of this extension to the approach are described in terms of their contribution to the design of in-tank interfaces, helmet mounted displays, training support, the development of operating procedures and decisions relating to the allocation of function.

Whilst the model has been developed specifically for tank-on-tank warfare, it is broadly applicable to all combat ID activities regardless of platform. Regardless of the vehicles concerned, the core activity of identifying another object in an environment remains constant. Minor changes are expected throughout the model; however, this model forms a solid basis for adaptation to other domains including maritime and air. The tank-warfare model has subsequently been successfully applied to police operations on the 22$^{nd}$ of July 2005 in Stockwell, with only minor modifications (Jenkins et al, in preparation).

The described approach is not intended to challenge more established NDM techniques, or existing approaches being applied elsewhere for the MOD (such as Watson and Wright, 2008; or the INIDER team); rather, it is presented as a compatible approach to compliment them. As the introduction has shown, there are significant overlaps in the aspirations and origins these approaches. The presented approach is intended as an addition to further inform some of the other aspects of decision making research listed by Rasmussen (1997), namely; the development of decision support tools through the modelling of knowledge-based problem solving, and the relationship between the ecology of work and the design of support systems.

In its current guise, this work originates from a theoretical standpoint supported by a small data collection activity. The approach requires further validation, particularly in support of its claims to aid the design of decision support systems. Extensions to this work, including further validation of the model, are presented in a proceeding HFI DTC report (Jenkins et al, 2008).

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