Applying Cognitive System Engineering to Cope with Complexity in Enterprises

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Abstract

Enterprises, commercial or even a military force, exist in a complex world. They have to continuously serve the purpose they are designed for, and to grow as opportunities arise. The operations of the enterprise are always constrained by available resources, governing regulations and the operations of competing enterprises. This leads to “wicked” and “messy” problems facing the enterprise. The enterprise has to detect and analyse changes, which place a risk on fulfilling the enterprise’s purpose, in the environment and inside the enterprise itself.

The enterprise therefore requires a management system, similar to a military Command and Control (C2) system, to monitor the status of the enterprise as well as the environment. The ability of an enterprise to exploit available information is crucial, despite the continuous increasing complexity. The management system has to assist the managers, or commanders, of the enterprise with sense making and decision making on the most suitable course of action.

Humans have the cognitive ability to develop creative solutions as required within the complex environment. The Human Machine Interfaces (HMI) between the humans and the enterprise Command and Control system must be geared to support and enhance the human capabilities. This HMI has to be developed to operate within complex environmental constraints while supporting complex social interaction and the cognitive strategies and competencies of the complex human decision makers. Cognitive System Engineering (Cognitive SE) has been applied successfully in the military and emergency response environment. Additional complexity assessment frameworks, such as Cynefin from Snowden and Kurz (2003), can be incorporated for making sense of the complex environment. These methods may also be applicable to other enterprises.

1 Introduction

The demands on Systems Engineering (SE) to produce systems capable of effective operation within complex environments are increasing. Due to complexity, the system requirements tend to be vague, fluid and conflicting. As a result no single solution to the problem exists and the current set of parameters may not be valid in a future context. The result of communications technology is increased interconnectivity between different systems. More data is available than ever before. However, it increases the complexity facing managers and commanders in performing their tasks. The ability to adapt to changing environments and handling of complex situations needs to be designed into the system. This paper will focus on the development of sense making and decision support systems within an enterprise, such as military command and control, where social, cognitive and other environmental factors result in an increase in complexity.

The sense making and decision making process require information on the operational environment. Within an enterprise this is available through an information or knowledge management system. The humans interface with this system through information or situation displays for interpretation and sense making. An effective interface or information display is crucial for successful sense making and decision making. One methodology to develop such an interface as well as the supporting knowledge management system is Cognitive SE.

SE techniques and process are often not applied with an appreciation of the human element operating with a complex environment. Up to now there has been a motivation for increased automation to negate variability in the system and the possibility of human error. The limitation is that all possible scenarios have to be identified during design of the system. As mentioned before, this is all but impossible for systems operating in complex environments. More often than not, the human operator is the most adaptable part of the system. Humans are more capable than machines to cope with unforeseen circumstances, provided they have the experience and information available to support sense making. Cognitive SE is an addition to system engineering to help and identify the cognitive and social requirements for the system from an ecological point of view. Militello et al. (2009) lists successes in landmine detection, global weather management in the US Air Force Air Mobility Command and emergency operations facilities. The failures of not applying Cognitive SE are numerous; they include the following famous incidents (Militello et al. 2009, Mcilroy 2011):

a) Partial core meltdown of the Three-Mile Island power plant in 1979.
b) The 1988 accidental shoot down of an Iranian Airbus by the USS Vincennes.
c) The 1994 friendly fire incident where two F-15 fighter aircraft shot down two Blackhawk helicopters in northern Iraq.

One approach to Cognitive SE is to apply the Cognitive Work Analysis (CWA) framework (Vicente 1999). It assesses the high level or strategic objective (purpose) and constraints of the system as well as the cognitive strategies and competencies employed in sense making and decision making. The output of the process is requirements for an ecological HMI, defining the information display and data distribution requirements. By designing the human operator, with his ability to use intuition and to detect complex patterns, into the total system will enable it to adapt and evolve along with the changes in the environment. Successes from the application of CWA lists from Militello (2009) are:

a) Global weather management.
b) Landmine detection.
c) Redesign of emergency operations facility.

This paper is in support of post graduate studies on the development of a HMI to assist commanders with sense making and decision making within a complex operating environment while performing Command and Control. The studies follow the approach of Design Science Research (March & Smith, 1995). This paper forms part of the “Awareness of Problem” and “Suggestion” phases of the research process. These steps are executed in the form of an exploratory research supported by a literature review. The remaining steps of “Development”, “Evaluation” and “Conclusion” will follow at a later stage.

This paper will first discuss the enterprise as a sociotechnical system to highlight the importance of considering people, processes and technical elements together in analysis of situation assessment requirements. This is supported in the next section by defining and explaining the complexities with an enterprise which leads to “Wicked and Messy” problems. Before presenting the Cognitive SE methodology, the theory supporting situation awareness, sense making and decision making is used to highlight the cognitive requirements of an HMI. Finally, a generic approach to CWA is presented that will result in requirements for an interface that is aligned with the ecological constraints of the environment as well as the human cognitive and social aspects.

2 The Enterprise

Swarz and DeRosa (2006) defines an enterprise as assembly of systems, consisting of people, processes and technology, with vague boundaries supporting operational capabilities. The Enterprise can be described as a socio-technical system, as seen in Figure 1, and may be an intentionally created entity to achieve a certain purpose (Alberts, 2011). The purpose of the enterprise may be to govern, serve, influence or create wealth.

When considering military command and control along with Alberts (2006, 2009, 2010), it is clear that command and control falls within the broad definition of an enterprise. Despite being a human activity, C2 is executed within a system, that consist of equipment and people (commanders and subordinates) and their processes organised to execute a task (Brehmer, 2010). The operations of the enterprise are always constrained by available resources, governing regulations and the operations of competing enterprises.

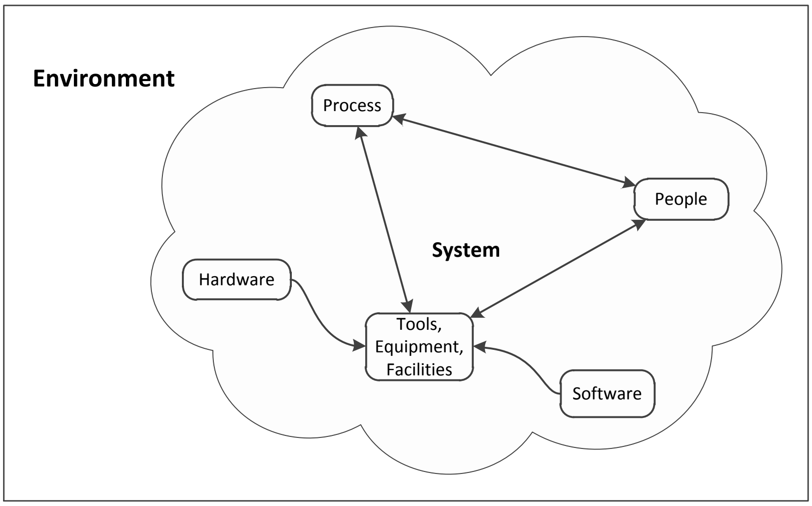

Figure 1: A Socio-Technical System

Enterprises are often open systems, being sensitive to influences from the environment or other enterprise systems. Many non-linear and intricate interactions between all the elements within and outside the enterprise cause complex behaviour. This result is emergence that causes the enterprise to evolve over time. DeRosa (2007) highlights that complexity within the enterprise guides effectiveness while order and structure provides efficiency. The aim is to find the balance between complexity and order. Even if the emergent behaviour is not predictable, some degree of control is still required. As a result the enterprise is faced with “wicked” and “messy” problems while striving to deliver value to its stakeholders. This continues in spite of changes in the environment, technology applied as well as the scope and characteristics of the users. It requires changes implemented through decisions at different operating levels, such as strategic, operational or tactical levels. These decisions have to be supported through a situation assessment of the environment and other contributing factors and sense making process.

According to the work of Sterman (2004), the process of decision making within an environment with inherent risks and delays result in a complex dynamic system which requires a structured approach with modelling and management. The design of the enterprise must support the gathering and assimilation of data to build information and enable learning on its functioning and the environment. This is to be supported with tools for sense making and decision making in a complex environment. Development of these tools starts with an assessment of the organisation and integration of work processes (Lintern, 2006). It must support effective human-human, human-machine and machine-machine communication. Humans still perform the decision making in enterprises; the machine supports the manipulation, distribution and presentation of data and information. Quality interface designs assist the human decision makers to make sense of the complex environment inside and outside the enterprise. This needs to be supported through governance structures and support of the systems.

According to Lintern (2008), a Cognitive System performs cognitive work such as perceiving, assessing, understanding, problem solving, decision making, planning and acting. Therefore, a Complex Sociotechnical System is a Cognitive System. At its core, a cognitive system will require of sensing, storing and management of information required for cognitive function. The interfaces between decision makers and the available information is one of the critical aspects requiring a careful design.

Depending on size and complexity, an enterprise is managed using computerised systems to gather information on the state of the system for situation awareness. The enterprise control system supports the detection, planning and implementation of changes to guide future behaviour of the enterprise. The critical aspect is to make sense on the current and possible future states of the enterprise within the complex environment. Thereafter, the control system supports decision making on appropriate or corrective actions to take to ensure short term and long term success. This makes the implementation of an interface between the enterprise control system and the human decision makers critical. The design of this interface requires an in depth understanding of the complexity facing the enterprise, as discussed below.

3 Complexity

In this section we provide a definition of complexity to support the understanding of the challenges facing sense making and decision making. Complexity and the resulting emergence are defined to support the discussion on “wicked and messy” problems. This is expanded into a discussion on the characteristics complex systems to support the assessment of socio-technical systems.

3.1 Definition of Complexity

Complexity as a concept has been with us for a long time, but it only since the development of computer systems and cybernetics that it has reached prominence (Pagels, 1988). It has also dramatically increased over the past three decades as technology allows for more and more information to be exchanged between elements inside and outside of systems.

The Merrian-Webster dictionary defines the word “Complex” as “a whole made up of complicated or interrelated parts”. Gell-Mann (1995) traces the definition back to the Latin word “Plexus” meaning braided or entwined. Therefore, “Complexus” means braided or entwined together. From this, we derive that “Complexity” refers to a number of elements or effects from the environment and a system that are intricately intertwined with a high level of interconnectivity. As a result, a complex system or problem cannot be decomposed in smaller, less complex, elements for piecewise problem solving. Complex issues have to be addressed as a whole as well as being decomposed.

Where humans are involved in the system, the term “connectivity” includes the effects of a decision or action by one actor influencing the behaviour of another human or the technical system. Due to complexity, the impact result of the action may not always be the consistent and is dependent on the state of the system and the environment. This implies that the context of information, decisions and actions plays a major role in the outcome.

3.2 Emergence

A major characteristic of complex systems is emergence. One of the earliest definitions of emergence is from Aristotle (Stepney, 2006), who stated that things which have several parts and in which the totality is not, as it were, a mere heap, but the whole is something beside the parts”. This is nowadays phrased as “Whole is more than the sum of its parts.” Fromm (2006) defines emergence as the distinction between the properties of the low level components and the global or high level patterns visible to the observer. A complex system has emergent properties if it consistently presents characteristics in a macro-state that is not present in the microstate. The emergent behaviour of a system cannot be predicted from looking at individual elements in isolation. This may even lead to novel behaviour of the system, which may be a surprise to the observers of the system. The observed high level novel behaviour is a result of the nonlinear interactions between the elements and/or the environment. The advantages and disadvantages of systems that are embracing emergence instead of ignoring or fighting it, as the following (Fromm, 2006):

a) Advantages and Positive Properties. Robustness, adaptiveness, fault-tolerance, scalability, concurrency, adaptability, flexibility, low brittleness.

b) Negative Properties and Drawbacks. Low predictability and understand-ability, controlling (emergent) behaviour is difficult, engineering design is hard, accidents and errors possible, restricted reliability for computational purposes.

3.3 Wicked and Messy Problems

Commanders of military operations, as well as managers of enterprises, are faced with complexity, uncertainty and novelty in everyday situations (Schmitt, 2006). They are required to solve “wicked” problems within the environment caused by complex operational situations that have moral implications. This is compounded by the social and cognitive aspects of the interacting humans. In order to solve these problems, any approach should be in line with and supported by human cognitive processes. The following reduced list of wicked problem characteristics from Rittel (1973) highlights the effect on problem solving and the resultant planning:

a) The problem does not have a definitive formulation and it is impossible to list all the possible solutions.

b) Wicked problems have no stopping rule as there are no criteria to indicate that the solution is found and successfully implemented.

c) The solution may not be a simple “true-or-false”, but rather a “good-or-bad” as many different judgements may exist.

d) There is no immediate and no ultimate test of a solution to a wicked problem as it may affect waves of consequences over a very long time.

e) It is not possible to learn about the problem by trial and error, resulting in a “one-shot operation” as every attempted solution changes the problem. There will be no second chance to fix an ineffective solution.

f) Every wicked problem is unique as it will always be possible to identify a distinguishing property.

g) Every wicked problem may be a consequence or symptom of another problem.

3.4 Complex Systems

A Complex System consists of a number of interconnected nonlinear elements that causes unpredictable behaviours. As a result a Complex System cannot readily be decomposed into independent and manageable elements for analysis. This is differentiated from the word complicated, meaning that the system contains many, yet linear and predictable elements. An abbreviated list of characteristics for complex systems as being applicable to decision support in command and control or any other enterprise is (Alberts & Nissen 2009, Cilliers 2004, Fromm 2006, Gleizes et al 2008, Sheard & Mostashari 2009,):

a) Complex Systems display emergent behaviour as a result of the actions of and interaction between individual agents as well as with a dynamic environment.

b) The behaviour of the system may be non-deterministic despite an apparent order and may even exhibit chaotic behaviour under certain conditions as a result of nonlinear dynamics.

c) Complex systems have unexpected and unpredicted internal interactions where changes in one element will influence the behaviour of others. The participants may not understand the cause and effect relationships of the networked interaction. The result is an inability to predict the likely effects as a result of alternative courses of action.

d) Complex systems are seldom developed as a whole; they tend to be formed through a process of integration an evolution. The different elements may be in different stages of a system life cycle and developed using different standards.

e) Complex systems have a significant human and social dimension that contributes to complex behaviour and the evolution of the system as a whole.

f) Knowledge and control is distributed in the complex system and also exist at different operational layers of elements or subsystems.

g) The Complex System has a micro- and macroscopic memory. What happened in the past is to a degree responsible for the current behaviour.

h) The Complex System has a high diversity of the participants. Multiple and interdependent chains of command exist. Also, the objectives of the participants may not be aligned. The participants' Situation Awareness" on the same information differs.

SE use models are used to understand a system and/or its operating environment. The implication of complexity is that it is impossible to build a model that accurately and fully describes the Complex System, as it has to be as large and as complex as the actual system (Cilliers 2004). The model has to include each and every interaction between the system elements. As a result it is all but impossible to predict the behaviour of a system accurately. However, modelling, complexity science and thinking does add value through learning by applying the process as well as the supporting culture. A suitable mental model to absorb and interpret information is important, despite making absolute sense of a complex system being close to impossible (Richardson 2000, Sterman 1994).

Skills for assimilating the available information and making decisions in uncertainty needs to be developed. This can be enhanced through simulations, which are based on mental models of the environment under consideration to understand the effect of certain influences and factors. The simulations are to be supported through scientific reasoning and enhancement of social interaction within groups operating within the complex environment.

Systems where humans tend to play a role have a tendency to be complex. Cross-boundary interactions between humans and machines characterise the modern world. The contributors to system complexity include the dynamic and context-dependant nature of cognitive work and the dynamic nature of socio-technical work settings (Fowlkes 2007, White 2008). The non-deterministic behaviour of people must be captured in the description of the total system. The success of the overall system will depend not only on the managing authority, but also on the cooperation of others. In development, the focus must be on supporting the human with the available technology. The way that humans think and operate must be brought into context of the physical system design to enhance sense making and decision making, as discussed below.

4 Sense Making and Decision Making

As discussed previously, command and control as well as other enterprises require sense making of the available information on the environment to make decisions on actions or the implementation of changes.

This section will provide a theoretical foundation on situation awareness, sense making and decision making to guide the development of information systems and their interfaces.

4.1 Situation Awareness

Endsley (2001) defines Situation Awareness as “the perception of elements in the environment within a volume of time and space, comprehension of their meaning and projection of their status into the near future”. Situation Awareness is a prerequisite for decision making (Vicente, 1999). Building and keeping effective Situation Awareness in a rapid changing environment is difficult and requires great effort to update information. Within military command and control a common Situation Awareness is required for effective decision making, highlighting the social interaction within an enterprise.

Endsley (2003) developed a model for Situation Awareness, simplified in Figure 2, and proclaimed that true Situation Awareness only exists in the mind of the operator. An interface is required between the information management system and the human decision makers to enable Situation Awareness. The presentation of information must be in line with natural cognitive patterns and processes for direct perception. An information bombardment is not the solution; a careful analysis is required to determine what is actually required for effective decision making. The information management system must support the processing and display of large volumes of data to support understanding of the situation. An understanding is required of how the users of the information will process and utilise it for decision making, including different cultural perceptions and available expertise. As the environment and available data or information gets more complex, the interaction between the Situation Awareness support system and the operator requires careful consideration.

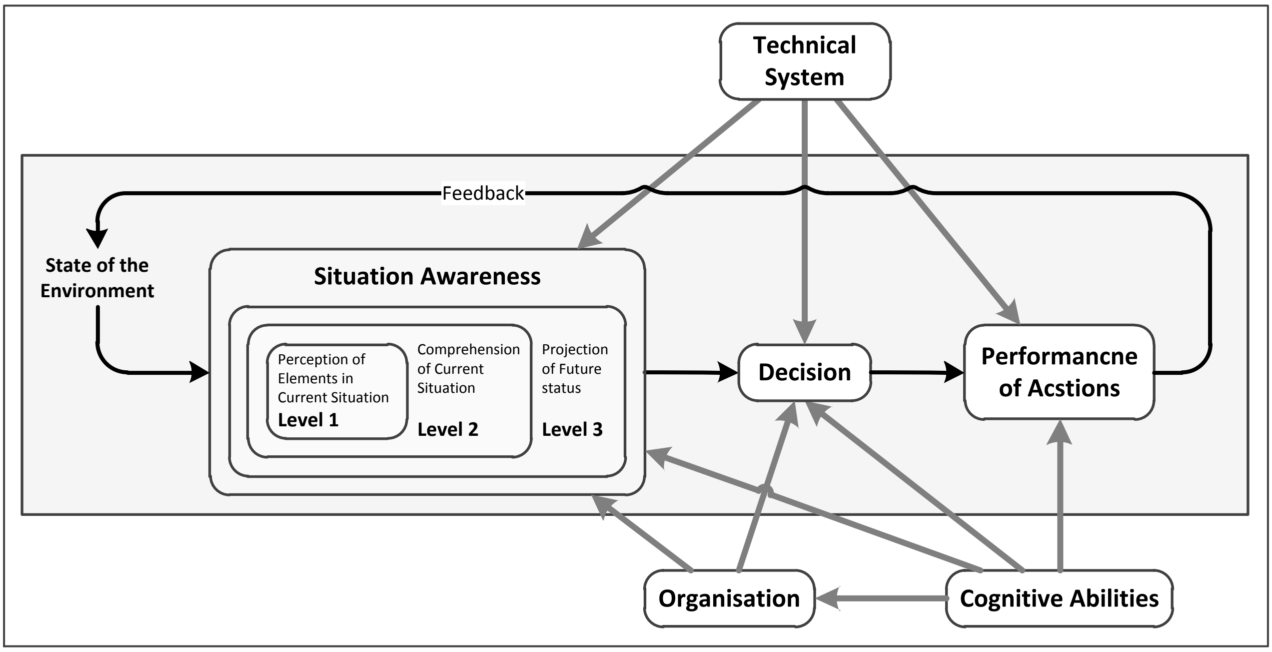

Figure 2: Situation Awareness Model

4.2 Sense Making

Command and control as well as enterprise management is about making decisions on how to adapt to a changing environment in order to achieve a set of goals. Sense making is central to decision making in support of command and control (Ntuen, 2006). It includes aspects of human cognition such as reasoning, pattern recognition, comparing of facts and differentiation between information that makes sense or not. Sense-making of a situation includes the integration of all the different interpretations of the role-players in the sense making process (Leedom, 2007). Sense-making tends to be a dynamic, continuous and negotiated understanding of the environment and is distributed between multiple participants. The different interpretations are from the different beliefs in terms of their cultural context, perspectives and previous experiences.

Information is the total property of the communication between two actors. According to Shannon (1948), information entropy defines information contents as relative to the total context of the message. The result is a complexity in the different interpretations and sense making of data and information. Therefore, sense making is dependent on how the information will be contextualised and interpreted.

Situated and distributed cognition needs to be considered when designing sociotechnical systems as they determine how humans assess the environment and interact with others (Lintern, 2008). Kurtz and Snowden (2003) proposed the use of their Cynefin framework in Figure 3 as a device for making sense in complex environments. It provides the decision maker with powerful constructs that are useful for making sense in complex situations such as "wicked and messy" problems. Knowledge of the location on the framework as well as the transitions over the boundaries is useful in learning about the requirements for coping with complexity.

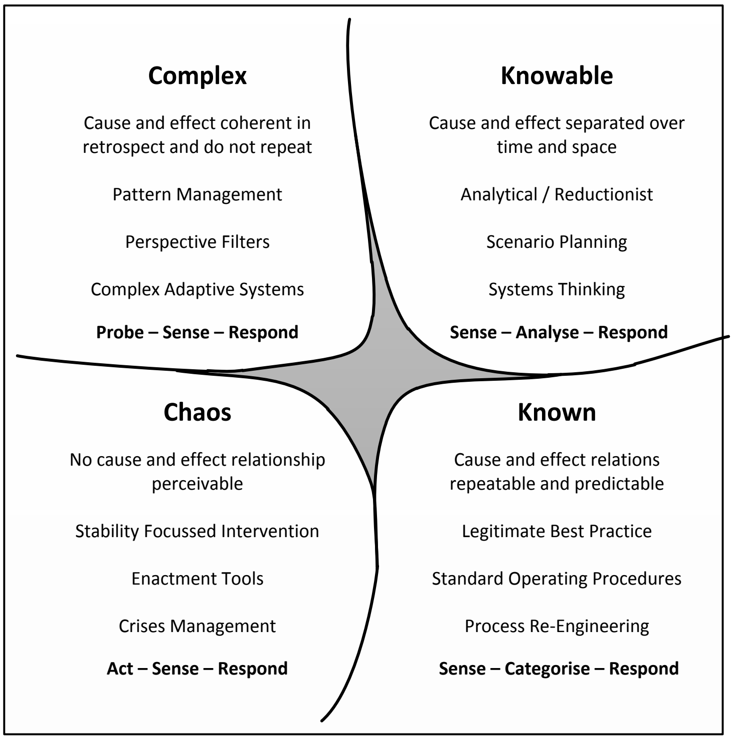

Figure 3: Cynefin Framework [29]

For example, if one knows that the problem or situation can be cast in the "Knowable" part of the framework, one can work towards specific types of solutions, where a question may have a finite set of well-constructed answers. One could device a set of policies to deal with outcomes and exceptions in the organisational context. In the "Known" domain, we can employ simple rules to link situations with actions, as a specific situation warrants a singular action, or set of actions. In short, in that domain one can use rules and regulations in an organisational context to ensure proper operation. Snowden always points out that the domain of "Chaos" is the interesting one: here it is best to act sooner rather than later so as to be able to survive. The "Complex" domain requires one to ask first and to look for patterns to try and understand. However, as the patterns may not be easy to link causally, the development of the appropriate response remains open to be influenced by context and the environment. An example is how to decide what level of nuclear shelter to supply to communities.

Another interesting aspect of this framework is the movement across the boundary regions. When things break down in the "Known" domain, it often causes chaotic situations; the system goes from very stable into unstable and unpredictable. In the original work Snowden points out that the "boundary" there is in fact a discontinuity. This is in contrast to the other areas where the transition signifies more contextualised understanding, going clockwise. If a stable political system, which derives its stability from strong and enforced laws, gets under social pressure, it often crosses over from a system where the outcomes of actions are known, to a system where the turmoil of a revolution makes it impossible to know what will happen next.

The information available in the information system must be presented through an interface (display) to the decision maker to support sense making. The method of presentation must be aligned with his mental models and what he expect to see about the progress of the mission and the environment to support natural cognitive processes for decision making. This includes making the operator aware of what is not known within the scenario. By making proper sense of a situation or problem will assist the subsequent decision making in choosing the most suited alternative course of action in support of the successful operation of the enterprise.

4.3 Decision Making

Decisions are often guesses about the future on which alternative will provide the best result (Bennet, 2008). Within Complex Systems, such as an enterprise, decisions are to be made in a changing environment while the impact of the decisions also changes the environment. Brehmer (2011) describes this as Dynamic Decision Making, with the following “wicked” and “messy” problem characteristics:

a) A Series of Decisions. Dynamic tasks cannot be resolved by a single decision. To successfully complete the plan, a desired conclusion is required.

b) The Decisions are Interdependent. The series of decisions are implemented through limited resources. The same resource may be required to perform more than one task, and often this cannot be done simultaneously.

c) The Problem Keeps Changing. This is due to own actions, external actions or independent environment changes. This factor is further complicated through a number of delays in the control process.

d) The Decisions have to be Made in Real Time. To be effective, decisions cannot be delayed until all information is available of the optimum conditions. Interactions and change have to be addressed in-time.

With the increase in complexity, the decision makers must utilise their intuition and judgement in addition to formalised processes and support tools. However, it is essential to develop a strategy to guide problem solving through a serious of leading decisions and actions. These include, amongst others, boundary management, absorption, simplification, sense and respond, amplification and seeding. Humans must be able to use their cognitive abilities and past experience for creative results. Knowing when to make decisions as well as being able to make them is crucial (Alberts, 2006). This is the transition from sense making to decision making.

Klein (2008) describes human decision making is largely an intuitive process affected by the ability to assess the situation and performing mental simulation on the possibility of success of a possible solution. The natural tendency is not to optimise a solution, but rather to implement the first satisfactory option. Experienced operators tend to spend more time on making sense of the situation to increase the speed of making a decision when required (Kobus, 2000). During the decision making process, decision makers continue to increase their understanding of the problem. They have to apply complementary cognitive processes to arise at a suitable solution. These natural processes should be supported in a sense making and decision making support system.

Schmitt (2006) highlights that these processes are getting more involved and complex when performed in group as the different participants, with cultural differences, may be at a different stage or have different situation awareness. However, forced synchronisation may inhibit effective natural problem solving. One way of solving “wicked” problems is through an argumentative process used to develop a shared understanding of the problem amongst the decision makers (Rittel, 1973). This may provide a key insight on the problem or the possible solutions, achieved through the combination of intuition (subconscious knowing) and reasoning (rational knowing). However, a shared mental model amongst decision makers is a prerequisite (Yen, 2006).

To ensure that the command and control or enterprise management system effectively support the decision makers to cope with a complex environment, an effective interface to the information management system is required. One way to develop the management system with its interfaces is by following a Cognitive SE approach, as introduced in the next section.

5 Cognitive SE

5.1 Introduction

As discussed before, the human remains central to the operation of complex systems. He is part of the cognitive system that controls the operations of the enterprise. The increasingly complex work domain, requires an effective sense making and decision making tools to help solve real world (“wicked” and “messy”) problems (Elm, 2003). Ockerman (2005) states that the objective of Cognitive Engineering is to develop an optimal interface, ensuring effective interoperability between man and machine. This is crucial in today’s complex systems where humans use machines to assist in decision making as part of a cognitive system. Traditionally, the focus of SE was on the technical aspects and automation of systems and not so much on the humans to meet the demands of the work domains (Bonaceto, 2006). However, often system errors attributed to the operator were actually design flaws from early on in the development cycle.

Lintern (2008) defines a cognitive system as a complex sociotechnical system that represents a thinking information system. It has a form of intelligence embedded through the coordinated collaboration between distributed human operators. Humans are to be included inside the boundary of the cognitive system as a human can reason while a machine cannot. Two humans in coordination can reason much better than one in isolation, placing emphasis on the implementation of a communications network and social integration. These are to be enhancing with ecological displays which are graphical rich and support the natural cognitive strategies of the human to reduce complexity.

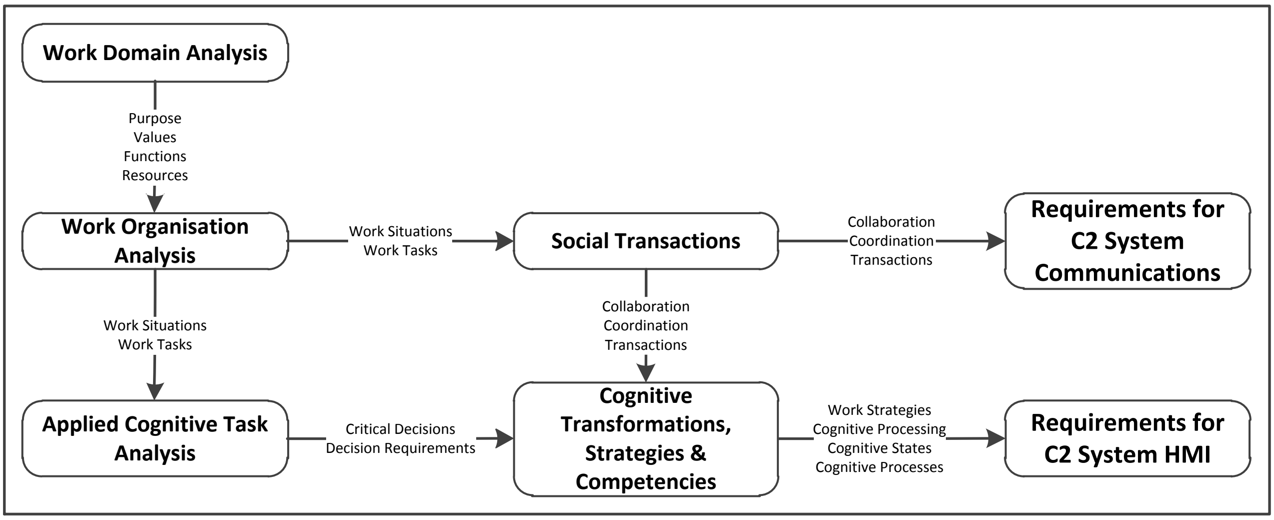

Figure 4: Cognitive Work Analysis Framework

One approach to Cognitive SE is the Cognitive Work Analysis (CWA) framework (Lintern 2008, Naikar 2006). CWA is an approach to develop formative designs for decision support systems. It considers the ecological constraints that may shape the execution of tasks as well as the cognitive approaches of the users of the system. CWA assist in the analysis, design and evaluation of large scale and dynamic socio-technical systems where people can and have to adapt to changes in the environment. The ecological constraints still allow for a variety of work patterns to solve unexpected problems and situations, resulting in a flexible decision support system (Vicente, 1999, 2000).

CWA provides a formative approach that focus on how work can be done and is used to develop “cognitive affordances” to support human sense making and decision making. They are devices that intuitively fit in with how human cognitive processes are performed. It affords workers the ability to solve unanticipated events through creativity and innovativeness. If the ecological and environmental constraints are neglected in the cognitive system design, operators may develop their own work around and other compensatory strategies to get the job done. This can be fatal in time pressured situations such as combat (e.g. weapon control systems), nuclear power plant control rooms and other emergency services (Mumaw, Roth, Vicente, & Burns, 2000).

The products of CWA define the required information content as well as the applicable context where it will be used (Bennett, 2008). The aim is to enable informed decisions using the interfaces to the knowledge management system. Operators need to perceive critical information on situational factors and to prevent reasoning about the factors (direct perception). Once a decision is made, the operators must be able to act directly on objects in the interface to execute control (direct manipulation). The discussion of the CWA process is mainly derived from the work of Lintern (2006, 2008) as provided in Figure 4.

5.2 Cognitive Work Analysis Framework

5.2.1 General

As stated before, CWA supports the development of cognitive systems that allow decision makers the required flexibility. The five main steps are described in detail below. It is important to note that the process start off with a focus on understanding the ecological elements before relating it to the cognitive capabilities of the humans. This enables operators to know what can be expected as well as being flexible in responses.

This ability of being flexible helps reducing the cost of the SE process through streamlining and limited redesign cycles (Vicente, 1999). The different steps are now discussed in deeper detail.

5.2.2 Work domain Analysis

The Work Domain Analysis provides the foundation for an ecological interface through understanding the effect the environment has on decision making. This analysis uses an Abstraction Decomposition Space to identify the goals and purposes of the cognitive system to provide a reasoning space about the environment. The designer of the cognitive system requires an understanding of the functional structure of the enterprise under consideration; what the operator must do and how the environment impacts on it. It is assumed that the problem solvers within the enterprise need to understand purpose of the system, the values and priorities of the system, the physical resources available and what the abilities of those resources are. The output model of this step is not task or event driven, but leaves space for events that may be anticipated or not. (Vicente and Rasmussen, 1992).

This process should be representative of a typical expert problem solver, within the enterprise, natural reasoning. Subject Matter Experts (SME) are used to provide insight on mental models, heuristics and workarounds. The means-ends relationships between the physical resources and functionality need to be highlighted to guide possible problem solving strategies. Within the abstraction levels the elements can be viewed at different states of decomposition as required by the level of analysis. The levels of the abstraction decomposition space are:

a) System Purpose. The System Purpose provides the reason why this specific cognitive system is being developed.

b) Values and Priorities. The reasoning process requires the principles, standards or qualities to be maintained during execution of the process.

c) Knowledge, Insight and Semantics (General Functions). This level provides the domain functions required to execute the work in satisfaction of the system purpose. These functions must be performed, independent of the physical elements utilised.

d) Facts, Ideas, Opinions (Physical Functions). The physical functions are implemented through the activation or use of the physical objects.

e) Source Objects (Physical Objects). The physical elements present in the work domain available to perform the work.

5.2.3 Work Process

A Contextual Activity Matrix from Naikar (2006) is used to represent the work situations and work problems. Some of the work tasks may be performed under different circumstance and scenarios. An important aspect is the context within which work is completed. This will determine what support is required to ensure safe and effective completion. This step is useful in identifying the different combinations of work tasks performed under specific conditions.

5.2.4 Control Tasks

The Control Task Analysis focus on the constraints limiting achievement of the goals and purposes identified in the Work Domain Analysis. It identifies the relevant information and relationships in solving specific situations. During the execution of tasks, solving of problems and making of decisions, transitions are made between different cognitive states as a result of cognitive processes. These are depicted on a Decision Ladder as developed by Rasmussen (1994) for information processing activities and the resulting states of knowledge. Figure 5 show the interpretation of Lintern (2008) of the implementation of the Decision Ladder for a Cognitive System.

The ladders does not serve as a model, but rather maps the decision making process. The process of expert problem solving may not follow the ladder in a linear process, but any cognitive state can be accessed from any other state through shortcuts. In combination with the Work Domain Analysis, this leads to the allocation of functions in terms of the knowledge, skills and abilities required for sense making and decision making. The decision ladders may also guide the inclusion of automation in the decision support system design (Vicente, 1999).

The effect of different circumstances on the Cognitive States and Processes must also be considered. Decision Ladders should be scrutinised to identify Cognitive States and processes that may be supported through technology, process or training improvements. The Cognitive Transformations Analysis provides a starting point for identifying Cognitive Processes that can be enhanced through different Cognitive Strategies or with different modes of Cognitive Processing.

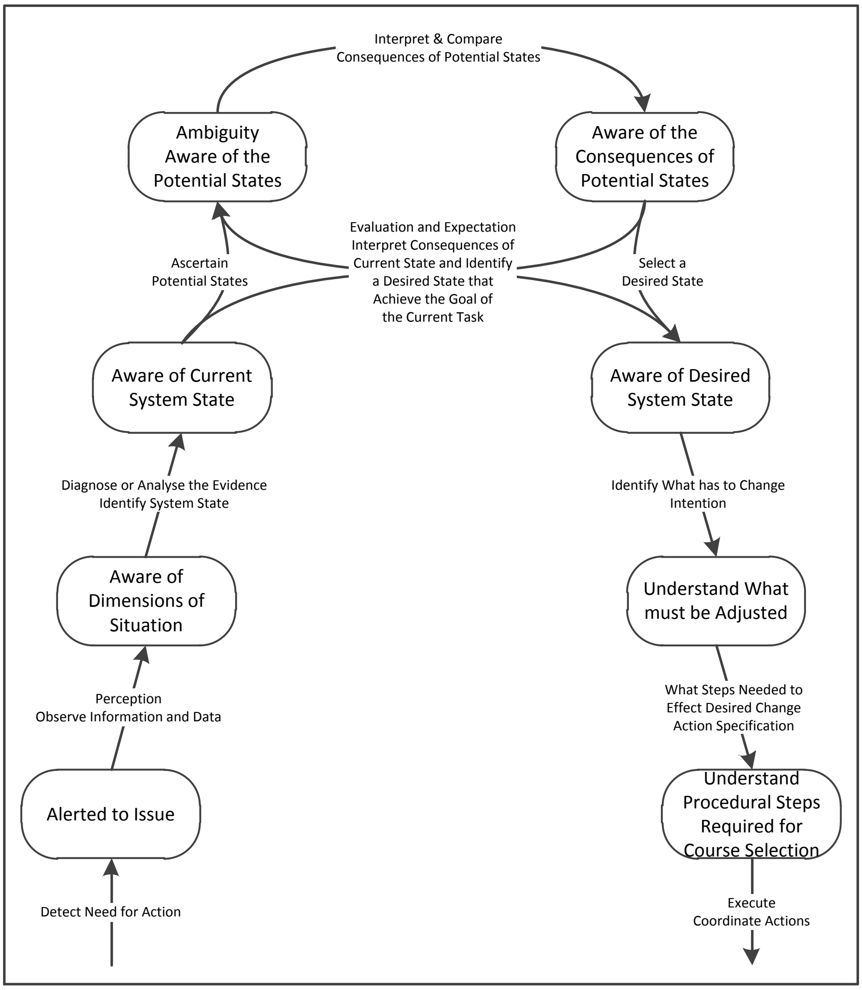

Figure 5: Decision Ladder

5.2.5 Strategies

The cognitive processes identified in the Decision Ladder is further analysed to determine the strategies how the tasks are executed, especially by experts. The typical strategies to be employed include a snap decision, searching for recommendations or to infer most suitable solution from structural principles. The knowledge of how and why workers may choose between different strategies will be useful in designing of a cognitive system. The output of the Cognitive Strategies Analysis is a detailed description of potential strategies and their application used to execute the Cognitive Processes.

One approach to be used is an Information Flow Map (Vicente, 1999). The focus is not so much on the exact procedure used to execute a task, but to identify the information required for a critical decision process.

5.2.6 Worker Competency

Rasmussen (1989) provides three different levels of activities used in control of a system. They are:

a) Skill-Based. Actions are taken reflexive and often reactive to a situation without conscious planning.

b) Rule-Based. The decision maker takes action based on a predefined set of rules that are prescribed for a specific situation. The rules and classification of the relevant situation may be the based on the experiences of a SME.

c) Knowledge-Based. The decision maker may require complex cognitive processing to analyse an unanticipated situation and determine the required set of actions. These situations may be open ended without predefined procedures.

Situations within cognitive tasks where each of these are possible needs to be identified as it will provide important queues for system HMI and training requirements. The important output of this phase is the identification of the perceptual pattern required to result in a coordinated action. A reasonably complicated cognitive task will require frequent and subtle transitions between modes of processing.

5.2.7 Social Organisation and Cooperation

The aim is to design effective organisations or structures with the required technologies that support the communications demands. As a complex sociotechnical system consist of distributed diverse human and technical functions, their interaction and roles must also be analysed. The coordination, responsibilities and roles of the different entities as well as information exchange need to be listed. A careful consideration of formal and self-organisation is also required. Within the cognitive domain, interaction exists between peers as well as between management and workers. Processes and technologies are required to support these informational interactions. This collaboration (lateral) and coordination (vertical) can be characterised in terms of the transactions performed. A social transaction occurs when some element, in this case information or an order, is transferred between Agents.

5.3 Sources of Information

The framework also requires a documentation analysis on the operational environment. Within the military scenario this will include doctrine as well as operational procedures and responsibilities. It is important to utilise experts throughout the process of developing interfaces as their operational experience and domain knowledge is used to identify cognitive processes and requirements as well as assisting in design evaluations Ockerman (2005). In future, less experienced operators can benefit from this. Scenarios are used to assess the effects and goals of a cognitive in context. It can also be used during interviews to elicit knowledge from operational stakeholders. Scenarios are used to gain an understanding of the effects and goals that ensure operational success in context. The inputs from Subject Matter Experts (SME) are critical in developing realistic and comprehensive scenarios.

Cognitive Task Analysis (CTA) as a useful method is to mine information from the SMEs Militello (1998). CTA utilises Task Diagrams, Knowledge Audit and Simulation Interviews to extract detailed information on decisions. The method focuses on the complex decisions and extracts the cues and strategies used. The information will guide the development of systems able to assist inexperienced operators with sense making and decision making.

6 Developing Requirements for Cognitive Systems

6.1 Concept Development

The information gained from the CWA is converted into requirements for the enterprise control or relevant command and control system Ockerman (2005). Again here the SMEs should be involved in assisting the design team. The design of the total enterprise system includes the description of the physical operational environment, organizational, structure, policies, and hardware. Additional steps, such as work load analysis, are used to support organisational design. Other modelling and simulation tools may also be required to assess the operation of the system.

6.2 Human Performance Assessment

The concepts and design of the command and control system requires assessment to validate the conducted analysis. This will include laboratory assessments as well as real field exercises. As this is only the literature research, the actual conduct of assessments will only be discussed in future publications. The typical metrics for assessment are:

a) Successful completion of tasks.
b) Time to complete a specified task by a specified user.
c) Percentage of tasks completed.
d) Time spent on errors.
e) Number of errors per task.
f) Number of commands used to accomplish task.
g) Frequency of and time spent on help or documentation use.
h) Number of runs of success and of failure.

i) Number of available commands not invoked.

j) Number of regressive behaviours.

k) Number of time users need to work around a problem.

6.3 Interface Guidelines

An ecological interface is created with the translation of the output of the CWA into a specific interface design (Bennett, 2008). The user must be able to read the relevant affordances, implying a direct perception. It must also enable the user to interact with the system using high capacity sensory-motor skills to execute actions for a capability of direct manipulation. The processing of data into information must be available to the operator, not being a black box. The assumptions and approximations must be explicit. The decision makers require tools for assisting in decision making and mitigate the risks of error and failure. A list of control system interface guidelines as derived from (Elm 2003, Endsley 2003, Rasmussen 1994, Vicente 1999) are as follows:

a) Provide operators feedback on the effect of actions to cope with possible time delays. This should facilitate error recovery with a functional understanding of their actions.

b) Critical cues or alarms for situations where shifting of goals and priorities are required must receive prominence on the display. The cues for action on the interface should provide a cognitive mapping to the actual functions taking place.

c) The interface should have tools to assist in hypothesis testing when the operator is faced with a new or unfamiliar situation that the system designers could not anticipate.

d) Information displays must be goal orientated by co-locating information required for a specific goal. Data rich environments must be supported by providing the capability for parallel processing and multi-modal displays. Always provide a situation overview to support global Situation Awareness. The interface should enable the operator to monitor routine and normal functions with "fringe consciousness".

e) The displays must be aligned with and externalisation of the mental model of the decision maker. It complements the cognitive capability of the human mind to avoid thinking patterns that may induce errors (fixation). It ensures ease of control by the human operator by being transparent to allow a total focus on the problem to be solved.

f) The information presented must be optimised to support decision making. This relates to the appropriate level and amount of information.

g) Operators require direct presentation of a high level Situation Awareness to address complexity, instead of lower level data still requiring interpretation. It ensures the human decision maker is presented with "information" required instead of raw data.

h) The level of confidence in the information must be indicated.

7 Conclusion

This paper has indicated that enterprises exist in a complex world where they are faced with "wicked and messy" problems. As en enterprise is effectively an open system, it is influenced and constrained by the environment through available resources, governing regulations and the operations of competing enterprises. Changes in the dynamic environment will influence the enterprise, necessitating a management system (monitor and control) system. The management system needs to enable its operators to make sense of the status of the enterprise as well as the influencing factors in the complex environment.

The human decision makers are part of the cognitive system used to manage and control the enterprise. The human operators interface with the management system through an HMI which displays information on the complex environment. Furthermore, humans have the cognitive ability to develop creative solutions as required within the complex environment. Therefore the management system interfaces must support the human's cognitive and social capabilities in situation assessment, sense making and decision making.

Our literature review revealed that Cognitive SE may address the human's cognitive and social capabilities. The Cognitive SE (and more specifically the CWA framework) is used to identify requirements for an effective HMI for direct perception. It is proposed that he CWA framework be used for the development enterprise management and more specific of a military command and control system.

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