The System Dynamics Approach to Network Centric Warfare and Effects Based Operations - Designing a "Learning Lab" for Tomorrow's Military Operations

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Abstract

Command of military operations requires leaders and teams who are able to make decisions and respond in an appropriate, timely manner even in highly uncertain situations. The degree of situational uncertainty has continued to increase as military requirements have evolved in response to changing conditions around the world and advances in information systems that have made more information available. It is in the light of recently developed, but not yet matured, concepts such as Network Centric Warfare (NCW) and Effects Based Operations (EBO), we discuss the radically changed conditions for acting and learning in the military operational environment. We suggest a new approach, linking the principles of best practice EBO modelling and analysis with system dynamic insights, yielding design requirements for a "learning lab" for Network Centric Operations. The purpose of the learning lab would be, through man-machine and inter-team interaction, to improve mental models of commanders and teams, and thus improved outcomes of future operations.

Introduction

Command of military operations requires leaders and teams who are able to make decisions and respond in an appropriate, timely manner even in highly uncertain situations. The degree of situational uncertainty has continued to increase as military requirements have evolved in response to changing conditions around the world and advances in information systems that have made more information available, faster than ever before (NATO, 2003).

To respond to the terrorist threat, for example, military forces must "anticipate the unexpected and be prepared for the unimaginable" (NATO, 2003). The people and organizations of the military must be adaptable and technology must enable their adaptability. Adaptability is both a proactive and reactive process and can be seen in what military forces do and how they operate.

Information systems are a critical component of adaptable performance – especially of distributed, decentralized, yet highly interdependent military forces required to deftly transition between modes of operation and levels of intensity (e.g., from high-intensity war-fighting to low intensity peacekeeping, or vice versa) in collaboration with joint and coalition forces.

As Horn (2003) makes clear: "Commanders will be required to operate in, and be comfortable with, ambiguous and uncertain surroundings. Their options for using force will often be restricted. In addition, of necessity, they will require the capability of adapting physically and theoretically to changes in the immediate operational area as well as in the larger international security environment. These sorts of uncertain situations will also demand that individuals, units and formations be agile, flexible and capable of responding to the unforeseen and unexpected." The future conflict will first and foremost be of an asymmetric[1] nature.

Network Centric Warfare (NCW) and Effects Based Operations (EBO)

The development of concepts such as Network Centric Warfare (NCW) and Effects Based Operations (EBO) are attempts to structure, understand and take advantage of the opportunities that are now exposed in the transformation processes involving technology, organisation, doctrine, training, leadership and culture. NCW essentially encompasses the idea of interconnecting a heterogeneous range of actors and objects (typically called effectors, sensors, decision makers etc) in the battle-space through telecommunication and computer networks. The advantages of NCW are (Diesen, 2004):

- The most ideally located decision maker may engage any target within range of the networked sensors, and may employ the best-suited effector for the engagement mission (self-synchronisation).
- Multi-role objects allow interchange of information and flexible usage of all resources (multi-functionality).
- All levels of the command organisation may receive and utilise the available information, at no incremental cost (information "overlaying").

The above benefits not only provide solutions and opportunities, but also pose central dilemmas. As an example, consider the self-synchronisation and overlaying aspects of NCW. In effect, these will lead to a "collapse" of the traditional command hierarchy (tactical, operational and strategic levels). When all actors receive all information, there is a high risk of information overload, let alone potential confusion when it comes to who is going to implement what decision. Will it be the strategic command or rather the individual solider in the battlefield (the paradox of the "strategic corporal")?

EBO may in many ways be regarded as the defence analyst's attempt to turn the multi-faceted implications of NCW into analysable and well-structured problems, in that it provides a modified and fruitful perspective on *operational dynamics*. That is, it offers insight into the "driving forces" governing modern warfare and conflict resolution. Davis (2001) defines EBO as "operations conceived and planned in a *systems framework* [emphasis made by this author] that considers the full range of direct, indirect, and cascading effects—effects that may, with different degrees of probability, be achieved by the application of military, diplomatic, psychological, and economic instruments."

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[1] An asymmetric threat is a concept used to describe attempts to circumvent or undermine an opponent's strengths while exploiting his weaknesses, and using methods that differ significantly from the opponent's usual mode of operation.

Instead of the established force structure and procedures providing a more or less given effect in relatively well-known settings (*platform* centric warfare), the problem is reformulated to being one of determining what combination of assets may yield a desired effect (*network* centric warfare). The advantage to the latter approach is that it is more appropriate for handling a wider range (even a priori unknown) circumstances.

As pointed out by Davis (2001), the main challenge is that current methods of analysis and modelling appear to be inadequate for representing EBO. Davis proposes the following principles as a guide for defining and conducting analyses, in order to take the "broad view" on defence (force and operations) planning:

- Defence planning should focus on mission-system capability, which refers to the ability to accomplish missions under a wide range of operational circumstances.

- Analysis dealing with EBO should fully confront the scope and magnitude of uncertainty and should deal explicitly with probability and randomness. E.g., assessments of capability should refer specifically to most-likely, best-case, and worst-case outcomes.

- Dealing with uncertainty will require low-resolution exploratory analysis for breadth, as well as more-detailed modelling and gaming for both depth and insight into underlying phenomena. This suggests a "family-of-models-and-games" approach in which information obtained from different members of the "family" is used to inform and cross-calibrate the whole body of knowledge.

- A key element of analytical work should be qualitative modelling, including cognitive modelling of the decision making and behaviour of commanders, political leaders, and even societies. Such modelling should be undertaken in an "uncertainty-sensitive" framework.

- Much of the related modelling should be organized around adaptive systems for command and control and other matters, rather than around the mass and physical characteristics of forces (focus on decisions and behaviours of people and organizations. This implies emphasis on the concepts and technology of agent-based modelling, as well as on system engineering.

- Analysts should vigorously pursue a new base of empirical information—including information obtainable from history and from a combination of gaming, man-in-the-loop simulation, and experiments in battle laboratories and the field. This information should be collected and framed in ways that illuminate complex and subtle relationships and that support uncertainty analysis.

To contrast the "traditional" manner of modelling with the EBO approach, Davis (2001) provides the following examples of reflecting EBO in combat modelling (while observing that some of the alleged dichotomies between attrition based operations and EBO may not be dichotomies at all):

Example 1: Halting an attacking force with long-range fire (e.g., long-range missiles or air raids). Analysis from an EBO perspective considers the possibility that the halt could be achieved much more quickly than is predicted by considering massive attrition alone –

especially if the effort is focused. To reach this conclusion, it is necessary to expand the modelling direct physical effects of the strategy, which depend on the enemy's scheme of manoeuvre (number of axes, dispersion along the axes, etc.) with models involving "soft factors" such as the enemy's apparent cohesion, morale, and motivation. Although such soft factors are usually resistant to precise assessment, they can be represented analytically. Further, the analysis demonstrates how an attrition-based model can be modified to reflect quite a range of softer effects and to become, in essence, a model for assessing EBO.

Example 2: Halting an attacking force with a combination of long-range fire and early-intervention ground forces. In this instance, the downside risk of inserting ground forces would be very high. An imperative would be to reduce the size of the downside risk (own losses), e.g., by considering a deeper defence line, delaying or slowing the advance through early and well-focused strikes, improving the capabilities of the ground force, slowing the enemy's rate of advance, or increasing the magnitude of the long-range fires and their assured ability to support the ground force. If such measures were not sufficient to greatly reduce the downside risk, ground forces would not be employed. As part of this example, a simple cognitive model of the commander can be used to essentially formalize the logic described above in words. The commander's decision is whether or not to insert the ground forces.

Cognitive models of operations = Command concepts

Essential to the successful conduct of a military operation is that the commander, his/her supporting staff, and subordinate units together have a "shared" mental conception of the tasks to be accomplished, the goal(s) to be reached, and the methods to employ. Builder et al (1999) have developed a concept called "Command Concepts", which in essence constitute the commander's mental visualisation of the course of the operation, including desired end state(s). At the most general (cognitive) level, it is required that the commander has the ability to create, disseminate and update/maintain a "command concept" for the planned operation.

Closely linked to command concepts is the Situational Awareness (SA). Endsley (1988) defines SA like this: "Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The SA concept is therefore essential to accomplish rapid and "correct" decision making in operations. According to Brewster (2002), many studies within military and scientific communities conclude that (military) commanders actually rely more heavily on an intuitive versus an analytic approach when in a field environment. The intuitive approach to decision making appears to be chosen when facing: ill-structured problems; uncertain or dynamic environments; time stress; and/or high stakes. The intuitive approach is based on pattern recognition and experience, and goes within the military profession under terms such as "fingerspitzengefuhl" and "coup d'oeil".

Integrating CC, SA and SD/ST

Knowing from the system dynamics (SD) literature that human decision makers generally have problems when making intuitive assessments in situations involving accumulations, time lags, feedback and non-linearities, it may be assumed that the problems will be no less for planners and commanders of military operations. It is thus a general observation that people perform quite poorly in systems with even modest levels of complexity. Sterman (2000) labels this kind of cognitive dysfunction “misperceptions of feedback”. The solution would be to develop “systems thinking” abilities.

Brehmer (2000) points to two main principles when it comes to interpret people’s problems in handling dynamic settings:

- Overemphasis on the present: Decision makers tend to attend to only the information currently at hand, and as a result experience difficulties in accommodating feedback delays. The world is perceived “here and now”, and the information is not processed any further.

- Lack of systems thinking: the tendency to think linearly, that is, to believe that actions and results are directly related and ignore the side effects of actions. This tendency can also be viewed as an over-reliance on information that is readily available, along with a tendency to ignore what must be inferred – such as side effects.

When discussing “command concepts”, Brehmer (2002) issues a warning against relying solely on (direct) feedback control of a command process. Without taking into account inherent delays, the command system would inevitably become reactive and lagging, resulting in loss of initiative and subsequently loss of personnel and equipment. A (mental) model needs to be able to produce reliable predictions of future events if it is to provide the basis for a functional command concept.

Therefore, systems thinking imply first and foremost striking a balance between the feed-forward and feedback modes of information processing. The feedback mode involves perceiving the outcome of an (single or series of) action or event, in order to interpret its causes (“meaning”). Feed-forward, on the other hand, is about being proactive – using interpretations to generate possible future causes of events (mental simulation). The quality of mental simulation will generally be dependent on the experience (”expertise”) of the decision maker, as well as the complexity of the situation.

The table below is an attempt to integrate command concepts (CC), situational awareness (SA), and system dynamics/thinking (SD/ST) abilities. The leftmost column summarises the requirements posed by CC and SA. The remaining columns exemplify challenges found in the categories of time lags, feedback and non-linearities, respectively.

SD/ST challenges CC/SA requirements	Time lags	Feedback (positive/negative)	Non-linearities
1: Perception Detect and classify relevant objects (static and dynamic) and “features” in text and on map.	The “Common Operational Picture” (COP) may be outdated, i.e., reflects a previous state rather than the current.	Misperception of the “age” of a given COP may inadvertently accelerate feedback processes.	A broad range of heterogeneous objects requires that mental models be more elaborate and complex.
2: Understanding Mental model (picture) of the current situation, including events and causes leading up to it. Assessment of forces “at play”, their traits, capabilities and command (personalities).	Different types of objects may have different times to target and effect (the difference being several orders of magnitude at the extreme).	Consider feedback processes when analysing possible causes of events leading up the current situation. (e.g. questioning the “true” motivation of the enemy).	“Force multipliers”: is the idea that two or more effectors engaging a target simultaneously yield a higher total effect than if the same effectors was employed sequentially.
3: Projection Mental visualisation of probable future developments of the situation. Assess congruence between plan and resources. Structure adapted to desired effect. CCIR including confirming and refuting signs. Enemy development. Evaluate C2 criticalities. Contingency plans.	Mental models need to incorporate the effect of delays resulting from e.g. congestion along lines of transportation; the time it takes to disseminate orders and intentions through the chain of command; the time from engagement and to results.	*Positive* (accelerating) feedback may dominate when the operation is on a “winning course”, i.e., gaining a foothold on enemy land may accelerate the progress. *Negative* (stabilising) feedback is dominant in the traditional attrition situation; when left undisturbed, forces will wear each other down to extinction.	Plans should incorporate the possibility that while forces engage and are interconnected in complex ways, a “chaotic” state may occur. While appearing to be uncontrollable, it is still important to understand what determines the seemingly “chaotic” condition.

A training solution for commanders and staff

Experimentation is required to define the training requirements, organizational design, and information system requirements for adaptable performance of military coalitions (NATO, 2003).

In connection with the development of NCW concept(s), it is necessary to create a range of arenas for exercising and testing, where one can get experiences with both technical and human aspects of the NCW concept. We suggest the development of a Minimalist Decision

Trainer[2], or “learning lab”, for NCW with focus on the human aspects. The training solution will have as its main ambition to expose and point to challenges, dilemmas and opportunities inherent in the NCW concept. By providing personnel with a foundation for reflection on these aspects, it is possible to contribute to both individual understanding and organisational development. As a prerequisite for NCW lies the development of a technology infrastructure, facilitating information gathering, sharing and presentation. In a “learning lab” setting for NCW, we assume the required technical infrastructure to be in place and fully operative, and will emulate[3] the most essential features of this infrastructure. The solution will on the basis of this assumption provide a “practice arena” for organising, information gathering, communicating and decision making (within certain boundaries).

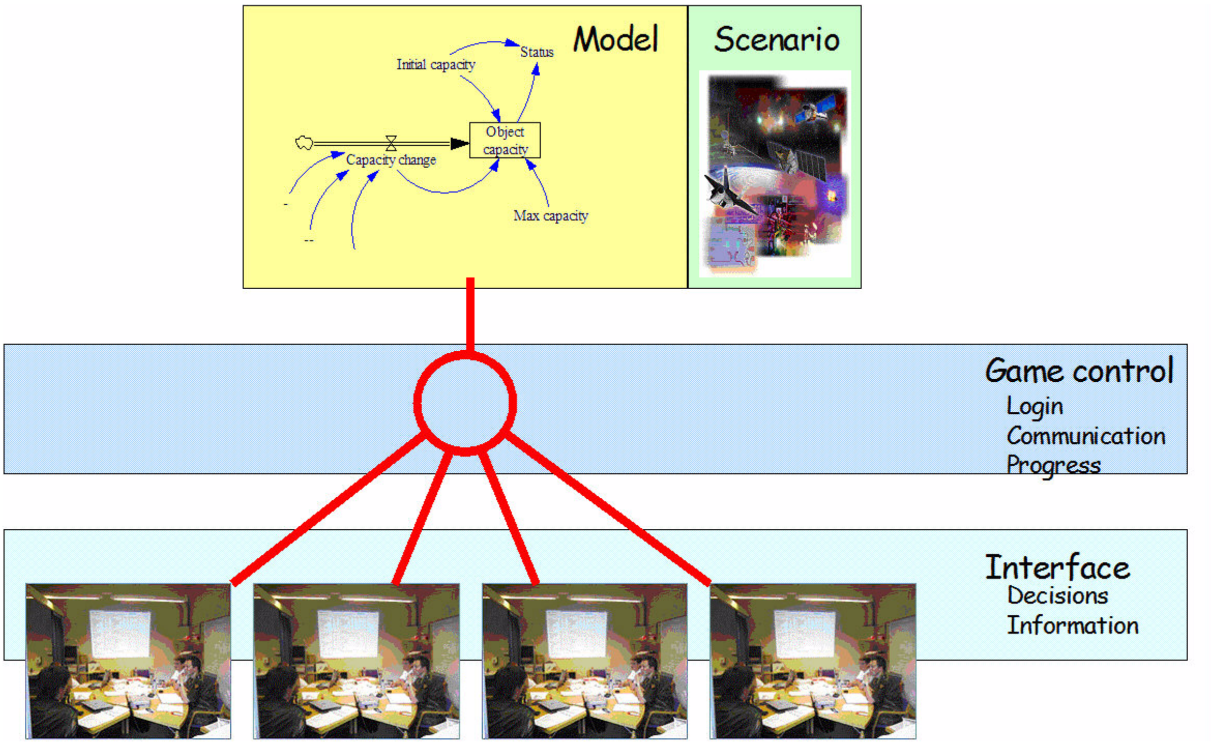

Diagram 1: Organisation layout of Learning Lab for NCW

The “learning lab” provides the arena where two (or more) teams, consisting of different units (a unit may in turn be a single person or a team), can meet to solve problems subject to a scenario. Every unit will have access to a networked personal computer. A simulation game will be run over the network, where participating units receive information and submit decisions. Together, the units’ decisions will have consequences for the progress of the game. By developing a broad spectrum of scenarios, and enforcing restrictions on information access

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[2] A Minimalist Decision Trainer (MDT) provides a solution for simplifying and compressing the training environment. MDT is designed to be a very simple and pedagogically focused simulation-supported system (i.e., microworld) for use in the training of General level commanders (both existing and to-be). MDT is aimed at putting a commander or the command group in charge of own logistics and operations resources in a scenario. The scenario may contain any implied or explicit mission. The resources reflect a combined joint operation; typically there will be less than a hundred units representing land, sea, air and other resources (Bakken and Gilljam, 2003).

[3] Thus, in gaming mode we operate some time into the future.

before and during the game, while allowing communication within team and between commander and team, it is possible to create valid experiences for participating players.

Main features of NCWsim©

The development of a "learning lab" for NCW (called NCWsim) started in January 2004, and we expected to run a first full-scale (12 players or more) demonstration game at the end of April this year. A key design principle has been to involve dedicated user organisations (e.g., the national joint operational headquarters) throughout the process. As such, the future users will have had major impact on design issues such as user interface, objects and their behaviour, communications channels, and range of scenarios to consider.

The final version of the simulator will have a scenario generator (from a database of relevant classes of challenges to national and international security) and automated game set-up functionality to facilitate play with broad range of scenarios. We employ a three-layer architecture: Vensim DLL provides the simulation, Visual Basic.NET acts as a "glue" layer, and Macromedia Flash is the graphic user interface showing dynamically updated maps. This architecture allows one to substitute Flash for other industry-standard operational displays and interfaces. A long-term ambition is to provide interface for agent-based simulation.

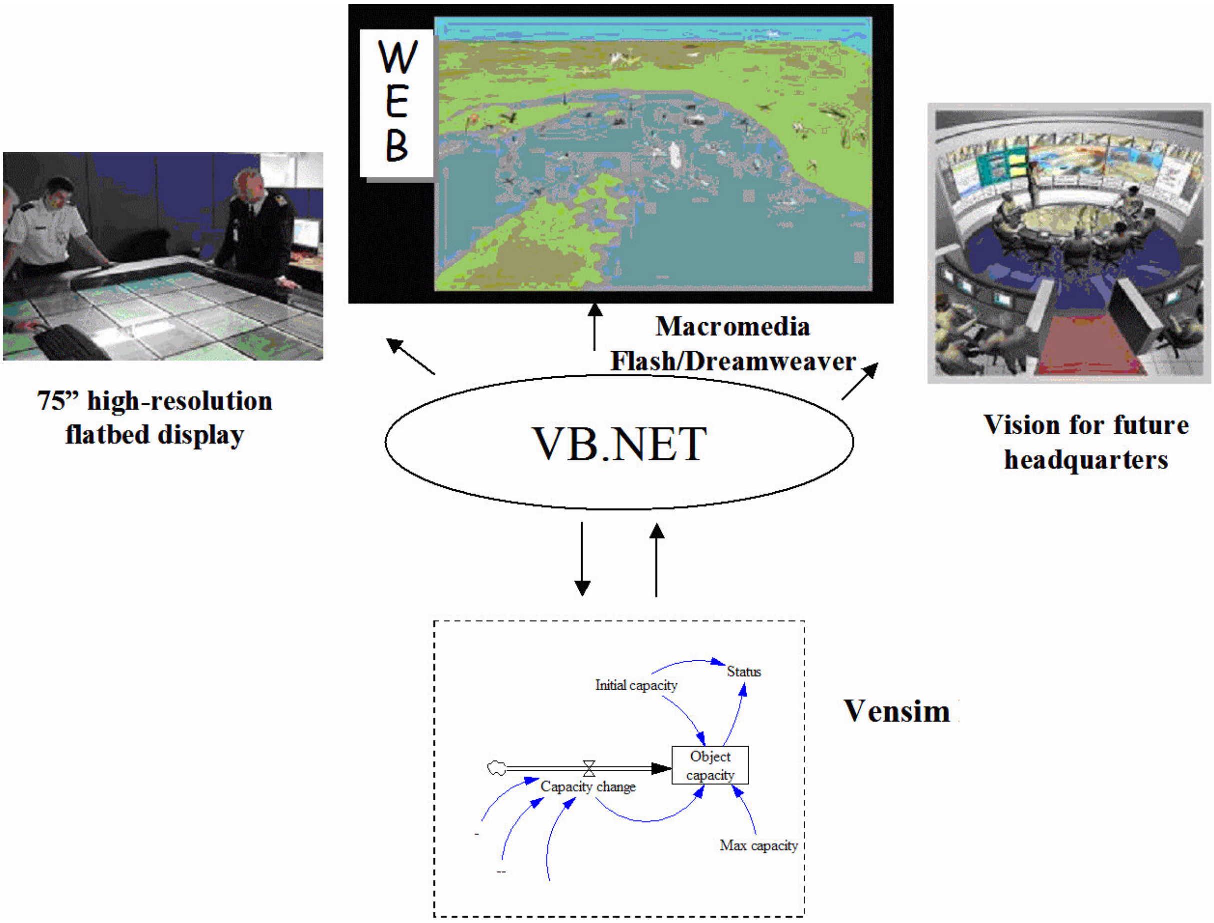

Diagram 2: Software/hardware architecture for Learning Lab for NCW

Other main features of NCWsim are:

- Provides a common operational picture (COP), which is subject to human interpretation (and misinterpretation).

- Allows distributed decision making – actions and responsibility are distributed among team members in a permanent or ad-hoc command structure. One may experiment with organisation forms such as hierarchy, network or self-organisation, and communication channels ranging from face-to-face (informal) to scheduled meetings, to written papers (formal).

- Supports "effect orientation" and the concepts of Network Centric Warfare and Effects Based Operations – in essence this is about implementing the right resources to the right time and place, and requires knowledge of the "driving forces" in a broad perspective. The decisions to be made come in two categories:

    - *Composition of resources into task groups, preceding the operation*
    - *Time/space coordination of resources while in operation*

- Friction and "chaos" are essential and inevitable features of the operational battle space, and therefore represented.

Conclusions

In this paper we have suggested a new approach to training within the concepts of Network Centric Operations and Effects Based Operations. To arrive at a solution rooted in theories of both modern military leadership as well as dynamic decision making, we have linked the principles of best practice EBO modelling and analysis with system dynamic insights. This approach has yielded design requirements for a "learning lab" for NCW. The purpose of the learning lab would be, through man-machine and inter-team interaction, to improve mental models of commanders and teams, and thus improved outcomes of future operations.

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