NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

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RTO TECHNICAL REPORT **TR-MSG-062**

Guide to Modelling & Simulation (M&S) for NATO Network-Enabled Capability ("M&S for NNEC")

(Guide de la modélisation et de la simulation (M&S) pour la NATO Network-Enabled Capability (« M&S de la NNEC »))

NMSG-062 Final Report.

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Key Audiences

1) NATO Partners.	• ACT • NATO Consultation, Command and Control Agency (NC3A) • NATO Industrial Advisory Group (NIAG) • NATO Underwater Research Centre (NURC) • Allied Command Operations (ACO)
2) National Representatives.	• Conference of National Armament Directors (CNAD) • Agile Mission Group (NRF) • NATO Military Committee • Nations (customers) • National Modelling and Simulation Coordination Offices
3) NATO RTA bodies whose activities largely depend on M&S as a lead investment in various capabilities as well as Net-Enabled Capabilities.	• Applied Vehicle Technology (AVT) Panel • Human Factors and Medicine (HFM) Panel • Information Systems Technology (IST) Panel • NATO Modelling and Simulation Group (NMSG) • System Analysis and Studies (SAS) Panel • Systems Concepts and Integration (SCI) Panel • Sensors and Electronics Technology (SET) Panel

4) The warfighters and national representatives associated with M&S of any NEC, from "start to finish".	• Warfighters at all levels, including planners, decision makers, analysts/scientists, modellists and simulationists, involved in the following:
	  • CD&E
	  • Acquisition, T&E, Logistics
	  • Operations
	  • Training and Exercises
	  • Joint Multinational and Inter-Agency Activities
	  • Force Development, Force Generation, Force Employment

Acknowledgements

NATO has developed a tradition of broad participation for International reporting of guidance and direction on issues fundamental to the Alliance. In keeping with this tradition, this **"Guide to M&S for NATO NEC"** is the result of that complex consultative process involving a large team of Subject Matter Experts (SME) from all participating nations and beyond, including other national SME directly involved in the Case Studies that formed the basis of the evidence-based approach used herein. Indeed, the process for preparing the Guide has proved as important as the final document itself. In coming together to share data, information, experiences, knowledge, and perspectives, the contributors have immensely strengthened the collective international understanding of the crucial value-added role that M&S can play as a lead scientific and technology (S&T) investment to NATO Network-Enabled Capability (NNEC), while using an evidence-based approach with a selection of Case Studies.

Sincere gratitude for this support, consultation, and guidance is extended to all members of this brilliant team. We came together as individual national SMEs, but we came out as one, providing what we believe is unique advice on NNEC, supported by a rather unique selection of Case Studies that should attract some attention. We are also coming out of this effort with warm professional relationships and friendships that will last a lifetime. It would be improper not to further extend my gratitude to Col. John D. ("JD") Graham (ret.) of CAE Professional Services Canada Inc. and Mr. Chris Pogue, Worldwide President of CAE Professional Services Inc. for invaluable discussions and inputs on M&S and NEC over the years. Finally, I must acknowledge not only the support of the NATO Modelling and Simulation Coordination Office (MSCO) but in particular the (then) Head of MSCO at NATO RTA in Paris, Mr. Paul Newman. Without his influence, we would not have jumped at the offer to build MSG-062 and we are grateful. Many thanks to all (see Official Members) for the tremendous effort and for what we accomplished together in this first version of the Guide (this is "**Guide to M&S for NATO NEC" v1.0, 2009**).

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Guide to Modelling & Simulation (M&S) for NATO Network-Enabled Capability ("M&S for NNEC")

(RTO-TR-MSG-062)

Executive Summary

A fundamental objective of NATO and one of the highest priorities of NATO ACT is to take full advantage of NEC. Realizing NEC implies three concepts:

1) That the Armed Forces will work in new ways;
2) That Government need to adopt new approaches; and
3) That Industry and Academia, with Government, need to continue to innovate in relation to: concept, design, acquisition, use and management of systems that support **military capabilities** and **Defence Against Terrorism (DAT) capabilities**.

The tenet of this Guide is that M&S can be applied to NEC, from CD&E, acquisition, training, exercises and operations, to provide the basis for enhancement in military effectiveness and transformation against the main security challenges of the future. The main goals of this Guide are:

1) To structure the "**Best Practices/Guidance**" around "**Principles**" or "**Gold Nuggets**" in four dominant topics to ensure that allied defence capability programs are truly able to support the birth and evolution of future Force Capabilities from CD&E, MA&S, Training and Exercises;
2) To provide real world **Case Studies** as anchor stones of supporting an evidence-based approach to documenting the "Principles" in real world practice both in military capabilities and Defence Against Terrorism (DAT) capabilities; and
3) To provide evidence-based advice on how a nascent NEC can be influenced by M&S in CD&E, acquisition, training, exercise and operations.

Taken from the following elements: CD&E, through-life management, material acquisition, T&E, logistics, training, agile operations, the human in NNEC and the impact of NEC on M&S, "Gold Nuggets" were documented and agreed upon as **24 Key M&S Principles in support of NNEC**.

This "**Guide to M&S for NNEC**" reports on these principles in support of NNEC and concludes that M&S is an enabler to achieving NNEC and shows how it can provide agility, proximity to end-users, support to agile Ops, support to complex Ops, support to shorter acquisition cycles and lesser costs in military capabilities as well as Defence Against Terrorism (DAT) capabilities.

Guide de la modélisation et de la simulation (M&S) pour la NATO Network-Enabled Capability (« M&S de la NNEC »)

(RTO-TR-MSG-062)

Synthèse

Exploiter pleinement la NEC est un objectif fondamental de l'OTAN et une des plus hautes priorités du Commandement Allié pour la Transformation de l'OTAN. La réalisation de la NEC implique trois concepts :

1) Les Forces Armées vont travailler d'une nouvelle façon ;
2) Le Gouvernement va devoir adopter de nouvelles approches ; et
3) L'industrie et le monde universitaire ainsi que le Gouvernement vont devoir continuer à innover dans les domaines : de la conception, de la réalisation, de l'acquisition, de l'utilisation et de la gestion des systèmes qui soutiennent les **capacités militaires** et les **capacités de défense contre le terrorisme (DAT)**.

Le principe de ce guide est que la M&S puisse être appliquée à la NEC, à partir du CD&E, de l'acquisition, de la formation, des exercices et des opérations pour fournir les bases d'une amélioration de l'efficacité militaire et une transformation face aux défis de sécurité majeurs du futur. Les buts principaux de ce guide sont :

1) De structurer « **les bonnes pratiques/les directives** » autour de « **principes** » ou « **Règles d'or** » en quatre pôles principaux pour s'assurer que les programmes de défense capacitaires alliés soient réellement capables de supporter la création et l'évolution des capacités futures à partir du CD&E, de la MA&S, de la formation et des exercices ;
2) De fournir des **études de cas tirées** du monde réel **qui** servent de points d'ancrage pour soutenir une approche basée sur l'expérience, afin de documenter les « principes » dans le monde réel concernant les capacités militaires et les capacités de défense contre le terrorisme (DAT) ; et
3) De fournir des conseils issus de l'expérience sur la manière dont une NEC naissante peut être influencée par la M&S dans le CD&E, l'acquisition, la formation, les exercices et les opérations.

A partir des éléments suivants : CD&E, gestion tout au long de la durée de vie, acquisition de matériels, T&E, logistique, formation, opérations légères, l'aspect humain dans la NNEC et l'impact de la NEC sur la M&S, des « Règles d'or » ont été élaborées et acceptées en **24 principes M&S clés comme support de la NNEC.**

Ce « **guide M&S de la NNEC** » rend compte de ces principes, conclut que la M&S est un moyen de faciliter la réalisation de la NNEC et montre comment elle peut fournir de la souplesse, de la proximité aux utilisateurs, un soutien aux opérations légères, un soutien aux opérations complexes, un soutien aux cycles d'acquisition plus courts et moins coûteux pour les capacités militaires comme pour les capacités de défense contre le terrorisme (DAT).

Chapter 1 – INTRODUCTION

Key Points in this Chapter:

- **M&S can be effectively used as a lead investment to enable the advancement and continuous evolution of NNEC both for the Alliance as a whole and individually for its member nations.**
- **M&S goes well beyond the investigation of the technical aspects of the NNEC digital infrastructure and into the realm of creating significant competitive advantage within a networked environment for the warfighter.**
- **One consequence of a highly complex environment is that our internal mental modelling ability quickly becomes overwhelmed.**
- **Using a Case Study based approach, this report represents guidance with which M&S as a lead S&T investment enables the realization of NNEC.**
- **M&S enables NNEC while providing agility, proximity to end-users, support to agile and complex Ops, support to shorter acquisition cycles and lesser costs in military capabilities as well as Defence Against Terrorism (DAT) capabilities.**

1.1 LEADERSHIP DIRECTION

NATO leadership has directed a series of significant changes in the way operations are planned and conducted. It has done so to provide more effective integrated use of not only military power, but all instruments of power and influence across the Alliance. Central to these changes is the effective implementation of a system based on the concept of NATO Network-Enabled Capability (NNEC). As expressed in NATO Allied Data Publication 34:

> *"NNEC can be described as the realization of a robust, globally interconnected, network environment (including infrastructure, systems, processes, and people) in which data are shared in a timely and seamless way among users, applications, and platforms, during all phases of civil and military cooperation (CIMIC) and war-fighting efforts. By securely interconnecting people and systems, independent of time or location, net-centric capabilities enable substantially improved military situational awareness and significantly shortened decision-making cycles".[1]*

NATO Allied Command Transformation (ACT) has recently announced its long-awaited list of priorities for the entire North Atlantic Alliance. It has been reported that the top priority of NATO ACT is network-enabled capability (NEC); three of the top five priorities of NATO ACT are also solidly anchored in NEC. [2]

This Guide will not discuss the appropriateness of pursuing NNEC, which is a given; the task to implement it has already been assigned by senior NATO leadership. Rather, the Guide will illustrate how the effective use of modelling and simulation (M&S) can assist in the development, generation, implementation, and effective employment of NEC to meet Alliance objectives within a complex and adaptive international security environment. The central tenet of this Guide is that M&S can be effectively used as a lead investment to enable the advancement and continuous evolution of NNEC both for the Alliance as a whole and individually for its member nations. Based on its significant expertise in the domain, the NATO Modelling and Simulation Group (MSG) has responded to NATO ACT priorities by developing this Guide on how to effectively use M&S to advance NNEC.

"Modelling and Simulation (M&S) can be effectively used as a *lead investment* to enable the advancement and continuous evolution of NNEC both for the Alliance as a whole and individually for its member nations."

The approach taken to publishing this Guide was to produce a compendium of papers, each developed by a single member nation or as a collaborative effort involving several nations. Each paper was produced using a Case Study and an evidence-based approach focused on documenting and illustrating how to effectively use M&S to advance NNEC. More specifically, the papers explore how M&S could effectively link sensors, decision makers, and weapon systems to translate information rapidly into synchronised and overwhelming military effect – fast enough that the adversary would be unable to effectively respond and counter.

Finally, the authors have all considered NNEC within a capability-based framework including people, processes, and technology at some point along the full capability lifecycle (encompassing capability generation, development, and employment). In so doing, the Guide expands the usage of M&S well beyond the investigation of the technical aspects of the NNEC digital infrastructure and into the realm of creating significant competitive advantage within a networked environment for the warfighter.

1.2 BACKGROUND

The international security environment in which NATO operates has always contained a myriad of agents interacting within diplomatic, social, economic, and military domains leading to its classification as a complex adaptive system. Several key aspects of such systems make the use of M&S appropriate and effective.

1.2.1 Multiple Independent Actions

The world is populated by a great many agents conducting seemingly "independent" actions that can each be individually modelled (represented). However, when permitted to interact, these agents seem to spontaneously organize themselves into a relatively stable long-term state without any apparent conscious plan. Classic examples are the global economy, in which multiple agents attempt to satisfy their needs by individually conducting a myriad of individual buying and selling actions thus spontaneously forming an economy or an ecosystem where biological organisms both influence and are influenced by changes in the environment, including the geo-physical environment and other organisms.

1.2.2 Interdependent Consequences

Another aspect of such systems is the interdependence of agents within them and the influence they exert on other agents across multiple domains in some way shape or form, whether the influence is observed and recognized or not. In the case of NNEC, the agents could be considered instruments of national or NATO coalition influence which, when applied in any one domain to achieve a primary effect, often generate secondary or tertiary effects in other domains. For example, control of the airspace will have an effect on the ability to control areas of land and sea below and adjacent to air operations. In addition, the use of military power will have an effect on the political and diplomatic landscape and the social and economic fabric of the areas within and adjacent to military operations. The relationships between individual agents can also be modelled, permitting interaction under certain conditions. Such modelling can represent the complexity of behaviours whereby seemingly "independent" agents perform individual actions resulting in system behaviours where they appear to spontaneously organize themselves into a relatively stable state without any apparent conscious plan.

1.2.3 Active Search for Competitive Advantage

A third aspect of such a system is that the effects observed as a result of these multiple influences are not simply passive reactions, but each agent actively tries to turn whatever happens to its advantage. This reveals an additional attribute of these systems: they are highly dynamic in nature, but in a spontaneous rather than predictable mechanistic cause-and-effect fashion, but are seemingly more spontaneous, more disorderly, more alive but not so completely unpredictable as to be considered chaotic. This type of system seems to have an ability to bring higher level order and lower level chaos into a tenuous balance. At this balance point, the system's constituent elements never seem to completely lock into place and yet never dissolve into total chaos either. These systems are said to live at the edge of chaos, at the tipping point between stagnation and anarchy where they remain spontaneous, adaptive and alive.

"… this Guide expands the usage of M&S well beyond investigating the technical aspects of the NNEC digital infrastructure and into the realm of creating significant *competitive advantage* within a networked environment for the warfighter."

1.2.4 Emergent Behaviour

Complex systems also often display emergent behaviour, meaning behaviour that isn't explicitly described by the behaviour of any of the individual components but rather is a new behaviour that develops due to interactions among the components of the system. These emergent behaviours are not easily predicted from knowledge of individual agent behaviours, but may be readily observed in complex adaptive systems, for example birds flocking together or the performance of financial markets. One cannot predict the system behaviour by studying individual agents alone; they must reach a critical mass and be permitted to interact before the behaviour emerges.

1.2.5 Tipping Points

Finally, due to the various factors outlined above, these systems will appear to shift into a much more turbulent region, at times in response to a relatively minor perturbation of the overall system. This has to do with the interconnectedness of the various agents within the system. Seemingly minor initial changes in one agent or relationship will have follow-on down-range effects throughout the system, well out of proportion to those expected. These are produced by positive feedback loops of secondary, tertiary, and higher order effects causing the system's stability to temporarily dissolve. The current global economic system may be a good example of this sort of behaviour, as it recovers from what many refer to as a 'meltdown' and now attempts to re-stabilize after being pushed from relative stability over the tipping point.

As complex as this process appears, each of the individual agents within a complex adaptive system can be modelled and run in simulation to combine and project likely overall system behaviours as well as to specifically look for "emergent" behaviour.

1.2.6 Models

A model is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process that has been designed for a specific purpose. A system may be defined as an entity that performs a specific function through the interaction of its parts. The strength as well as the weakness of modelling systems derives from the fact that the models are simplified representations of systems and their components that intentionally exclude certain aspects of the real things they represent. Thus, models are abstractions that reduce the complexity of a system to enable a better understanding of the specific aspects of interest and their

impact on performance. Models must therefore be constructed in such a way that makes it possible to consider all of these significant aspects.

For this reason, multiple models are often created for any agent operating within an environment. The selection and use of a specific model must be based upon the aspect of the agent's behaviour under investigation as well as the level of aggregation of individual agents and their effects. For example, an aircraft may be represented by a complex high fidelity physical model that runs non-real-time for engineering test and evaluation purposes or it can be represented by a lower fidelity performance model that runs in real-time for human decision-in the-loop training. Similarly, aircraft can be modelled as individual entities, flights, sections, packages, or even entire fleets of aircraft depending on the granularity required of the investigation. Care must be taken to ensure that the model selected is appropriate to meet the requirements of the user – a mismatch may provide what appears to be a reasonable result but in fact are completely misleading.

1.2.7 Simulation

A simulation is the manipulation of a model in such a way that it represents the expected behaviour of an individual agent or an entire system over time. Simulations can be run real-time, near-real-time, or non-real-time depending on the user's requirements and objectives for running the simulation as well as the number and complexity of the modelled agents in the system and the available processing power to run the simulation.

"One consequence of a highly complex environment is that our *internal mental modelling ability* quickly becomes overwhelmed..."

Running models of agents in simulation shows the potential effects of the behaviour of individual agents on each other, revealing display behaviour that affects other agents and their behaviour, which in turn affect the original agent's behaviour, one has the complex feedback dynamics needed for emergence. Because these interactions are highly complex, we are unable to easily predict their outcomes. One consequence of a highly complex environment is that our internal mental modelling ability becomes overwhelmed, and we either fail to expect any result, or expect results that are simple (linear) extrapolations of observed behaviours.

1.3 APPLICABILITY OF M&S

1.3.1 Implicit Mental Models

This last point is the key element of why the effective use of modelling and simulation is critical to the effective design, implementation, and employment of NNEC. Each element of the international security environment, be it space, air, land and sea military power or diplomatic, military, economic, and social instruments of influence, is a highly complex agent of change. Each is also constantly changing in response to changes in the environment; militaries update equipment and modify strategies, tactics, techniques, and procedures, which continually drive required upgrades to the education and training of personnel. In diplomatic domains new alliances are formed, international legal instruments created, relationships built with key partners while focused study is conducted on adversaries and neutrals to understand and influence their behaviours.

The consequence of the high complexity of each element in the international security system is that our internal mental modelling ability quickly becomes overwhelmed with critical questions such as:

- Whom to connect with;
- How to connect;

- What information to share that is of importance to our partners;
- How to effectively collaborate with partners to share knowledge and understand current and projected system behaviours;
- How to coordinate individual actions for the greatest positive effect; and
- How to avoid negative unintended consequences become critical but overwhelming questions.

While this situation can occur within complex military operations, it is equally if not more likely to occur within complex multi-agency domestic security or DAT operations. At best, the situation results in missed opportunities to leverage existing synergies. At worst, the efforts of partners attempting to achieve the same strategic goals may be inadvertently disrupted or even countered by each other's actions.

1.3.2 Discovering and Leveraging Synergies

Through the effective use of modelling and simulation, it is possible to formalize and capture the internal mental models of the best and the brightest minds in each domain. The individual agent models can be linked according to current known relationships and run in simulation within a scenario to validate expected results but also to specifically search for "emergent behaviour," that behaviour not explained by any one agent's behaviour but is exclusively produced through the complex interactions of multiple interdependent agents. In so doing, M&S can help discover new positive synergies to be leveraged or negative unintended consequences to be avoided.

1.3.3 Highlighting Gaps

M&S can also highlight gaps, conflicts and mismatches of roles, responsibilities and authorities across various agents working toward a common goal within an NNEC environment. Again, due to the inherent complexity of the system as a whole, such issues may not be readily apparent within a static environment but may come to light due to failures during execution that could have been avoided if identified early through effective modelling and simulation.

1.3.4 Supporting Decision Superiority

NATO leadership has recognized the building block approach to the transformation they seek (see Figure 1-1). First, M&S can provide NNEC to connect all partners and make available the baseline knowledge and expertise inherent in the Alliance. Second, it will use the network to build a repository of historical and real-time information – to achieve information superiority. And finally, the information will be used within context provided by either internal mental models or other logical representation of a system's behaviour to project and weigh likely outcomes to actions and achieve what is termed "decision superiority".

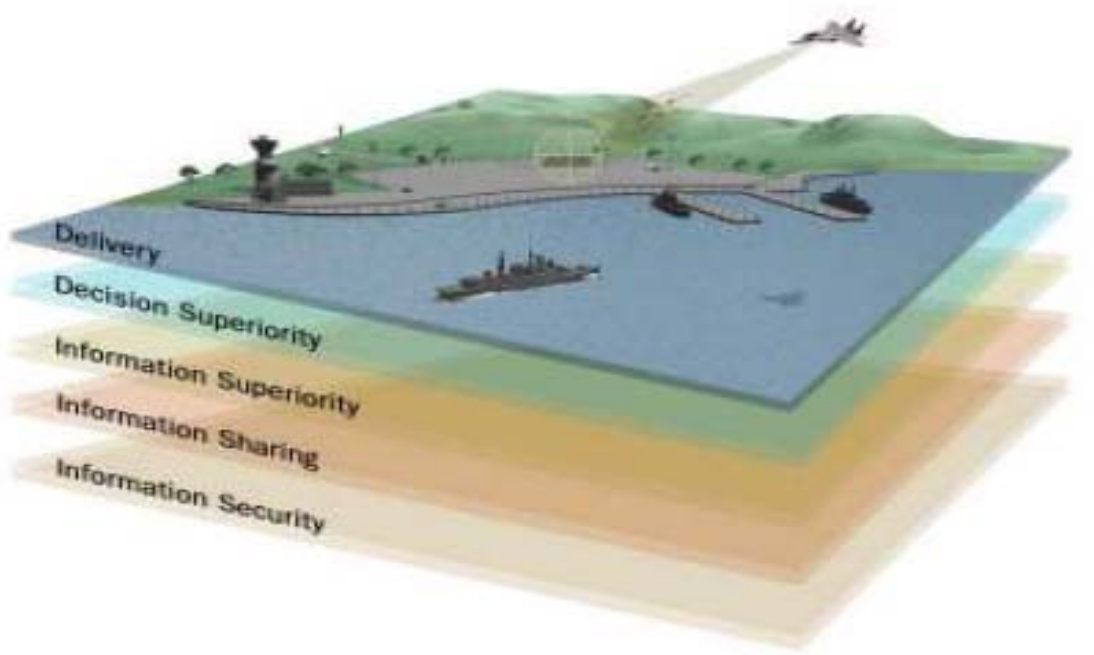

Figure 1-1: M&S Supports the Fundamental Building Blocks Required to Achieve NNEC [3].

Decision superiority may be described as the competitive advantage through which we should be able to exploit the full range of our available capabilities. To choose an optimal course of action, we must develop and maintain, as accurately as possible, a model to explain and understand the current situation and how it developed. We must also be able to project how it will likely develop over time. We must assess what values, beliefs, and objectives drive the actions of others involved, and what capabilities are available to them to turn the situation to their advantage. It is also important to be aware of what may influence our own actions as well as the outcomes of these actions. Decision superiority is thus dependent on achieving at least two concepts: information dominance and shared situational awareness.

If we can anticipate with any degree of certainty how others will act or react, then we should be better positioned to make decisions that will allow us to either leverage or negate their actions or perhaps drive a change in their behaviour to our advantage in meeting our objectives. An efficient and logical means to understand these complex qualitative problem sets weighs the value of relevant factors, evaluates risks against benefits, and develops coordinated courses of action. Working with a variety of contributing partners, we must be able to tie individual decisions to national strategy, develop mutually supporting courses of action, and accurately document the rationale for specific military actions. The process will not guarantee the "right" decision for every contingency, but it should enhance the overall quality of decision making and the connections between these decisions.

1.3.5 Measure of Success

The ultimate success of NNEC may be measured by the extent to which individuals actively seek out and access other individuals' experience, insights, and professional expertise through the social and technical networks it provides. These efforts could validate existing knowledge or create new knowledge and make it readily available within some problem-solving or decision-making process.

1.3.6 Providing a Low-Risk, Low-Consequence Environment

M&S can be used as a key enabler to provide a low risk and low consequence of failure environment, showcasing its significant benefits within a complex adaptive environment and establishing confidence in NNEC across the Alliance.

"Using a Case Study based approach, this Guide shows how *M&S, as a lead S&T investment, enables NNEC*."

The following chapters provide arguments and representative examples of how M&S can be (and is currently being) used effectively to realize NNEC and its benefits. For those with responsibilities within the force or capability development areas related to NNEC, Chapter 3 on M&S support to CD&E will of primary interest. For those responsible for NNEC capability generation there are separate chapters dealing with M&S support to through-life management (Chapter 2), acquisition (Chapter 4), and training (Chapter 5). Chapter 6 deals with the effective use of M&S to support the conduct of operations within an NNEC environment and will be of primary interest to frontline leaders at every level, from the strategic to the tactical. The final chapters will be of interest to all, dealing with the M&S support for understanding the human element of this complex adaptive system as well as the projected evolution of M&S to continue to support NNEC.

This first version of the Guide focuses primarily on NNEC within the military context. As the issues it addresses occur within a complex and adaptive NNEC environment, the system will likely evolve and drive changes for the effective use of M&S in this area. In addition, the full vision for NNEC is not restrained to an application within the military domain alone; it is also expected to be a key enabler for effective collaboration and cooperation across military, diplomatic, economic, and social efforts as well. The Guide will be updated in keeping with this evolution and in response to feedback from related communities.

1.4 REFERENCES

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Chapter 2 – M&S USING SYSTEMS ARCHITECTURES IN SUPPORT OF THROUGH-LIFE MANAGEMENT FOR NNEC

Key M&S Principles

1) **M&S that uses architectural techniques to measure interoperability – a fundamental property of NEC – provides a key decision support tool for managing investment in systems that contribute to NEC mission threads.**
2) **NEC is a Systems-of-Systems (SoS) problem that can be understood through effective use of enterprise architectures.**
3) **SoS architectural modelling underpins the through-life management of NNEC.**

2.1 THE SYSTEM-OF-SYSTEMS NATURE OF NEC

The term "system of systems" (SoS), has gained currency as a means of distinguishing particular systems features that call for special development and management attention. Maier [1] listed the features of SoS as follows:

- Operational independence of elements;
- Managerial independence of elements;
- Evolutionary development;
- Emergent behaviour; and
- Geographical distribution of elements.

"Systems must be added to or removed from the SoS over time … there is no 'clean sheet' approach. M&S can provide a *vital decision support tool* when introducing new systems within an NEC".

Since NEC exhibits all these of features (in abundance), developing systems that are suitable for NEC must involve an understanding of SoS problems. Appropriate M&S can address some important implications of the above features. "Element" in this context means a monolithic system (such as a particular military asset, e.g., aircraft), and the operational and managerial independence of elements implies the need for advanced command and control structures so that the SoS may deliver enhanced performance of some military benefit over and above that which can be achieved by the individual (monolithic) systems that contribute to it.

The feature "evolutionary development" implies that systems must be added to or removed from the SoS over time so that management of legacy, obsolescence, and compatibility must be explicitly considered. This consideration is very important: there is no "clean sheet" approach to developing the SoS, so M&S can provide a vital decision support tool when introducing new systems within an NEC. This process could take place over long time spans applicable to through-life management of assets and systems, or it could take place in the short time span applicable to the rapid composition of capabilities into force structures as carried out by commanders in the field. [2]

Emergent behaviour – the unexpected behaviour of the SoS that cannot be predicted from those of its individual systems of which they are comprised – poses a particular challenge, because this has implications for safety, security, and other dependability characteristics. As a result, so-called normal accidents may occur, in which all systems operate as they should, but the combination of those operations can lead to unsafe states [3]. At the time of writing, this feature poses a major obstacle to the realization of NEC ambitions because of the difficulty it creates for qualifying system of systems. M&S that applies scenarios within architecture frameworks is being developed to address this challenge and will likely become an important aspect of M&S for NEC in the future.

Geographical distribution of the elements means the individual systems can exchange information (but not mass or energy).

Mittal et al. (2009) have observed that the main distinguishing feature of SoS is interoperability, or rather, a lack of interoperability [4]. Consequently, much of the applicable M&S for SoS concerns interoperability which has particular relevance to through-life management for NNEC.

2.2 NEC-READINESS

Figure 2-1 presents a set of NEC-readiness themes [5] derived by the NECTISE [6] project. The interrelationships of these themes measured appropriately determine the readiness of systems for participation in NEC. Agility is at the heart of these themes as the main objective of NEC. Agility is achieved and balanced by interoperability, availability, affordability, and dependability. All of these aspects are supported by collaboration and knowledge management. M&S can be used to support systems development and, by implication, associated investment decisions for through life management by aiding the system designers and procurers in achieving an appropriate balance of the readiness themes. Thus, M&S provides decision support in the choices made by stakeholders in the through-life management of systems that contribute to NEC. The Case Study presented below focuses on the use of systems architecture to identify interoperability weaknesses in mission threads and to prioritize investment options in their resolution to support agility, dependability, and availability balanced by affordability.

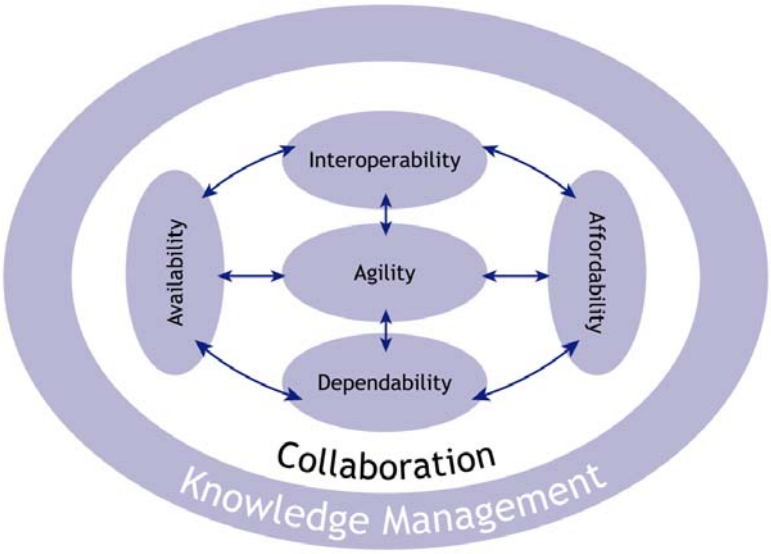

Figure 2-1: The NECTISE NEC-Readiness Themes.

2.3 THE RELEVANCE OF ARCHITECTURE FRAMEWORKS TO THROUGH-LIFE MANAGEMENT

Architecture Frameworks (AF) such as those of NATO (NAF), the US Department of Defense (DoDAF), and the UK Ministry of Defence (MoDAF), form the basis for much M&S in support of through-life management, acquisition and, in very recent times, operational planning. Such frameworks capture, as a minimum, the operational, technical, and systems view of the architecture and provide a common language through which different organizations can design and operate SoS. They are important applications in acquisition processes and provide a starting point for M&S that is applicable to through-life management.

2.4 MODELLING AND SIMULATION FOR INTEROPERABILITY AND INVESTMENT DECISIONS

Interoperability is a fundamental requirement of NEC-ready systems, but it should be understood that interoperability is also relevant at several levels. Ziegler and Hammonds have suggested three levels: pragmatic, semantic, and syntactic [1]; the Case Study that is described below is mainly concerned with the syntactic (i.e., that the message can be received and parsed by its receiver).

The series of Fleet Battle Experiments (FBE) carried out under the U.S. Chief of Naval Operations used architectures to analyze operational tests of Net-Centric Operations (NCO). The following Case Study is based on the ninth such experiment (FBE-I), which represented a major breakthrough in the use of such M&S and had a direct impact on the application of NCO in conduct of operations during the invasion of Afghanistan in 2001. Such a success qualifies this approach to be regarded as a best practice; however, Dickerson and Mavris, who provided this Case Study, note that architecting skill plays an important role and that the attention paid to this endeavour is critical to the success of the approach [8]. The architecting principles explained in detail by these authors should, therefore, be thoroughly studied by a new practitioner wishing to apply the technique outlined below.

The Case Study uses DoDAF, but it could be carried out with any of the other appropriate architecture frameworks, such as NAF.

Briefly, an operation is represented in a typical Operational View – 1 (OV-1) diagram and the interoperability for a part of that operation is captured in OV-6 diagrams. Various mission threads are considered. The mission threads represent that chain of events and communications used in the NEC activity described in the OV-6. Data on the interoperability between the various elements of the SoS is derived from a list of interoperability issues reported during the course of operations. Applying this data within the mission thread reveals a number of interoperability weaknesses and/or failings. Fixes for all such interoperability issues have been proposed and costed. The object of the M&S is to optimize the improvement (i.e., choice of combination of fixes) against the cost and the effectiveness. This latter is derived from a set of relevant scenarios that are prioritized in terms of likelihood. The optimization maximizes the number and likelihood of scenarios to determine the bundle of fixes to be delivered within a set budget. This provides a rational basis on which to choose from a set of potential interoperability investments. Standard optimization approaches can be used.

The Case Study outlines the process in more detail, but for a full explanation the reader is referred to Dickerson and Mavris [7].

Interoperability is a fundamental characteristic of NEC, and determining the best options for maximizing interoperability is a priority when designing new systems or upgrading old systems that participate in NEC.

The use of a detailed architecture in combination with data gathered from operations is a good practice to support through-life management of NNEC. The architectures derived to support such activities can have great utility in additional simulations for many purposes and, thus, warrant the time investment required to create them. Systems of Systems architectures underpin the development of systems that contribute to NEC. The 'gold nugget' or "Key M&S Principle" presented here is the extension of systems architectures for use within an M&S strategy to support interoperability planning as a part of through life management for NNEC.

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Chapter 3 – M&S IN SUPPORT OF CONCEPT DEVELOPMENT AND EXPERIMENTATION SUPPORTING NEC

Key M&S Principles

4) **The approach to explore the way ahead of a NEC is by means of CD&E, which should be based on a campaign of experiments that use live, virtual, and constructive simulations in an iterative, scientific way.**
5) **Simulation allows for experiments that would otherwise be too dangerous, expensive, time consuming, or even impossible.**
6) **Simulation development should not start from scratch, but instead reuse assets that are part of a permanent simulation capability.**
7) **Managing a persistent simulation capability can benefit from Capability Maturity Model Integration (CMMI) with M&S key process extensions.**

3.1 FUTURE NEC CONCEPTS

Future NEC concepts promise high potential for efficient and effective military operations. The introduction of NEC, however, has a high impact on the organization, training, doctrine and material acquisition activities of the defence establishment, so simply throwing new technologies at the warfighter might not produce the expected results. The introduction of NEC, therefore, should be managed as an organizational transition by conducting experiments and trials, starting on a small scale.

Periodical, iterative experiments that involve stakeholders allow an individual organization to discover what concepts work and what concepts do not, evolving towards operational introduction. This is where the CD&E approach can help to explore the road ahead. As mentioned in The Technical Cooperation Program (TTCP) GUIDEx, [1], a campaign of experiments is a sound strategy for exploiting simulation using a balance of Live, Virtual, and Constructive simulations. Stakeholder involvement is key to sustaining momentum while managing a transition. Such involvement requires short time intervals between experiments. In particular, non-live simulations have a potential to explore various solutions in a short time and in a cost effective way. This is where M&S can support the CD&E process. Although M&S technology is a key enabler for shortening time between experiments, it would be unacceptable to start M&S development from scratch for each experiment. Reusing and tailoring "off-the-shelf" simulation assets is a proven strategy for better, faster, and cheaper development and is in line with evolving experiments. Furthermore, in the NEC context, interoperability with other organizations is vital. In this chapter, key issues regarding M&S supporting CD&E for NEC are addressed.

3.2 CONCEPT DEVELOPMENT AND EXPERIMENTATION FOR NEC

3.2.1 CD&E Approach for NEC Organizational Transition Management

It has been long understood that a technical network is at the centre the NEC concept. However, the book *Network Centric Warfare* argues that the act of networking, rather than the network itself, is what should be

emphasized [2]. Networking may involve the sharing of information, collaboration, or both. Collaboration can focus on the interpretation of information, deciding the nature of an appropriate response (planning), the allocation of resources, or action (execution). To achieve this level of collaboration, NEC requires not only elements of armed forces to be able to share information and collaborate, but also require changes to doctrine as well as processes to achieve widespread information sharing and collaboration across existing organizational lines and echelons. It also requires changes in the distribution of decision rights and responsibilities (authority). NEC does not only imply a change in information systems, but rather a transition from one organization to another.

A challenge in this transition is that NEC as a concept has never been implemented before. However, simulation through CD&E can provide a "dry run" of new organizational structures and their implications. Through CD&E, causes and effects can be predicted through simulation long before the concept is put into practice. The CD&E approach may well be the best option to get to informed decisions in contexts that are often hard to engineer using classical means, such as:

- Enhanced operational effectiveness through balanced innovation of organization, processes, doctrine and equipment;
- Cause and effect relationships and evidence based arguments to decide which options and investments to pursue; and
- Balanced and tested specifications for capability investments.

"Through CD&E, causes and effects can be *predicted through simulation long before* the concept is put into practice. The CD&E approach may well be the best option to get to *informed decisions* in contexts that are often hard to engineer…"

The next section describes NEC experimentation and how it may be supported by M&S in greater detail.

3.3 EXPERIMENTATION FOR NEC

3.3.1 Identify Experiment Objectives

Experiment planning begins with carefully considering the experiment's objectives. Make sure that these objectives are explicitly expressed according to SMART criteria, being "Specific, Measurable, Attainable, Relevant and Time-bound."

3.3.2 Conduct Experiments Iteratively to Accumulate Knowledge and Explore Potential Solutions

Future NEC concepts are often not concrete enough to introduce operationally. This is why iterative development of experiments supported by simulation provides a means to gradually create the insight needed to grasp the concept and its implications. M&S technology is a key enabler to involve stakeholders and let them experience what concepts have potential and how to manage them.

Iterative experimentation allows stakeholders or customers to explore the concept in an evolutionary way. Keeping stakeholders involved requires short time intervals between experiments in order to maintain momentum. This has also been addressed in the GUIDEx as Principles 5 and 14 [1].

3.3.3 Conduct a Campaign of Experiments Exploiting Modelling and Simulation

Necessary acceptance across NATO requires NEC experiments to be conducted in a coalition of nations. This process often involves a campaign of experiments that are supported by constructive, virtual, and live simulations that originate from the nations themselves. Such complex multinational campaigns must be conducted in a cost effective way, in a short period of time, with consistent quality. This requires aligning the way people work and how they use their supporting means (e.g., tools and M&S assets). This process has also been referred to in the GUIDEx as Principle 4.

3.3.3.1 Simulation for CD&E

Utilizing various kinds of M&S to conduct experiments enables one to address all requirements of a good experiment, as can be seen in Figure 3-1. Apart from the aforementioned constructive, virtual, and live experiments, analytic wargaming is another means of simulation.

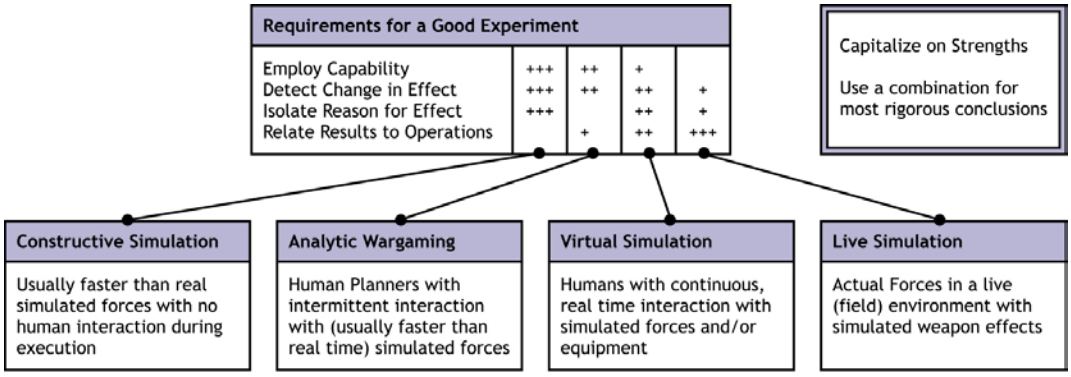

Figure 3-1: Experiment Requirements [3].

3.3.3.2 Why Use Simulation in Experiments?

There are several reasons for using M&S technology in experiments. First of all, it allows one to experience things that are otherwise impossible, dangerous, time consuming, or too expensive. Secondly, it can shorten the time interval between experiments, which may lead to better and more effective stakeholder involvement[1]. Thirdly, simulation helps to exploit the art of hiding detail and complexity, such that one can focus on the most important aspects.

The above benefits of using simulation can be exploited optimally in a campaign of experiments, in which constructive, wargaming, virtual, and live simulations are combined (see GUIDEx Principles 10 and 13).

3.3.4 Apply Verification and Validation

Validation is the process of determining whether simulation assets are fit for purpose depending on their intended use in experiments. Typically, causes and effects in CD&E should have a valid representation in comparison to causes and effects in an NEC environment. Unfortunately, it is often impossible to compare simulation results against authoritative referent data when dealing with new and unfamiliar concepts. However, the following validation strategies have been proven useful:

[1] See also GUIDEx Principle 14.

- Reuse assets that have been validated previously in comparable experiments.
- Use subject matter experts in the experiments to validate the used assets.
- Use subject matter experts to review the conceptual models early in the development.

Verification of the models is also important; with each level of complexity in the model the coherence must be maintained.

3.5 MODELLING AND SIMULATION DEVELOPMENT

3.5.1 Establish a Permanent M&S Experimentation Capability in Place to Enable 'Better, Faster and Cheaper' Development

Short development periods between experiments, is key to customer involvement. Development should be based as much as possible on reusing and adapting existing successful simulation assets. Other advantages of reusing are reliability, maintainability, and validity. In addition, having short development periods between experiments encourages customer involvement. Having a permanent CD&E capability in place will make these conditions possible.

Establishing a permanent, stable CD&E capability is a significant undertaking for an organization. Any facility requires continuous attention and maintenance in order to keep it up to date for the experiments that it needs to facilitate now and in the future. Such a capability requires generic infrastructure (accredited networks), generic functionalities, and visualization solutions (synthetic environments, etc.). Development guidelines, asset reuse and a common architecture, provide support for the complete development cycle. International standardization is crucial to enabling interoperability with other M&S partners, thus benefitting a whole community.

Running a persistent CD&E capability implies having in place:

- An infrastructure;
- An architecture that enables generic tools, services and assets;
- A process and the means and tools to facilitate individual experiments;
- Daily facility management; and
- The capability to invest wisely in the development of the facility in terms of future requirements of the facility.

A generic, persistent capability is necessary to keep experiment development lean and mean. However, using such a facility requires flexibility; whenever an experiment changes, a facility must adapt as well. Maintaining an up-to-date, persistent capability calls for continuous improvement of assets, development processes and the organization itself. Just as in software engineering, a comparable continuous improvement approach has lead to the Capability Maturity Model Integration (CMMI). Although CMMI has no special focus on M&S, it has been proven very useful. With respect to M&S, it is advised to also pay attention to related processes such as: synthetic natural environment management, scenario management, federation management, and security logging and analysis.

3.5.2 Establish Mandate over M&S Assets

In iterative experimentation, a planned experiment is likely to be a continuation of previous experiments. An organization that is conducting experiments must have the authority to adapt M&S assets how and when

they see fit. It is unacceptable to be dependent on third parties that have their own agendas; third party dependencies and vendor lock-in should be avoided. Investing in a persistent CD&E capability could be in vain if required upgrades can't be planned in time and on budget because of external dependencies.

3.5.3 Practice Conceptual Modelling

Selecting which M&S assets are fit for purpose can be done only if stakeholders understand and agree on the intended use of those assets in an individual experiment. Conceptual modelling is a proven way of transforming implicit assumptions to explicit ones as a means of communication and elaboration. Because large portions of a conceptual model can be reused, it is important that stakeholders understand the intended use for each experiment, especially if the experiments evolve over time.

A conceptual model is regarded as an important deliverable at the verification and validation stage for reviewing whether assets are correct and fit for purpose.

3.5.4 Derive Shared Data from One Single Authoritative Source to Ensure Correlation

It is important that participants in an experiment share the same experience, especially in a virtual simulation. In order to accomplish this, distributed M&S assets must share data and processes that correlate in time and place. This correlation is important for data that is exchanged dynamically during simulations, but also for data that has a more static character, such as a scenario definition and a SNE database. Unfortunately, legacy simulators have their proprietary data formats at various resolutions. One strategy to overcome this diversity is to derive this static data from one single authoritative source. Such a source must meet the highest fidelity and highest detail that is needed in the experiment.

3.5.5 Specify Common Shared Meta-Models for Interoperable Data Exchange

In NEC experiments, it is likely that various assets need to exchange data, for example. Typical data that is to be exchanged is:

- Ground truth data;
- Sensor data via the sensor grid;
- Weapon data via the weapon grid;
- Command and control (C2) data via the C2 grid; and
- Logging data for overall analysis (see also GUIDEx Principle 12).

In case machines have to interpret this data, it is advised to adopt a common shared meta-model to which individual assets have to adapt. Each experiment can have a different focus, though it is likely that large portions of meta-models can be reused over various experiments.

Some domains have intermediate exchange data models that have high potential for reuse, such as:

- Real-time, Platform-level Reference Federation Object Model (RPR-FOM) for High-Level Architecture (HLA) federations as ground truth exchange data in simulation domain; and
- The Command, Control, and Communications (C3) Information-Exchange Data Model (C3IEDM) and Coalition – Battle Management Language (CBML) in the C2 domain.

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Chapter 4 – M&S SUPPORT FOR ACQUISITION, TEST AND EVALUATION, AND LOGISTICS FOR NNEC

Key M&S Principles

8) **The approach to explore the way ahead of a NEC is by means of CD&E, which should be based on a campaign of experiments that use live, virtual, and constructive simulations in an iterative, scientific way.**
9) **Simulation allows for experiments that would otherwise be too dangerous, expensive, time consuming, or even impossible.**
10) **Simulation development should not start from scratch, but instead reuse assets that are part of a permanent simulation capability.**
11) **Managing a persistent simulation capability can benefit from Capability Maturity Model Integration (CMMI) with M&S key process extensions.**

4.1 APPROACH TO ACQUISITION

"Though still an immature domain, there is a growing number of Case Studies that have documented the successful use of M&S as *a lead investment for Acquisition* in Defence NEC as well as Homeland Security NEC."

There comes a point in time during the development of a capability where one must shift from a largely abstract and intellectual paradigm to a more physical and pragmatic paradigm. Within the defence community, this transition brings with it what has been traditionally referred to as the acquisition cycle – the activities that ultimately lead to the procurement of system platforms and equipment to be fielded to address a recognized gap in capability. For the purposes of this document, the term *acquisition* will refer to those activities directly related to the procurement of tangible assets that contribute to the generation of capability. It will not include the acquisition of complete capabilities or of intangible items such as knowledge, experience, and processes.

Within current fiscal realities, one thing that is generally common across all national and organizational boundaries is the dynamic between acquisition costs, operational costs, and total program costs. According to an October 2003 report on the Concept of Operations for Synthetic Environment Based Acquisition by the Canadian Department of National Defence (DND) Materiel Acquisition and Support Directorate, the following was identified:

> *"Evidence suggests that the total life cycle cost of a system is influenced 28% by the actual acquisition costs, and over 60% by the ongoing operations and logistics costs. However, 70% of the total life cycle costs are already "locked-in" by decisions made during the acquisition phase of the life cycle."[1]*

Based on these statistics, it would be wise to spend time and resources in the early stages of acquisition to avoid potential problems in the longer term. In essence, one should strive to create an environment where senior leaders and managers are provided effective support to make informed decisions early in the process. Several efforts [2] over the past decade have shown that modelling and simulation provides the potential to

create a more comprehensive analytical environment, thus enabling informed decision making, resulting in a better understanding of the total cost from the perspectives of financial cost as well as risk.

The implementation of a capability within an NNEC environment will be best accomplished through a structured acquisition approach comprising three primary components:

1) People (knowledge, skills, and experience);
2) Processes (organizational structures, relationships, and activity processes); and
3) Technology (tangible equipment and platforms).

Notwithstanding the fact that many nations are undergoing a transformation in their approach to acquisition, traditional activities that focus on systems and technology still prevail in many circles to this day. The effectiveness of a network-enabled capability will truly rely on a balanced approach among the three components identified above.

"M&S can provide a synthetic environment representing the NNEC framework within which member nations can test and evaluate *any proposed capability acquisition* for its ease of connection onto the network."

Diverse member nations will continue to acquire the majority of their assets through national programs; however, within the context of the NNEC concept, NATO aims to integrate and collectively use national capabilities consistently and in a coherent manner. Consequently, NATO finds itself in an interesting position when it comes to acquisition (or procurement) in that, as an organization it has some general responsibilities and authorities to procure equipment in support of its mandates; it also, however, has to account for member nations bringing with them their own procurement strategies and processes, which may not align ideally with the acquisition strategies of NATO as an organization. Within the context of NNEC, NATO's specific acquisition responsibilities include ensuring that NATO will assume include the provision of capabilities that connect and permit inclusion into the network of individual national capabilities, independently procured and provided by contributing nations for operations. Through an M&S-derived synthetic environment that represents the NNEC framework, member nations can test and evaluate how any proposed capability acquisition could connect onto the network.

The steps of a generic acquisition process are as follows:

1) Requirements definition;
2) Design specifications;
3) Analysis of implementation options; and
4) Test and evaluation.

The authors fully acknowledge that defence organizations worldwide have been moving toward a more holistic approach to acquisition, particularly from a capability development and generation perspective; however, this chapter has been consciously written with a specific focus on procurement activities. Other stages of the capability life cycle are addressed in subsequent chapters.

4.2 M&S SUPPORTING ACQUISITION IN GENERAL

It can be said that M&S is not necessarily used consistently within the acquisition process; indeed, this observation was made in the NATO Feasibility Study on Modelling & Simulation Technology in Support of

Simulation Based Acquisition [3]. The use of M&S as a technology aid to acquisition can be seen as another step in the evolution toward a more holistic synthetic environment approach in support of the development, generation, and employment of capabilities. In this light, the notion of using M&S to inform decision making during the acquisition of systems, and eventually entire capabilities, would be one of the stages in achieving the more coherent and consistent use across the entire capability life cycle. As such, it is important to recognize and understand that any use of M&S at the front of the dedicated acquisition activity should flow logically from any efforts that were made during the earlier stages of capability development, such as CD&E. The following paragraphs discuss the ways in which M&S has the potential to support acquisition activities in general, based on the construct defined earlier in this chapter.

4.2.1 Requirements Definition

This first phase of the acquisition process is the boundary between capability development and acquisition. As such, it demands the translation of operational requirements established in the later stages of capability development to technical requirements necessary for effective and efficient acquisition. As the operating environment and our response to it becomes more complex, so does the task of specifying all requirements related to functionality and connectivity.

M&S approaches and technologies can provide two readily apparent services to this sometimes daunting task in two ways. First, it has been said that a picture is worth a thousand words, so M&S technologies and visualization techniques can be extremely effective. They provide decision makers not only static images, but also full animation and in some cases fully immersive and analytical environments, facilitating a much higher level of understanding of the problem space This alternative approach has the potential to be much more effective and efficient when compared with trying to “paint a picture” through the use of words alone.

The second area where M&S has potential is more tangible. Provided that the models of the problem space have been verified and validated (whether reused from the CD&E phase of activity or developed specifically for acquisition), then it is possible for these models to be used in refining and articulating the boundaries of the solution space. This activity would be possible through a series of M&S supported experiments or scenarios focused on generating data based on measures defined as necessary for the desired capability.

However, a word of caution is warranted when reusing any existing models or simulations. A reminder of the fundamental definition of a model provides justification: a model is a representation of some portion of the real world *for a specific purpose*. This caution holds true for all steps of the acquisition process and the capability life cycle as a whole.

4.2.2 Design Specifications

Acquisition professionals are faced with the task of identifying potential solutions that meet the operational and technical requirements developed to address a capability deficiency or gap. For capabilities proposed for within a NNEC environment, this task involves activities that can be grouped into two categories. First, the design specifications of proposed solutions must be assessed to determine if they meet the minimum requirements. These requirements consist of two distinct yet equally critical elements: operational functionality and technical connectivity. Operational functionality involves the ability to address the problem at a minimum standard, while technical connectivity ensures the ability to connect to the network. Next, the solutions that meet the minimum requirements must be assessed for relative merit. This assessment can be accomplished through some form of trade-off study that compares and contrasts overall performance.

At each of these stages, M&S can be used to assess proposed solutions to pre-defined cost, performance, and time metrics to achieve the desired operational effectiveness. One approach to supporting the use of M&S is to specify the requirement to submit models as part of any response to a request for information or proposal. The submitted models would then be assessed during the bid evaluation process and could then be reused (if appropriate) during follow-up activities.

4.2.3 Analysis of Implementation Options

Following the down-select (short-listing) of the most promising potential solutions (based on comparison of their relative merits as individual components), the next task is to assess their relative merits as components within the broader system. As described in Chapter 2, this is a critical step within an NNEC paradigm and expands the use of M&S beyond the verification of component performance. This step uses M&S to indicate each individual component's contribution to overall system performance within the NNEC system-of-systems construct. This "systems view" is critical for NNEC acquisition support because it's perspective is from a higher level than individual components behaviour and focuses on higher order issues of how the component performs as an integral part of the larger system-of-systems or a network-enabled system.

From the components identified and down-selected as potential solutions through design specification testing in the previous step, re-using the component models and integrating them into a broader system-of-systems modelled environment can provide insights into overall system behaviours and performances. These behaviours and performances can be observed, measured, compared, and contrasted as various potential components are substituted into place. As was highlighted in Chapter 2, this is a critical step, since within a system-of-systems networked environment there is no "clean slate" where independent components cannot be introduced without affecting in some way shape or form, existing capabilities within the system. That being the case, the acquisition communities can procure platforms and equipment on behalf of Force generators in the hopes that their introduction into the broader system will work out well, or they can proactively investigate and identify emergent behaviour based on M&S decision support to make better informed acquisition decisions considering higher order system behaviours.

The preceding steps are focused on decisions related to evaluation of the overall effectiveness of the system related to two specific points in time, the current system's performance and the future system's performance based on the procurement and introduction of some new or improved capability. However, there are often protracted periods of time between the initial operating capability – when the new capability first appears in an operational setting at some locations while at others, legacy components remain in service – and the final operating capability, when the implementation of the new capability is considered complete.

As always, overall system performance optimization within an NNEC paradigm is the primary objective however, system optimization is no trivial task within a fully networked complex adaptive environment. The many components within the system never completely lock into place, but rather the entire system continuously morphs as changes are constantly made and the system adapts, each individual agent attempting to optimize their competitive advantage. As described in Chapter 1, emergent behaviour cannot be easily predicted by considering the behaviours of individual agents but only becomes apparent when complex interactions are permitted to occur. This interaction is further complicated throughout the transition period because potentially both new and legacy components are concurrently interacting within the environment in what are intentionally significantly different ways and so add to complexity for the duration of the transition. In theory then, according to complexity theory, using modelling and simulation we can test various implementation plans related to timing and locations of technology insertion and specifically looking for early emergent behaviour to occur in order to leverage positive synergies early and to the maximum extent possible.

4.2.4 Test and Evaluation Studies

Test and evaluation (T&E) in the operational world is equivalent to verification and validation within the software or M&S world. As such, T&E should be viewed as a series of activities that occur throughout the acquisition period as opposed to a concluding activity that is exercised solely on the target system or solution.

In this context, procurement officers and managers should be encouraged to define their activities based around the construct of requiring assuming they will need contractors and solution providers to deliver virtual prototypes of suitable fidelity early in the acquisition process. These prototypes could then be subjected to any of a series of tests and evaluations (developmental, engineering, or operational) depending on the phase of procurement and the nature of the prototype provided. For example, a technically high-fidelity model would be subject to "engineering T&E" whereas a high-fidelity system performance model would be subject to "operational T&E". This approach is more likely to detect any issues that would result in operationally unsuitable problems with the system early in the procurement cycle, thus allowing modifications to be made before making a final commitment to manufacturing.

Once physical prototypes are ready, M&S can provide value added by enabling several synthetic test cases (trials) prior to a live test case. In this fashion, any live trials then serve to validate models and simulations, which in turn provide a higher degree of confidence in simulation-based test results. As the models and simulations mature over time, a point can conceivably be reached wherein simulation-based tests may provide a more comprehensive method of evaluation than live trials because of the flexibility and adaptability of synthetic environments.

Throughout all of the activities identified in this section, the managed use of M&S in support of acquisition can effectively support more comprehensive and informed decision making by enabling objective, defensible, and structured analysis. In so doing, maximum benefit from such this approach can be beneficial only if the resulting data, information, and experience is captured and stored where it can be easily accessed. This information will support subsequent phases of the capability life cycle (training, mission rehearsal, operations, disposal) and contribute to an audit trail detailing how any given project reached a specific point. Consequently, M&S support to acquisition relies heavily on information storage and sharing mechanism, as well as governance, processes, and leadership to facilitate the use of the mechanism. This integrated approach (people, processes and technology) to using M&S in support of acquisition can help define and manage the scope of related activities and, ultimately, has the potential to improve the capability life cycle as a whole.

4.3 ACQUISITION OF NETWORK-ENABLED CAPABILITY

Those involved with and responsible for developing a network-enabled capability have identified the need to approach the problem space in a holistic fashion and take into account not just the required technology, but the people and processes as well. NATO supports this approach through identification of cognitive challenges (cultural and individual) as well as technical challenges in its Concept and Vision document. This approach is further reinforced in the UK Ministry of Defence Joint Services Publication 777 (NEC) wherein NEC development is grounded on three dimensions: infrastructure (equipment/technology), information (processes/ structures) and people (individual and teams). The JSP 777 document also stipulates that NEC development can be well served and informed by research, analysis and experimentation, particularly through integrated analysis and experimentation campaigns [4].

4.3.1 Parallels in M&S

The past decade has seen a significant increase in the use of networked and distributed environments for the conduct of modelling, simulation, and synthetic-based activities and events. As a result, defence-oriented M&S has had to bring together people, assets, and resources that have been operating independently. The most recent improvements to interoperability and increase reuse in this domain have centred on the IEEE 1516 Standard known as the High Level Architecture (HLA). One component of the 1516 Standard is the systems-engineering-like process known as the FEDEP (Federation Development and Execution Process) that underpins HLA activity. The FEDEP process, like systems engineering, provides guidance to managers, engineers and technologists during the establishment and execution of a distributed simulation activity with a prime focus on generating interoperability amongst a variety of individual simulation systems and devices. This interoperability is accomplished at the technical and syntactic levels wherein pre-negotiated data exchanges are implemented through a publish-and-subscribe mechanism in software.

4.3.2 The Federated Approach

According to the NNEC concept and vision, the acquisition (development) of NNEC is intended to be done in a federated fashion – the bringing together of existing assets, systems and capabilities through the use of data and information networks – in a fashion not unlike that described in the preceding description of HLA. Thus emerges the resounding parallel between the intention of NNEC and the activities of the defence simulation realm over the past two decades. Consequently, it is anticipated that personnel charged with generating NNEC could benefit from the experience and knowledge of the defence simulation communities.

The NNEC Concept & Vision published by NATO in January of 2006 identifies the reliance "upon a federation of networks, services and processes" in a services-oriented approach [5]. As M&S evolves, it is migrating towards a web-based, service-oriented delivery construct. The parallels between existing M&S efforts and the concept underlying NNEC are apparent. Therefore, one could logically conclude that from the highest of levels there are likely to be benefits and value added in providing simulation-based services to the development and generation of NNEC.

4.3.3 Core Aspects and M&S Relevance

During the formulation of the NNEC concept and vision, NATO articulated several core aspects related to managing the development of NNEC. The following points highlight these core aspects and identify how modelling and simulation has the potential to provide assistance and value added:

- NNEC implementation processes will be aided by a strategic framework that will evaluate the intended capabilities prior to operational employment.
    - M&S services can provide consistent and controlled environments to facilitate the evaluation of capabilities. In addition, networked and distributed synthetic environments can provide a structure that reflects/represents the strategic and conceptual framework.
- Effective management of NNEC development will require the ability to measure progress.
    - Replication and representation of NNEC components and capabilities in simulation can facilitate direct data collection in support of progress measurement[1].

[1] See the NITEworks website, available at http://www.niteworks.net/, and NITEworks partners website for other specific experiments, including joint data collection studies (http://www.thalesresearch.com/Default.aspx?tabid=375).

- NNEC planning, development and implementation will need to accommodate a wide range of national capabilities, which in turn is dependent upon the willingness of member nations to support development of common standards and interfaces.
    - NATO nations have encountered similar circumstances within the realm of distributed simulation efforts during the past decade. The prime example of this is the First WAVE Exercise that was conducted in support of exploring the benefits associated with Distributed Mission Operations (DMO). Another example involving multiple nations is the annual Coalition Warrior Interoperability Demonstrator (CWID) activity, which evaluates technologies and capabilities for exchanging information[2].

Modelling and simulation has demonstrated its relevance to the acquisition community through several key efforts and procurements. Whether they call it Simulation Based Acquisition (SBA) or Synthetic environment Based Acquisition (SeBA), capability planners are recognizing and experiencing the benefits that can be realized through the use of M&S approaches, techniques, and technologies. One Case Study wherein M&S has been leveraged to advise and influence acquisition is the US DoD Joint Strike Fighter (JSF) program. During the procurement of the JSF and its associated systems, government and industry established central repositories of models, simulations, and synthetic environment components to aid in the development and delivery of the capability. On the industry side, Lockheed Martin provided the JSF Distributed Product Description (DPD), which addressed operational performance, logistical characteristics, and cost. This description spanned from the engineering level, through engagement and mission levels, up to the campaign level. On the government side, the JSF Program Office provided the "surrounding" simulation environment to include threat systems, friendly systems, logistics resources, C4I, and environmental representations (terrain, atmosphere). The overall resulting toolset was comprised of a strike warfare collaborative environment and an engineering and manufacturing collaborative environment. Consequently, JSF procurement activities were supported by networked models and simulations that collectively represented the complex operating and engineering environments to aid in decision making.

In addition to defence NEC, there are a few emerging Case Studies where M&S was used to support some aspects of acquisition of NEC in Homeland Security as documented in the following Case Studies. A review of Canada's protective security measures had identified some vulnerabilities of Canada's marine ports for illicit shipments of radioactive material. In the RADNET Case Study [6],[7], M&S was used to investigate the value added of a real life working model of network-enabled radiation detection capability for border security. The EXIT08 Case Study [8] consisted of a dirty bomb exercise with an Inter-Agency and multi- jurisdiction scenario for a Major Event Response Capability exercise. Extremely realistic live simulations of chemical, biological and radiation agents were used to in part to realistically assess the value of network-enabled CBRN mobile labs capabilities (a Whole-of-Government Major Events Response Capability) provided. In the C2Sim Case Study [9], distributed M&S was used to address and enhance the NEC (preparation capability and response capability) of emergency management partners, particularly those associated with major events in Vancouver.

Further, the acquisition of Joint Fires Support Capability as a vital NEC for many nations was preceded by significant M&S activities (see Joint Fires Support Case Study [10] and; UK Employment of Fires Case Study). The latter Case Study was rather revealing since *UK Employment of Fires* ("N-E Fires"), documented the **benefits of M&S to the Employment of Fires as an NEC** with the following benefits, in order, before the actual acquisition itself:

[2] See the Coalition Warrior Interoperability Demonstrator US website, available at: www.cwid.js.mil/c/extranet/home and UK website available at: www.cwid.org.uk.

1) Situational awareness;
2) Time;
3) Flexibility;
4) Coordination;
5) Optimality of results; and
6) Mission success.

It remains critical to note that all the above required the following common elements to get there: connectivity, common data formats, common doctrine, and common procedures [11].

4.3.4 Challenges

One of the challenges NATO has identified within the NATO Vision and Concept document is developing and implementing new operating procedures without jeopardizing operational effectiveness. One benefit that simulation can provide is the ability to explore new concepts, procedures, and technologies within a synthetic operating space, free of dependency on any operational resources. During recent years, methods and technologies have matured to the point that once concepts are proven in simulation, they can be transitioned to the field gradually by integrating them with live assets and resources as required.

The cognitive dimension of NNEC has been determined less mature than the technical dimension, and consequently, it is in need of fundamental discovery efforts. Human-in-the-loop, simulation-based experiments can support such discovery efforts, using technologies such as virtual simulators and virtual world environments.

4.3.5 Advice from the Grass Roots

In a report (see Dahmann et al., 2002, below) addressing the use of M&S to support C4ISR (C4I Surveillance and Reconnaissance) acquisition and transformation, the MITRE Corporation and US DoD Program Executive Office (PEO) Metrics identified several enhanced roles for M&S:

- Analyses of alternatives for concept and technology development;
- Early operational assessments in system development and demonstration; and
- Operational test and evaluation in production and deployment.

The report identifies one particular challenge of the C4ISR (systems-of-systems): “individual systems are acquired asynchronously,” but commitment to production and the conduct of test and evaluation can be risky without “full system demonstration.” M&S capabilities can help explore the benefits, challenges, and potential solutions in such complex and diverse environments prior to expending valuable resources (money, personnel, and time) on prototype or production systems. This provides added value in the form of risk mitigation and more informed decision making during the early stages of acquisition (i.e., requirements definition and specification).

An interesting quote from the MITRE report supports the key messages of this chapter: “It is important to emphasize that technology alone will not solve the challenges associated with the pursuit of NNEC. Changes in culture, organization, and process will play an equally important role in achieving a truly network-enabled capability.” [12]

"All acquisitions must be considered in a system-of-systems context. Further, to acquire a system-of-systems, a *strong and integrated M&S capability* is required."

4.4 BENEFITS

As stated before, NNEC is the capability that will enable nations to federate their individual systems and capabilities into an interconnected environment, in a systems-of-systems fashion, to increase operational effectiveness. Likewise, in the realm of networked and distributed simulation, participants federate their individual simulations and tools in a networked synthetic environment to generate a more comprehensive representation of the operating environment, providing greater benefit to all players. This composable approach to the problem space transcends both domains, thus providing indication that both realms have the potential to achieve synergies that will bring value added on both sides of the equation, and they will likely be able to inform and benefit each other.

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Chapter 5 – M&S SUPPORT TO TRAINING AND EXERCISES FOR NNEC

Key M&S Principles

12) **A single system cannot meet the needs of NEC training. The NEC training capability must mirror the flexibility and agility found in the NEC environment itself, i.e., the NEC training and exercises environment (and the supporting M&S) must themselves be network enabled.**
13) **M&S provides a training environment that realistically represent the complexity, flexibility, and adaptability of an actual NEC real-world operating environment.**
14) **Use standards whenever possible, for example: a) when simulation systems are developed; b) for technical architectures; c) for verification and validation; d) for data representation; and e) synthetic environments and scenarios.**
15) **The development of training and exercise capabilities needs to be developed through an incremental and evolutionary approach, supported by an architecture framework such as NATO Architecture Framework (NAF).**
16) **M&S must be aligned to the technical capability of the supporting NATO Information Infrastructure (NII) for NEC.**

5.1 THE ROLE OF M&S IN TRAINING

To realise the potential of NEC, technological advances have to be matched by a parallel development of people through education, training, and exercises. A main challenge to the realisation of NEC is to fully incorporate the human dimension into its development. People require proper education and training to exploit and share the increasing wealth of available information, to collaborate, and to make decisions in various distributed temporarily teams. This chapter will address the role of M&S in training and exercises for NEC, by first discussing NEC training needs and the requirements these needs put on training and exercise capabilities. It will also explore why M&S plays a decisive role in meeting these needs and requirements as well as how M&S should be employed to support training and exercises.

5.2 NEC TRAINING EXERCISE NEEDS

Inherent interdependencies between individual instruments of national influence (which can be thought of as nodes within a security network) demand that the decisions on their use be collectively considered and their actions coordinated to be consistently effective in meeting objectives. To achieve the first goal – collective consideration of decisions on the use of the various instruments – it is critical that the decision support provided is linked and that decision-makers are all considering decisions based on the same baseline assumptions and information. Rapidly evolving technologies provide a means to achieve levels of interoperability and connectivity between the different elements of the security network that were previously unattainable. However, to fully exploit these network-enabling capabilities and maximize the effectiveness of the available technologies within such complex systems or networks requires personnel highly trained and experienced in the processes and manipulation of supporting technologies. It is therefore critical that training be recognized as an important line of development of NEC. NEC training is, in essence, there to support people by providing the knowledge, skills,

and experience to effectively exploit an information-rich networked environment, which is necessary to conduct coordinated interdependent actions and perform operations in a more effective and efficient manner.

While training is important to develop personnel proficient in exploiting new opportunities provided by NEC, NEC will also have a major impact on how training is conducted and delivered. In keeping with the saying "train as you would fight and fight as you have trained," NEC will impact all levels of training – individual, team, and collective – by actively immersing personnel in education and training interactions on the very same network connectivity they will eventually use in operations and in providing operational support.

"While training is important to develop personnel proficient in exploiting new opportunities provided by NEC, *NEC will also have a major impact on how training is conducted* and delivered."

To obtain maximum effectiveness from the actions performed within the network, NEC training must be able to provide competencies at several levels. First, it must focus on elements of education, skills, and experience required at the individual, team, and collective levels to master information-rich environments. For example, the training teaches how to find, manage, and assimilate information into usable knowledge and then share that knowledge with others who need it. Second, common processes need to be learned and incorporated into everyday use in a way that considers both intended and unintended consequences of actions and their potential impact on interdependent actions by others within the network. Consistent use of common processes will help organizations form networked, ad hoc teams quickly to meet the demands of a complex and adaptive adversary. NEC training must also be conducted to develop proficiency in the collective use of those common processes for collaborative decision making across the network, which help synchronize actions and focus their effects. Finally, training will be instrumental and will be required to build trust and confidence between people across organizations who have to collaborate on a distributed and temporarily basis [1].

Proficiency in the use of network-enabled capabilities will provide the processes and mechanisms to effectively achieve organizational decision superiority. Individuals will be able to access, filter, and use critical information within an information-rich environment to build knowledge and push that knowledge across the network to others they identify as requiring it. As well, they could post it on the network so that others attempting to source the knowledge may pull from it. Common NEC processes will provide the means to collaboratively consider knowledge and critical assumptions and using predictive models to weigh intended and unintended consequences of interdependent actions throughout the decision-making process. As a result, these network-enabled processes should provide the means to make more informed decisions faster, arriving at the optimal path to achieve the desired outcomes while avoiding inadvertent counterproductive actions and their risks – the essence of decision superiority.

The role of effective training in the use of network-enabling technologies will be particularly important in the joint, interagency, and multinational arenas. Individuals must be prepared to form collaborative teams which may or may not be co-located and work together for critical planning and decision making in highly complex operations. Joint, interagency, and multinational collective training will be of critical importance due to the anticipated use of ad hoc, task-tailored force packages and agile mission groups that will morph according to need. Personnel must become proficient in not only maximizing the technologies but also in exercising the mental agility to consider the implications and consequences of collective action. This mental agility will be developed within collective training sessions across multiple organizations and command levels. For such training to be realistic, there will not only be a requirement for all participants to be represented, but there will also be a demand for the interactions to be conducted within a more distributed training environment.

With the increased complexity of the security environment demanding more adaptive and flexible network-enabled operations in response, there will be need for an increased number of training opportunities to provide a representative sample of scenarios that could be encountered. The training will likely not only include traditional pre-deployment training but may also encompass continuation training while deployed. Continuation training is useful since both as the adversary and the environment during a mission may evolve, demanding rapid change to tactics, techniques, and procedures. Modelling and simulation can provide more training opportunities as well as facilitate in situ continuation training at both lower costs and risks while at the same time providing a greater breadth and depth of training stimuli than has been previously achievable.

"Synchronized decision making requires training and teamwork skills. Since teams are often formed quickly, training needs to account for this and extend beyond persistent teams. To achieve *decision superiority*, training objectives should *relate to the key desired outcome of NNEC* information."

The training audience of today is becoming more and more immersed in a networked environment on a day-to-day basis. Traditional social networks are increasingly being augmented with high speed digital networks that provide persistent rich channels of communication. This connectivity combined with the increased use and familiarity of online computer games and the vibrant communities they attract has created an expectation that operational training will provide the same or higher level of connectivity as well as realistic immersive environments. Used correctly within well-established boundaries and supporting specific objectives, modelling and simulation can meet and exceed these expectations.

As the complexity of the expected operating environment increases and the range and scope of participants expands, the use of modelling and simulation is gaining importance. For example the operational environment, within which Civil/Military Cooperation (CIMIC) is a key element. Live training in this environment would demand that both civil and military organizations be concurrently available to conduct a collective training exercise. However, with the effective modelling of the specific attributes and behaviours of both organizations, each could effectively train with their simulated counterpart regardless of the counterpart's actual availability. This does not decrease the value of live collective training involving both partners in real time, but in fact will likely increase its value by permitting training planners to focus only on high-intensity and high-impact training to validate prior training objectives met in an immersive synthetic environment and to provide more personal interaction among organizational representatives.

CIMIC in a networked environment will increase in importance especially in a complex operating environment. CIMIC is increasingly vital to achieve mission success in international coalition operations and it is also of key importance to be able to deal with complex natural and man-made emergencies and crises affecting large areas and, populations and, and critical infrastructures such as those for communication and information infrastructures. Crisis situations require rapid reaction as well as establishment of organizational and international cooperation. In such situations, issues relating to organizational boundaries and national borders have to be put aside to enable ad hoc civil/military teams have to achieve close cooperation, effectiveness and timeliness of response. For this purpose, M&S can be utilized for developing and evaluating procedures for this cooperation and for understanding potential problems that can be encountered. There are two distinct perspectives to be covered with respect to training of civil and military personnel for CIMIC:

"*CIMIC in a networked* environment will increase in importance especially in a complex operating environment. CIMIC is increasingly vital to achieve mission success in international coalition operations…"

1) Training of the personnel on civil and military technologies and systems to leverage adaptation to use shared resources effectively and efficiently (the principle concepts for this kind of training are integration, interconnectivity, and interoperability).
2) Training that deals with human systems, management, and team interaction. Although the first kind of training will enhance the capability through more effective and efficient use of systems, in order to achieve communication, coordination, and cooperation of organizations, training of the individual must focus on increasing the understanding of both civil and military organizational cultures, procedures and constraints.

By ensuring that the M&S environment is network enabled, it will provide increased flexibility as to which representative systems are brought together and federated for a particular purpose. It will provide an accurate representation of the operating environment for the training audience at any given instant in time and can mimic the dynamic nature of the environment as well. It is unlikely that training provided by relatively fixed architectures and structures will meet the level of agile flexibility that will define network-enabled operations. To be effective, a training capability to prepare for network-enabled operations will have to mirror the increased flexibility of a network-enabled environment and replicate the same level of organizational flexibility and agility found within the real-world operational context.

A persistent training network will allow individuals and organizations to search for and join planned and ongoing training sessions that will meet their specific needs. Where no immediate opportunities exist, there may be an opportunity to use the persistent training network to invite others to collectively participate using the same concept as is used in online computer games or to simply construct your own realistic training event through the use of simulated participants who are unavailable within a synthetic environment.

5.3 WHY USE M&S TO MEET NEC TRAINING AND EXERCISE REQUIREMENTS

Network-enabled operations are distinctly different from more traditional military operations and as such, personnel must be trained for success within the new operating environment. It has been argued that the training environment must effectively and efficiently deliver the complexity, volatility and agility required to mirror the anticipated real-world operating environment. Within this dynamic training environment, modelling and simulation can provide realistic levels of complexity, dynamic flexibility and adaptability as well as the classical advantages of simulation based training; reduced costs and risks and the avoidance of environmental or operational restraints. In addition, modelling and simulation provides persistent availability permitting the increased diversity and frequency of training required.

To gain experience in understanding and coping with the multitude of seemingly chaotic inputs within a complex adaptive environment such as the modern day security environment, training must mirror the anticipated real-world context to the maximum extend possible. However, to amass the number of participants from the wide range of organizations and expose them to actual threats within possible scenarios is not always practical and in some cases not possible without assuming clearly unacceptable risks and costs. To overcome these constraints and restraints, training can be provided in a network-enabled synthetic environment where only some play is conducted by live participants while other aspects are represented by simulated elements. The potential advantage of modelling and simulation is particularly evident in complex, distributed and interconnected environments where participants performing interdependent tasks may be physically distributed with knowledge of related activities provided solely by information exchanged across a communication network. In these cases, modelling and simulation can be effectively used to represent any number of distributed activities

distant from the immediate actors in an identical manner as would be present in the real world under actual conditions. By generating a stream of information presented using the same system interfaces as would be used in live operations, participants are fully immersed in a realist training environment. The creation of various states, situations and configurations in simulation of a network-enabled environment is not only the most cost effective method to provide training opportunities, it may be the only way to meet individual organization's training needs without putting excessive demands and strain on other supporting organization's time and resources. Through the utilization of reusable simulated elements, models that are tested and approved through a validation and verification process, numerous training environments can be constructed quickly and efficiently to meet the specific training needs of any contributing organization in the network.

From the description above it is apparent that a single inflexible training environment will not likely meet the varied needs of all participants for training within an adaptive networked environment. To be effective, the training environment must provide an ability to mirror the real world in the same manner in which NATO Governments, contributing coalition partners and Non-Government Organizations will ebb and flow with respect to both presence and influence within a theatre of operations.

5.4 HOW M&S CAN BE USED TO MEET NEC TRAINING AND EXERCISE REQUIREMENTS

In essence, M&S can be used as a substitute for any entity or element within the international security environment. As specific models will intentionally simplify certain aspects of the entities they represent, it is essential that users confirm that the model proposed for use in a training simulation is right for the specific training objectives. For example, for flight crew ab initio training it is critical that higher fidelity physics models of aircraft performance be used while the terrain database models are of less importance. The issue is not where the virtual aircraft is flown but rather how the aircraft performs. On the other hand, for operational mission rehearsal or mission preview, high fidelity terrain database models may be critical for flight crews to become immersed in the external environment they will encounter and only a medium fidelity aircraft flight model may be required.

To reduce the need for deployment, operational systems that integrate M&S could be used as much as possible for in situ continuation training. This option would avoid the cost of dedicated equipment and infrastructure to support training. Using a common supporting infrastructure could further reduce systems demands. Thus, the training environment should adhere to and be able to exploit the capability of the NATO Network Information Infrastructure (NII), including, for example:

- Common supporting digital infrastructure;
- Alignment of data, metadata, and interface standards;
- Common transmission infrastructure – physical or logical; and
- Common tools for processing, analysis, and visualization.

M&S can also be used for training to enhance operational readiness early in a capability lifecycle (see First WAVE Case Study). As has been previously described, M&S can be effectively used throughout the concept development and experimentation phases to ensure new capabilities meet operational expectations regarding function, performance, and interoperability. Near the end of the capability development phase just before an acquisition decision, prototype equipment will often be stimulated with simulated inputs and operated by operational experts using proposed tactics, techniques, and procedures as a final test of the capability being considered. If there is a positive decision to acquire the new capability, then once the production specifications

have been established, M&S of the new capability can provide an opportunity to train personnel in its use well before the first delivery of equipment. This should permit not only an earlier opportunity to pre-train personnel in the operation and use of the new capability developing operational expertise but also permit a shorter integration and acceptance period for the new equipment into the system because key members of the operational communities will have experience and confidence in its use when the first deliveries to the field are made (e.g., see NATO First WAVE – MTDS Case Study).

For the end user or operator within a distributed network-enabled environment a data stream generated through M&S will be essentially indistinguishable from a data stream generated from a real-world source. While M&S offers a level of training complexity not previously attainable, it does demand that checks and balances be put in place to ensure that what originates in the synthetic environment remains in the synthetic environment and cannot be sent across live systems and interpreted as actual real-world events.

To establish these checks and balances, data streams that are generated through M&S must be tagged in such a way that the receiving systems can clearly distinguish them from actual real-world reports of events and subsequently display them to humans-in-the-loop as such. As an additional check, developers may want to consider integrating software rules that demand simulated stimuli can only be received in "'simulation' or 'training' mode" and that while in this mode only simulated responses will be allowed. Such software lockouts are currently integrated into aircraft systems that isolate live onboard weapons while operating in a simulation mode for training and do not permit their expenditure.

Finally, it must be acknowledged that while in simulation mode, operational systems could be "offline" from the real-world events while processing, analysing, and displaying simulation data from models. As a result, it is imperative that triggers be incorporated into the system so that if a significant real-world event is detected and reported, upon receipt of the data stream the system automatically dumps the simulation, notifies the participants of the change in status and immediately reverts to "online" status allowing the system to once again assume its real-world operational role.

5.4.1 Individual Training

The effective use of M&S to support individual training within a network-enabled environment will likely begin by creating a synthetic space, including virtual classrooms, libraries, laboratories, and operational workspaces. This will create a positive virtual new learning environment enabling personnel to access information and interact with virtual instructors and classmates. The intent will be to initially access pertinent information within context to gain knowledge on the principles and applied theories behind a new capability. With a broad understanding of the functional capability and the part the individuals play in its operation, the synthetic environment will also permit these same individuals an opportunity to gain initial experience in performing their individual tasks with interdependent or complementary tasks being performed through constructive simulation under normative rules and set procedures. This effective use of M&S will permit a level of individual competency to be developed laying the foundation for higher levels of coordinated team and collective training.

5.4.2 Team Training

While individual competencies are a solid foundation for operational success, many of today's security and defence activities are collective in nature and completed by teams. These teams develop characteristics that cannot be defined only by the individual skills of its members. Team characteristics emerge over time as members interactions occur for sharing information, knowledge, and experiences to solve complex problems

between individual team members, and these affecting collective behaviour. M&S can play a significant part in providing a synthetic training environment similar to that provided for individual training but expanded to the next higher level.

While team training is best accomplished with actual team members, M&S can provide an ability to conduct team training sessions when some team members are unavailable. If two or more members are available, constructive simulation can be used to fill the other roles. As well, M&S can facilitate more efficient, focused training for complex or critical team processes involving interactions between specific personnel when only minimal participation of other team members is required. In such instances, M&S can again be used to represent interactions of these less involved team members without requiring them to participate in what would be lower value training for them. Finally, the environment beyond the team – including other friendly teams, the adversary, neutral third parties, and the physical environment – can all be represented with a synthetic environment within which the team members actively training can work for the training of active team members.

5.4.3 Collective Training

The argument developed for how M&S can be used to enhance team training can all be made for larger aggregations of collectivism including joint, combined, and interagency structures. It should be noted, however, that as increasing numbers of models representing progressively more diverse elements within these larger interconnected structures are brought together in a synthetic environment, the technology required to support it may become strained, as it does in the real world. Under such conditions, training personnel must be ever vigilant in remaining focused on employing the appropriate model for the specific training objectives, balancing the level of fidelity and resolution required within the limits of available technologies.

5.5 HOW M&S SHOULD BE EMPLOYED FOR NEC TRAINING AND EXERCISES

Principles on how M&S should be employed to support training and exercises for NEC are outlined as follows. These principles are based on evidence drawn from case studies provided by NATO and individual member nations. Emphasis is put on collective training as this type of training will make the largest contribution to realize the potential of NEC, but it is also the most challenging from an M&S standpoint. As should be apparent from the above discussion, the training and exercise environment for NEC should itself be network-enabled. Thus, underlying principles to achieve such a network-enabled training and exercise environment are introduced in the following discussion below. Such a training and exercise environment should form a coherent and composable training capability that allows different NEC training event and exercise needs to be met by assembling specific components and common services using an M&S infrastructure compatible with NII.

5.5.1 Establishing Network and Common M&S Infrastructure and Services

Conducting distributed training exercises in a networked synthetic environment requires people with special skills for setting up and managing technical systems and for defining and coordinating the exercises. To perform geographically distributed exercises cost effectively, a permanent central coordination, management, and control facility should be considered. A central facility should offer services for briefing and debriefing, data logging and analysis, and facilitating video/audio conferences.

Successful distributed training in a networked environment requires networks with sufficient bandwidth, security, and network services between participating sites. Interconnecting systems from different system owners

and with potentially different classification levels is probably the single most challenging issue [2]. Security issues and time needed to implement networks should not be underestimated. Permanent networks should be established, if possible. Processes and procedures for resolving security issues should be established. Security issues include:

- Harmonization of classification levels among multiple nations;
- Determination of the classification level of an exercise;
- Protocols for sharing classified data among multiple nations;
- Connecting systems with different classification levels;
- Encryption of networks (e.g., encryption equipment, key distribution); and
- Protection of sensitive data (e.g., performance data).

The natural and man-made environments must be represented in a consistent manner throughout the network-enabled training environment. Depending on the purpose of the training, the Synthetic Natural Environment (SNE) data may be fictitious, geo-typical, or geo-specific. Moreover, databases employed by different subsystems, including Computer Generated Forces (CGF), sensors (visual, IR, radar, etc), communication, electronic warfare, etc., must be correlated.

Scenarios and representation of natural and man-made environments are crosscutting and are utilized in a majority of the networked components that constitute a training and exercise system. Furthermore, their development requires specific knowledge and expertise as well as considerable effort. A common tool set should be established to produce scenarios and SNE databases in standardized formats.

Reuse of various types of assets, including tools and data produced throughout an exercise process (planning, preparation, execution, analysis and reporting), is recommended. Repositories should be established in order to promote reuse of assets. Scenarios and SNE databases are examples of valuable assets subject to reuse.

A set of common services can avoid duplication of work, reduce the number of systems, reduce the complexity of the overall networked system, and generally increase cost effectiveness. The following are candidate common services which should be considered:

- Exercise and simulation management;
- Standard gateways to live, virtual, and constructive simulations;
- Computer generated forces;
- Weather and terrain interaction;
- Video/audio conferencing; and
- Distributed data logging and analysis.

5.5.2 Exploit Live, Virtual and Constructive Simulations in Combinations

To meet the changing requirements of how, where, when, and how often training and exercises for NEC should be delivered, all the different types of simulation (live, virtual and constructive, or LVC) and their combinations need to be exploited. Furthermore, exploiting opportunities for combining different types of simulation is necessary to provide a training and exercise environment that represents the complexity and scale, both in time and space of an NEC environment to a sufficient level. Furthermore, embedded training capabilities need to be

linked to simulation centres, for example, on-board embedded training capabilities should be linked with shore-based training centres.

In the British Army Training Unit Suffield (BATUS) Case Study, live land force training is placed in a joint virtual-constructive environment (synthetic wrap-around) to provide the land context for air mission training. Land CGF and air virtual simulation are combined with live land simulation resulting in an expanded battlespace. The synthetic wrap-around enhances component tactical level live and Human-In-The-Loop (HITL) simulator training and place live exercises in the context of NEC.

Exploitation of augmented reality (AR) technology for the live forces helps blend the real and synthetic environments. For example, representation of HITL simulators and constructive entities can be layered on top of observation instruments of a Forward Air Controller (FAC) in Close Air Support (CAS) operations.

An overarching LVC simulation architecture does not yet exist, but studies and research are underway.

5.5.3 Use Standards to Increase Interoperability

Federating training systems across networks is feasible due to the use of standards. Standards are crucial for performing simulation data exchange, developing common representations of the natural environment, and interfacing with command and control systems. Thus, a minimum set of necessary standards should be established to ensure system coherency. An exhaustive list of standards applicable to M&S is available in the *NATO Modelling and Simulation Standards Profile* [3]. Standards have been identified in the following functional areas:

- Verification and Validation (V&V);
- Simulation systems development;
- M&S scenarios;
- Modelling (including conceptual modelling and M&S representation);
- Software engineering standards applicable to M&S;
- M&S interoperability standards;
- Data standards (including data production, data mediation and exchange, data engineering); and
- Visualization.

Applicable NATO Standardization Agreements (STANAGs) are as follows:

- Verification and validation of simulations:
  - The IEEE 1516.4 “VV&A Overlay on the HLA FEDEP,” part of STANAG 4603.
- Simulation development:
  - System engineering processes for simulation development (FEDEP), part of STANAG 4603.
- Simulation technical interoperability:
  - Standard for technical architecture (HLA), STANAG 4603.

- Synthetic, natural and man-made environmental databases:
  - Representation, description and exchange of environment data: SEDRIS, STANAGs 4662, 4663 and 4664 (not yet ratified).

5.6 HOW TO EVOLVE TOWARDS A NEC TRAINING AND EXERCISE CAPABILITY

As argued above, a single training and exercise system cannot meet the needs of NEC training and exercising. The required NEC training and exercise capability needs to evolve from the current situation characterized by limited interoperability and a number of stand-alone, monolithic training systems designed to fulfil the training requirements of a single service platform, system and force component without consideration on how it can constitute a part of a networked environment. It is likely that the NEC concept itself will evolve as experience is gained. This also calls for an evolutionary and incremental approach to develop the NEC training and exercise capability. Rather than developing a new capability from scratch, as was pointed out in Chapter 2 there is no "clean slate" and the migration from legacy "stovepipe" to distributed NNEC training within a synthetic environment involves bringing (modified) existing and future systems into a networked environment. For such an approach to succeed the evolution and the increments must be governed and carried out as a consistent and coherent program.

The training and exercise environment needs to evolve in a way similar to the phases of transformation, which has been defined for force and supporting CIS to realize the longer term ambition of NNEC. These phases of transformation have been defined as Deconflicting (deconflicting services and cultures); Coordinating (increased connectivity); Collaborating (collaborative NRF capabilities); and Coherence (coherent network-centric) [4]. For such a transformation to work, a supporting architectural framework needs to be adopted. The same is true for the evolution of an NEC training and exercise capability to work. For instance, in the UK's Network Enabled Training Capability (Land) (NETC(L)) Case Study [5], MODAF is employed as the framework to support the development of the NETC(L) goal architecture [6]. The use of architectures facilitates a shared common understanding between stakeholders; alleviates problems with a possible lack of a central authority that controls all elements of the development programme; contributes to achieving interoperability between systems; and helps to express and manage the diversity of functions, technologies, and architectures of the systems to be networked, including training and exercise management processes and supporting systems. For an architecture to cover these diverse aspects, several viewpoints need to be employed (operational, system and technical), and they need to be expressed in a standardized, mandated way, e.g., the NATO architectural framework (NAF).

To exploit the already large investments in training and exercise systems, legacy systems should be adapted and modified to adhere to and be part of a networked environment. The Norwegian Joint Air Defence Experiment (JADE) Case Study [7],[8],[9] showed this approach to be feasible by federating legacy trainers. Interfaces to each of the training systems were either established or extended/modified to adhere to defined common simulation architecture. Issues concerning semantic model interoperability were resolved by either adjusting models residing in the different simulators or by introducing additional components which substituted legacy models.

5.7 TOWARD IMPLEMENTING NEC

The implementation of network-enabling capabilities within NATO will call for new knowledge, skills, and methods of developing experience that are not yet fully developed. The network will provide access to a

wealth of information and knowledge and an ability to collaborate with any number of organizations whose effects are interdependent. However, while the effective operation of the security and defence system demands ever-increasing competence in coordination and collaboration across a wide spectrum of contributing partners, the cost of end-to-end exercising of the system is prohibitive, and scheduling the availability of all participants would be extremely difficult at best.

M&S can effectively provide a networked synthetic environment where individual, team, and higher levels of collective training including joint, interagency or multinational training can be conducted on demand within a fully immersive synthetic environment focused to meet the specific needs of the available audiences.

5.8 REFERENCES

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Chapter 6 – M&S SUPPORT TO AGILE OPERATIONS AND COMMAND FOR NNEC

Key M&S Principles

17) **The use of M&S will be increasingly important to support current and future operations, particularly in coalitions.**
18) **A holistic approach is needed, covering all aspects from training to post-operational analysis, which will allow the full re-use of M&S tools and data.**
19) **Integration of M&S in Command, Control, Communications, Computers, and Intelligence (C4I) is essential to permit the optimum benefit to be obtained and while immature, ongoing research needs to be maintained.**
20) **Use of M&S to support complex operations needs to be seen by all concerned as 'business as usual'.**

6.1 IMPORTANCE OF MODELLING AND SIMULATION

The use of M&S will be increasingly important to support current and future operations, particularly in coalitions. A major opportunity exists for effective in-theatre M&S support to operational planning, decision-support, and rehearsal tools for the warfighter in agile operations, including agile operations and the "3 Block War" concept. M&S can also readily be used at a tactical level to support the C2 activities of enhanced situational awareness, distribution of commander's intent and up-to-date environmental and threat information. By the use of common standards and installed operational C2I network bearers, more effective reachback and dialogue with non-deployed command can be achieved.

The benefits of relatively simple 3D visualisation of current geographic information, including complex environments such as urban areas (ideally updated to reflect their current state of destruction) and force positioning (blue, red, white, etc.), cannot be underestimated. The potential advantage of overlaying synthetically enhanced information on real-world scenes ("augmented reality") is only just starting to be explored.

Increasingly, M&S tools will be integrated with operational C2I systems and infrastructure, offering great potential for more timely and relevant advice and visualisation, derived from the most up-to-date information. Although some safety and integrity issues exist concerning the mixing of real C2I and simulation derived projective or enhanced data, these can be managed with sound design.

More timely and continuous Course of Action (COA) analysis will be possible, providing the commander with guidance and feedback.

In summary, NEC can transform capabilities to support troops in action, as well as provide valued outcomes. M&S has the potential to provide the following valuable support to the warfighter in theatre:

- Enhanced awareness, decision support, analysis, and feedback at all levels.
- Enhanced distribution of command intent, and awareness at the engagement level.
- Planning and decision support tools.

- Mission Rehearsal and in-theatre training.
- Post-action analysis.

Whilst the use of M&S by land forces during an engagement is unlikely, it does have potential utility for maritime and air forces. At the tic (troops-in-contact (TIC)) level, there is rarely time to use M&S for results to yield useable information, but it could be used to model longer term issues (e.g., on a deployed ship).

"Whilst M&S support to *agile operations* is an immature area, there is already significant utility to be obtained from the proper use of M&S."

Interviews with analysts providing operational support to troops in theatre confirmed that although M&S is regularly used in pre-deployment training (covered in Chapter 7), it is more difficult to know the extent to which any given tool is used in theatre (and for what purpose) as operational considerations are rightly given priority.

Care should always be taken to ensure that the constraints and capabilities of the M&S tools are understood in the given context. Failure to do so means that whilst results from usage outside the verification and validation limits might yield apparently useful information, the reality is that they must be treated with extreme caution, and correspondingly greater weight should be given to other decision-making processes.

The final section in this chapter will offer advice and guidance as to how current M&S capabilities can assist troops in theatre, the maturity of the tools available and provide recommendations for future direction.

6.2 CHARACTERIZING THE REQUIREMENTS AND BENEFITS

6.2.1 The Requirements

The M&S requirements at the national force level and for the NATO response force in agile operations include the following:

- M&S to support NEC-based decision-making process (e.g., support to decision making and C2 in complex networks of people, systems and information);
- Providing Course of Action (CoA) analysis;
- Assessing the likely cost to humans, collateral damage, etc.;
- Planning and mission rehearsal at all levels;
- Provision of task-tailored "augmented reality" for enhanced situational awareness[1] at all levels across the network;
- Providing ongoing real-time (during operation) and non-real-time (post-operation) analysis; and
- Providing ongoing maintenance and update of models for future use.

[1] Provision of augmented situational awareness at the tactical level, e.g., Coalition Operational Picture (COP) will in turn lead to improved shared awareness. In this context, situational awareness is defined as the means of transmitting information, and shared awareness as communicating and drawing of conclusions from information.

6.2.2 The Benefits

Information shared over a network leads to increased shared awareness and distribution of command intent, resulting in enhanced force agility through the following means:

- M&S enables an iterative cycle of planning and testing, allowing an examination of the impact of variations within the OODA (see Figure 6-1: Observe, Orient, Decide, Act) loop. A Battlefield Damage Assessment (BDA) carried out at the end of each cycle allows the lessons learned to be fed back into the planning cycle.
- A tight coupling of the simulation and command chain/C4I allows continuous M&S support to decision making. This transforms decision making and collaborative decisions by allowing variations in proposed decisions to be tested before a plan is implemented.
- The benefits to the campaign of using M&S at the planning stage will more than compensate for a potentially longer timeline.
- Increased shared situational awareness and distribution of command intent can be enhanced by integrated M&S/C4I tools.
- Use of M&S at the rehearsal stage plays a valuable role in building trust across networked teams, who may be required to work together at very short notice.
- M&S support to in-theatre dynamic analysis leads to improved understanding and shared awareness.
- Use of M&S for CoA analysis leads to an improved understanding which may then be applied to subsequent operations.

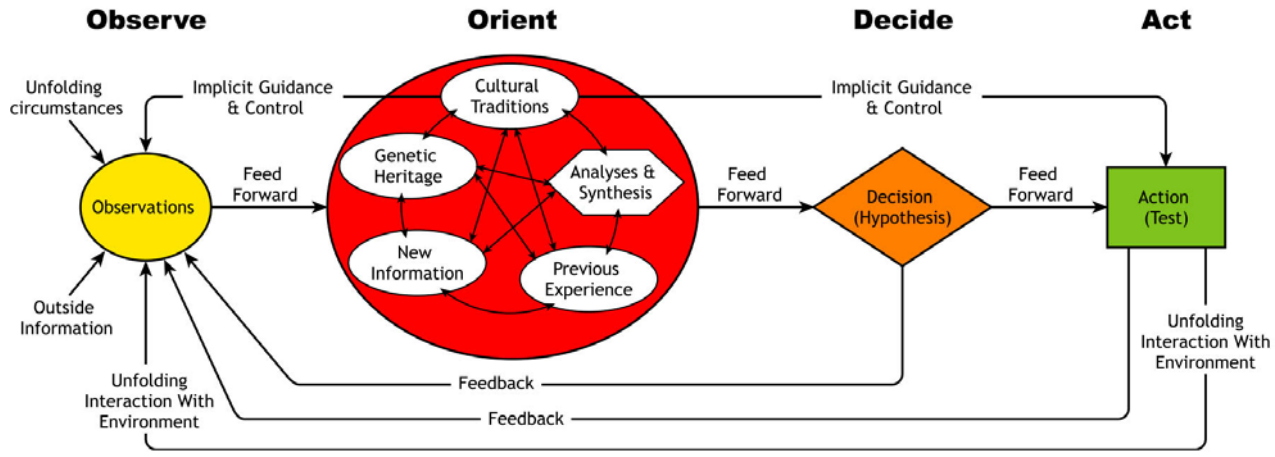

Figure 6-1: OODA Loop.

6.3 M&S INTEGRATION WITH C4I SYSTEMS

The integration of M&S with C4I systems, particularly with operational command systems such as the Joint Automated Deep Operations Coordination System (JADOCS), will be *key to exploiting M&S for NEC-enabled operations and will provide enhanced operational benefits* whilst making use of the existing infrastructure.

Architectural Frameworks such as MoDAF and DoDAF should be used to provide a common toolset for the integration of C4I and M&S. For example, DoDAF can be exploited to underpin conceptual modelling for NEC operational architectures.

Interoperability issues exist in both the M&S and C2 domains, and the level of effort required to achieve full integration should not be underestimated, especially where systems from multiple nations are being integrated. Open architectures, common standards, and interfaces should be used whenever possible to maximize flexibility. The integration should be tested as rigorously as possible prior to deployment to ensure not only that it exhibits the expected behaviours, but also that the benefits and drawbacks of the setup – including any potential security issues – are fully understood[2].

Many tools current at the time of writing represent a traditional C2 structure – this will need to develop to allow an accurate picture of the behaviours under NEC to be given. As C2 in the field needs to be rapidly reconfigurable to adapt to changing circumstances, M&S should be used to test a number of possible new C2 structures, to gain an understanding of the issues and benefits associated with each one.

JADOCS is currently in use with several US combatant commands, all US military services, and several allies and coalitions. It uses embedded M&S support to provide enhanced battlespace visualization and joint operations planning. For example, JADOCS uses M&S tools to provide battlespace visualization of coordination measures, ingress and egress routes, and air defence threats. CINC and staff can visualize friendly fires in 3D space over any area. Battlespace geometries can also be overlaid with imagery and terrain data to improve situational awareness for deep operations planning focused on deconflicting air interdiction missions with active long-range artillery fire.

6.4 M&S TO SUPPORT AGILE OPERATIONS

6.4.1 Pre-Deployment Training

The Netherlands Organisation for Applied Scientific Research (TNO) Case Study Command in NEC, which has been tried and tested in experimental conditions, stated that "If your routines are single warfare, when mentally loaded, you fall back to single". Unless constantly trained in NEC so that it becomes – and remains – second nature, in a crisis, troops will revert to what they are most familiar with (e.g., if routines are single warfare, that is what troops will fall back to).

Most training for agile operations will be carried out before deployment to theatre[3], but it also needs to be maintained while in theatre using both in-camp and potentially just-in-time training embedded with the fighting unit.

6.4.2 Planning

Although 'no plan survives contact with the enemy', testing any plan in advance with M&S will help to highlight the potentially vulnerable aspects, and allows mitigation options to be considered.

At the strategic and operational levels, the effective use of a range of models within a synthetic environment transforms decision making – particularly collaborative decision making – by allowing the collaborators to

[2] NMSG-048 is currently exploring the benefits of the C-BML (Common Battle Management Language) – see Case Study to follow.

[3] See Chapter 5 on training and exercises.

gain insight into the impact of variations of interdependent variables that could influence the outcome within any proposed plan by testing through simulation before live implementation. Examples of such interdependent variables can be a wide variety of factors that influence the outcome including assumptions on adversarial intent, force strength and available capabilities, environmental or meteorological predictions, the status of friendly forces, or the actions of neutral non-government organizations operating in the environment. By running a variety of sets of interdependent variables within a number of optional courses of action, the Commander can gain insights on best- and worst-case scenarios as well as intended and unintended consequences of any given course of action for achieving not only military objectives, but also broader national or coalition objectives in other domains. Conclusions can then be drawn on an optimal course of action based on possible risks and benefits – ideally – before any first engagement with the adversary.

This use of M&S to provide a broad overview is not normally possible within the tighter timescales of a tactical engagement. However, a general knowledge of the larger strategic and operational models that gave rise to the Commander's intent and lower taskings may provide insight on the optimal manner to modify tactical plans as the situation evolves while still concurrently achieving tactical and higher order objectives.

6.4.2.1 Support to NEC Decision Making

As network-enabled capabilities and supporting doctrine evolve, there is an increasing opportunity for M&S to support joint and coalition operations across tactical levels. Key to delivery of this capability is the human element underpinned by information and training to improve trust, collaboration, and to improve the Commander's situational awareness and decision making. The use of affordable and rapidly adaptable M&S in theatre can greatly enhance theatre specific, pre-deployment training and in-theatre mission preparation, planning, and rehearsal. These can offer direct benefits in support of current operations.

Using mission command, high level plans are cascaded down from Headquarters then implemented by troops on the ground, who adjust the plans to match situations as they evolve. NEC is seen as a key means of facilitating this process.

M&S must not only reflect the impact of NEC, but it must also be implemented in such a way that the M&S outcomes are a realistic representation of such operations.

"M&S can be used to both maintain skills learnt prior to arrival in theatre and to train for *situations which only become apparent after arrival* in theatre."

For the purposes of both campaign planning and mission rehearsal, the NEC decision-making processes must be second nature to troops in theatre. Although this would initially be addressed as part of pre-deployment training (covered in Chapter 5), the skills must then be maintained using M&S during deployment. In addition, the types of situations troops in theatre are likely to meet may only become truly apparent after arrival, and M&S can be used to provide "just in time" training for these events.

6.4.2.2 Network Coverage Planning

Derivation of network requirements in terms of coverage, capacity, and latency – coupled with the ability to plan and deploy key infrastructure – is fundamental in support to agile NEC-based operations. This planning can become critical in complex environments such as urban areas.

There are many examples of M&S-based tools to support wired and wireless communications design, and these need to be effectively integrated to better support the operational Commander.

6.4.2.3 Course of Action Analysis

The prime utility of M&S for CoA analysis is in de-risking a mission by providing information to a Commander to enable the decision-making process, and examining the 'what if' questions likely to arise within this.

On completion of an action, M&S can support the Battlefield Damage Assessment (BDA) in carrying out post-action analysis and feeding back the lessons learned into the planning cycle. The joint Unmanned Aerial Vehicle (UAV) Experimentation Programme (JUEP) project found the use of data capture and analysis tools could provide a useful means of replaying the scenario immediately after it occurred. The revised plans can then be modelled once again to assess the effectiveness of the changes made.

Tools typically used by Support to Operations analysts providing advice to commanders in this context would include movement calculators, casualty calculators, logistics calculators, force ratio tools, and planning tools. Whilst the primary function of the planning tool is to analyze and assess operational plans while they are still in the process of formation, analysts in the field also use it to provide analysis within the planning cycle, with answers produced in minutes rather than months. It is worth noting that currently much of the terrain visualisation is carried out using Geographical Information System (GIS) toolsets rather than on bespoke M&S applications and programs.

Currently, the opportunity exists for an M&S toolset that can be used at a tactical level to support the C2 activities of enhanced situation awareness, distribution of commander's intent, and up-to-date environmental and threat information.

6.4.3 Preparation

6.4.3.1 Operational Logistics

M&S is increasingly being used to plan the effective management of logistics, accessing operational databases and advising on movements. Further, emerging generations of NEC systems and platforms are fitted with advanced Health and Usage Monitoring Systems (HUMS), which have the potential to allow commanders to make better operational, tactical, and logistical decisions. There are benefits in using M&S for advance planning, especially with regard to "just-in-time" delivery, and in reacting to replanning requirements.

6.4.3.2 Rehearsal

M&S can be used prior to action to test the outputs of the planning phase, including variations on operational agility, and to train troops in theatre prior to engagement ("just-in-time" training). This allows troops to explore – prior to engagement – the potential impact of the variations on themselves and others, as well as on the course of the engagement.

Visualisations of the environment can be invaluable in familiarizing troops with the terrain in which engagements are anticipated – be it topographical or urban. This activity will lead to a better picture of the situational awareness than could otherwise be expected. It could also highlight potential issues; the lessons learned from M&S can then be fed back into the planning cycle.

6.4.4 Mission Execution

Within the complex environment where modern operations are conducted, network-enabled capabilities and M&S capabilities provide strong mutual support. On the one hand, the feed-forward predictive capabilities

provided through M&S outputs can be readily shared across the network as highly effective decision-support tools for planning operations and influencing the outcomes. On the other hand, the rapid feedback capability available within a network-enabled force provides a means to identify discrepancies between the outcomes predicted by the M&S outputs and the observed outcomes. These deltas can be used as a basis for rapidly updating the individual and system models including changes to assumptions, known capabilities, and interdependencies, and then modifying plans according to updated projections.

This is currently an immature area where further research is required. The tempo of operations may mean that warfighters will need to be convinced of the utility of M&S in this area.

6.4.5 Post-Operation Analysis and Lessons Learned

On completion of a mission or operation M&S can support BDA in carrying out post-operation analysis. By applying observable battle damage to models of affected capabilities, the likely overall capability degradation may be more accurately assessed. In addition, secondary and further downrange impacts on interdependent capabilities within the broader system can be scientifically assessed.

The basic intent of any lessons learned program is to transition individual learning experiences and lessons from them into broader organizational learning so that each individual within an organization can gain from the experiences (both positive and negative) of others. In the context of agile operations, the basis of individual and collective decisions in the planning, preparation, and conduct of those operations is normally a form of M&S, be it a mental model or a computer simulation, which permits the forward projection of likely outcomes as a result of chosen actions. By using formalized and documented M&S, all individuals can benefit from the expertise of the top few and where deviations occur from the predicted outcomes generated through the M&S, post-operation analysis can identify likely errors in the model or assumptions which can be fed back and validated to and provide a means for broad organizational learning.

6.5 CASE STUDIES

6.5.1 Deployed Integrated M&S for Operations

The UK Deployed Integrated Modelling & Simulation for Operations (DIMSO) project has demonstrated an integrated M&S tool suite to support forces in theatre conducting their missions across the full spectrum of military operations.

"The use of currently available *M&S technologies can improve operational readiness* and the more effective use of resources."

Integrated M&S and Synthetic Environment (MS&SE) suites based on affordable commercial technologies can provide rapid generation of 3D terrain, specific to a theatre of interest, with accurately modelled communications, ISTAR, kinetic and non-kinetic effects and interactive opposition forces and civilian populations. These suites offer the benefits of improved operational readiness through faster and more cost effective delivery, with less time away from home in the weeks before deployment. Once in theatre, they provide the ability to better prepare and adapt to the evolving situation. In some circumstances, these are the only affordable way to deliver the necessary advances in the human line of development.

High fidelity MS&SE suites are available today and are contributing to preparation and pre-deployment training of UK forces deploying to theatres. Many of these have emerged in ad hoc fashion to fill gaps in current

capability. A comprehensive understanding of the user need is required to improve what is available, and the DIMSO project will demonstrate the deliverable benefits to current operations and beyond.

Key objectives of the DIMSO demonstration include the following:

- Integrate with existing mission planning toolsets.
- Enable more effective use of limited resources on operations.
- Improve availability and responsiveness of M&S tools for support to operations.

The following four key observations were captured from the stakeholders involved:

- Integration with current operational planning equipment is essential.
- Fidelity and visualisation of the terrain database is critical to the effectiveness of the tool.
- There is a need to minimize or eliminate additional logistical or bearer infrastructure burden.
- Additional training burden should be minimized.

The first phase of DIMSO activity established a baseline of understanding of the current and future capability of such a toolset. The concept will benefit from a relatively small development push in order to generate a mature deployable capability in the near term.

The Verification and Validation (V&V) of the first phase was based on UK Ministry of Defence (MoD) DEFSTAN (Defence Standard) 03-44. The standard, however, was found to be insufficiently flexible and would need to be modified to be of use in the fast-moving environment experienced by troops in theatre. Nevertheless, the importance of ensuring that any M&S activity undergoes suitable V&V cannot be over-emphasized. There is a very real danger that the use of any model in a context for which its suitability has not been confirmed could give a false picture with potentially disastrous consequences.

6.5.2 Simple Battlegroup

In 2002 the Simple Battlegroup (SIMBAT) model deployed with troops on a Tactical Engagement Simulator (TES) exercise at the British Army Training Unit Suffield (BATUS). During one of the engagements, the effectiveness in live conditions in support of the planning process was tested. It was found that the set-up time required prevented the M&S results from being produced in a useful timescale, but did demonstrate that the results obtained were remarkably similar to those from the exercise. Although this was carried out several years ago (2002) similar issues are still often found with the set up times of M&S applications: toolsets intended for used by troops in theatre need to be chosen carefully to avoid this.

6.5.3 Coalition Warrior Interoperability Demonstration

The Coalition Warrior Interoperability Demonstration (CWID) exercises concluded that while many C4I systems claimed interoperability with others, full interoperability was rare, and most systems had varying degrees of reliance on manual workarounds. The level of workarounds needed, and their burden on the operators – which will vary according to how familiar the operator is with the system – require further attention. Tight coupling of simulation and command chain/C4I does, however, enable continuous M&S support to decision making. Using of synthetic wrap for experimentation/validation of C4I /M&S integration has been shown to significantly enhance component tactical-level live and HITL (Human-In-The-Loop) simulator training. This method can also be of use to troops on deployment.

6.5.4 Coalition Battle Management Language

A successful interconnection of C2 systems using the Coalition Battle Management Language (C-BML; Figure 6-2 interface (NMSG-048) and the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM; Figure 6-3) was demonstrated with systems from 6 nations providing a limited C2 to simulation interoperation [1],[2]. A second technical experiment will develop a 2-way interface with situation reports, and a third experiment will involve military personnel to measure the operational benefits.

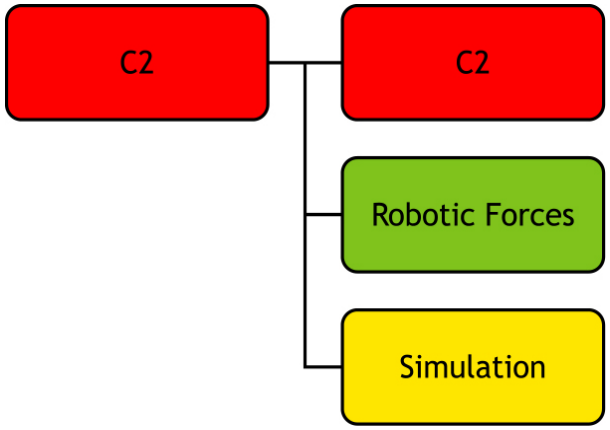

Figure 6-2: C-BML – Coalition Battle Management Language.

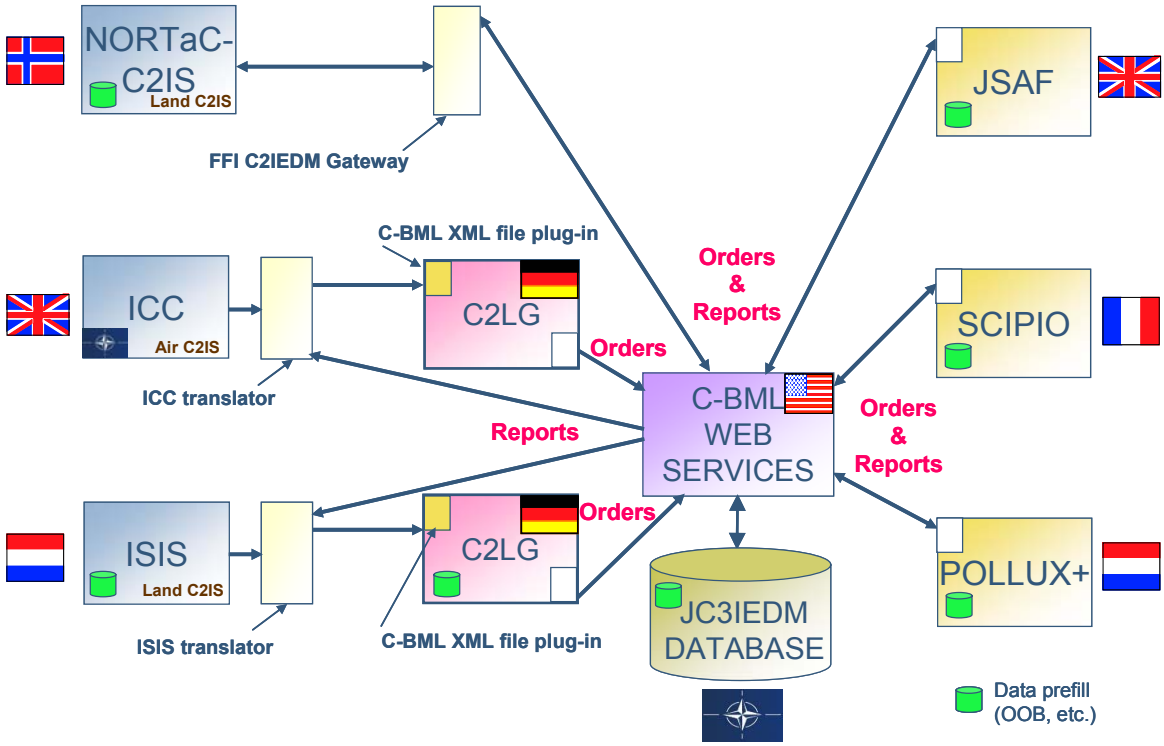

Figure 6-3: C-BML: MSG-048 2008 Demonstration Architecture.

6.6 HUMAN FACTORS

M&S can be used to run distributed mission rehearsals for a particular mission for troops in theatre who have not previously trained together. This exercise can also help build trust by giving troops the experience of working together in a variety of simulated situations and can help them to understand the capabilities of unfamiliar equipment, for example that belonging to another coalition nation.

Without being familiar with the benefits of M&S, some Commanders may be reluctant initially to accept advice derived from it. However, once M&S becomes part of "business as usual", it will rapidly become apparent that the use of M&S will significantly enhance the commander's ability to operate.

It should be noted, however, that no model can be more than a representation of the real world and must be managed as such. Otherwise, there is potential for the visualisation to mislead, or provide "perfect perception", which troops would not have in real life. This unrealistically favourable impression of a situation can result in "negative training". These and similar issues are explored further in the Human Factors chapter.

6.7 GUIDANCE AND RECOMMENDATIONS

In order to maximize the potential of M&S support to agile operations, it is essential to put in place a coherent and robust plan of development supported by experimentation. Without planning, M&S is likely to be overtaken by other events which have been – rightly or wrongly – perceived as being more important.

Training with M&S is an emerging field, and while a number of suitable M&S tools exist, very few have been tried and tested for use by troops on deployment. Research in this area is ongoing, and new tools that should be available soon are under development. In all areas, there is potential for further research, integration with existing tools, and definition of best practices. Based on current toolset maturity and operational experience, the following guidelines can help guide the use of M&S:

- Any M&S model used must have been **verified and validated as fit for the intended purpose**, and it is important to remember that model outputs are only as good as the data that goes into them.
- The use of M&S has the potential to **improve situational awareness** at the tactical level. Further integrating synthetic information into vision and sighting systems needs to be considered.
- There are many examples of **M&S-based tools to support wired and wireless communications** design; these need to be more effectively integrated to better support the operational Commander.
- M&S can be used to support dynamic analysis in a fast-changing environment, but to maximize these benefits M&S requires the support of a robust analysis of the outcomes.
- **Care needs to** be taken to avoid the pitfalls arising from misinformation of visualisation, which can result in 'negative training'.
- It is important that **M&S be quick to set up**, have a low logistics footprint, and be easy to use.
- Data capture in theatre should be given as high a priority as practicable to ensure data is available for future reuse. With increased instrumentation, and NEC, the automation of such data capture should be increasingly common.
- Using M&S to support troops in theatre should be considered "business as usual" and be embedded in processes as well as in thinking and planning tools.

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Chapter 7 – M&S TO ENABLE THE HUMAN DIMENSION OF NNEC

Key M&S Principles

21) **There is a range of new Human Dimension (HD) challenges related to both central NNEC ideas and the wide spectrum and variety of operations today. Addressing such HD issues requires the use of more "light weight" technologies such as gaming/ massively multi-player gaming for cheaper, more easily accessible experimentation and training.**

22) **It is important to focus on "people-to-people" training and experimentation to *change* how *people* think and work together. Accelerating the pace of HD (how quickly people work together to achieve a common goal) in NNEC requires the use of all aspects of simulation-based technologies available today (and ahead) to accelerate the pace of the HD in NNEC.**

7.1 IMPROVING THE WAY PEOPLE THINK AND WORK TOGETHER

The national approaches to NEC tend to vary slightly within NATO countries. This seems to be the result of different military traditions evolved within different cultures. The goal of this chapter, however, is not to focus on such differences, but to address one of the common main denominators for implementing NNEC, described in the *NATO NEC Feasibility Study* as "the way **people** think and work together" [1].

The NNEC concept makes it clear that implementing NNEC involves the way people think and work together. At the individual level, such factors include as personality, intelligence, knowledge, values, and beliefs as well as the social, cultural, and organizational contexts within which they work. Many of these aspects are not directly addressed within the current NNEC Feasibility Study but are stated as important, especially when it comes to their longer term impact of networking and information sharing, which can in turn affect the length of decision-making cycles. These aspects affecting the cognitive and social domains and are in fact recognized as some of the most crucial in the transformation efforts towards NNEC, even though they may be hard to grasp.

This chapter focuses primarily on selected aspects from a social science and cognitive science point of view, the human dimension, regarding central NEC ideas and the wide spectrum and variety of operations today. Issues discussed in this chapter are therefore not an exhaustive overview. Thus, other important aspects such as considering the human element in the development and application of M&S tools are not addressed here. This is basically because that it is an area that mainly concerns how to improve M&S-tools and models – not the people, processes, organizational and cultural issues themselves. Within NATO, all nations have long traditions in testing the "system" with "human-in-the-loop". Traditionally, in the M&S realm and within NATO the "Human-In-The-Loop" has been the preferred approach when taking into account human factors, allowing one to test or simulate systems, platforms, technical solutions, NATO procedures, or planning methods, among other activities, that involve humans. With a "human-in-the-loop" approach, one can find out where the human fails, and therefore where to improve the activity in question to better support the humans in their interaction with the "system." However, how humans interact with other humans to solve problems – in a highly complex and rapidly evolving environment – across conceptual, functional, and technological levels, remains one of the crucial human factor challenges in NNEC. Enhancements in modern simulation-based technologies make addressing these critical issues feasible.

In this chapter, by utilizing all the aspects of simulation-based technologies available today and ahead, we argue that a widespread employment of various kinds of simulation based technology has a unique potential of accelerating the pace of the human dimension, thus being one of the true key enablers of NNEC.

"…simulation-based technology has a unique potential of accelerating the pace of the human dimension, thus being one of the *true enablers of NNEC*."

7.1.1 Objectives

The objectives of this chapter are to provide guidance on the following:

- The range of new Human Dimension (HD) challenges related to both NNEC and the wide spectrum and variety of operations today.
- How the "people factor" introduces new challenges to the M&S community.
- The importance and possibilities of using simulation-based technology to enhance human skills, both individual and social.
- How simulation-based technology can contribute and how it should be exploited to resolve some central HD challenges of NEC.

7.2 WHY HUMAN DIMENSION IS IMPORTANT IN NNEC

Traditionally, the M&S community has for obvious reasons focused on "hard" skills such as the handling of weapons, computing missile tracks, and operating aircraft. NNEC introduces "soft" skills such as social relations, negotiations, collaboration across cultural boundaries, sharing information and situational awareness, and trust. These skills call for an increased focus on organizational, social and cultural awareness and clearly stress the importance of the human dimension to fully bringing out the advantages of NNEC. For example, NNEC is intended to allow the armed forces to operate with increased responsiveness, flexibility, and agility. It proposes to offer greater connectivity and technological advancement, through a more dynamic C2 structure, increased information sharing and shared situational awareness, greater devolvement of responsibility, and the rapid formation of task groups unconstrained by geographical boundaries and cultures.

Today's modern military operations are complex and highly constrained. They are a complicated assembly of individuals, networks and organizations required to perform as teams, often ad hoc and in a distributed environment. This new approach differs considerably from traditional approaches in which success means capturing territory and defeating the opponent physically (see Figure 7-1). This increased complexity creates an emphasis on the human dimension for:

- Building trust quickly in ad-hoc teams;
- Developing the social skills required to handle increased diversity and cross-cultural communication;
- Understanding new concepts;
- Obtaining organizational flexibility; and
- Collaborating within distributed and ad hoc teams.

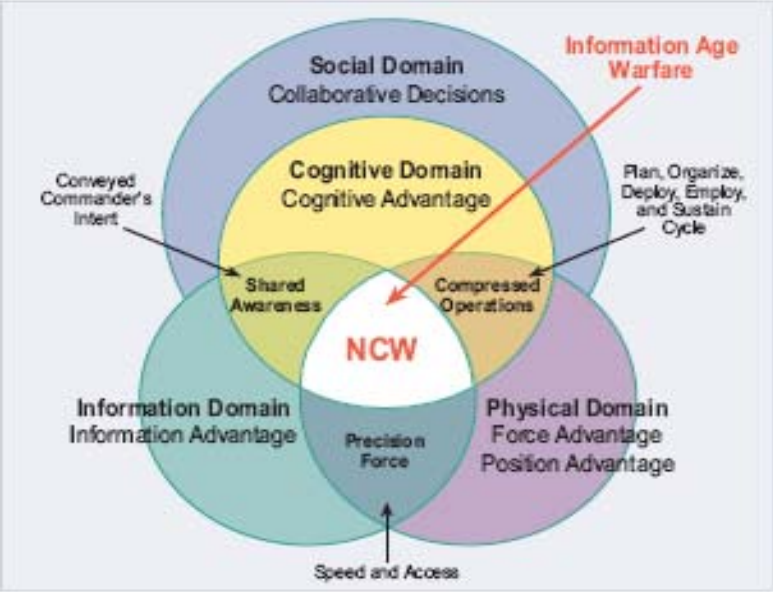

Figure 7-1: Example from Network-Centric Warfare, of the Importance of the Human in NEC [2].

The type of warfare that NATO nations are facing in Iraq and Afghanistan today is also drastically different from the conventional mass on mass warfare where the opposing forces are known and recognized, where actions are based on the presumption that the front lines of each side are well defined and armed forces are likely to respond in a prescribed way. By contrast, asymmetric warfare – which encompasses terrorism inflicted on civilians – introduces hostage situations, terrorist actions, peacekeeping, psychological operations, and civil affairs, all of which require an increased level of regional and cultural awareness. Terrorism raises a variety of cross-cultural communication issues. Unpredictable behaviour of the enemy and unpredictability of regional and cultural awareness in such situations are challenges.

7.3 HUMAN DIMENSION CHALLENGES IN NNEC

The introduction of NNEC can bring with it a range of new HD challenges related to both central NNEC ideas and the wide spectrum and variety of operations today. These challenges include decentralization of authority (leadership), cross-cultural collaboration, information sharing and shared awareness, differences in technology skills and ability, and organizational interoperability.

Developing common ground is a particular challenge in NNEC due to the high diversity of not only national cultures but also languages, procedures, and professional cultures as well as differences in national caveats. Additionally, the level of experience working ad hoc and distributed vary not only between nations but also within them and among their personnel (including both individual and organizational competencies). These differences have an impact on the process of creating common ground and achieving coordination.

There is in particular a challenge to enable accurate and speedy awareness of what are the specific human factor challenges for organizations in particular operations. Additionally, there is a challenge to train specific skills for teams or organizations involved in solving the operation. It is furthermore a challenge for research as well as practice to develop a more precise understanding of what are critical skills that are needed in the kind of interaction assumed in the full utilization of NATO NEC, as well as how to train these skills in a suitable way.

Solving joint tasks by taking advantage of the total mix of sensor and effectors available across national military boundaries is central to NATO NNEC. In order to achieve this aim there is a need to share intentions, reach agreements, and ultimately put military capabilities to use without regard to their national origin (given that it is politically feasible). In other words being able to coordinate joint resource is crucial in order to take advantage of the networked-enabled capabilities, and being able to achieve coordination rests on the ability of the actors to achieve common ground.

Common ground is conceived of as a mutually acknowledged shared frame of understanding underlying communicative activity. It is achieved through social activity and the ability of the communication partners to take the perspectives of the others, which underlies the sharing intentions, reaching agreements, and putting capabilities to a synchronized use. Developing a shared cognitive frame of understanding (culture) is a crucial aspect of the activity of taking the perspective of others.

7.4 RESOLVING HD CHALLENGES THROUGH M&S

Simulation- based technology has the possibility to contribute in many areas to resolve HD challenges. It can contribute to the human factor research within NATO, in concept development and experimentation (CD&E), in the education system (all levels), and in all forms for of training and practice from tactical to strategic levels, including multinational team training (coalition) and civil/military collaboration. Many of these possibilities are not yet fully exploited, but research from within the NATO countries strongly supports these assumptions, and the interests of fully exploiting these possibilities within the military communities are rising – fast.

The continuous enhancements of various simulation-based technologies today open up a whole new world of possibilities for addressing the complexity of the human dimension in NNEC. Our Case Studies have shown that one can create various kinds of situations suited for special training and experimentation needs. Together with Massively Multi-Player (MMP/MMOG) gaming technology, the possibilities of alternating between single-player, multiplayer, on-line and off-line play create multiple ways of utilizing this type of technology in various settings to support a variety of needs. This gaming technology is easily accessible and geographically independent. It is easy to operate even for non-technical people and easy to modify or change if needed [3],[4].

The full utilization of simulation-based technology for research rests on an analysis of whether and to what extent the recreated situations and environment actually resemble the ones actors would face in their real operations. Given these preconditions, simulation-based technology is a suitable tool for researchers who want to study possible antecedents of the choices and interactions of decision makers because it provides a high degree of control of the situational and environmental factors. The extensive opportunities for observing, recording, and capturing data through M&S makes it a useful research tool for data collection and thus subsequent analysis.

When time, personnel, and financial resources are limited, using a game environment that allows distributed collaboration can enable cross-cultural as well as other human factor experiments. The results from the Case Study LTAMC Research (leader and team adaptability in multinational coalitions) show that there is a future for such methods in both cross-cultural as well as other human factor research, for military and civilian purposes alike [5]. The study focused on collaboration across national cultures in NATO, including a focus on cultural adaptability, information sharing, situational awareness, organization (structure, processes, flexibility), teamwork, trust, and national cultural and individual differences. The study suggested that an Internet-based research testbed built around a commercial off-the-shelf multiplayer role-play is a sound methodology to build such skills [5]. As we are still in the early days of building the knowledge of how to create and use good simulated environments for research in human factor areas, this one study only begins to show its potential.

There is, however, a need to be aware of the limitations of such studies in terms of generalizations; certain processes risk being influenced by the research tool.

Distributed, game-based simulations may also help teach and enhance skills in handling cultural diversity by exposing personnel to those of various other nations and/or to other branches of the military, as well as to civilian actors. By setting up a virtual space, it can be easier to conduct joint/combined training for decision-making that requires interaction beyond performing standard operating procedures within their own units. Training and preparation for civil/military collaboration would also be possible. This type of activity is often necessary since HD challenges are sometimes realized only through interaction.

The Case Study Command in NEC has shown how these game-based simulations can work. Ad hoc and diverse teams or staffs form a major challenge to effective networked collaboration. However, the Case Study showed that M&S may be particularly useful for the preparation of joint exercises, giving the personnel opportunities to become familiar with one another and develop shared frames of understanding. Distributed, game-based simulations may also contribute to training needs, such as cultural awareness and tactical team training [6].

Another area in which M&S may be useful is during planning and execution of NEC operations involving units with headquarters that are distributed. It can be used as a way of rehearsing a plan and possibly for other parts of a planning process. It might have the same role in execution of operations, allowing for swift rehearsal of alternatives. Especially in the area of distributed coalition training, initiatives have already been put in place to explore the potential of virtual world technology (MMOG) in a low-level training scenario. During 2008 and 2009 the US Army Research, Development, and Engineering Command, Simulation and Training Technology Centre (RDECOM – STTC), along with US Army Research Institute for the Behavioural and Social Sciences (USARIBSS), and the UK Land Warfare Centre are conducting a distributed coalition training experiment [7]. This is a series of six experiments focusing on multinational training where soldiers from both armies are given the opportunity to plan and work together in a virtual world and conduct non-combatant evacuations and support operations. One of the key benefits reported from this experiment was that the immersive nature of virtual worlds enabled US and UK soldiers to experience coalition training without the expense of transporting people and equipment.

Personnel can also use M&S to train for specific skills needed in particular theatres, for instance language training. There are several games that provide such language training, for example the PC-based game Tactical Iraqi Language Trainer (DARWARS) used among the US troops in Iraq today [8]. This game requires street smarts and cultural savvy, rather that the usual hand-eye coordination skills. These skills are practiced on site and help to develop a higher degree of self awareness in dealing with other cultures. This method seems to be effective and has proven to be far more instructive than learning in the classroom before deployment. Other examples of tactical language training games are Tactical French trainer for use in sub-Saharan Africa, and Pashto trainer for Afghanistan. The possibilities for training and practicing various negotiations situations (important in any political/diplomatic situations or on the streets) is supported by the use of the Tactical French trainer, which emphasizes learning to deal diplomatically with locals and establishing rapport with them.

In the areas of asymmetric warfare and missions other than war, the USARIBSS has conducted research on distributed, multi-player simulations (based on a virtual world called OLIVE) for training dismounted soldier tasks [3]. The opinion-based information gathered indicates that the system can prepare troops for more expensive live drills and actual deployment by integrating basic warrior skills with reinforced situational awareness, decision making, and asymmetric warfare skills. The program is continuing with new development

by the RDECOM-STTC. In addition, the USARIBSS is using the asymmetric warfare–virtual training technology (AW-VTT), based on OLIVE, to research challenges in the use of distributed, game-based simulations for training soldiers.

A number of studies suggest that simulation-based technology also provides the possibilities to experiment with new organizational procedures that otherwise would have been impractical or impossible. For instance, in the Case Study Battle Griffin Experiment [9],[10] the researchers experimented with central NEC-related organizational variables such as flattening of the organizational hierarchy, decentralization of decision-making, self-organization and synchronization of forces, different team structures and composition of teams. The Battle Griffin experiment was designed according to essential NEC ideas: resources belong to the network rather than the platform, push & pull (i.e., from push to pull-oriented supply chain), flat organization (peer-to-peer), and horizontal collaboration. The use of a simulated environment to stimulate a distributed Command and Control Information System (C2IS) demonstrator with "live" data made this type of experiment feasible. A military (flat) organization with distributed collaborative teams using shared resources is difficult to construct without the help of a research enabler like M&S.

M&S systems have always had a place in the military education system, but we foresee even larger use for these new tools in areas that have so far been difficult to address. For example, *M&S could be used for critical reasoning*, testing possible new doctrines, identifying weaknesses, and *challenging established ways of doing things by **showing** simulated examples*. Further, M&S has been used to enhance other skills important to NEC such as information handling; communication and language; self and team management; and cognitive, social, and cultural skills.

7.5 SOME CONCLUDING TECHNOLOGICAL AND STRUCTURAL CONSIDERATIONS

From a human factor perspective, one of the main obstacles that seem to restrain a more widespread use of simulation-based technology today is that most of the M&S tools in the military forces are very expensive and complicated, since they have been developed to provide a robust simulation environment. They are also often focused on classical military platforms (aircraft, sea vessels, and land vehicles), in contrast to the NNEC vision, which is network-oriented. Aspects like these may reduce the desired effect on enabling the human dimension in NNEC. The M&S tools are often inaccessible and difficult to operate. The developing and operating costs of these systems are often very high. These facilities have much "embodied intelligence" and will still be very important in training highly skilled military experts in various settings. However, the possibilities for a more widespread use and utilization of these systems are, at least today, limited. They need to be network enabled as pointed out in several of the other chapters.

It will be important to de-couple today's strict requirements between the location of the simulators and users. It should be possible to access important training simulators from all locations, as continuous learning may be much better than "crash courses" at one dedicated site. Running the simulator from the real operations scenario (site) could be more effective and focused on the most required skills. Many more games/simulators could eventually be available on iPods and PDAs. Games could also be used as plug-ins to (and in conjunction with) dedicated military simulators. These developments would allow significant expansion of today's simulators at a very low cost.

In order to get a better picture of the effects of M&S on the human dimension, many more people of various skills and levels, across both domains and geographical boundaries, need to use simulation-based technology in a much larger scale than they do today. This is now possible. Today many of the M&S tools are more light

weight, cheaper, more easily accessible (through the network, preferably 24/7), and much easier to operate. The latter point is very important; to be effective, M&S technology must be easy-to-use and operate, even for non-technical personnel. In the game world, one can create various kinds of situations suited for special training and experimentation needs. The possibilities of alternating between single-player, multiplayer, on-line and off-line play create multiple ways of utilizing this type of technology in various settings and supporting needs.

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Chapter 8 – EVOLUTION OF M&S IN THE NNEC CONTEXT

Key M&S Principles

23) M&S as a formal discipline has rapidly expanded into new roles and provides 'unthought-of' new abilities to support the commander. This expansion is in part a result of significant developments in computing power and evolution of computer programming knowledge and capability.

24) Due to six key reasons, the "Operational Pull" for M&S is escalating significantly and is requiring M&S technologies to change and evolve.

8.1 THE EVOLUTION OF MODELLING AND SIMULATION

Throughout the evolution of M&S, several issues have emerged including:

- Development of augmented reality;
- Service Oriented Architecture (SOA) implementation;
- Standards (evolving and new);
- Technical interoperability (levels, e.g., HLA compliant);
- Degree to which M&S employed is interoperable across NATO (e.g., CGFs, entities, behaviours); and
- Security implications of M&S when used to represent real systems and operational capability.

Although M&S has likely been used in the formulation of battle plans since the dawn of time, it is only since World War II that its use as a formal discipline has ballooned into new roles that provide unthought-of abilities to support the Commander. This evolution of M&S has occurred as a result of significant developments in computing power and evolution of computer programming knowledge and capability.

Computer-based M&S has evolved significantly since World War II, at which time it provided the capability to model the behaviour of munitions rounds fired from different weapon systems. This work resulted in tables for daily use by soldiers and sailors. This use of computing technology enabled the initial development of what would become today's computers. With the resultant exponential growth in technological capability, M&S flourished, and the capability available has grown significantly.

By the early 1980s, the computing power was advanced enough to allow work in artificial intelligence to begin. Computing speeds and memory reached the point that initial implementation of rule-based systems and object-oriented software was viable. This has lead to almost 30 years of progress that has made the capability for augmented reality affordable. With this continual evolution of M&S capabilities new problems become viable for solutions based upon this technology.

Within the last dozen years, as the computing infrastructure has continued to improve and the experience with computer-based M&S has matured, the benefit of having different models work together sharing data and results has been recognized. This drive to link simulations has resulted in numerous standards being developed to provide the means for the technical interoperability of systems built in isolation. These standards include the

HLA and Distributed Interactive Simulation (DIS) standards. Today's evolution to a Service-Oriented Architecture (SOA) will continue to push the interoperability of M&S and will enable M&S to integrate better with operational systems.

The continued use of this technology will see it being subsumed into the overall command and control systems architecture as a component or service much the same way that rule-based systems and object-oriented software are now just tools for a programmer to use to solve problems. When this integration occurs, it will be of great importance that this technology is capable of being employed effectively across NATO. This eventuality highlights the requirement to address interoperability of M&S with agreed-upon entity behaviour, interoperable Computer-Generated Force (CGF) software, integration strategies, and other capabilities. The use of M&S within live systems will also demand a focus on security, which will require a robust V&V process that includes security assessments of the code design and security measures employed on the network supporting the activity.

8.2 THE "OPERATIONAL PULL" FOR M&S

8.2.1 Six Key Factors

At one time, M&S was considered to be a method of idea development away from the actual battle in both time and space. However, the nature of M&S, as it is seen by the operational community, is changing. The following six key factors are behind the growing "Operational Pull" for M&S:

1) Technology's speed (i.e., Moore's Law), visualization, processing, and ability to present information in more intuitive ways are improving at exponential rates, and these improvements have also led to convergence of technologies. As a result, the expectation for capabilities is also increasing – the operator wants more; this insatiable appetite for more is changing networking.

2) Young people have a considerable impact on demand for technology; having grown up with it, their ability to multi-task and to simultaneously assimilate multiple sources of data has far surpassed the older generations'. Because of their comfort with technology, young people regularly use more advanced technology (through simulation) than what is currently operational. For example, the US Marine Corps regularly trains troops on the video game "America's Army." Each Marine is provided with a copy of this computerized game and is expected to use it on a regular basis. On the negative side, users may believe all that is presented on their video screen, i.e., they may not question the veracity of the information presented.

3) The nature of warfare is changing, including the speed at which the actual battlefield changes. Coalition forces must work together for missions with different equipment and communications channels to accomplish different tasks. The operators may have differences in language; in Tactics, Techniques and Procedures (TTP); and in skill levels. Simulation provides a means to develop coherence, integration, and trust between units. Additionally, the integration of disparate entities must be completed usually in a very short period of time.

4) Today's battlefield has a sophisticated, but hierarchical chain of command that must stay inside the enemy's OODA loop and so must work at lightning speed. M&S has the potential to support this need as it can be used to increase the speed of decision making.

5) Force Readiness is currently determined via operational and logistical reporting. This laborious evaluation of assets in differing states of readiness is currently completed by hand. Force readiness

measurements are used to allocate and plan resources for mission portfolios. M&S could play a role in reducing the complexity of this reporting system.

6) The process between identification of lessons learned and new doctrine and capabilities will involve CD&E with a wide spectrum of M&S.

8.2.2 Mission Planning, Rehearsal and Training

The evolution of defence C2 systems will integrate mission planning, rehearsal and execution to allow wargaming of plans, pre-mission training and operator skill development, as well as support operations by alerting operators to mission plan and execution differentials. As illustrated in Figure 8-1 (see the Canadian Joint Fires Technical Demonstration Project Case Study), the evolution of C2 systems must encompass the following architectural concepts:

- Mission planning involves the execution of the mission planning process.
  - At this time the planning process is generally completed on a 96-hour rotational basis; however, if M&S were used to tease out various courses and options, it may be possible to shorten this planning cycle time and produce a higher quality product.
  - M&S can support the risk assessment of proposed courses of action, providing feedback which could help propose a better course of action with a better understanding of risk and mitigation strategies. This step should provide a better understanding of the mission plan, which inherently includes the briefing of mission Commanders. This step will become increasingly important as we move towards a more land joint and coalition battlespace.
- Rehearsal of the chosen mission plan by the staff officers tasked to execute the plan will result in further refinement of mission planning and better understanding of the nuances and cascading minutia that will result in better execution.
  - This rehearsal would be achieved by populating the models and simulation with the mission plan. The simulation would then create the Common Operating Picture (COP) and Situational Awareness (SA) within actual C2 systems in real time that enable wargaming of the mission plan prior to execution, or the system should be able to simulate faster than real time.
- Execution occurs after a plan is made and transmitted to the operational community. However, as the adage goes, “No plan survives initial contact with the enemy.” Thus, once a plan is executed, it is continually updated and refined as required when feedback arrives (e.g., assets change, more is known of the terrain).
  - At this time, the current operational picture (situation) must be given to the mission planning cell where, using M&S, they will be able to refine the plan. There is a need to do this with great alacrity as one must endeavour to stay within the OODA loop.
- The M&S product overlays from mission rehearsal will provide a datum from which to measure mission progression and identify friction points – areas where risk realization is occurring thus triggering the need to re-plan. Once this has been triggered M&S can be used to help with the re-planning.
  - Again there is a need for alacrity and thus the M&S mission planning cell must work closely with the operation staff executing the mission.
- M&S will, if executed as stated above, display the logistic deviation from the original plan, be it a change in the delivery location, method, or time. M&S will greatly enhance the ability to respond to logistical requirements.

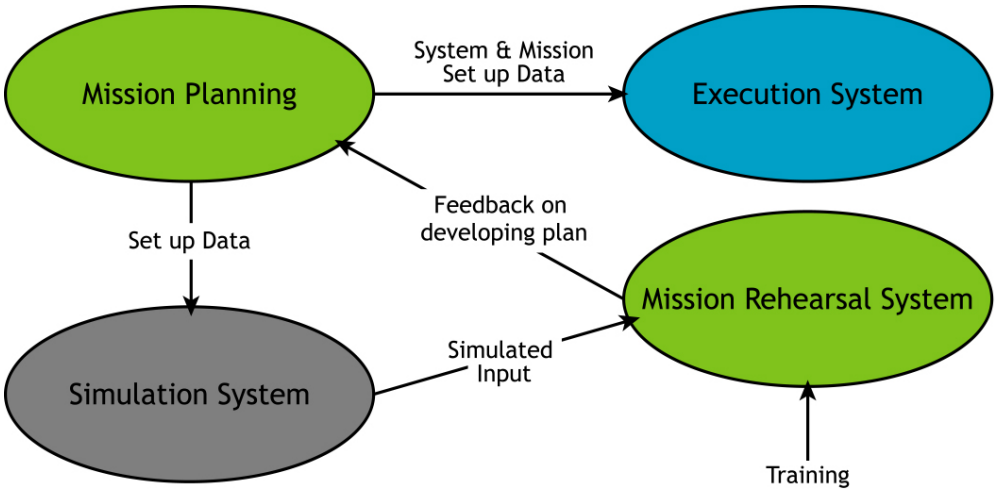

Figure 8-1: Joint Fires System Link between Mission Planning, Rehearsal, Training and Execution [1].

8.2.3 Simulation Feed to C2 Systems

The use of Computer Generated Force (CGF) software to populate data into operational systems is a key enabler for mission planning, rehearsal and training. This software allows the operator to engage in a wargame (mission rehearsal) using the operational tools and environments. Simulation of a wargame scenario that feeds operational C2 tools has been used for a number of years in support of soldier training both as part of course work and operational readiness preparation and assessment. This technology can facilitate the exercise of planning and decision making from national to command-post levels. Doing so requires that the virtual environment be able to provide a verifiably correct flow of data for each of the systems that would be available at the command level.

8.3 IMPLICATIONS FOR M&S

M&S systems must be capable of working in real time in order to match the behaviour of the actual C2 systems. This puts constraints on the simulation to be able to compute at an advanced time in 0.5-second to 1-second increments.

The real-time constraints, combined with CGF performance and scalability, is affected by the model size. A full joint operation could easily require the modelling of a battalion of 2,000 individual soldiers and their vehicles, sensors, and weapon systems as well as unmanned vehicles. The air side could include fast air, helicopters, unmanned air vehicles, and loitering weapon systems that require hundreds of model entities. A naval task force would include dozens of entities. When the ‘red’ and ‘white’ entities are entered there could be tens of thousands of entities. These entities will require complex model behaviours that, in turn, need an architecture comprising multiple simulators federated together to ensure that the models perform consistently with the real-time requirements.

In addition, C2 systems leverage a multitude of data formats, and these systems are not going to change to support the M&S. The M&S solutions will need to respond to these constraints on design. Indeed, fundamentally different data constructs are required to support land, naval, and air operations. These differences stem from two

command differences – reporting *tracks* versus *contacts and individuals* versus *platforms*. The land environment works with contacts and tracks individuals that are amalgamated into larger units. The Air Force and Navy work with tracks that represent planes and ships. The individuals are inherent in the vehicles.

Model behaviour between federated CGFs significantly impacts the ability to provide meaningful advice to the user. As indicated above, there will be a significant number of systems providing the federated simulated environment. As well there are often different simulation tools in the federation. Within this federated environment, the model interaction within different simulations must have the same level of fidelity. For example, when a troop of soldiers modelled in one environment approach a helicopter in a different environment the behaviour of the soldiers must be consistent. As the soldiers climb aboard the helicopter the two simulation environments are providing parts of a larger entity. These models need to work in concert with the same, appropriate behaviour.

In the federated environment, the model's ability to replicate real-world sense capability will significantly impact the **military utility of the simulation**. If these tools are being used to inform the development of operational plans, for example, and the models find red force elements where there should be none, locate red force elements early, or miss red force elements that should have been sensed, then the mission planners will draw incorrect conclusions regarding the risk and viability of the courses of action being considered. This type of occurrence will quickly destroy trust in the system.

Currently, there is a significant momentum within the operational community to transition the C2 systems to operate within an SOA. **C2 tools that utilize an SOA are already appearing in theatre**. In order for the architecture above to integrate into the Command systems architecture, the simulation will need to work within this architecture, provide a service and be a consumer of C2 services.

In addition, support of mission training and operational readiness evaluation will require integration of human-in-the-loop simulators such as air plan simulators, dismounted soldiers, and ship bridges as entities within a simulation environment. The real-time and behavioural issues mentioned above will be pervasive with this integration.

As the convergence of C2 and M&S occurs, it is necessary to ensure that there is a clear separation between C2 and M&S within the logical architecture. The command architecture must remain the target which the M&S community cannot expect to change. The C2 architecture must also remain functional without the M&S piece. Thus there needs to be a clear demarcation between the C2 and M&S capability.

As the convergence of C2 systems and M&S occurs, there is a growing **pressure to have the simulated entity models to be controlled from the C2 systems**. For example, if there is a digital control system that allows the commander to cause a real-world asset to execute a command, then this digital command needs to also cause the simulated entity to react, as in a fire control system or the tasking of an airplane to attack. If a command is issued within the C2 system to an asset, like an artillery piece, to fire and, in the real world this would occur without a human-in-the-loop then this command should be passed into the virtual world and executed.

Before any mission occurs, there is a large amount of information collected to support it. This information (including maps, our understood red force order of battle, and intelligence) is used in the mission planning process and is populated into the C2 systems. The M&S environment should integrate this battlespace characterization information and be able to develop appropriate models. During execution of a simulation (in support of operations or not) there needs to be an ability to inject the intelligence reports into the maps and to then model and adjust the simulation behaviour to reflect the new understood reality.

8.4 THE FUTURE FOR M&S IN RELATION TO THE OPERATIONAL COMMUNITY

There is currently a pull from the operational community, while at the same time there is push back from the M&S community. If there is no congruence, the two communities will find themselves on different paths without meeting the operator's needs – which is the real goal. When this has occurred in the past, where there has been an "Operational Pull" and the R&D community has not responded, the result has been a stagnation in R&D until a new operator focus was found, i.e., the operational community worked around the push-back. AI is a great example where the early R&D research resisted the pull for this subject to become an engineering domain.

It is also necessary to recognize that the adoption of a technology into mainstream results in programmatic changes. There is a need for **M&S to transition from being a specialty to becoming the accepted norm** of an engineering discipline. When this transition occurs there are two significant implications:

1) Technological growth in the field of M&S and the need to provide support to capability development in support of military operations are two distinct pressures. The rapid change in technology will enable the M&S community to take on an ever-increasing level of complexity; and
2) Better tools and model reuse will enable rapid development of simulations that can address specific problems.

The "**Operational Pull**" **for M&S** will demand that the underlying integration architecture be informed by and operate in the existing and evolving C2 architecture. Operational systems have a significant imposition on the flexibility for developing M&S solutions, including the following:

- More rigorous design and documentation requirements.
- Formal development processes.
- Formal test and evaluation.
- Model validation.
- Interoperability.

"The *Operational Pull* for M&S will demand that the underlying integration architecture be informed by and operate in the existing and evolving C2 architecture."

Finally, operational systems must also be capable responding to customer/operator on questions of trust, i.e., the system must be capable of stating a percentage of probability that an action will occur.

8.5 REFERENCES

[1] Adapted from Bowen, D. and Prudat, G. (2007). "Canadian Joint Fires: Overview and M&S Vision", *Proceedings of the MSG-062 Workshop on M&S for NNEC*, Ottawa, Canada, 19 September 2007.

Chapter 9 – SUMMARY AND CONCLUSIONS

Key Points in this Chapter

- **Using a Case Study / evidence-based approach, this report represents guidance with which M&S as a lead S&T environment enables the realization of NNEC.**
- **Across CD&E, through-life management, material acquisition, T&E, logistics, training, agile Ops, the human in NNEC and the impact of NEC on M&S, "Gold Nuggets" were noted and agreed upon as 24 key M&S principles in support of NNEC.**
- **M&S enables NNEC while providing agility, proximity to end-users, support to agile Ops, support to complex Ops, support to shorter acquisition cycles and lesser costs in military capabilities as well as Defence Against Terrorism (DAT) capabilities.**

9.1 SYSTEM-OF-SYSTEMS PERSPECTIVE

NATO, like many of its individual member nations, has accepted and adopted a perspective on world affairs that is based upon a model of a complex adaptive system-of-systems. A number of NATO members have focused on different elements in their approach to NNEC:

- The US has focused on the network as a means to conduct operations and have labelled their effort Network-Centric Warfare (NCW).
- Canada has focused on the network as a social as well as technical structure that enables better informed complex reasoning and provides an environment for the planning, coordination, and conduct of interdependent actions. This coordination would take place across the military, includes all instruments of national influence, and refers to Network-Enabled Operations (NEOps).
- The UK has adopted a military focus with emphasis on the coherent integration of sensors, decision-makers, weapon systems, and support capabilities. Its target is to ensure network-enabled capabilities that may not be fully integrated on a day-to-day basis, but have the inherent ability to be rapidly brought together and integrated to form tailor-made task forces to meet a national need. The UK refers to its approach as the achievement of Network-Enabled Capabilities (NEC).

As a standing Alliance, NATO has chosen the UK perspective of being "network enabled," that is, ensuring a planned level of interoperability across capabilities that permits their rapid integration when required but does not demand that they be connected in advance for protracted periods of time.

It is no coincidence that the key driver of the move to acknowledge and leverage inherent synergies across social and technical networks is based on a model describing **international affairs as a complex adaptive system-of-systems**. Confidence in this perspective has been achieved through a variety of means, from informal discussions that may not explicitly acknowledge the foundation of M&S to formal scientific investigations that develop detailed models across various domains and run them in simulation to explain observable events and project events that have yet to occur. Regardless of the means, the participants are conceptualizing the behaviour of various agents at play in the environment and proposing relationships or abstract linkages between them to explain observable behaviour, often focused on outcomes that have either

provided significant advantages or disadvantages. For situations with negative outcomes, **modelling provides the intellectual framework to assist in assembling the known facts and assumptions** in such a manner that explains the outcomes and "makes sense" of what is known or suspected. Using those same models running in simulation can give decision-makers the opportunity to project forward and anticipate potential problem areas and consider solutions.

9.2 EFFECTIVE USE OF MODELLING AND SIMULATION TO ADVANCE NNEC

9.2.1 Summary

The preceding chapters have attempted to guide the reader through the full lifecycle or through-life-management of capabilities as described in Chapter 2, highlighting opportunities to effectively use M&S to advance NNEC. Capabilities have been defined as not simply comprising technology within platforms and equipment, but including people and processes essential for putting the technology to use. In addition, the desired capabilities have a definite lifecycle that must be managed from early definition of a gap or deficiency through development, generation, and finally operational employment. At each step the authors have indicated the effective use of M&S along this path through reference to case studies that have proven their utility.

Using a *Case Study / evidence-based approach*, this report represents guidance on how M&S, as a lead S&T investment, enables the realization of NNEC.

In the concept development phase described in Chapter 3, the general theme has been to first create an executable federation of individual agent models representing current capabilities within the system-of-systems and permitting these agents to interact within the federation. From this baseline, new or updated capabilities can be added to the federation according to the development and acquisition plans of NATO member states. Force developers are permitted to **run simulations in a synthetic environment under conditions that would either be cost or risk prohibitive** while manipulating one or more variables in one or more agents and record the observed expected and unexpected behaviours. Beyond the pragmatic risk and cost reduction of using M&S, it provides the only opportunity for force developers to create virtually an operating environment of the future. Within a synthetic environment, **capabilities not yet in existence can be modelled by projecting trends** in the advancement of science and technology, permitting researchers to investigate how these trends will affect the behaviour of future systems.

The support provided by M&S during the acquisition or capability generation phase has been limited to a discussion in Chapter 4 of acquisition of technology within equipment and platforms as well as a discussion of M&S support to the acquisition of knowledge, skills and experience for personnel in Chapter 5. Processes – the third pillar of the capability triad of technology, people, and process – has not been directly addressed within this document; however, reference was made in several sections to the identification and testing of updated tactics, techniques, and procedures used by personnel to optimize the performance of available technology.

Both Chapters 4 and 5 dealing with the acquisition of elements of network-enabled capabilities highlighted the accepted and often subconscious use of M&S to support the acquisition of individual capabilities. However, although this lower level of M&S at the individual capability remains necessary within the NNEC paradigm, it is not sufficient. It does not utilize the full potential of M&S for investigating the broader system-of-systems behaviour at the heart of the NNEC concept and misses the opportunity of intentionally looking for and leveraging emergent behaviours within these complex systems.

Chapter 4 went on to point out that not only can **M&S be an essential tool in advancing NNEC**, but also that the acquisition of a **pervasive M&S capability for the Alliance is in fact a leading-edge network-enabled capability for NATO**. Through the acquisition of robust and secure networks for experimentation using M&S, operational networks have been developed once confidence in the network elements have been proven adequate for the tasks. By testing the networks supporting M&S transmitting simulation-generated data, leading-edge technologies can be assessed for use in real-world operational networks. The traffic loading as well as all message formats can mirror real-world networks; however, because no real-world data is being transmitted, if the network is compromised, there is little to no risk. Finally, as was stated, M&S can be used to stimulate proposed new systems, particularly system components that deal with data processing and transmission. For example, radar data processors can be stimulated through M&S of transmitter/receivers which provide the raw sensor signals for the data processor to process and provide to all downstream users represented on the network. The range and reach of the outputs is completely scalable to the intent of the testing, whether it is engineering test and evaluation (ET&E) or operational test and evaluation (OT&E).

"*M&S enables NNEC* while providing agility, proximity to end-users, support to Agile Ops, support to Complex Ops, support to shorter Acquisition cycles and lesser costs in military capabilities as well as Defence Against Terrorism (DAT) capabilities. "

Acquisition goes well beyond the purchase of equipment and technologies to include the accumulation of knowledge, skills, and experience through education and training as highlighted in Chapter 5. The use of M&S to represent the adversary has always been an essential part of training as adversaries are evidently not receptive to acting as training aids for their competitors. The classic advantages of **simulation-based training – reduced costs and risks as well as the ability to train with capabilities not yet fielded** apply here. However, as the problems the adversary poses become more complex, and as we develop our own "networked" solutions, M&S support to training becomes increasingly important. Each system within the interdependent system-of-systems can be modelled and networked according to how we see the adversary and how we are connected ourselves. As collective simulation-based training opportunities are provided, those organizations with the interest and capabilities required may participate in the training session. Alternatively, they may simply permit their part to be played through modelling and observe the session to gain insights and understanding on interaction and interdependencies based on how they are formally planned to occur according to established tactical, techniques and procedures. In so doing, they can either focus on gaining valuable direct experience in an NNEC environment through active participation or they can explicitly look for emergent behaviour in activities related to their roles, responsibilities, and authorities within the system.

A more subtle way for M&S to significantly assist in the advancement of NNEC is the manner in which a persistent synthetic environment provided through modelling and simulation presents as **means to gain confidence and experience in effectively leveraging other capabilities** resident within the system. By utilizing the ability to source knowledge and experience of other interdependent organizations within the network-enabled environment and collaboratively plan coordinated use of external capabilities, NATO members and other ad hoc partners will be able to gain valuable experience and confidence in their ability to recognize and leverage synergies and avoid negative unintended consequences of interdependent actions.

The **confidence gained through collaborative training will logically spill over into the conduct of live operations** as discussed in Chapter 6. As was brought forward, planning has always been based on a projection of likely outcomes resulting from possible courses of action and the selection of what is considered the most advantageous outcome in meeting established objectives. Decision support provided by the effective use of M&S, in particular the ability to visualize significant amounts of information when considering

interdependencies, cannot be overstated. As well, M&S can provide a highly realistic synthetic environment for individual mission rehearsal providing tactical operators with an opportunity to execute upcoming missions in a realistically complex threat environment at low cost, low risk, and low consequence of error. In addition, the ability to **rehearse within a secure synthetic environment** does not expose the planned activity to possible observation by the adversary potentially warning them of an imminent action. Finally, during the conduct of operations, M&S can use **augmented reality** to provide supplemental information to "filling in the blanks" with respect to missing information based on matching partial data provided by on-board sensor systems connected to database of the models describing the sensor profiles of real-world entities.

The human dimension of NNEC, discussed in Chapter 7, highlights the critical role M&S plays in establishing common ground among the many and diverse participants in the NNEC environment. While M&S will continue to be an invaluable tool in the development and testing of improved human/machine and human/system interfaces, the implications of the network-enabled environment to enhance human/human interactions in collaborative decision-making is an area of opportunity where the effective use of modelling and simulation has already provided and will continue to provide tremendous benefits. The obvious role M&S can play in this area is to create **low cost, low risk, and low consequence of error synthetic environments** that present real-time complex problem situations to specifically targeted organizations and individuals. The use of M&S in this context provides several key advantages:

- First, the simulation can push discrete event data across multiple systems that are in current use by operators.
- Second, within the network architecture, participants may choose to act independently, coordinate actions after planning internally within their organization or collaborate with interdependent organizations from the start.
- Third, in each case, a detailed log of all input stimuli and resulting interactions can be maintained as well as decision timelines and outcomes recorded.

Finally, results from a variety of runs with varying use of the network-enabling capability can be compared and contrasted providing insights on issues such as knowledge sourcing behaviours, trust in information provided, and individual abilities to assimilate and effectively utilize knowledge from the network to solve appropriate segments of complex problems.

At a more abstract level, M&S can be used not only to stimulate human activities across networks, but to create internal mental models and forward projection through simulations. In fact, people use this type of M&S, either consciously or unconsciously, in making decisions day to day. **Making these internal models explicit through formal M&S, and then comparing, contrasting**, and harmonizing them, creates a broader mutually shared framework for understanding complex situations. As a result, models can be used to **make sense of observed behaviours** and to collectively project likely outcomes with or without interventions. In effect, it increases the baseline knowledge of all participants permitting a more comprehensive and harmonized understanding of the situation from the start as a critical foundation for meaningful collaboration and collective problem solving.

Finally, the evolution of M&S was discussed in Chapter 8 in the context of co-evolution of modelling and simulation and computing power available through networks. Again, the assertion was made that modelling has always been used for human decision-making. At times, the use of modelling was difficult to recognize as such because the user only saw the outputs of the models, for example, a ballistics table for munitions. But as more complex calculations within models demanded greater processing power, modelling became a key driver in the development of the computer. When even more power was required, it drove the development of

networked individual computers to aggregate the necessary collective processing power to perform the complex calculations. Now, as NATO moves toward its real-world objective of greater networking of capabilities, it is driving the need to evolve M&S to mirror this networked paradigm with large federated networks of simulations.

The authors suggested that the demand for realistic M&S and the use of virtual synthetic environments will likely significantly increase as the user population becomes more familiar with such technology. The current generation entering the workforce has not known a time without computers (and real-time computer "gaming") and will expect an integrated use of such capability for **rehearsal of complex tasks and as a powerful decision-support tool**.

As NATO moves toward an increasingly dense network-enabled construct, it will be expected to provide the network backbone for command and control of military capabilities on which contributing member nations will connect to form an effective fighting force. While NATO has accepted the responsibility to design and provide this network backbone, its utility will be greatly diminished if a significant number of capabilities from contributing nations cannot connect to it due to a lack of interoperability.

To minimize this risk, senior NATO leadership has identified M&S as a key enabler to test interoperability within a synthetic environment and created an M&S Master Plan (MSMP). The plan includes activities to identify technical standards that will foster interoperability across NATO M&S with a specific goal of supporting the Alliance's activities in the areas of research, capability development, acquisition, training and exercises as well as the planning and conduct of operations.

> ***Twenty-four key M&S Principles*** **in support of NNEC were noted and agreed upon across CD&E, through-life management, material acquisition, T&E, logistics, training, agile Ops, the human in NNEC, and the impact of NEC on M&S.**

While this issue is important to NATO as an Alliance, it is equally important to member nations which control their own acquisition programs for national capabilities. Throughout the development phase and in advance of actually generating and fielding military capabilities, member nations must be provided with a means to assess whether they will be interoperable with other contributing nations' capabilities and easily integrated into combined joint task forces connected by the NATO network backbone. M&S of the connecting network itself will provide member nations with both technical and functional standards as well as a means to test interoperability as an essential step in the capability development and generation phases.

The use of M&S capabilities can provide effective decision-support tools for NATO and all member nations to **plan their capability development** and acquisition investments more wisely knowing in advance they will able to integrate into the NNEC environment, provide NATO personnel experiential training opportunities in an operational working environment and permit investigation and analysis of various courses of action during real-world operations.

As was noted in the introduction, the **ultimate success of NNEC will likely be measured by the extent to which individuals actively seek out and access other individuals' experiences, insights**, and professional expertise through social and technical networks NNEC provides. They may do so in an effort to re-validate existing knowledge or create new updated knowledge and make it available within some problem-solving or decision-making process. Throughout this document, arguments and representative examples of how M&S is being effectively used to provide a low risk and low consequence of failure environment where NNEC can be

tested. It has also provided some examples of its significant benefits of M&S and the confidence established in it across the Alliance.

Looking back, the evolution of the current M&S situation could be explained in its most basic sense according to the following chronology:

1) Early modelling required a heavy computation workload, which put a high tax on human time for clerical work.
2) Technology was used in response to develop computers to relieve the computational workload.
3) Removal of the workload constraint permitted to models become even more computationally complex.
4) Technology was used in response to develop network computers to aggregate computational power.
5) Removal of the computational constraint permitted the further development of functional sets of federated models for complex adaptive environments.

There is now an opportunity for complementary functions in decision-making related to complex adaptive systems using the relative strengths of both M&S technologies and human creative capabilities. With formal computer-based M&S, computers are capable of rapidly calculating, aggregating and preparing the necessary data and present it in a user-friendly format as a highly effective decision-support tool. However, there will likely remain, even with the most powerful computations, a level of ambiguity within complex adaptive systems that humans will need to creatively resolve. In all supported decisions, whether related to **capability generation, development, or operational employment, network-enabled M&S will allow the human (Commander) to focus more time to the valuable creative aspects of the decision-making process**.

This first version of the Guide focuses primarily on NNEC within the military context. As in any complex adaptive system, the overall system behaviour of the international security environment will continue to change. It is also expected that **M&S capabilities will continue to evolve, providing ever increasing fidelity** as the speed, power, and reach of distributed M&S across networks becomes more pervasive. While M&S is likely to provide decision-makers with increasingly powerful decision support, it will not likely reach the point of fully automating key decisions themselves. In addition, the full vision for NNEC is not restrained to application within the military domain alone; it is also expected to be a **key enabler for effective collaboration and cooperation across military, diplomatic, economic, and social** efforts as well. As the implementation of this process progresses, feedback is received, and the agents operating within the environment adapt, the Guide will be updated.

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Appendix 1 – LIST OF CASE STUDIES USED IN THIS GUIDE

Fleet Battle Experiments (FBE-I) – US Chief of Naval Operations

- Mentioned in Chapter 2.
- Use of systems architecture to identify interoperability weaknesses in mission threads to prioritize investment options.

NATO FirstWAVE; Mission Training via Distributed Simulation (MTDS)

- Mentioned in Chapter 4 and 5.
- Distributed M&S for training, exercises, and even acquisition of such mission training capability.
- Demonstrated the ability and potential of mission training via distributed simulation (MTDS) to provide a realistic operational scenario for collective training of NATO combat crews in coalition air operations.

NITEWORKS

- Mentioned in Chapter 4.
- Niteworks is an innovative and agile enterprise for military capability-based acquisition and evidenced decision support (http://www.niteworks.net/).The UK Niteworks capability has always been deeply rooted in NEC and warfighting CD&E. It has produced numerous unique NEC related case studies, including how ISTAR (Intelligence) data collection capability might be managed in a joint US and UK operation.

US DoD Joint Strike Fighter (JSF) Program

- Mentioned in Chapter 4.
- Use of central repositories of models, simulations, and synthetic environment components to aid in development and delivery of the JSF capability (advice and influence acquisition).

RADNet

- Mentioned in Chapter 4.
- Used to investigate the value of a real-life working model of network-enabled radiation detection capability for border security.

EXIT08

- Mentioned in Chapter 4.
- Use of live simulants of radiation, chemical, and biological agents to assess in part, the required capabilities of CBRN mobile labs in a network-enabled context for a whole-of-government response to major events.

Joint Fires Support TDP

- Mentioned in Chapters 4 and 8.
- Documented the benefits of M&S in support of Joint Fires as a network-enabled capability before actual acquisition.

UK Employment of Fires

- Mentioned in Chapter 4.
- Documented the benefits of M&S in support of Employment of Fires as a network-enabled capability before actual acquisition.

C2Sim

- Mentioned in Chapter 4.
- Use of distributed M&S to improve the NEC of emergency management partners.

NETC(L)

- Referenced in Chapter 5.
- Target concept for the future training capability to deliver training required for networked-enabled operations.

JADE (Joint Air Defence Experiment)

- Referenced in Chapter 5.
- Investigation of technical feasibility and training effectiveness of networking and adjusting existing stand-alone training systems as a first step towards a network-enabled joint collective training capability.

DARWARS

- Mentioned in Chapter 5 and 7.
- Future vision of being able to train anywhere, anytime – persistent training network.

JADOCS (Joint Automated Deep Operations Coordination System)

- Mentioned in Chapter 6.
- In the context of M&S integration with C4I Systems.
- Uses embedded M&S support to provide enhanced battle space visualization and joint operations planning. In particular, used in the recent UK national demos of NMSG-048 C-BML.

TNO Command in NEC

- Mentioned in Chapters 6 and 7.
- Context – persistence in training.

- Unless constantly trained in NEC so that it becomes second nature, in a crisis troops will revert to what they are most familiar with.
- Command in network-enabled capability was designed to investigate the related "human" issues in NEC.

Deployed Integrated M&S for Operations (DIMSO)

- Mentioned in Chapter 6.
- An integrated M&S tool suite to support forces in theatre conducting missions.

SIMBAT (Simple Battlegroup)

- Mentioned in Chapter 6.
- A model that was deployed with troops on a tactical engagement simulator exercise at BATUS.
- Results obtained were remarkably similar to those from the exercise.

CWID (Coalition Warrior Interoperability Demonstration)

- Mentioned in Chapter 6.
- The use of synthetic wrap for experimentation/validation of C4I /M&S integration has been shown to significantly enhance component tactical level live and HITL (Human-In-The-Loop) simulator training, and this can also be of use to troops on deployment.

C-BML

- Referenced in Chapter 6.
- A successful interconnection of C2 systems using the C-BML interface (NMSG-048) and the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) was demonstrated with systems from 6 nations providing a limited C2 to simulation interoperation.

LTAMC Research (Leader and Team Adaptability in Multinational Coalitions)

- Mentioned in Chapter 7.
- The use of a game environment that allows distributed collaboration can be what makes cross-cultural as well as other human factor experiments feasible, in terms of time, personnel, and financial resources available.

Battle Griffin Experiment

- Mentioned in Chapter 7.
- Simulation-based technology gives also the possibility to experiment with new organizational "way of doing things" that otherwise would have been impractical or impossible.
- The use of a simulated environment to stimulate a distributed C2IS demonstrator with "live" data made this type of experiment feasible.

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Operations research
Requirements
Simulation
Systems engineering
System of systems

14. Abstract

A fundamental objective of NATO and one of the highest priorities of the NATO Allied Command Transformation (ACT) is to take full advantage of Network-Enabled Capabilities (NEC) to build a robust, globally interconnected network environment for data sharing. This Guide discusses how modelling and simulation (M&S) can be applied to NEC, from Concept Development and Experimentation (CD&E), Acquisition, Training, Exercises, and Operations, to enhance military effectiveness and transformation, and prepare for the security challenges of the future. This Guide structures "Best Practices" of M&S around "Key Principles" in each chapter, provides real world Case Studies, and offers evidence-based advice to achieve the following objectives: 1) Ensure that allied defence capability programs are truly able to support future force capabilities from CD&E, Material Acquisition, Training, Exercises to Operations; 2) Document the principles in real world practice, for both military capabilities and DAT capabilities; and 3) Provide evidence-based advice on how a nascent NEC can be influenced by M&S from CD&E to Operations. This Report documents 24 Key M&S Principles in support of NATO Network-Enabled Capabilities (NNEC) of interest to Armed Forces, Governments, Industry and Academia, concerned about military and Defence Against Terrorism capabilities.

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