16th ICCRTS

"Collective C2 in Multinational Civil-Military Operations"

C2 Challenges for Modelling and Simulation

Topic 7: Models and Simulation in C2

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Abstract: It has long been apparent that modeling and simulation (M&S) should be able to provide indispensable tools for military decision-makers. However, other than specific, usually standalone, narrow-application tactical decision aids, few simulation tools are available. In general, M&S technology advancement has been driven by three application areas: training, commercial gaming, and operational analysis. Occasionally, simulations developed in these areas are modified to provide support tools for the tactical or operational decision-maker, but command and control (C2) by itself has not been a driver.

This paper addresses the problem from a C2 point of view in order to derive the requirements M&S technology must meet to support C2 applications. These requirements are then matched to current M&S technology trends to determine the gaps and major challenge areas. It is contended that the main challenges are not in simulation fidelity or necessarily in simulation speed, but in the areas of simulation configurability and analysis of results.

Introduction

The fundamental element of command and control (C2) is the commander's intent [1]; that is, the expression of the commander's will to shape the battle-space in a particular way. Thus, the study of C2 is about understanding how the Intent is formulated, communicated and implemented; and how those functions can be done better or assisted.

Simplistically, commanders have used tools to assist in their solidifying the vision of the battlespace in the form of maps or sand tables etc. from the advent of warfare. The use of depictions of what is believed "to be" to then explore the "what if" of how it might have, could have, or will be changed, is fundamental to military planning.

The multiple levels of situational awareness (SA) [2] are one model of trying to understand the process of moving from 'what is" to what "might be". Since the advent of computer systems, simulation has been used in a similar fashion. It is a short step from using a computer to keep track or display a model of the current situation (finances, sales or military disposition) to stepping that record forward in time under various assumptions; that is simulation.

Not surprisingly then, simulation has been used for many years to forecast potential military outcomes. These applications started out as fairly simple programs running on large physical computer installations. As computer hardware shrank in size and increased in computational power, simulations have correspondingly increased in capability, detail, and fidelity. In general, however, command level (also sometimes called engagement level) simulations still require substantial human resources to configure, use and maintain. Thus, while simulation has moved with some success into headquarters that can support the staffing resources, smaller command formations (or commanders themselves) have been limited to specific tactical decision aids (TDA) such as sensor performance prediction and route planning tools.

There is a frustration inherent here – since on the face of it – there is so much in common between the perceived functions of a commander/command staff and simulation; yet, that potential has yet to be widely obtained. This paper proposes to examine this question with the aim of provoking a discussion on how to bring the sciences of C2 and Modelling and Simulation (M&S) together to fulfill the expected potential.

Background

To set the stage for this discussion, take the situation of support to a naval task group (TG) commander. Naval task groups typically consist of a mix of different types of platforms with varying capabilities (including the logistic tail) that may transit over distances of hundreds of nautical miles and multiple national jurisdictions. In the late 1980's there were two tactical decision aid (TDA) systems being trialed in the USN and subsequently in the Canadian Forces: the Joint Operational Tactical System (JOTS) and the Integrated Tactical Decision Aid (ITDA). One of the expected benefits was support to TG (then referred to as squadron) staff in planning TG disposition and both systems had simulation-based functionality enabling a TG command staff to setup a disposition of assets and time-step over a planned position and intended motion (PIM) track against an opposing force.

As part of the CF evaluation they were deployed side by side in the Squadron office on the command ship for a major fleet exercise [3]. The staff had some prior training and familiarity with both systems. However, in the two week exercise period there was almost no use of the simulation capability. In scientific testing the simulations were quite reasonable. So why weren't they used? Essentially, the staff never had the spare time to use it – dispositions were worked out, but using professional knowledge on a sheet of paper in between fulfilling the report requirements of the afloat and ashore bureaucracy. In fact, the major use of the systems was to produce overhead slides for the commander's briefings.

From an engineering point of view, it could be said that the staff just needed more/better training, or the systems needed better integration with other ship systems. From an operational research analysis, it was clear the staff needed tools to handle the bureaucracy of running the TG more than tools for tactical planning. Thus, there was a mis-match between the expected tool usage and the requirement. It should be pointed out that the JOTS system was installed on Canadian ships and its successor GCCS-M continues to be used [4,5]. However, the system was installed for interoperability with coalition forces and operational-level picture compilation, not for the simulation-based planning tools.

In this case study, the simulation tools did not provide enough extra benefit, to the staff, to overcome the perceived extra resource requirement (time, understanding, etc.). A similar experience has been seen in acoustic range prediction systems where, the capabilities of these sophisticated simulations are seldom fully realized except when used by very motivated or technically inclined personnel. While viewed as critically important tools they are often used in the simplest and most straight forward modes.

In the naval TDA evaluation above, observation showed that the simulations were just too slow – it took substantial time to set up a problem, substantial time to run it (go get a coffee and wait), and, on one of the two systems, substantial time to display a result. [3] Thus, on top of the mis-match to staff needs, usability barriers kept staff from exploring the system capabilities to discover areas where the tool might have provided extra value.

Surdu et. al. [6] did a similar analysis of the potential for simulation to support the operations centre of the future. Their analysis produced a list of functionality based upon the use of simulation to support current C2 processes, mostly based around availability and usability concerns.

From these types of studies there are at least two types of barriers to achieving the expected potential of simulation to support C2. First, there is a requirement to identify and target real and critical C2 problem areas, and second to produce solutions that are practically usable by C2 personnel.

The first barrier is properly the subject of the C2 research and operational community to understand and develop clear use cases for where assistance is required. The second type of barrier belongs in the overlap between C2 research, cognitive science and human factors analysis to develop criteria and requirements. In order for the simulation community to develop appropriate technology, the C2 community must develop clear problem and usability requirements. In this the author is advocating a process that is closer to Brehmer [7], in that requirements should be based in understanding required functionality first and then determining how to fill those requirements, than a process that incrementally builds on current practices [8-10]. Although, it should be admitted that well directed and structured incremental developments can provide substantial capability gains.

Science of C2 inputs

The topic of command and control has a great breadth, but in general is one of trying to understand the processes by which command is developed and control exercised. In this paper the author contends that the lack of impact from simulation is due to a mis-match between the tools being offered and the needs of the users. This speaks directly to the study of command and control: if there is a mis-match occurring, what is it and why does it occur?

The combination of the change in international politics resulting from the end of the cold war and the rapid increase of wide spread networking has led to the study of the resulting effect on command and control in a number of areas. In particular, this paper will look at the following four general areas to determine if there are implications for the use of simulation to support command and control:

1. Rational/Analytic versus Naturalistic decision-making;
2. centralized versus network-centric “edgy” C2 organizations;
3. asymmetric warfare complexity; and,
4. joint – coalition – whole of government operations.

<u>Rational/Analytic versus Naturalistic Decision-Making</u>

In pace with the development of the science of combat over the past century has been the development of military planning processes. In response to the natural desire by commanders to reduce the risk and to attempt to control the expanse of unknowns in combat, processes have been developed to assist in developing optimal courses of action (COA). The processes have generally been developed in line with theories of rational decision-making from economics and business [11]. Under these theories a decision-maker generates all possible COA and completes a thorough, unbiased, analysis of all factors. Following evaluation against a comprehensive set of criteria the optimal COA is chosen. Practically, there are too many unknowns in combat to meet the theoretical requirements. However, it has been argued that a process that forces decision-making as close to the theory as practically possible should provide a military advantage. Planning processes have been made part of doctrine for all levels of military organizations and taught widely to military leadership.

Typically, a planning process requires that a number of COA be developed to fulfill the commander's intent. Implementation is usually done via in-depth analysis of intelligence data and application of military knowledge from a team of relevant military professionals to develop a small number of practical COA. These COA are then analyzed and the commander makes a choice of the COA to be implemented. This plan is then passed down to the next level of command to initiate their planning process. Although described as linear, in general this is an iterative process with feedback from both lower and higher levels. In addition, there are opportunities during the process for back-briefs and discussion between command levels to ensure that there is commonality of understanding.

At the end of the cold war, and with the advent of increasing numbers of non-traditional missions (peace-keeping, peace-making etc.), it became evident that the process does not match how many commanders work, especially when under time-pressure [12]. In practice many commanders were not developing a wide range of COA and conducting the specified in-depth analysis. Instead, relying upon their experience, commanders often moved, quite quickly, to a practical COA and, with a minimum of modification, were getting on with the job.

This has led to an examination of naturalistic decision-making theory and is now resulting in hybrid systems/processes [13,14]. Essentially, decision-making theory is now admitting that while rational/analytic processes provide a mechanism for handling unknown missions and situations, the processes can easily become overly time-consuming and under-emphasize the experience of military commanders and staff. Further, the 'rational" process' aim for optimality is far from normal for humans who more often strive for the first solution that satisfies the evaluation criteria, a process that has been termed "satisficing".

Stepping back to the JOTS/ITDA evaluation for the CF, both systems had tools created to support a rational/analytic process of planning and operations. However, the tools expected a staff that were concentrated upon tactical force-on-force naval combat and involved in conducting an operational planning process. Instead, the limited CF TG staff was operating in well understood circumstances where their own experience allowed them to develop reasonable COA in much less time then it would have taken to set up and run a single simulation. Staff also clearly felt that their accumulated judgment was more than sufficient to determine the "satisficing" merits of a particular plan. Further, the logistics and paperwork load of running a multinational task group provided little extra time for "what if" planning while in the midst of operations.

A key element of naturalistic decision-making is the requirement for experience. In situations where a commander does not have sufficient experience, the commander will have difficulty both in developing an initial COA and with verifying its ability to satisfice. Historically, it has been well known that commanders need a wide range of experience; which is usually obtained as a junior officer and through training and exercises. In today's context of rapidly changing warfare environments this requirement is no less important, but the timescales often preclude a commander from obtaining the experience personally *a priori*. When there is time for analysis, rational decision-making offsets the lack of experience with a new situation. However, under time pressure a commander will fall back on naturalistic processes; thus, it is important for an organization to ensure that hard won experience with new situations is passed to other commanders in a timely fashion.

It is clear from both Davis and Kahan [13] in an air force context, and Volwell [14] in an army context that there are requirements to support both rational and naturalistic decision-making across a spectrum of C2 functions (planning, re-planning, monitoring etc). Surdu and Roman

[15,16] come to similar conclusions in their analyses. Thus, C2 support tools must provide functions or resources that support these hybrid processes.

Some of the implications for the use of simulation to support C2 are:

1. Tools must complement human COA development and analysis, not try to replace it.
    a. Fit to the timescale of decision-making
    b. Incorporate and provide access to experiential knowledge as it is developed by other commanders.
    c. Provide value added such as exploratory analysis of variations on candidate COA
    d. Provide results that are intuitively understandable by military operators, and are credible in known situations.
    e. Provide means of identifying important decision points and conditions to assist in the development of Commander Information Requirements.
2. Tools need to facilitate the intuitive specification of staff developed COA and translation to a format that allows ready/automatic interaction with digital information tools (databases, electronic charts, geographic information systems, and simulations) to allow distribution.
3. Tools are required that allow the reproduction of operational experiences for training purposes for new commanders and staff prior to deployment. Training simulations and war-games are required to provide incoming commanders and their staff with as wide a variety of experience as possible in order so they can take full advantage of either rational or naturalistic decision-making processes.

<u>Centralization versus the Edge</u>

The increasing extent of networking available in society has led to a series of military concepts known as Netcentricity, or Network Centric Warfare. Essentially, this concept held that ubiquitous networking and bandwidth availability would enable increased communication and information availability. This in turn would enable increased shared understanding, collaboration, agility and self-synchronization of operations. Starting from a traditional, hierarchical C2 structure, which can be viewed as a tree, the basic command and control concept that developed can be viewed as a flattening of the tree and addition of many more links between the lower levels. Essentially, this amounts to pushing authority and decision-making as far down the structure as possible; from the centre to the edge. Underlying these concepts is the realization that the increased networking/communications is globally available and therefore adversary decision-making cycles will also be reduced. The implication is that blue forces can not just rely upon the technological increase in the speed of communication to maintain a decision-making advantage.

Analysis of net-centricity [17] concluded that while the technology of network connectivity was an enabler, the technology could just as easily be used to enable a centralization of C2. The difference was one of outlook and philosophy in the use of the technology by an organization or individual commander. In both C2 structures increased information and analysis are required, but perhaps most importantly where an organization ends up on the spectrum between complete centralization and full edge-enabled C2 is a matter of trust and understanding. Ultimately, the responsibility for the completion of a mission rests with senior commander; where the "buck stops." Delegation of authority and responsibility relies upon the level of trust each level of command has that the next layer down of the organization understands and can implement the mission as delegated.

In the case of centralization of command, the increased networking and information availability necessitates tools to handle the increased information required by the commander and tools to enable the increased amount/detail of unit supervision required to obtain/maintain decision-making superiority. In this case fewer tools are required for subordinate units.

On the edge side of the C2 spectrum, fewer information and analysis tools are required at higher levels, but more tools are required for subordinate units to understand their and other unit's roles and missions within the overall plan.

Thus, tools are required that provide real-time monitoring of progress against the plan – so that as the plan encounters foreseen or unforeseen events, decisions can be made faster than an adversary can react. Whether, the tools are at the central command or in the hands of subordinate units (at the edge), they must match current situational data to that expected by the plan and provide anomaly detection of significant differences. In the case of foreseen situations, applicable planned options should be available to users; in the case of unforeseen situations, tools are required to enable rapid re-planning/reaction to take advantage or mitigate the effect of the situation.

Again, in both cases, there is a requirement to transmit knowledge/understanding of the plan across the organization. In the centralized C2 case, the need is to communicate detailed unit mission orders to units and detailed situation reports back from those units. In more "edge" oriented units the need is for collaborative plan development and understanding – units need to know more of what other units are doing (or will do) so that they can self-synchronize.

Put in terms of simulation requirements, these tools are less analysis and planning tools and more real-time monitoring tools. This indicates a requirement for integration with combat systems to obtain real-time situation data updates, coupled with anomaly detection tools to detect emerging differences with the plan. Reaction and re-planning applications will impose time-scale constraints and indicate the need for interfaces that support naturalistic decision-making.

Within the reaction/re-planning functions tools need to provide knowledge of the macro-effects of unit micro-actions.

Separate from the monitoring task is the requirement for communication of the plan across the organization. This is traditionally done via verbal and written orders, with back-briefs for verification. However, Hazen and Randall [18] postulated the use of simulation to represent both commander's intent and operational plans, thus, utilizing the simulation configuration and run parameters as a perhaps richer communication channel. The viability of this type of application is dependent upon a common reproduction of the simulation runs for each user and the ability of the simulation to accurately portray the key facets of the plan for each unit.

<u>Asymmetric Complexity</u>

Following the end of the cold war, western military have been tasked with a variety of missions; few of which have come close to a 20th century traditional force-on-force engagement. While few of these missions are really new; they have been substantially different from the missions for which western military primarily train.

This asymmetric warfare can be characterized by lack of symmetry in numbers and quality of resources; but also in terms of a lack of symmetry in accepted rules of engagement and motivation. In most cases, the groups opposing top-rank military forces have had little chance of prevailing against the combat power such a force can bring to bear in open battle.   Hence, opposing forces have usually avoided open force-on-force combat and relied upon longer term attrition, terror and diplomacy campaigns. For example, when an adversary can consistently conduct an exchange of the other side's multi-million dollar missiles for its own thousand dollar targets a long-term result in the adversary's favour can be predicted.

In these campaigns, identification of the adversary by the larger force is a major concern, while identification by the adversary of the larger force is rarely a challenge. This has led to the understanding that the battle is not as much one of securing control of territory or the destruction of enemy forces, as it is a battle for the hearts and minds of the population inhabiting the territory. Central to this battle may be the provision of security for that population, which often includes securing control of the territory and destroying enemy combat capability; however, the overall effect desired is the positive support of the intervening force by the population. The recognition that the military objectives have become more complex has led to the concept of effects based operations (EBO). [19-20]

At least initially, both rational and naturalistic decision-making processes were compromised due to a lack of understanding of the nature of the warfare required for analysis on one hand, and the lack of experience of commanders on the other. Hard won experience over the past twenty years has improved this situation markedly.

This experience shows that understanding the population's culture, language, customs and community inter-relationships is critical to both winning their support, and the identification of adversaries. It is important to understand not just the adversary centres of gravity, but the centres of gravity of the population, so that missions can be crafted that both attack the adversary and support the population. Further, as these missions can be protracted, the economic, political and cultural impacts of operations need to be considered. Thus, mission planning must consider not only the initial primary effect of operations, but also the longer term secondary and tertiary effects. As an example, there are increasing reports [21] that the influx of western money into Afghanistan to pay for logistics and reconstruction projects has radically skewed local economies, encouraging the corruption and warlord-ism that were part of the reason the Taliban originally gained control of the country.

While not denigrating the complexity of force-on-force conflict, asymmetric warfare has a complexity that is often beyond the capability of any single commander (possibly at any level). It is also true that experience, understanding of human-nature, and informed intuition are possibly the greatest tools a commander has in these cases.

In terms of simulation support to C2, there is a clear requirement for tools that include factors such as economic, cultural and social issues. In particular, there is a need to replicate neutral and third party behaviours within the models so that the result of military engagements can be used as inputs in the non-combat modules. For example, the loss of a bridge could be catastrophic for the economy of a village with far reaching negative impacts, while spending an extra hour distributing medical aid could be critical to a positive outcome.

The modeling of these types of complex inter-relationships is not straight forward and will require considerable verification and validation. Especially in cases where the force has little experience, the integration of subject-matter experts into the plan evaluation process should be mandatory. The implication here is for tools that facilitate the fitting of engagement results to expert knowledge and Human Intelligence (Humint) empirical data. These tools should also allow a commander to develop an understanding of why particular changes in tool configuration enable a better fit to the real world. While "black box" systems are useful for prediction purposes they do not provide the explicit causal links that produces understanding. Being able to link changes in configuration to changes in outcome in a meaningful way requires either in depth knowledge of the simulation's algorithms or an ability to trace the changes to particular decisive chains of actions in the simulation.

Given the level of complexity, it is likely that a suite of simulation tools will be required to cover the variety of inter-related systems; for example, social network models to examine effects on societal relations and economic models to examine effects on the economic viability of the area. Since, these systems are inter-related there is a requirement for the models to exchange data and interoperate.

The increase in complexity and types of effects that commanders need to consider indicates the need to expand the information repositories available to commanders to include information on societal, cultural and economic data. As with military data, these new information repositories must be accessible, updateable, provide intuitive visualization of the data, and be interoperable with other tools. Thus, a geographic information system that combines societal and economic information should also be usable to initiate and feed evaluation modules in military engagement simulations. For example, the systems might provide the data required to evaluate the effect of taking out a bridge on the likelihood of obtaining cooperation from the local population.

As complexity of the situation and supporting simulations increases there will be an increasing need for configuration control and management of simulation outputs. While strict reproducibility of simulation results has become increasingly difficult due to the technological complexity of modern computing – it is clear that commanders will need to have some basic level of reproducibility of results both in order to replay for analysis and to enable plan monitoring comparison to real-time operational data.

Joint/Coalition/Whole of Government/Comprehensive

In combination with the increase in complexity of the warfare environment, a wider variety of responses and responder organizations are now in use. Coalitions have become the norm; coalitions of differing national military forces, and coalitions of military, government and non-governmental organizations. In some cases, the command chain remains clear, but not often, and even then a commander's resources can come with a wide variety of capabilities, rules of engagement and cultures. More often, command is a multi-headed monster spread between operational, strategic, national and inter-organizational levels. In these cases, military commanders must also become proficient in diplomacy and civilian politics, balancing the needs and aspirations of a wide variety of organizational objectives and priorities.

In many cases the military will not even be the lead agency; for example security missions for international events such as an Olympics. In other situations, key players are truly independent of any national structure or control, necessitating collaborative or consensual C2 structures.

Even within purely military coalitions, differences in military culture abound; there is a truth contained in the old joke about the meaning of an order to "secure the building" for army, navy or air force (occupy with force, buy or lock it). National differences in culture and understanding of intent statements must be constantly on the minds of commanders working with coalitions of forces.

The implications for command support simulations are the need for flexibility in defining capabilities and expected behaviour for different units in a coalition. Simulations will need to take into account differing battle rhythms, cultures, doctrine, rules of engagement and response times to orders.

If simulation is to be used as a common tool for plan development and distribution then the simulation tools and configuration data will need to be available or usable by all partners in the planning. This could mean the use of distributed simulation, the dissemination of a common simulation engine or the use of a family of validated simulations. In all cases, it is imperative that all users/partners of the system are able to produce equivalent results in the areas critical to the operation.

If critical aspects of the tool are not distributable, for example the underlying configuration data for unit capability, then compromises will be required. One possibility is a visualization tool that allows the replay of select simulation runs.

The requirements for the analysis and monitoring of a wider range of players are similar to the requirement for the inclusion of a wider range of activities arising from the complexity issue above. In this case, commanders need tools and systems to keep track of the capability and/or inclination for different organizations to conduct different missions or functions. In monitoring these activities the quality and timeliness of update reports is likely to vary widely, thus, the requirement for a commander to predict how a particular organization may be progressing in their area could be critical; for example, is it reasonable that a particular organization has not yet reported on having achieved their portion of a task – should the plan include a task to check with them?

The tool being used by the commander to monitor execution of the plan must facilitate effective control of the much looser organized coalitions. Similarly, processes for planning an operation need to build into the plan the larger expected variability in both execution and reports on progress.

Current Simulation Technology Research Areas

There are a wide variety of simulation research projects underway to support military operations and many are also motivated by the potential to support C2. However, the majority of military simulation efforts are driven by the training and education community, just as the overall simulation community has increasingly been driven by the commercial gaming community; that is where the resources can be found.

The following are a selection of current simulation technology research areas:

1. Coalition Battle Management Language (CBML) – technological standards to facilitate the communication between combat systems and simulations. May allow simulations to be initiated by the operational picture within a combat system or to download developed tactics to a combat system.
2. Military Scenario Definition Language (MSDL) – commonality in description of military scenarios allowing different simulations to use a common scenario definition.
3. Crowd modeling – provides realistic background action for urban and security scenarios (or evacuation modeling).
4. Visual Analytics – processes for handling the data overload problem involving improved methods of visualizing data and the process of deriving information, often geographically based.
5. Distributed simulation – technology for linking together existent individual simulations to provide simulation federations to fit new problems, and enable more reuse. HLA and DIS
6. 3D visualization – immersive, more realistic views of simulated worlds and/or data.
7. Virtual Worlds – frameworks enabling the user to completely immerse themselves via avatars into the simulated space for a first hand experience.
8. Cultural modeling – activities to provide simulated entities a variety of differing (and realistic) reactions rooted in cultural definitions.

9. Agent based modeling – adaptive behaviour for entities to allow both more intelligent behaviour and a reduction in the amount of initial configuration required.
10. Multiple Trajectory – simulation control mechanisms for the explicit tracking of dynamic simulation runs. The methodology allows a simulation to branch at simulated decision points rather than picking a single value and proceeding.
11. Integrated terrain and sensor databases – providing a single geographically referenced data source combining both elevation and material characteristics.

Discussion

From the analysis of C2 theory it can be seen that support tools that are designed to only support a rational/analytic process are likely to be problematic in that they are unlikely to meet the requirements of naturalistic decision-makers. Further, since even within the rational decision-making process the generation of COA is often based upon a brainstorming of experienced officers, (i.e., a sort of group naturalistic decision-making process) COA generation tools will need to meet a brainstorming decision cycle time. Tools aimed at assisting the analysis portion of the process require ease of configuration and the ability to be configured to generate a variety of evaluation measures and display formats. They must allow the operator to determine why a particular result occurs.

Davis and Kahan [13] explore not only the implications of a combined rational/naturalistic planning process but also look at a variety of techniques to allow the US Air Force Commander's Predictive Environment to attack the problems of complex mission environments. They suggest a combination of war gaming, red team analysis and simulation to support the analysis and development of flexible, adaptive and robust (FAR) plans and strategies.

Surdu and Kitka [16] and Roman and Surdu [15] have a vision of simulation tools that are intuitive to configure and interpret. The Deep Green US Army project takes this further to propose the integration of planning and operational monitoring tools. While they propose a "new" type of simulation engine, the key feature is the ability of commanders and military staff to use the tools without a large simulation support staff.

The simulation requirements derived above are fairly general. Table 1 gives a number of requirement categories that form common themes and matches them to current simulation research.

The next step is to apply human-factors engineering techniques to these general categories in order to determine requirement constraint bounds. The application of techniques such as cognitive work analysis [22] can refine understanding of processes and determine focused areas for the application of support tools. In addition, detailed experimentation is required to understand constraints such as the impact of wait time for analysis results on the cognitive processes for brainstorming COA or the iterative development of plans.

Based upon these theoretically generated and operationally defined requirements a gap analysis can be conducted to determine where technological (and in particular simulation) research is required to develop tools to support C2. Examining Table 1 shows that the majority of simulation issues are in the areas of interfacing with the operator (input of ideas, recording of experience, output of analysis) and the expansion of tools to include non-military aspects. Table 1 also indicates that current simulation research efforts do not fully cover any of the C2 requirement themes. While there are a wide variety of simulation research efforts, there is little evidence of a unifying program of research, although the Deep Green program to support Army COA [16] is encouraging.

Table 1: General C2 themes and supporting Simulation research activities		
	C2 requirement Theme	Simulation Research
1	the need for intuitive interfaces that allow commanders to translate their ideas to a digital format.	Tablets and surface computing
2	the need for analysis generation times to match commander cognitive processing cycles.	Multiple Trajectory modeling Parallel processing, cloud computing Distributed simulation
3	the need to capture experiential data as it becomes available in a digital format that is usable by both on-scene commanders and those training for deployment.	Lesson learned databases
4	the need to expand mission critical data collection, storage and analysis to include cultural, economic and societal information; and the ability for other digitally based tools to access the data.	Crowd modeling Social and economic simulations
5	the need for visualization tools that enhance commanders understanding of large amounts of data and information. These tools need to be matched to the commander's mental models.	Visual analytics and Geographic Information Systems.
6	the need for common tools, or tools that can provide equivalent outputs from equivalent inputs, across C2 structures and multiple organizations.	Verification, Validation and Accreditation (VVA) processes to provide simulation standards, measures and trust.
7	the need for interoperability between tools and operational C2 systems	CBML MSDL Distributed Simulation
8	The need to transfer experiential knowledge to other current and incoming commanders and staff	Virtual Worlds and serious gaming
9	The need for commanders to understand why a change in input parameters makes a change in the output.	Multiple trajectory modeling Simulation replay systems

This paper has essentially postulated that simulation support to command and control has often followed a naturalistic decision-making process where current simulation tools are applied to a particular perceived situation. It is the author's contention that to provide tools with wide and robust applicability requires a more rational process of analysis based out of C2 research, coupled with human factors techniques to derive performance requirements, and implemented by simulation experts.

As an example of how this process might proceed four general C2 research issues were examined to derive C2 tool requirements. Without going into specific performance requirements these tool requirements were then matched to research themes in simulation to provide an initial look at where simulation research is needed.

In order to obtain the perceived benefits of simulation to military commanders the C2 research community needs to develop clear statements of C2 problem areas and the resulting requirements. This requires an integration of the following complementary research programs:

1. the development of C2 process models and understanding of the impact of a variety of organizational and cultural factors upon them;
2. the human factors study of operational C2 decision centres to develop metrics on ergonomic and cognitive parameters;
3. the development of intuitive and usable interfaces between the human and digital worlds; and,
4. the development of practical simulations of complex military-socio-economic processes.

Conclusion

There is a perceived high correlation between simulation technology and the requirements of military decision-makers for tools that let them handle the complexity of modern warfare. In spite of massive increases in simulation capability in the past twenty years simulation technology is still not widely used in C2 systems. This paper has postulated that there is a fundamental mis-match between current simulation technology and the actual requirements of military decision-makers. Further, it is contended that in order for useful simulation technology to be developed specifications originating from the C2 community are required.

Using four current areas of C2 research an initial set of high-level military C2 tool requirements were derived. These were then compared to current simulation research and development efforts to provide an initial gap analysis. The primary area where simulation technology development is required is in user-interfaces. It is finally concluded that an integrated research program of C2 theory, human factors development of requirements and simulation interface research is required to make substantive progress in developing appropriate tools for military decision-makers.

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