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Title: Extending C2 Frameworks for Modeling and Trials: A Novel Approach to Assessing Technology Insertion

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Abstract

Existing military C2 frameworks are limited in assessing the impact of technology insertions. While these frameworks have been useful in highlighting technology related issues and their direct effects within the organization, they have been less useful in exploring the links between C2 changes and battlefield effects. Additionally, these frameworks tend to focus on a limited set of key performance impacts. Given the trend to introduce new C2 technologies at lower tactical levels within Land military forces and the complex socio-technical issues which arise, the requirements for a broader C2 assessment framework become more pronounced. We propose a novel C2 assessment framework, developed using a multi-disciplinary approach that builds on existing modeling and trials frameworks. This novel framework bridges the gap between traditional C2 measures and battlefield performance, and encompasses methods from various disciplines including systems engineering, operations research and human factors.

Introduction

Existing military command and control (C2) frameworks have been useful in highlighting technology related issues and their direct effects within an organization. They are, however, limited in assessing the full range of impacts resulting from technology insertions and in exploring the links between C2 changes and battlefield effects. Additionally, traditional C2 frameworks have not adequately covered the wide range of key performance impacts common with technology insertions, particularly regarding human factors outside the physical ergonomics field.

More recent military C2 frameworks such as NATO's *Soldier Modernisation Measurements for Analysis* (NATO LG1, 2005) provide a systematic process and model for evaluating C2 technology insertions. These frameworks focus on mission level capability, usually represented by task-based performance (speed and navigation performance for example), with little or no exploration of links between C2 technology changes and higher-order battlefield effects. As the doctrine of NCW and its proponents continue to push for new technologies, C2 frameworks will be required to not only identify changes in mission level performance, but explain them on a socio-technical system level. This approach will allow a more holistic assessment of the technology without excluding non task-based criteria such as cognition and network performance.

This paper will introduce a novel framework to support C2 assessments which is based and extends on existing models. The aim of the approach is to identify potential causal links between technology insertions and battlefield effects, in order to assess the operational costs and benefits of C2 insertions into the battle group (BG) at lower tactical levels. A key product of the proposed framework is an analytical plan that improves the likelihood that analysts capture the right data, at the right time, in the right place, in order to answer the right questions (Curtis, Dortmans and Ciuk 2006).

It is proposed that existing C2 frameworks do not adequately provide the basis for making holistic assessments of operational costs and benefits. Given the broad range of disciplines required to make holistic assessments, a single methodological approach is unlikely to suffice, and a multi-disciplinary approach is therefore required. Additionally, military socio-technical systems are necessarily complex, comprising many inter-related and co-acting human, technical and environmental influences. Therefore, there are unlikely to be simple causal relationships between technology insertion and performance outcomes. In attempting to link cause and effect in such a complex socio-technical system, complex systems approaches are also required.

Complex systems are difficult to analyse because the interdependency between system components means that they cannot easily be deconstructed into a series of manageable or predictable pieces (Alberts & Hayes, 2006). This complexity leads to an intractable situation for the analyst in the field attempting to explain the causes of observed mission outcomes. While characterizing a complex system completely is arguably impossible, it may be possible to provide a less complex view of the system for a particular context (Gharajedaghi, 2005). The belief then is that, through a complex systems approach, it is possible to come up with a justifiable and tractable system representation for evaluation of C2 technology insertion. Such a representation may identify the key interrelationships without unduly simplifying causes and effects.

Our approach aims to capture a broad and comprehensive range of the complex interactions arising from C2 technology insertions and their impact within the organization through to their battlefield effects.

Existing Frameworks

A number of existing C2 assessment frameworks were considered for use prior to developing our own framework. However, we identified a number of deficiencies in these frameworks that restricted their usefulness with tactical C2 technology insertion assessments. These limitations included: the breadth of performance outcomes covered, the explanatory power of the assessments, the level at which C2 insertion occurs and the ability to address the performance costs associated with technology insertion. A sample of these frameworks is discussed in the following paragraphs.

A current trend in Western military forces is pushing new C2 technologies down to the lower levels of the command structure (Platoon and Fire Team for example). This trend is based on the tenets of Network Centric Warfare (NCW) which aim to improve collaboration and coordination by employing advances in communication and computing technology (Schmidtchen, 2007). Much of the impetus for the introduction of NCW has been led by the US military, where NCW is an operational-level concept placing an emphasis on technology solving military problems (Cebrowski & Garstka, 1998). The US Military's high level NCW Framework describes how improved information and network quality flows through to improved war fighting effectiveness.

Court (2006) developed a modified version of this framework which supports the UK's version of NCW - Network Enabled Capability (NEC). Court (2006) conducted a thorough review of the available literature, including case studies and experiments from NATO, the UK, the USA, Canada and Australia, and included key human factors research into decision making and automation. While Court (2006) concluded that the evidence generally supports the original US hypothesized NCW benefits chain, several key modifications were also proposed. Court (2006) highlights how benefits of NCW are reliant upon various inputs. For example, quality networking will not by itself produce improved shared awareness; the system also needs to ensure that quality information is produced in the first place and that it is easy to share that information. Furthermore, using shared awareness to make quality and timely decisions will not by itself maximize the benefits gained from networked information, unless it is also accompanied by adaptive C2 processes. Finally, Court (2006) emphasizes that highly trained and capable people are required if full benefits are to be achieved. Court's (2006) framework is one of the first models to identify some of the critical assumptions and preconditions to effective C2.

Ultimately, the NCW and NEC frameworks demonstrate too high a level of abstraction to be useful in assessing the effect of the introduction of a new C2 technology at the tactical level. Additionally, they do not explicitly address potential costs as well as benefits from the technology. The US NCW framework generally assumes a linear flow of benefits, with improved networking leading to improved information sharing. This in turn leads to better quality (team) interactions, and then on to greater individual and shared awareness. Greater individual and shared awareness in turn leads to better decisions, resulting in better actions, synchronized entities and effects. These benefits are said to flow through to improved operational effectiveness without providing the justification or logic for this assertion. The UK's modified framework, while also aimed at too high a level for our purposes, does identify some key additional performance modifiers that are required to fully realize the benefits of networked systems (information quality, ease of sharing, C2 agility, and well trained and capable staff).

NATO's *Soldier Modernisation Measurements for Analysis* framework (NATO LG1, 2005) provides a generic model to be used on trials and in simulation modeling. The framework is constructed on a hierarchical task analysis of typical soldier activities (navigate, move, engage, observe and attack for example). A series of measurements corresponding to these tasks and activities is also provided, classified by a particular level of analysis (force effectiveness, mission outcome, mission effectiveness, soldier task effectiveness and soldier task performance). The measures are also situated within vignettes (such as advance, assault and debrief), which provide the context for the measures. These measures are useful in assessing soldier performance, and the aggregated mission level performance, but give no insight into why C2 changes affect outputs. Additionally, the framework does not fully account for the effect of C2 changes being implemented at lower levels of the command structure.

A recent RAND study (Gonzales et al. 2005) explored the linkages between network centric operations capabilities and combat power within Stryker Brigades. In exploring this issue, the study examined the extent to which Network-Centric Operations (NCO) principles, a development of the original NCW tenets (Alberts and Garstka, 2001), are realized in this new type of unit. These principles are embodied in the NCO conceptual framework which illustrates the linkages between war fighting elements of the Stryker Brigade and "key NCO capabilities or attributes and their relationships, influences, and feedback mechanisms" (Gonzales et al. 2005, p. 17). The Rand study's framework provides a clear example of how to assess the impact of network effects inherent in C2 insertion on battlefield effects. Their framework however, is too narrowly focused for our purposes as it:

- excludes non-NCW influences that might be experienced with C2 insertion,
- employs a limited view of mission effectiveness that is based primarily on lethality and survivability, rather than a broader definition that encompasses a wider spectrum of operations, and
- does not consider operational costs within the framework.

In summary, generic frameworks adapted for C2 tend to assume NCW benefits as outputs and do not adequately consider the operational costs of technology introduction. In addition, the intermediary human, technical and systems factors within socio-technical system are rarely considered. Therefore any benefits measured cannot be traced back to specific technology impacts on factors within the organization. Ultimately, there are no frameworks to our knowledge, which adequately represent C2 technology insertion impacts at lower levels in the organization.

The Framework Development Process

Given that the results of technology insertion are multi-faceted, including technological performance aspects as well as human performance issues, and systems aspects, we took a multi-disciplinary approach. The research team included operations researchers, human factors specialists, systems analysts, military personnel and technologists, while research methods were used from the operations research, systems engineering and human factors fields.

Figure 1 illustrates an overview of our proposed Framework. The development process started with an initial review of previous research in the C2 area, augmented by information obtained from face to face interviews with subject matter experts (SMEs). This process led to the identification of mission effectiveness criteria and critical issues, which contain hypothesized effects of the introduction of a Battle Management System (BMS). A BMS comprises various software tools integrated with digital maps providing warfighters with an increased planning, navigation and battlefield analysis capability. The BMS is also the central C2 technology being introduced into the Australian Army.

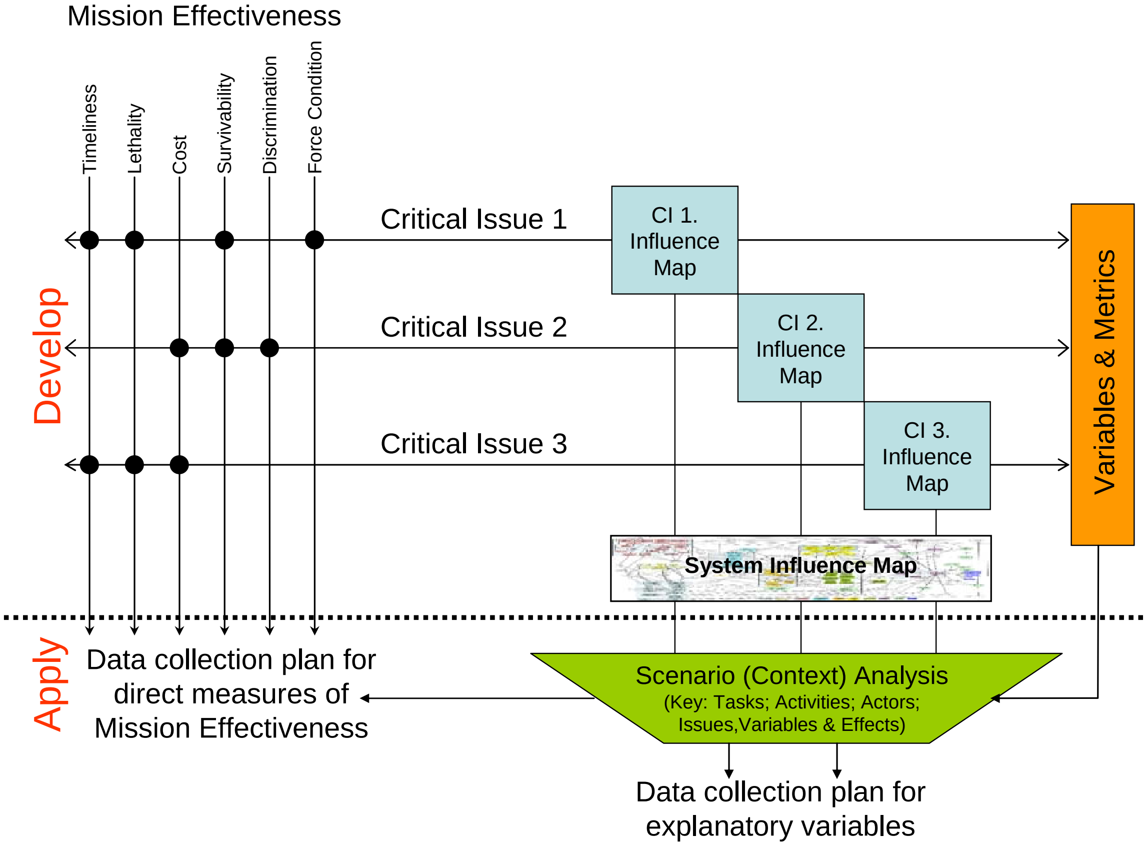

Figure 1: Diagrammatic representation of the framework development and application process

Figure 1 shows how the Framework combines these hypothesized cause and effects for each critical issue, and how those linkages eventually flow through to data collection plans for both intervening variables and direct measures of mission effectiveness[1] (which represent BG performance criteria). The sections which follow provide a more detailed account of the Framework's components and how they were developed.

[1] Mission effectiveness is defined as the ability of the military unit to successfully accomplish a mission while not causing unintended harm.

Reviewing the Body of Evidence

Initially, a study was conducted to identify the potential impacts arising from the technology insertion. This study included reasonable expectations arising from Army SME interviews as well as hypotheses from the literature. The interviews used an adapted version of the Simulation Interview (Militello & Hutton, 2000), which is used for investigating the use of future systems. This technique focuses on the actions and critical cues used within a scenario and then adapted to include probe questions relating to the interaction between an operator and a new system. The associated literature review which was part of this study spanned various fields including human factors, communications and networking, and in-theatre operational reports.

Identifying BG Performance Criteria

A key emphasis of the Framework is on performance from the perspective of the battle group commander rather than the perspectives of other stakeholders. This means we are not primarily focused on the performance of individual subsystems, but rather, on how the battle group completes its final mission. The battle group performance criteria, developed in conjunction with SMEs and from the literature, are shown in Table 1, along with their descriptions and rationale for inclusion.

Table 1: BG Performance Criteria

BG Performance Criteria	Description	Rationale for Inclusion
Survivability	Own forces killed, incapacitated or captured such that they are unavailable for re-tasking at the end of the mission, expressed as absolute numbers for both.	Survivability was included as it could be reasonably argued that from a BG commander’s viewpoint that the lower the casualties sustained the better the outcome of the mission. That is, it is not sufficient to merely complete the mission if the Force is consumed in the process.
Lethality	Enemy killed, wounded or taken prisoner so that they can take no further part in the campaign (including enemy who retreated/ withdrew so as to take no further part in the mission).	Lethality was included as it could be reasonably argued that the more enemy casualties resulting from a conventional war fighting mission, the better the outcome of the mission.
Discrimination	Collateral damage suffered by neutral elements or civilian infrastructure.	Discrimination captures the ability of the force to not cause unintended harm while executing its mission and therefore, in a complex war fighting context, contributes directly to the outcome of a mission. That is, achieving a military objective while causing high levels of civilian casualties may be considered a failed mission from a campaign perspective.
Timeliness	Time taken to achieve key mission events (as defined by	Timeliness was included as it could be reasonably argued that the quicker a

	Standard Operating Procedures).	mission is completed, the harder it is for an enemy to respond effectively, and the better the outcome.
Cost	The usage of fuel, rations, batteries, ammunition etc.	Cost is included despite it not necessarily being an important consideration of the BG Comd as to the success of the mission. However, like discrimination, it is seen as important from a higher command/campaign viewpoint in defining the outcome of a mission. It is a critical variable in comparing efficiency between treatment groups in executing the same mission.
Force Condition	A measure of the ability of the force to continue operations in terms of the physical and mental condition of the soldier at the end of the mission (due to adequate nutrition, rest, medical treatment) as well as morale.	The ability of the Force to continue operations after completion of a mission was added as a potentially very important consideration that might be affected by technology insertions.

Identifying Critical Issues

From the simulation interviews and literature reviews mentioned above, a number of critical issues that are likely to be heavily impacted by the introduction of new C2 technology were identified. These critical issues serve several key purposes in the framework. Firstly, they allow the initial hypotheses to be gathered together as causal links. Secondly, they are clearly identifiable themes that can be easily recognized in the field by analysts as part of the data collection activities. Examples of some of the critical issues identified include: the coordination of offensive support; fratricide and the use of voice versus data.

Representing Research Hypotheses as Inter-related Cause and Effects

Developing a representation of the potential effects of a C2 technology insertion is an iterative process. A view of these hypothesized effects was iteratively developed using a diagrammatic approach sometimes known as concept or influence mapping. Working from an initial high level model of the casual chain (similar to the model proposed by Court, 2006) more complex interaction diagrams were developed for the various system sub components. These components encompassed diverse areas such as network performance, cognitive states and team qualities. These were then re-integrated into a single view of all (networked) hypothesized interactions. Figure 2 below illustrates a simplified version of this single view, focusing on the introduction of the BMS.

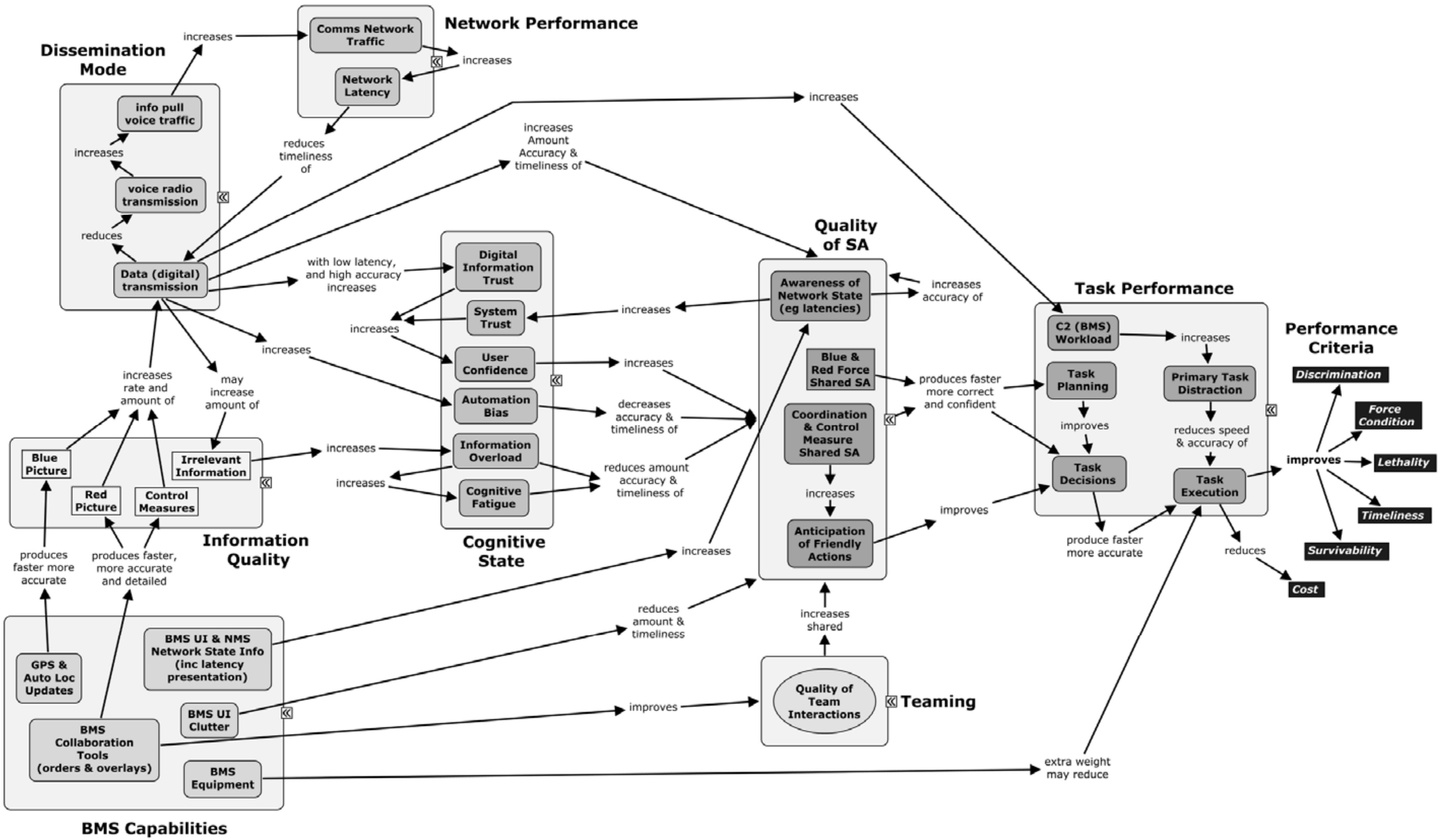

Figure 2: Causal - Influence mapping of the hypothesized effects of the introduction of the BMS

As part of this process we also incorporated individual cause and effect diagrams for each critical issue. This acted as an iterative way to ensure that not only all relevant hypotheses were included in the larger diagram, but also that the interactions between the critical issues themselves were not over looked. The final diagram was then checked for inconsistencies and duplications. Although the complete influence diagram is difficult to read, it does provide a comprehensive and more understandable view of the problem space if one focuses on a single critical issue (fratricide for example) as shown in Figure 3 below.

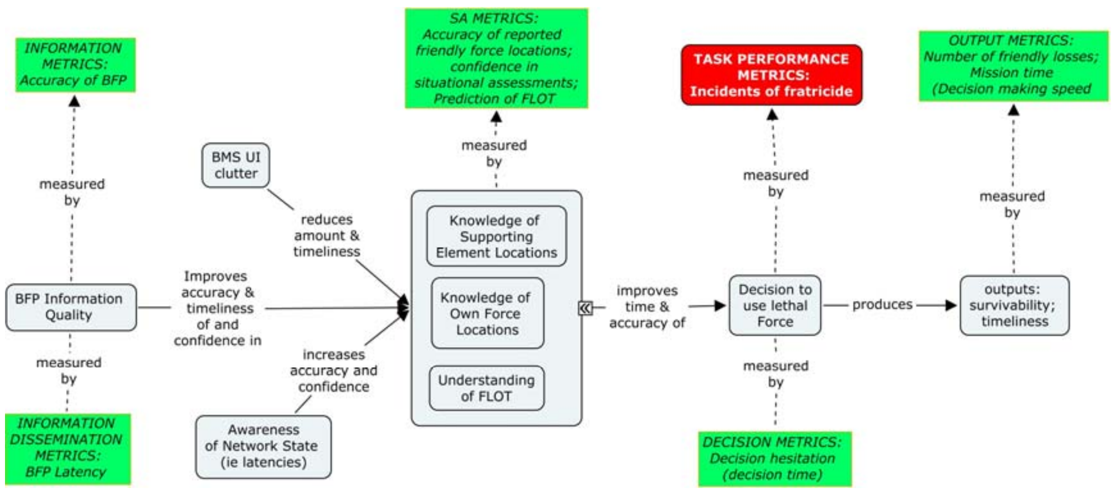

Figure 3: Fratricide critical issue influence diagram

Figure 3 demonstrates how the influences relating to incidents of fratricide (in the context of the introduction of C2 technology) can be clearly identified and operationalized. This provides an effective 'cheat sheet' for analysts on the ground or research designers in the early part of their designs.

Identifying Potential Metrics & Measures

Based on our literature review we identified the key variables that need to be measured at each point in our chain of possible cause and effect. For example, in order to analyze the effect of the new technology on the coordination of Offensive Support you might need to measure blue picture update rates, network latency, the ratio of pushed versus pulled information, various aspects of participants' cognitive state and their levels of situation awareness, as well as key aspects of task performance. We also identified potential ways that this information might be collected (remembering that this would be activity dependent).

The Framework Application Process

The Framework described above provides a holistic and synthesized view of the possible ways the introduction of the new C2 capability might affect BG performance, as well as suggested ways to identify and measure the potential flow on effects for each critical issue. While this is useful in itself, the primary purpose of the framework is to help analyze the effect of the new technology in specific situations. The strength of the Framework is the direction given to help analyze these effects in realistic situations.

Scenario Analysis

The potential effects of the technology insertion were applied in the context of stakeholder provided scenarios. The model developed above was used to identify the potential effects of the new technology in the context of a specific mission. Swimlane diagrams were used to identify all the tasks and activities of actors for the key phases of this mission. This was achieved using a combination of SME input, war gaming and historical analysis. The swimlane model was then extended to link the scenario with critical issues, key variables and performance criteria.

Figure 4 below provides an example of a sub portion of this analysis. The first seven columns in the diagram represent the actions performed by key actors in the scenario. Some actions are depicted as intermittent or recurring (rounded rectangles) and others as 'one off' activities (ellipses). The rows represent distinguishable tactical tasks.

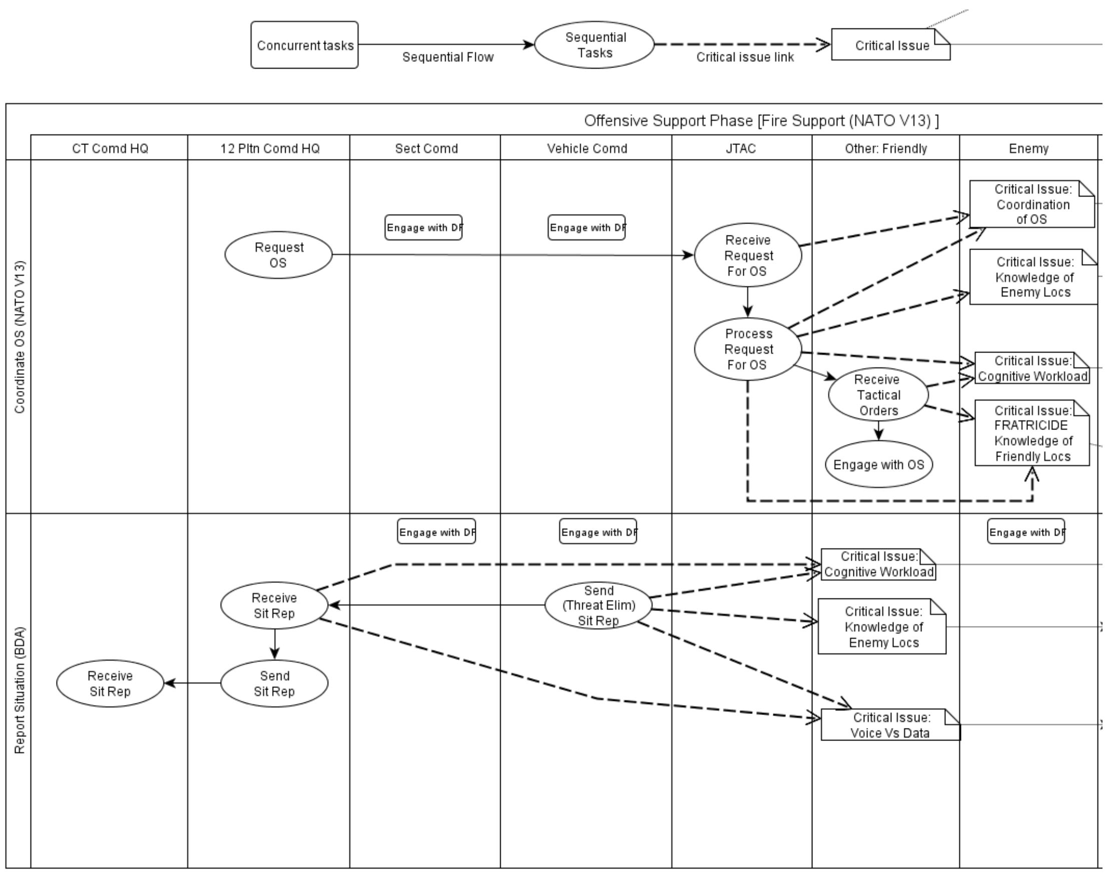

Figure 4: Swimlane diagram for a portion of a scenario

The key part of the analysis is shown in greater detail in Figure 5 below. Here we identify, for each activity, the critical issues that may be affected by the introduction of the new technology and from there, the possible tangible effects the technology might have on task performance in that circumstance. Key variables were also identified that modify the effect of the BMS on BG performance criteria.

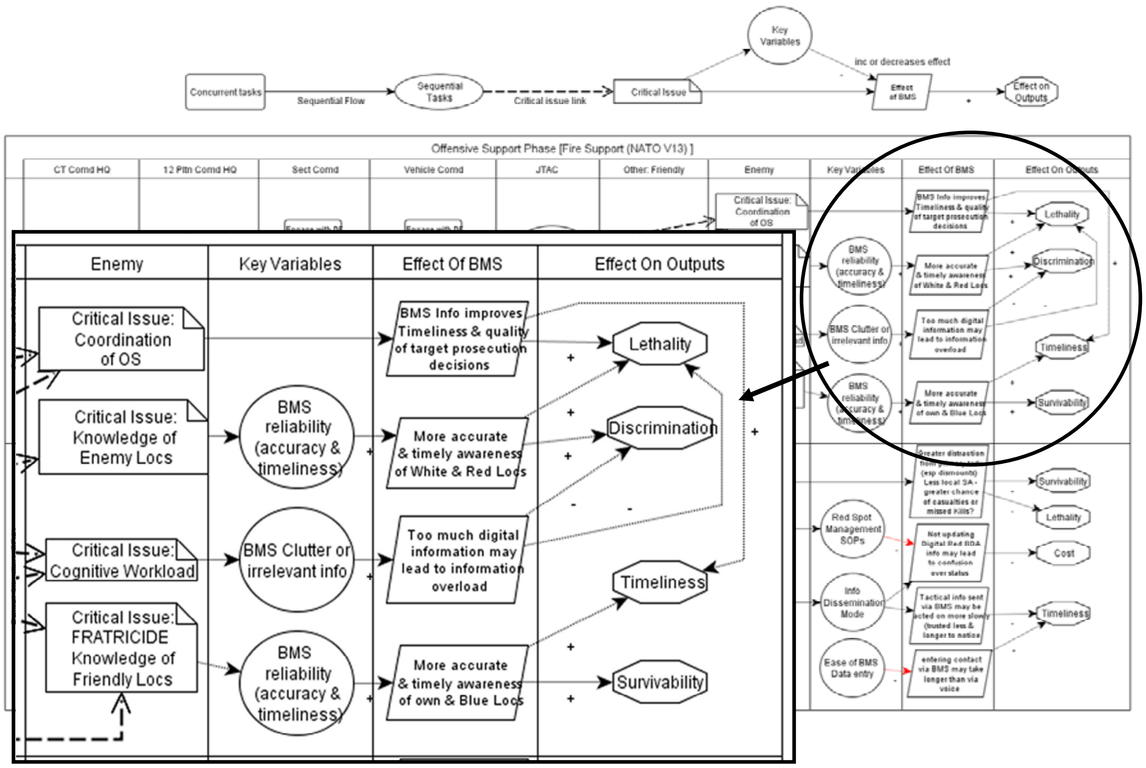

Figure 5: Extention of Swimlane diagram to show potential effects of using a BMS

The swimlane models are then validated through SME war gaming. This provides an accessible way of engaging the key stakeholders which would not be possible using complex cause and effect diagrams, as shown in Figure 2.

Developing the Analysis Plan

The next stage in the framework is to design an analysis and data collection plan based on the above swimlane model(s). Mapping the collection plan against the model, will ensure that the right data will be collected from the right place at the right time to support later analysis. The nature of this analysis plan will of course be dependent on the planned activity (simulation or field trial for example).

Analyzing the Effects

The final stage is to analyze the results. We expect that the results will be evaluated at two levels. First, the results will be analyzed at the critical issue level by identifying how the chain of cause and effect influenced a particular key issue. Second, we will conduct a separate analysis of the effects on our identified higher level Battle Group performance criteria (survivability for example). Here we will use our cause and effect model to work back down the influence chain to assess whether the C2 technology in question made a difference, and if so, how.

With the collection and analysis of data, it is possible to begin identifying probable causal links within the model and permit more informed judgments and decisions regarding operating procedures, acquisition, employment and training.

Conclusion

In summary, generic frameworks adapted for C2 tend to assume NCW benefits as outputs and do not adequately consider the operational costs of technology introduction. In addition, the intermediary human, technical and systems factors within the socio-technical system are rarely considered. Therefore any benefits measured cannot be traced back to specific technology impacts on factors within the organization. Ultimately, there are no frameworks to our knowledge, which adequately represent C2 technology insertion impacts at lower levels in the organization.

The framework proposed within this paper extends on these current military C2 frameworks by permitting not only the assessment of net operational costs and benefits, but also provides insights into the probable causes of these effects. Though capturing the complexity of a military socio-technical system was difficult and time-consuming, the resulting benefit far outweighs the initial costs in terms of time. Rather than simply identifying that a particular measure of performance (or even overall mission success) has been improved due to a particular C2 technology, we propose that this framework will allow an explanation of why and how that performance was increased (or how that success was achieved). This information is useful across the entire Defense Organization, and allows a more directed and rigorous approach to the evaluation and assessment of technology insertion at lower levels of the command structure.

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