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Modelling of Command and Control Agility

Topic

Topic 5: Modelling and Simulation

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Abstract

Different Systems Engineering techniques and approaches are applied to design and develop Command and Control solutions for complex problems. Command and Control is a complex sociotechnical system where human commanders make sense of a situation to support decision making, planning and distribution of orders with decision support and communication systems. The complex and dynamic operational environment make Command and Control systems difficult to develop. A modelling and assessment methodology in support of Systems Engineering is required to understand the behaviour and underlying structure. It must capture the dynamic interaction as well as the effect of humans performing work in a complex environment. Cognitive Work Analysis and System Dynamics are two complementary approaches that can be applied within this context.

1 Introduction

Command and Control (C2) systems are complex, dynamic, and context dependant with social and cognitive humans operating under risk, uncertainty, and time pressure (Alberts 2011). Development of C2 systems often consist of integrating new technology into existing systems through application of Systems Engineering processes. Systems Engineering uses modelling to explore structural, functional, and operational elements of the problem and solution space (Hitchins 2008). However, standard Systems Engineering processes can struggle with complex Sociotechnical System (STS) which exhibit dynamic behaviour as many unintended or unpredicted consequences may be experienced. The new artefact often leads to new task possibilities that evolve user requirements (Carroll & Rosson 1992).

Theory on STS provides a framework to approach modelling and analysis. STS consist of humans applying technology to perform work through a process within a social structure (organisation) towards achieving a defined objective (Bostrom & Heinen 1977, Walker *et al* 2009). Work can become complex due to dynamic interaction between the people themselves, between people and technology as well as the environment. Within the context of this paper, complex STS rely on humans using information to assess a situation and devise plans to solve problems. These systems are used as a control measure to ensure successful implementation of plans in constrained and variable operational environment to achieve a successful mission.

The aim of this paper is to develop a modelling and analysis methodology. Current C2 theory will be analysed for relevant characteristics to be modelled by the appropriate methodology as part of the Systems Engineering process. The two approaches used in the modelling methodology are Cognitive Work Analysis (CWA) and System Dynamics (SD).

CWA is a framework to analyse the way people perform work in an organisation while taking the environmental constraints into consideration. The outputs of CWA are constructs or models that capture the structure of the problem. Functions provided by different technological elements are linked to the functional requirements of the system to achieve its purpose (Lintern 2012). However, CWA is limited in investigating the dynamic effect of decisions and policies on the system (Cummings 2006). The dynamic behaviour of the complex STS can be analysed using SD which uses the structure of the system in simulation. SD looks at the effect of feedback and delays on the operation of the system as a result of decisions based on policies to understand the problem (Sterman 2000).

The Design Science Research (DSR) framework will be used to guide implementation of the methodologies. DSR aims at creating technology for a human purpose, as opposed to natural science, which is trying to understand and define reality (March & Smith 1995). The proposed methodology will be demonstrated in a case study through modelling and analysis of the impact of a new collaboration technology on border safeguarding operations.

2 Command and Control

2.1 Command and Control Systems

Military theorists and thinkers throughout history have recognised that military commanders are faced with complexity, uncertainty, and novelty. War presents an environment with complex problems affected by chance, contextual complexity, nonlinear interaction, collective dynamics, and adaptation (Cil & Mala 2010, Beyerchen 1992, Clausewitz 1976). The C2 system support designing courses of action through problem solving within a military context as well as controlling their execution. The purpose of C2, as a force multiplier, is to bring all available information and assets to bear on an objective to ensure the desired effects through effective utilisation of limited resources (Smith 2007, Van Creveld 1985).

The “Command” part of C2 represents the art of planning an advantageous encounter with the adversary with the appropriate resource at the right place and time. As it is almost impossible to predict the behaviour of the adversary, the science of “Control” is required to steer the outcome of the conflict into a favourable direction. Control is the process of determining the relationship between desired and actual results to take corrective steps through direction and coordination of actions. However, delays in the different phases of the cyclic C2 process may cause complex dynamic interaction. Commanders make decisions in a changing environment while the impact of the decisions may also change the environment. Decision making in an environment with inherent time pressure, risks, and delays results in a complex dynamic system that require careful modelling and understanding (Alberts & Hayes 2006, Van Creveld 1985, Brehmer 2005, Brehmer 2007, Brehmer & Thunholm 2011, Sterman 1994, Ntuen 2006).

One of the most widely used models of C2 is the “Observe-Orientate-Decide-Act” (OODA) loop from Boyd (1987). However, the OODA loop does not incorporate the commander’s intent, planning, exit criteria or systemic delays (Grant & Kooter 2005). The OODA loop is a model for winning and losing as a modern view on strategy and tactics, not specifically for implementing and developing C2 systems. Therefore, Brehmer (2005) expanded the OODA loop with cybernetic model inputs, manoeuvre warfare concepts, and dynamic decision making to form the Dynamic OODA (DOODA) model, as provided in Figure 1. The DOODA model highlights the process of sense making in relation to the mission objectives and the command concept.

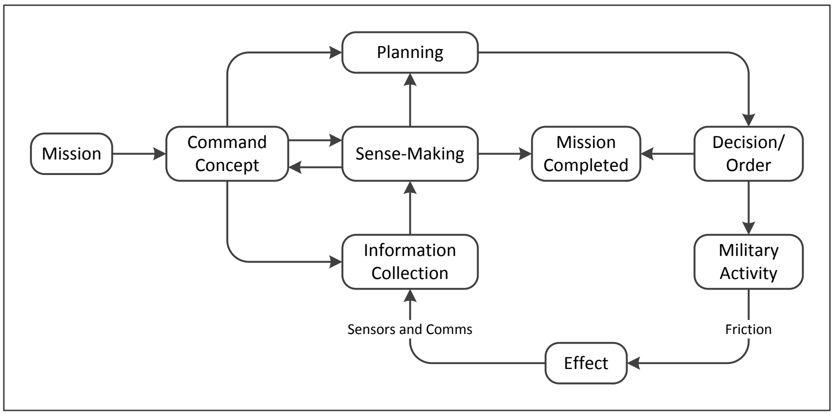

Figure 1: Generic Command and Control Model (Brehmer 2005)

A C2 system consists of equipment (communications and interfaces) and people (commanders and subordinates) organised in a structure (often very hierarchical) to execute a task through processes on decision support interfaces. Communications technology allows for the distribution and integration of information, requiring decision support tools capable of working in the complex environment. C2 requires human interpretation to make sense of complex situations with cognitive and social skills. However, the human increases system complexity as behaviour is context and task dependent, using different perspectives, skills, and experience. Different decision makers may have different levels of responsibility, objectives, chains of command, decision cycles, timelines, and methods of decision making (Alberts & Nissen 2009, Smith 2007, Janlert & Stolterman 2010, Lintern 2012, Endsley *et al* 2003, Hallberg *et al* 2010, Brehmer 2007).

2.2 Sociotechnical Systems

C2 is an example of a complex STS. The term "Sociotechnical" refers to the interaction between "social" humans and "technical" systems (Walker *et al* 2008). During the 1950s the introduction of new technology to improve efficiency and productivity of organisations did not meet expectations. This led to the introduction of the sociotechnical approach that focussed on the joint optimisation of social and technical subsystems (Baxter & Sommerville 2011, Bostrom & Heinen 1977, Trist 1981). STS theory highlights the importance of social humans in the organisation instead of only relying on technical improvements to solve complex issues.

People perform work in organisations, utilising technological artefacts, to achieve economic performance and job satisfaction. Technological artefacts consist of the tools, devices, and techniques to transform inputs into outputs for economic gain, as seen in Figure 2 (Bostrom & Heinen 1977, Walker *et al* 2008). The social subsystem addresses structure of the organisation, encompassing authority structures and reward systems, as well as people in the organisation with their knowledge, skills, attitudes, values and needs. Being an open system, the complex environment also affects the STS. The socio and technical interaction can be non-linear as a result of unexpected, uncontrolled, unpredictable, and complex relationships. People also have the flexibility and intellect to reorganise and manoeuvre in order to address challenges and changes in the environment (Walker *et al* 2008).

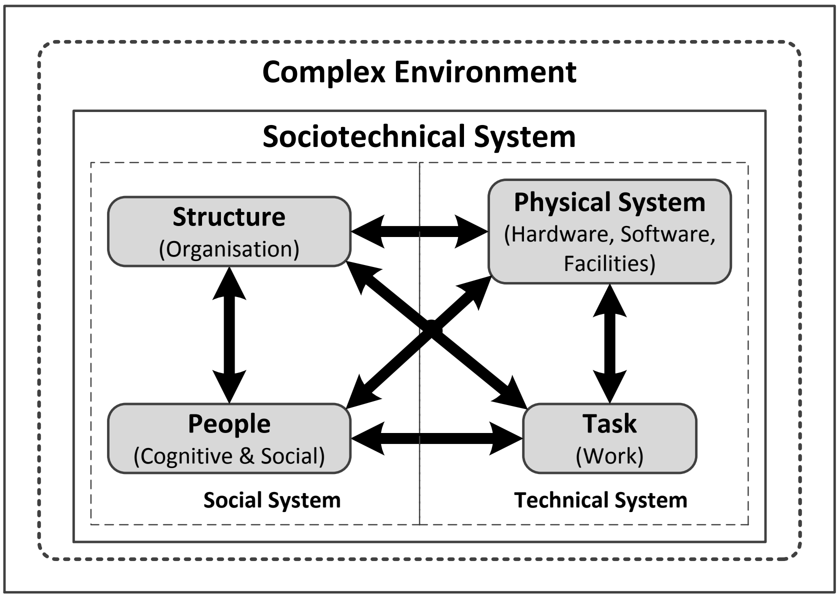

Figure 2: Sociotechnical System

2.3 Complex Systems

The term "Complex" is defined as "a whole made up of complicated or interrelated parts" which are intricately intertwined with a high level of interconnectivity (Merriam-Webster Dictionary, Gell-Mann 1994). Complex system elements have non-linear interactions (including feedback loops with delays) that cause non-deterministic, emergent, unpredictable, and unexpected behaviour. Complexity may exist in simple systems, owing to dynamic context-dependant interactions and feedback between elements. Complexity can be a characteristic of the artefact technology or its situated use in the environment. Critical tasks in complex systems tend to be time limited with decisions and actions that depend on feedback having delays (Checkland & Scholes 1990, Hollnagel 2012, Fowlkes 2007, White 2010, Janlert & Stolterman 2010).

Behaviour as a result of human decisions and actions may not always be consistent and is dependent on the system's initial states. These have a high degree of uncertainty for decision makers to solve (Checkland & Poulter 2007, Pries-Heje & Baskerville, 2008, Rittel & Webber 1973). Methods to analyse and design modern systems for successful operation in a complex environment need to address the social, cognitive and dynamic complexity in the system (Janlert & Stolterman 2010, Reiman & Oedewald 2007, Lintern 2012, Bahill & Gissing 1998).

The causes of C2 system complexity include large problem space, uncertainty, risk of hazard, social interaction, being distributed, dynamic interaction, and time pressure (Vicente 1999). According to Ashby's Law of Requisite Variety, to control combat as a system, the variety of states within combat itself must be similar to the controller of the combat system (Moffat 2003). The focus of the work tends to be on anomaly detection, escalation, and problem solving through cognition as opposed to routine tasks requiring a formative development approach (Baxter & Sommerville 2011, Carroll & Rosson 1992). Therefore, the C2 system requires complex and agile capabilities for modern military operations. Agility consists of responsiveness, versatility, flexibility, resilience, innovativeness, and adaptability (Alberts 2011).

2.4 Systems Engineering

The objective of System Engineering is to solve problems by developing systems through the application of Systems Thinking (Hitchins 2008). A basic Systems Engineering process starts off by distilling the needs of stakeholders, along with characteristics of the environment, to develop concepts and define requirements. Systems Engineering requires modelling of system behaviour to investigate the dynamic and non-linear interaction. A model describes system structure and behaviour through abstracting reality, simplifying complexity, considering constraints, and synthesizing results. Modelling of complex STS also have to capture human work in the system. Models are utilised to experiment with knowledge on the problem, test assumptions, and to develop an understanding of the implication of different solutions (Hitchins 2008, Oliver *et al* 2009, Stanton *et al* 2012).

Stand-alone systems can often not meet the requirements of complex challenges in the real world. As a result more systems are integrated for better control and information exchange. Modern C2 systems tend to be developed through piecewise replacement of subsystems with new technology. The cross-boundary interactions between non-deterministic humans and machines must be considered. Integration of new technology into a complex STS cannot only rely on historic case studies and associated data for analysis, affirming the need for experiments to explore different scenarios and identifying possible counterintuitive effects (Bar-Yam 2003, Sheard & Mostashari 2009, Hitchins 2008, Alberts & Hayes 2006, Cooley & McKneely 2012, Papachristos 2011).

The next section will discuss modelling and assessment methodologies suited for complex STS. These will be moulded into a framework to support building knowledge on the system to be developed and the associated problems.

3 Command and Control Modelling and Analysis

3.1 Cognitive Work Analysis

CWA has been applied in systems analysis, modelling, design, and evaluation of complex STS such as C2, aviation, health care and road transport (Jenkins *et al* 2009). It supports the formative development of "how work can be done" instead of normative models (how the system should behave) or descriptive models (how the system is actually behaving) (Vicente 1999). The theoretical roots for CWA are in Systems Thinking, Adaptive Control Systems and Ecological Psychology. Work is defined as an activity aimed at accomplishing something useful with a purpose, values, and success criteria. Work consists of a combination of cognitive and physical elements that interact with each other. The system must enable the human actor to perform his work effectively within the environmental constraints, with the required technology and supporting organisational structures (Lintern 2012, Naikar *et al* 2006).

The CWA process starts off with a focus on understanding the ecological elements before relating it to the cognitive capabilities of the humans to enable flexibility that helps reduce the cost of development (Vicente 1999, Bennett *et al* 2008). The ecological constraints still allow for a variety of work patterns to solve unexpected problems and situations resulting in a flexible decision support. The five phases of CWA include Work Domain Analysis (WDA), Control Tasks Analysis, Strategies Analysis, Worker Competency Analysis, as well as Social Organisation and Cooperation Analysis (Bennett *et al* 2008, Lintern 2008, Naikar *et al* 2006, Vicente 1999, Jenkins *et al* 2009).

The WDA elicit and present information on the system from existing documentation and expert users to understand the functional structure of the enterprise and environmental effects on work. It identifies the goals and purposes of the cognitive system in a top-down approach. This is integrated with a bottom-up view of available physical resources for the human operators to achieve the purposes of the system. Since modelling is not task or event driven, many possible instantiations due to dynamic interaction between technical systems, the environment, and people are captured (Naikar *et al* 2006, Vicente 1999). The other phases will not be discussed in this paper.

Despite its advantages, CWA does not support developing a complete understanding of the STS system's dynamic behaviour. CWA constructs do not support cause-and-effect relationship analysis due to unanticipated and intentional events or the effect of time in critical C2 environments. CWA also tends to be used for analysing existing systems instead of designing revolutionary and novel systems, motivating the need for additional tools (Cummings 2006).

3.2 System Dynamics

The concept of SD was developed to investigate the effect of feedback in social systems through Systems Thinking. The different modes of behaviour as a result of high-order nonlinear systems were related to complex problems in management and economic decision making. SD presents a method that combines qualitative modelling of complex STS with quantitative simulation (Forrester 1968, Sterman 2000, Meadows 2008, Wolstenholme 1990).

System structure is the source of system behaviour and consists of interlocking stocks, flows, and feedback loops. SD employs Causal Loop Diagrams as well as Stock and Flow Diagrams to present the process and information structure of the system for discussion between stakeholders. Causal Loop Diagram shows the causal influences between variables to identify the feedback structure of the dynamic system. Delays in feedback loops cause inertia in the system that may lead to dynamics and oscillations (Sterman 2000, Meadows 2008). Stock and Flow Diagrams show the structures that represent the physical processes, delays and stocks that are related to the complex dynamic behaviour in the system over time. Stocks indicate the state of the system as a result of the history of changing flows to cause delays, inertia and memory. The causal connection between the stock and the flow due to decision rules result in feedback, which is important to understand the behaviour of the system (Sterman 2000, Meadows 2008).

Behaviour observed over a long time leads to dynamic patterns of behaviour of the system that support learning about the underlying structure and other latent behaviours. SD support assessment of C2 systems to gain an understanding of the social and technical interaction in a dynamic environment. SD can also be useful to assess the interaction between the different levels of the C2 hierarchy and the environment (Lofdahl 2006).

3.3 Design Science Research

CWA and SD are two fundamentally different methodologies, which need integration through a framework to support modelling and learning as part of the design phase in the Systems Engineering process. DSR has been proposed as a framework for information system development through the creation of artefacts for a human purpose (Hevner *et al* 2004, Venable, 2006). The two basic activities in DSR methodologies are designing a novel and useful technological artefact for a specific purpose as well as evaluating its utility. Design is the process of creating a new artefact (construct, model, method, or instantiation) that does not already exists in nature (March & Smith 1995, Hevner 2007, Pries-Heje & Baskerville 2008, Baskerville *et al* 2009, Simon 1996).

Artefacts are developed as part of a sequential problem solving process to gain new knowledge, as seen in Figure 3 (Peffers *et al* 2007). First, new problems or opportunities may be discovered through new developments in industry or operational environment. Next, knowledge on the problem is analysed to determine the objectives, functionality, and contribution of the solution artefact. The solution artefact is then created through design and development. A demonstration is required to assess the utility of the artefact before time and resources are committed to a thorough evaluation. Evaluation is conducted through simulation, experimentation, or case study. The aim is to gain knowledge and experience in application of the artefact to solve a problem. The outcomes are measured and compared to the objectives of the perceived problem state and solution values through.

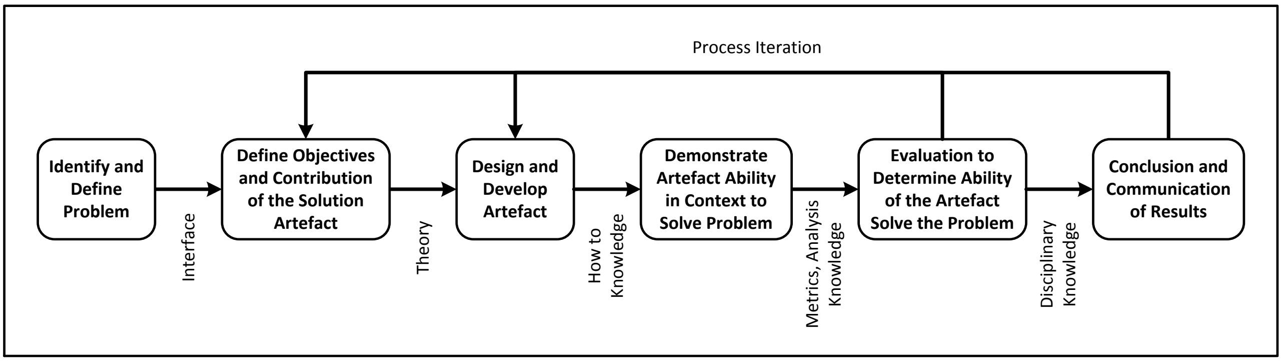

Figure 3: The General Methodology of Design Research

3.4 Modelling and Analysis Methodology

The theoretical discussion up to now highlighted the fact that development of complex STS depends on effective modelling and assessment of a system as well as the environmental influences. Such an approach must address human work with the technical system in a complex environment. Knowledge on the problem enables successful solution implementation through Systems Engineering. The modelling and analysis methodology presented in Figure 4 integrates the theory on CWA, SD and DSR, as discussed above.

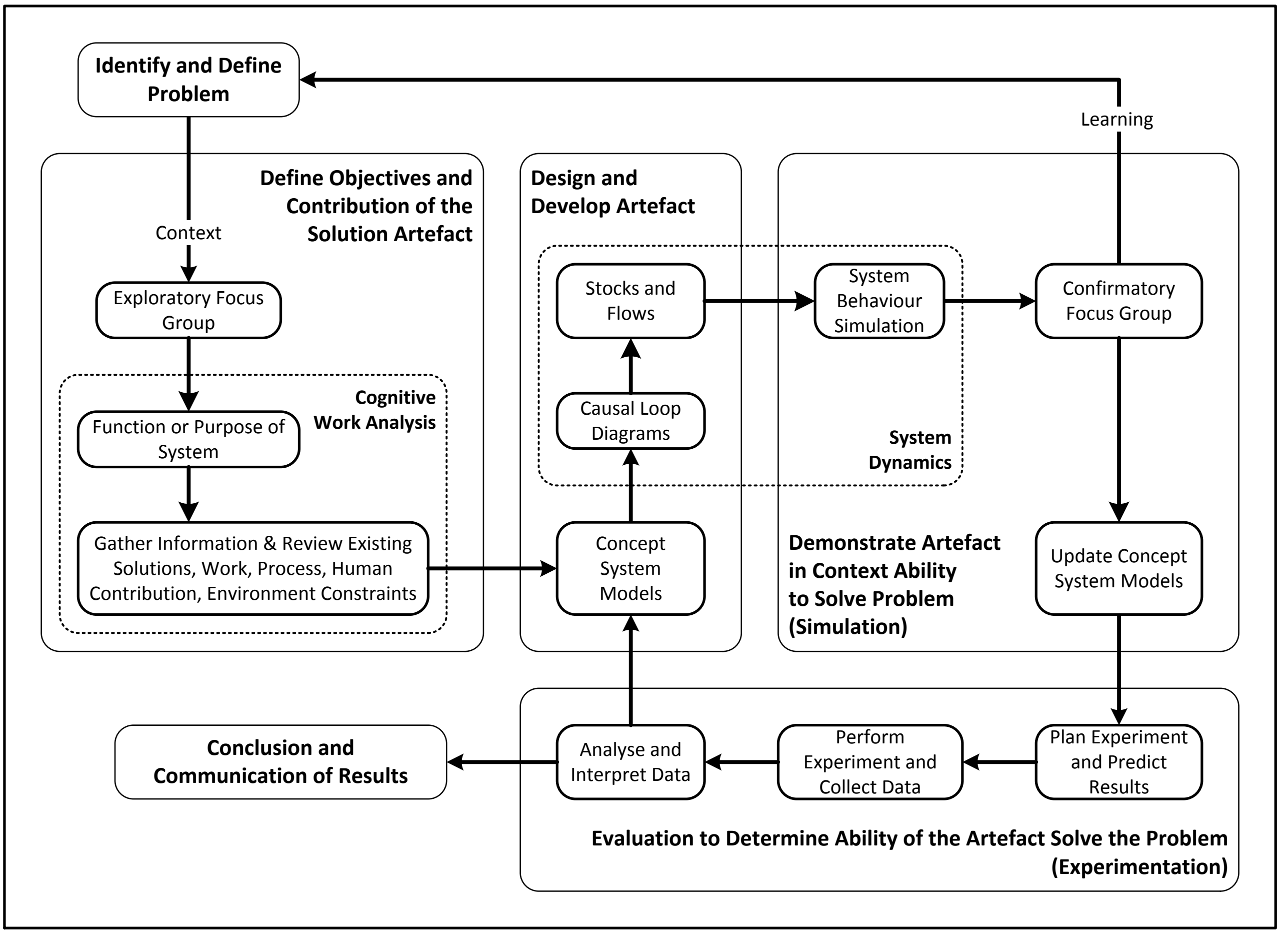

Figure 4: Modelling and Analysis Methodology

Modelling and assessment need an identified and defined problem to be solved. This may be due to new technology available to improve a system (technology push) or from changes in environmental constraints that inhibit the effectiveness of a system (technology pull). In the second step CWA presents the current information on the system and operational requirements within the context of the problem. Available information from documents and users are captured in constructs. An Exploratory Focus Group will be useful in capturing the views of role-players on the problem and required capabilities of a solution. Focus group advantages are flexibility, direct interaction with respondents, large amounts of rich data with diverse views through shared understanding (Tremblay *et al* 2010, Sterman 2000).

The next step in the DSR process is to design and develop the solution artefact. A model of the complex STS is used to assess the problem situation and solution artefact. Existing and generic models of the complex STS is enhanced with information and knowledge captured in the CWA framework. The model includes constraints of the organisation and environment with a focus on how people apply the artefact to perform work towards achieving organisational objectives.

SD modelling process develops a Causal Loop Diagram and Stock and Flow Diagram. The utility of the model is demonstrated through SD simulation to understand the effect of different technologies on complex STS dynamics. The purpose of the SD is not to predict how successful the system will be, but to understand the effects of certain causes of possible system behaviour. Since SD does not focus on human processes, the inputs of the CWA are crucial in modelling the problem. In this methodology, there is no direct link between the CWA and the SD model. CWA helps to develop the STS models to initiate SD modelling and simulation. The outputs of this combined modelling approach support planning of experiments and guide the analysis of recorded data. Results of the simulation and utility of the artefact are assessed through a Confirmatory Focus Group (Tremblay *et al* 2010, Sterman 2000).

The final part of the methodology assesses the artefact focus through experimentation. New knowledge and understanding on the problem and system also lead to improved models. Once an acceptable result is achieved the outcomes can be communicated to the relevant stakeholders. The methodology is now demonstrated in the next section on a C2 system for border safeguarding operations.

4 Command and Control Case Study

4.1 Identify and Define the Problem

Researchers proposed new communication and situation awareness display technology, based on smart phones and web services, to enhance C2 collaboration for border safeguarding operations. The case study will examine the effect of this new technology on a C2 system for border safeguarding. Border safeguarding entails control and enforcement of state authority on national borders to curb cross-border crime such as illegal immigration, rustling of livestock, poaching, and smuggling. The main goals are the following:

a) Gather information and intelligence from sensors or interaction with the local communities.
b) Management of resources to ensure availability when required.
c) Take action when required, which includes passive measures such as to confuse, divert, avoid detection or distract.
d) Planning courses of action for prioritised tasks.
e) Liaise with other departments and entities involved in border safeguarding operations.
f) Preserve forensic artefacts for prosecution.

4.2 Define Objective and Contribution of the Solution Artefact

The C2 system for border safeguarding operations as captured in an Abstraction Decomposition Space through a WDA is shown in Figure 5. The aim is to capture the real issues of performing work with C2 in border safeguarding operations. A focus point was to relate technological artefacts to objectives of the C2 system. The information gathered in the focus group was captured within the CWA framework. A focus group, consisting of designers and users of C2 systems were conducted to gather information on the requirements of a C2 system. The physical objects in Figure 5 relates to the capabilities to be installed on smartphones used for C2.

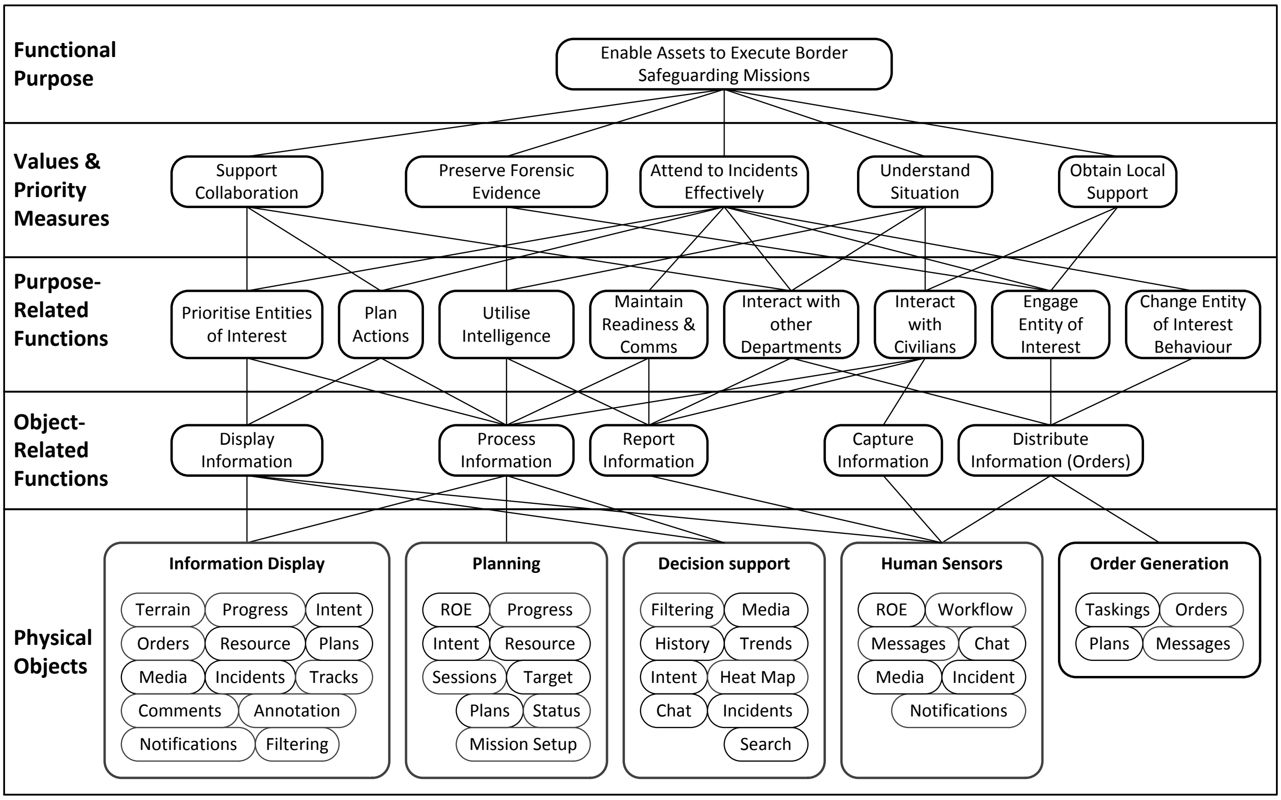

Figure 5: Work Domain Analysis

4.3 Design and Develop Artefact

4.3.1 Command and Control System Model

The solution artefact is captured in the form of a physical system model. This is the same as Model Boundary and Subsystems Diagram (overall architecture of the model) from Sterman (2000). The generic functional C2 model (DOODA) from Figure 1 is converted to a system model in Figure 6 with inputs from the CWA in Figure 5. The diagram identified the following links between functions and system elements:

a) Command Concept. The command concept is captured through the mission and intent which relate to the Values & Priority Measure is the second row of the WDA. This involves the identification of guidance, priorities and constraints in the system. It cannot be allocated to a single subsystem, but will rather be an input to the planning and sense making process.

a) Information Collection. Within this case study information is collected by human sensors with hand held mobile devices (e.g. smartphones) through interaction with the civilian population in the environment. This has the ability to capture photos and videos as well as adding context in the form of text notifications.

b) Sense-Making. The new technology will display information and provide tools to analyse (process) intelligence in support of understanding the situation. This will be used to identify and prioritise incidents in the environment to be addressed.

c) Planning. Planning relies on understanding of the situation, the intent and state of available resources. This is converted to orders and distributed to the relevant resources for the required action.

Information from the CWA is used to adapt the generic functional model to the specific requirements of the C2 system with the technology introduced. The physical elements are allocated to support the required functions of C2 with help of the CWA. The system elements of Information Display, Decision Support, Planning, Orders, and Human Sensors are different capabilities or configurations of tools in the collaboration technology. A cursory look at Figure 6 already indicates some feedback loops within the system, which is indicated by the flow of the arrows.

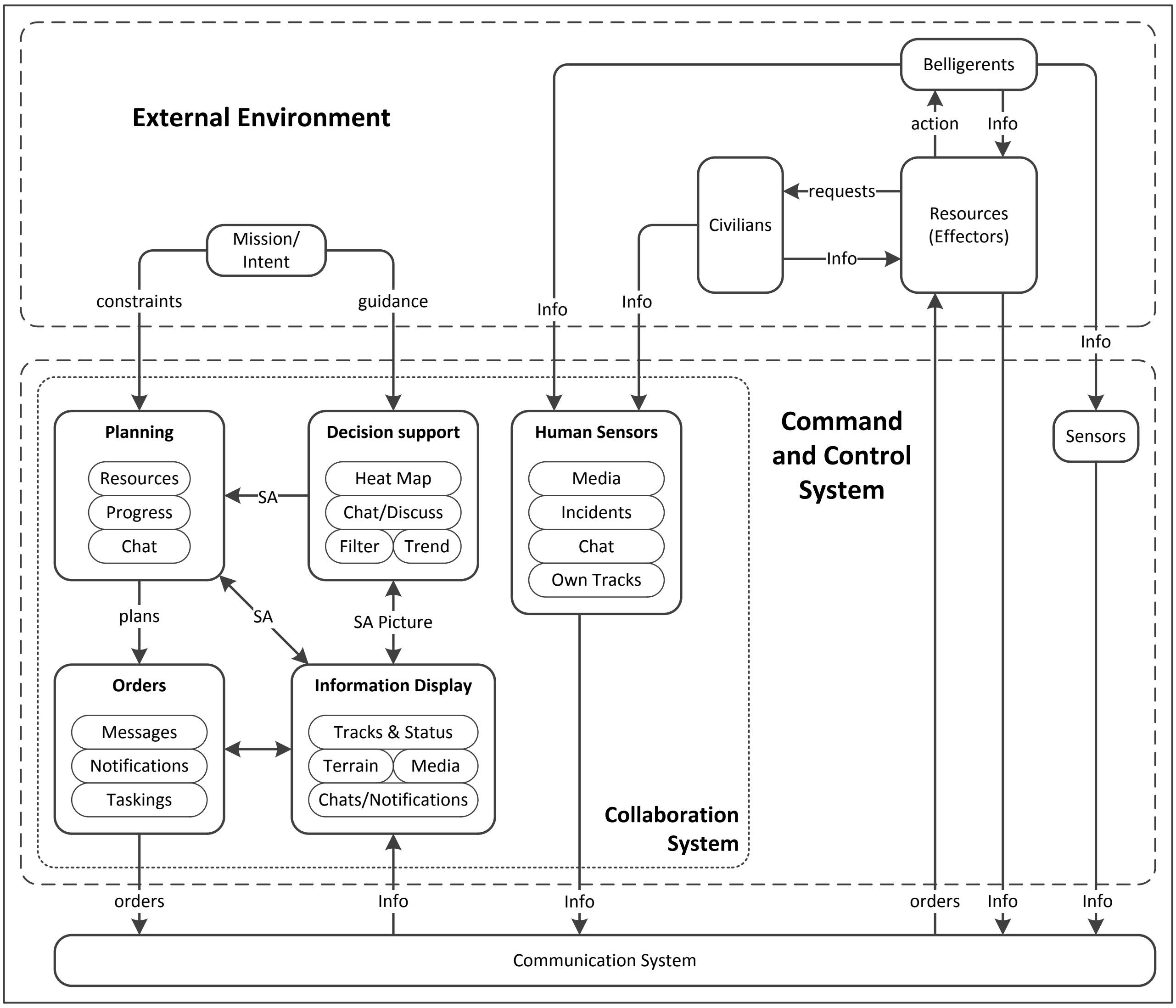

Figure 6: Updated Command and Control System Model

4.3.2 Causal Loop Diagram

The CWA, with focus group inputs (Figure 5), has been used to develop a system model (Figure 6) for C2 in border safeguarding with a new collaboration technology. This model is the basis for identification of causal loops in the system. The dynamic hypothesis is that the proposed collaboration technology will improve situation awareness to ensure that incidents will be better addressed for effective operations. The role of the human decision maker is incorporated in the collaboration system. The Causal Loop Diagram, as seen in Figure 7, is constructed through identification of the variables in the system elements from Figure 6 that influence each other and operation success. The three main loops, which are of interest to this paper, in the Causal Loop Diagram are the following:

a) Own Force Feedback Loop. The available Information (positional and status) leads to increased situation awareness supporting decisions that direct own force action through planning and orders. (Reinforcing Loop)

b) Criminal Action Loop. Observed criminal action (through sensors) adds to the available information to support situation awareness and decisions. The resulting own force action will address the criminal action and reduce it. (Balancing Loop)

c) Human Sensor Loop. Human Sensors observe criminal action as well as receive inputs by the civilian population to add to the available information to support situation awareness and decisions. The resulting own force action will address the criminal action and reduce it. (Balancing Loop)

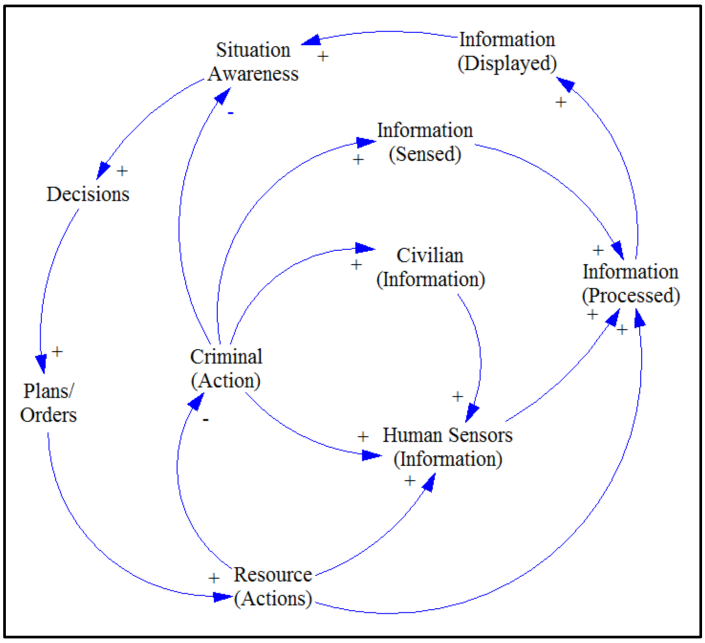

Figure 7: Causal Loop Diagram

The Causal Loop Diagram highlights the fact that the "Human Sensors" are an important node in the C2 system, as it is a source of information on own positions, criminal action and intelligence from the civilian population. It is also important to note that in a border safeguarding environment it is assumed that criminal activity is not aimed at the C2 system and own forces. As a result, information and system operation will not be degraded. However, criminal activities will result in changes in the problem situation which will degrade the current situation awareness until the new information is processed.

4.3.3 Stock and Flow Diagram

A Stock and Flow Diagram is constructed, as seen in Figure 8, to represent the C2 model information flows from Figure 6 and relationships identified in the Causal Loop Diagram in Figure 7. The variables in the Causal Loop Diagram are allocated to either Stock or Flows.

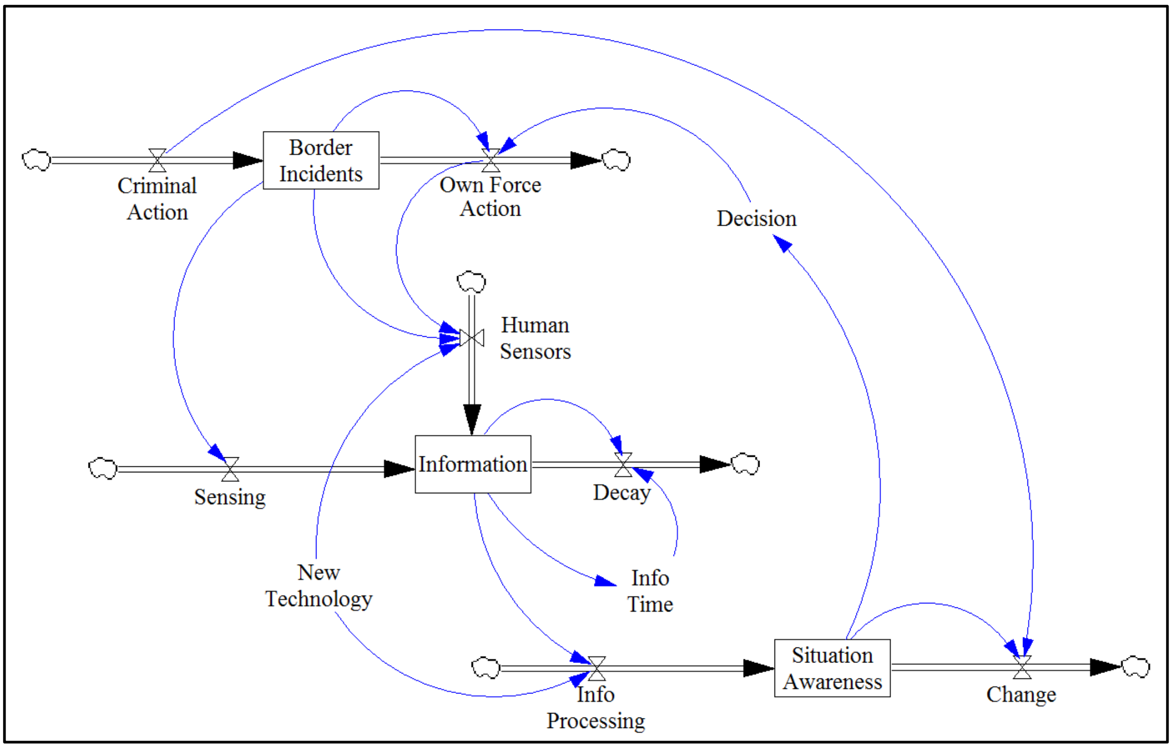

Figure 8: Stock and Flow Diagram

The main stock in the model is information on the border environment due to criminal action. Information is gathered, distributed, processed and displayed to support planning and decision-making. The stock and flow for Border Incidents relate to the external environment for the system under consideration. The third stock represents the Situation Awareness developed with the C2 collaboration system. This is present in the minds of the decision makers, making this a complex STS model.

Criminal action leads to the build-up of incidents which needs to be attended to by own forces. As seen in Figure 6, information on the border incidents are gathered through sensors (e.g. radar and optical technology) or through human sensors operating inside the environment. This leads to an accumulation of information in the system which has a limited time of value. Therefore, the stock of information decays over time. Situation Awareness is developed through processing and interpretation of information. This leads to decisions on action to be taken by own forces in reaction to incidents. The understanding of the current situation is reduced when new incidents occur in the environment.

The aim of the new technology is to enable human operators in the operational environment to be sources of information. This includes reporting of own actions and statuses as well as observation of incidents. The new technology will also assist commanders in analysing the available information. At this stage no delay in implementation of decisions is considered for simplicity.

4.4 Demonstrate Artefact in Context Ability to Solve Problem

SD simulation with the Stock and Flow Diagram from Figure 8 demonstrates the ability of the model to assess the impact of collaboration technology on the complex STS. The behaviour of the system is analysed to understand the requirements on technology artefacts to be implemented. The input of criminal action in the environment is simulated by a pulse train over a period of 20 hours. The assumption is that an incident occurs every five hours, of two hour duration. The baseline level of Border Incidents is provided in Figure 9 without any action of friendly forces or C2. Note that the level step up at 5 hour intervals due to the pulse train input of incidents.

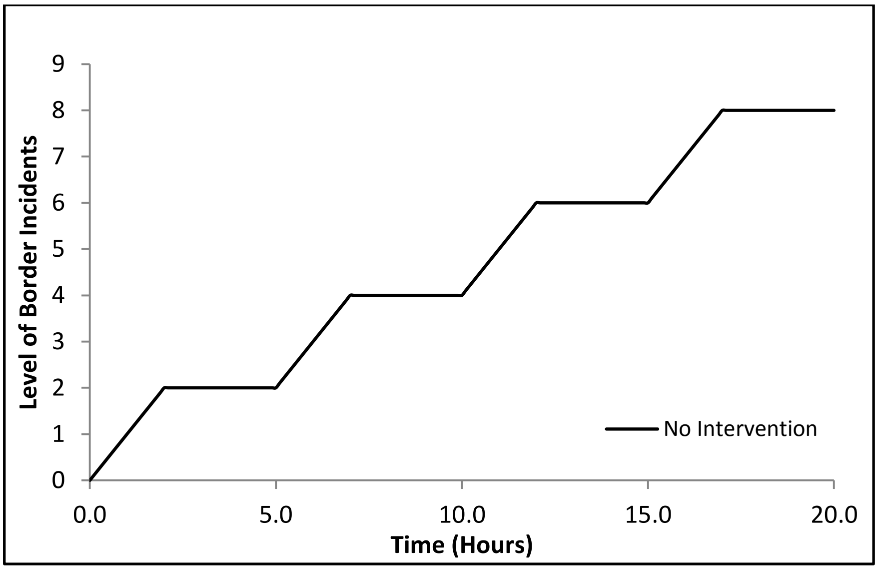

Figure 9: No Intervention or Command and Control

The level of the problem situation as affected by the C2 system over the simulation period is provided in Figure 10. Simulations were conducted with the contribution of the new collaboration technology set to values of 0 (No Collaboration Technology), 1 (Limited Collaboration Technology) and 2 (Enhanced Collaboration Technology). The simulation output in Figure 10 indicates that increasing the contribution of Cognitive Support Technology, the incidents occurring will be resolved in a shorted period and with a lower level (intensity). The difference between the first and the remainder of the incidents are due to information and situation awareness in the system that results in better responses.

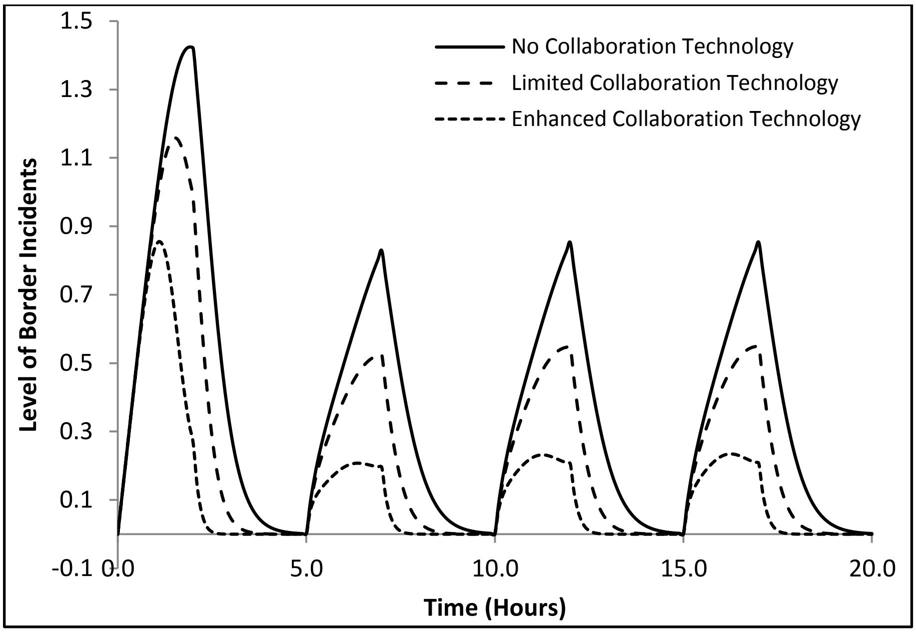

Figure 10: Level of Problem Situation

The level of information in the system increases drastically (Figure 11), because the new collaboration technology enables human operators to act as additional sensors. They report their position and status as well as their observation on criminal activities.

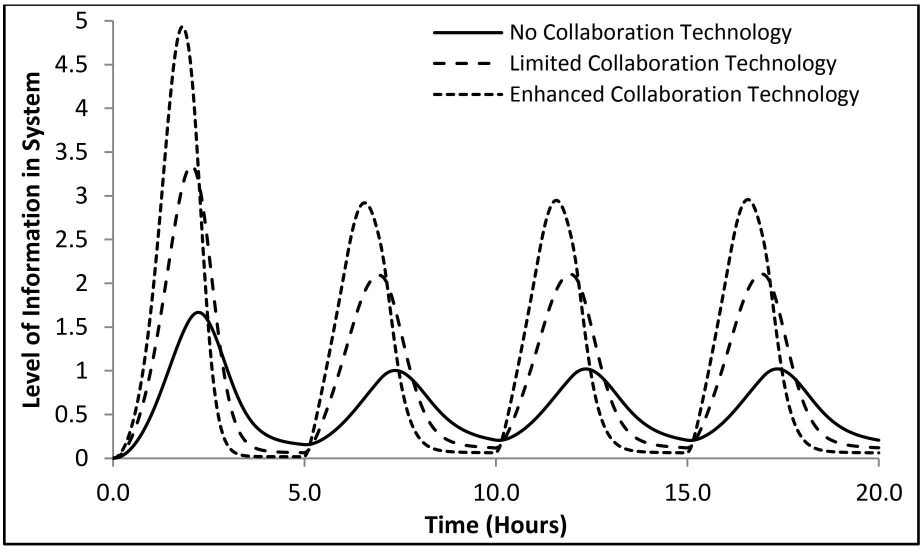

Figure 11: Level of Information

Finally, the level of situation awareness available to make decisions on actions is shown in Figure 12. Again the contribution on the new technology is clear through the amount of information available as well as intelligence analysis support. It is interesting to note that the situation awareness dips at the intervals where the environment changes due to criminal action. This necessitates situation awareness to be built up again for effective action.

Despite using linear input values, the output of the SD simulations indicates where and how the new collaboration technology will influence the system. Knowledge gained from this exercise will assist in planning experiments with the system. This should also be used to identify parameters for measurement with predicted expected values. Future research will aim at using more realistic input data as well simulating over longer periods. Furthermore, obtaining a generic and tested SD model for C2 will assist in assessing the effect of changes to the system will have.

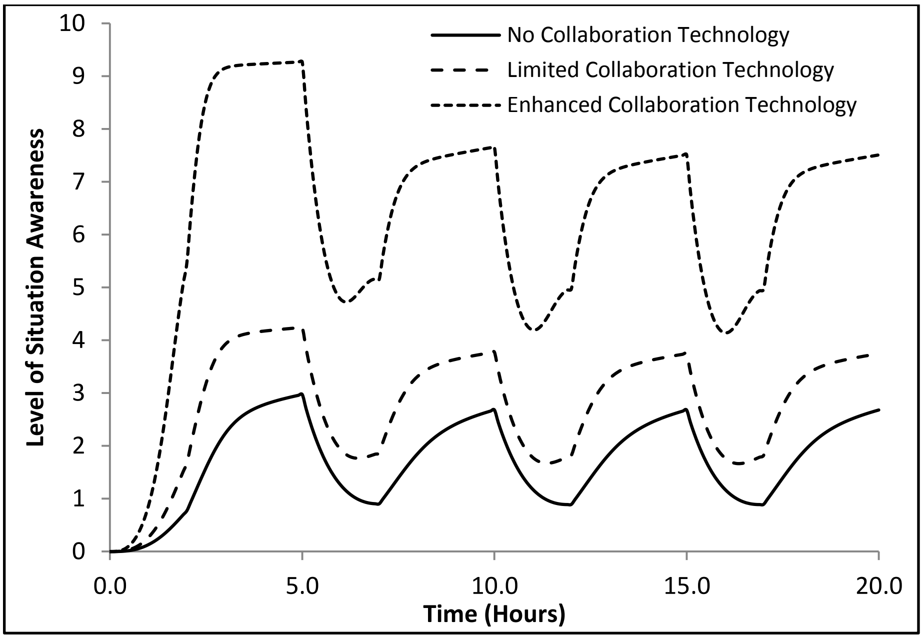

Figure 12: Level of Situation Awareness

4.5 Evaluation to Determine Ability of the Artefact Solve the Problem

The output of the previous phase will be used to plan field experiments with a C2 system and related technology in a border safeguarding operations environment. The analysis and interpretation of measured outputs will support knowledge on the problem and help identify requirements for system development. The cycle of learning will also improve the models for further learning. The actual experiments are outside the scope of this paper.

5 Conclusion

Careful modelling and analysis are required to develop complex a Sociotechnical System. This is applicable where human commanders use a C2 system, consisting of decision support and communication, to make sense of a situation in support of decision making, planning, and distribution of orders. Effective modelling can support experimentation to gain an understanding of the system requirements under diverse conditions.

The modelling methodology needs to capture the human contribution to the system success as well as the dynamic interaction due to effect of the environmental constraints and system operation. The inclusion of CWA and SD in a DSR framework will support modelling of C2.

This paper demonstrated the modelling methodology for border safeguarding operations. Some interesting observations, that may not always be intuitive, could be made on the contribution of cognitive support technology to the C2 system. This can be used to guide allocation of development priorities as well as planning better measurements during field experiments.

Another contribution of this approach is the development and continuous refinement of a generic C2 model for SD. This will provide a reference implementation for future modelling and analysis efforts. The proposed methodology now needs to be used in other scenarios for further refinement.

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