Using the decision-ladder to add a formative element to naturalistic decision-making research

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ABSTRACT

Motivation – To develop a model of how decision-making can proceed within an environment, independent of situation or actor. Research approach – Based upon the decision-ladder, an approach for capturing an event and actor independent model of decision-making is presented. The example of land-based combat identification is presented. Findings/Design – Two new representations are introduced to aid domains understanding and 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 based upon their location in the world. Research limitations/Implications – Applicable to decision-making in complex sociotechnical systems. Originality/Value – The approach presented is not intended to replace existing decision-making analysis techniques, rather, based on similar data collection procedures, its aim is to complement them with a more formative integrant. Take away message – The understanding of decision-making can be enhanced by also considering decision-making independently from actor and context.

Keywords
Decision-making; Decision-ladder; Activity analysis; Constraints; Formative; Cognitive work analysis

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 context and the type of output heavily influence the chosen approach 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
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, alternately, 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. 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; specifically the second and fourth – relating to developing knowledge-based decision support tools and capturing the relationship between ecology and sensemaking.

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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 (in press), 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 payers; and
- Organisational norms and goals that must be balanced against the decision makers 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 decision are actually made. The contribution of the decision ladder is on focusing on the decisions that could be made within a certain situation.

For these reasons, it is contended that an approach based upon CWA’s decision-ladder can be supplemented to NDM studies to provide a less context-specific, knowledge-based description of the decision-making process; further it is contended that this informs the development of decision support systems. The remainder of this paper is devoted to describing such an approach.

**Control task analysis (ConTA)**

The second phase of CWA, Control Task Analysis (ConTA), 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 paper will focus on the elements of the framework that model activity analysis in decision-making terms.

**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.

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 in 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.
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The overall goal and constraints of the system
To (insert goal) (insert constraint) ?

The specific tasks of goal and constraint are selected
To (insert goal) (insert constraint) my chosen goal ?

Evaluate performance

The options available to change the system state is it possible to (….)?

System states are multidimensional containing different classes of information
What is the (…)?
Is there (…)?

Information contains one class of information these can be informed by requirements to develop system states
What is the (…)?
Where is the (…)?

Alerts are the actions within the system that indicate a need to make a decision

Figure 1 – Description of decision-ladder

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 paper will focus on the decisions required for combat identification (combat ID) in land-based warfare. Specifically, the focus will be on tank crews identifying other armoured vehicles in combat scenarios.

Combat identification 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 for interoperability amongst forces, further accentuates the challenge of combat ID.

The example of 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).

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) is 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.

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 paper discusses its application to existing systems; be it identical or similar. 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 stage 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 tanks 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 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 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 shown in Figure 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 a target’ (the alert). Constraints could be in conflict as well as the ‘combat effectiveness of other friendly units’. These constraints could be in conflict in certain situations, where an element of risk is paced 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.

**Stage 2 – Alert**
The SME was asked to begin the walk-through 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 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/handling off), request for support (external to sub-unit), and environmental anomalies (dust cloud, etc).

**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 target identification. Examples of information elements include the location of the target and the platform (the term used to represent the experts tank), the targets 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.

**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 targets intent could be informed by fusing a number of the following information elements; the target’s location, heading, gun position, 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.

**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.
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.

Stage 7 – Target state
The target states mirror the option 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’.

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.

Stage 9 – Procedure
The procedure lists questions related to the steps required to achieving each of the listed tasks. For example, determining the steps required to get the platform to the desired position.

Validating the model
One way of internally validating the model 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.

The model was also externally validated with a further eight experienced tank commanders, seven of whom had recently returned from large-scale exercises in Canada.

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 paper 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 identification 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. Rasmussen et al (1994, p129) highlights 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. 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)
Figure 2 – Decision-ladder for target perception

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 targets intent, the top line of Figure 3 captures the related information elements; the location, gun position, heading, positioning (dig 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 contain 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.

Clustering elements within the system

As previously eluded to, the elements in the decision-ladder can be further categorised by their location within the environment. The location 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.
Figure 3 – Relationships between system states, information and options (black cells indicate a relationship)

<table>
<thead>
<tr>
<th>System States</th>
<th>Information</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>System States</td>
<td>Information</td>
<td>Options</td>
</tr>
<tr>
<td>System States</td>
<td>Information</td>
<td>Options</td>
</tr>
</tbody>
</table>

Figure 4 – Location of elements in the world
CONCLUSIONS

This paper 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. Classifying the elements in terms of their location within the environment also captures further data. 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.

The described approach is not intended to challenge more established NDM techniques; rather, it is presented as a compatible approach to compliment NDM. As the introduction has shown, there are 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.

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REFERENCES


Naikar, N., (under review) A comparison of the decision-ladder template and the recognition-primed decision model.


