Session 11
Simulation Applications III

UNDERSTANDING AGILE ORGANIZATIONS

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ABSTRACT:
Agile organizations emerge from the exploitation of complex informal networking within the organization (either explicitly or implicitly). Agility is a core concept for our future defence force structures. We thus need to understand how agility can be created and sustained in such future force structures, and how it can be modelled in order to assess its benefit.

As part of this development of understanding, we focus here on the way in which the agents in such simulation models need to interact and share information with each other in a complex and adaptive way, forming a 'complex adaptive network'. A classification of such complex networks is described. At the top level of this classification we give examples of innovative work in progress, using exploratory simulation modelling to help understand the characteristics of agility.

Key Words: Agility, Defence, Simulation

1. INTRODUCTION

The attainment of Network Enabled Capability (NEC) is a key objective for the UK Ministry of Defence. The 'epochs' of NEC are shown in Figure 1 as a journey, moving from Initial, through Transition to the Mature stage of NEC, which is the UK long term goal.

To capture and quantify the benefit of the journey towards the NEC Mature state, we thus need to develop a set of computer algorithms which can be used by a range of simulation models. The key drivers in this journey, as shown in Figure 1, are increasing shared situational awareness across the force, and increasing the agility of the command process. The challenge is to capture these essentially human attributes in our closed form ('constructive') simulation models.

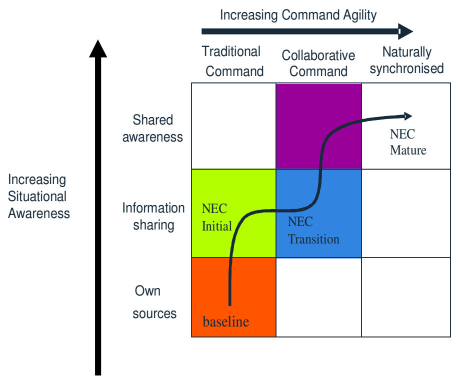

Figure 1: The NEC Journey.

In order to help achieve this, my current work has progressed along two fronts, the first being a problem structuring phase where we try to understand the true essence of the 'NEC Mature' stage, and the second being a set of mathematical algorithms to implement this understanding in our simulation models. In this paper, I have focussed on some of the problem structuring aspects of this work.

2. PROBLEM STRUCTURING - UNDERSTANDING AGILE NETWORKS

Agility starts with the development of complex, informal networks (Atkinson and Moffat, 2005) which may well change and adapt over time. We call these *Complex Adaptive Networks.* A complex adaptive network is a complex adaptive system, and can be defined in terms of a number of key attributes which derive from Complexity Theory, as shown in Figure 2 below, adapted from (Atkinson and Moffat, 2005).

Complex Adaptive System Attribute	Application of this Attribute to an Information Age Force
Non- linear interaction	Combat forces composed of a large number of nonlinearly interacting parts.
Decentralised control	There is no centralised control dictating the actions of each and every combatant.
Self-organisation	Local co-evolution induces long-range order.
Non-equilibrium order	Military conflicts, by their nature, proceed far from equilibrium. Correlation of local effects is key.
Co-evolution	Combat forces must continually co-evolve in a changing environment.
Collectivist dynamics	Cascades of local effects ripple through the system.

Figure 2: Attributes of a Complex Adaptive System.

3. CLASSIFYING COMPLEX ADAPTIVE NETWORKS

In (Atkinson and Moffat, 2005) we introduce the idea of a classification of such complex networks. In order to understand the emergent behaviour of such complex networks of people and systems, we need to develop some properties of networks which allow us to understand when they are essentially different, and thus display different properties. Thus we need to link network assumptions to network emergent behaviour. This can be measured either statically, through the resultant 'topology' of the network as measured by its node and link structure, or through its 'dynamics', such as the growth and decay of nodes, the way in which edges link up or break over time, and the sharing of attributes between nodes, resulting in clustering behaviour.

The classification of such complex networks can apply at a number of levels, as shown in Figure 3. At the Base level we consider the basic node and linkage topology and link dynamics of complex networks. At the Median level, we consider the local interaction between 'intelligent' nodes (people or systems), sharing a number of attributes of information, and the resultant clusters or cascades of sharing of information which emerge across the network. At the Top level, we consider how these feed through into Network Enabled Capability. We start by considering what we call the Base level.

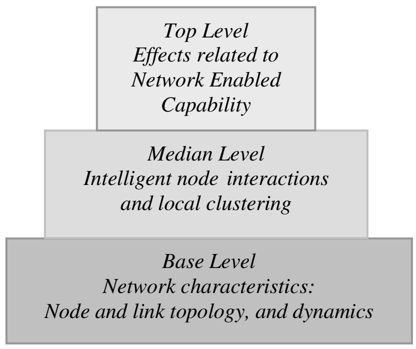

Figure 3: Classification of complex networks at base, median and top levels.

3.1 BASE LEVEL CLASSIFICATION OF NETWORK TYPES

It is clear from (Albert and Barabasi, 2002) that a key classification property of a network at this Base level is its distribution of degree – i.e. the distribution of the number of links per node of the network, which is a measure of the relative *richness* of node connections. In addition it is possible to investigate the *average path length* (the mean number of links in the shortest path between two randomly chosen nodes) and the *clustering coefficient* (a measure of how well linked the neighbours of a given node are). All of these are useful measures of network connectivity, and lead to a first level classification of networks into the three main types; *Random Networks, Small Worlds, and Scale Free Networks* (see for example Atkinson and Moffat, 2005, Ch 2, 4).

Other characteristics of networks which can be investigated at this level are the *growth* of new nodes over time, and how these new nodes 'plug in' to the existing network. For example, we can consider the *preference for attachment* of links to nodes in terms of both node '*fitness*' and node '*richness*'(see for example Atkinson and Moffat, 2005, Ch 4). We can also consider the vulnerability of the network to node or link loss (in terms of the possible break up of the network into disconnected components which cannot 'communicate'). This can be radically different for each of the three categories of network we consider.

3.2. CASCADING FAILURES AT THE MEDIAN LEVEL

Moving up to the Median level of Figure 3, we can consider more dynamic properties of the network; we refer to the interaction of intelligent nodes (people and systems), and how they cluster locally at this Median level of our classification. An example defence application is in the context of nodes which are people (military commanders) linked across an information network. A cluster of such nodes corresponds to a set of such decision makers who agree to share the same critical information elements driving their decision making, and who agree on the interpretation of these information elements at any given point in time.

In this case, we are looking at how people and systems interact across a complex information network, sharing information and making decisions. We assume that the topology of our informal network is Small World in form. Thus we have a number of clustered Communities of Interest (CoI) linked by longer cross-community links, as shown for example in Figure 4 (taken from Perry and Moffat, 2004).

These clusters take information from a number of sources, and share it across the cluster. The benefit of sharing such information richly within each Community of Interest can be measured quantitatively using Shannon Information Entropy. On this basis, it is possible to develop a number of metrics of such collaboration, and these are embodied in the Dstl *Collaboration Metric Model* (CMM). This is an analytic model based on the approach laid out in (Perry and Moffat, 2004).

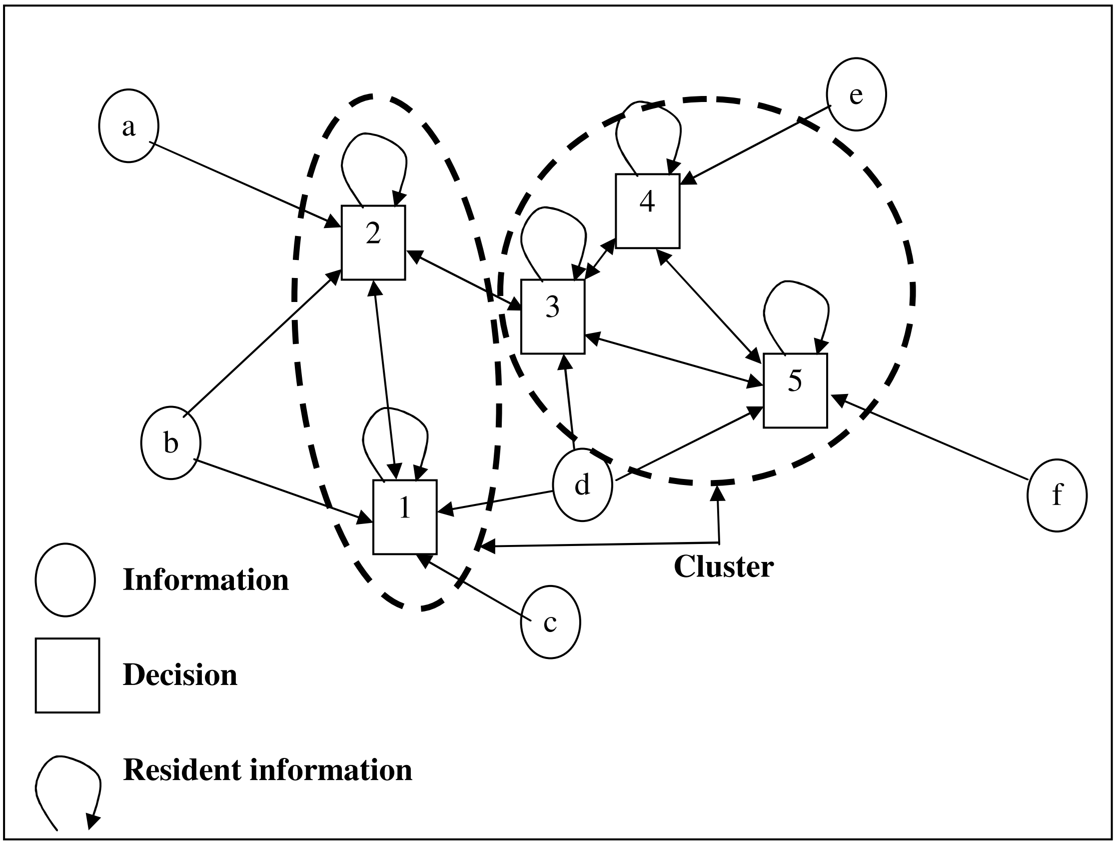

Figure 4: Clustered Communities of Interest and longer cross-community links.

Moving up to the Top level of Figure 3, we are now dealing with effects and how they relate to Network Enabled Capability. To increase our understanding, we are developing innovative simulation models, including the 'Three-Block War Testbed', which explore some of these effects in a future context.

4. THE THREE-BLOCK WAR TESTBED

Within the context of an Agile Organization, we discussed in (Atkinson and Moffat, 2005) the values and trusts between 'actors', their commitment to objectives, their current situational awareness and their predictive situational awareness. We then discussed how such actors create 'cascades' of effects in both the physical and psychological domain, through their actions. Networks of interaction between individual actors leading to effects correspond to the much more *self-organising* nature of conflict which we are attempting to understand. To explore some of these ideas we have thus developed a constructive simulation model which we call the 'Three-Block War Testbed'. General Krulak, US Marine Corps, coined the term 'Three-Block War' in discussing contingencies in which US Marines may be confronted by the entire spectrum of tactical challenges in the span of a few hours and within the space of three contiguous city blocks.

The Three-Block War Testbed represents a 'messy' peacekeeping operation with military, Non-Government Organisations (NGOs), insurgents and civilians all interacting. We analyse the effects that the insurgents create in terms of a cascade of interactions between the peacekeepers and insurgents. This work was carried out in conjunction with the University of Cranfield under a CASE award PhD by Frewer (2006).

The approach we have taken to this modelling is based on ideas drawn from complexity and natural synchronisation. In order to create a model of the correct scale, we have taken a number of ideas from the complexity based MANA model (see for example Lauren at al, 2007). MANA represents two different classes of actor (Red and Blue) and assumes a conflict interaction between them. We have thus had to generalise the approach of MANA in a number of ways to suit this new environment, and to create a model which reflects a larger number of classes of actor.

The key factors which our model takes into account are:

The location of other actors;
Civilians in need;
Services (Water and Electricity) which need to be fixed;
Peacekeepers, NGOs, Insurgents and Civilians, and their relationships.

4.1 THE INTENTS AND RELATIONSHIPS OF THE ACTORS

There are four different classes of actor in the simulation (Peacekeepers, Insurgent, NGOs and Civilians). They are not split down more finely. Peacekeepers are mainly external personnel who are there to keep the peace and protect civilians and NGOs. The NGOs represent the mainly external personnel who are there to help the local population. The Insurgents are members of the local population who may disagree with the military presence, and who have combat capacity. Each actor has a relationship to each of the other actor 'classes', defined as Friendly, Cooperative, Neutral, Uncooperative or Hostile. Currently these relationships remain constant throughout a run of the model (but could be made dynamic). All of the conflict in the model is assumed initiated by the Insurgents.

To reflect the 'natural synchronisation' aspect of Figure 1, although the actors have long term 'intents' as described above, all of their local movements are determined by what they perceive is happening around them and their relationships with other actors.

Movement in the model is represented in a similar way to that used in MANA. A utility function is defined for each of the cells the actor could move to, and the actor moves to the cell with the highest utility. The utility for a move to a given cell is based on a number of factors as listed below:

The perceived locations of other actors of the same and different types, and their relationships;
The number of civilians in need at the proposed cell location;
The need to fix water or electricity supplies at the proposed cell location;
Whether there is conflict at the proposed new cell location.

Informal networking in terms of the perceived locations and relationships with other actors influences the utilities of possible cells which the agent could move to, and thus influences the emergent behaviour of the model. This networking could be made more complex (with associated benefits and frictions) through local sharing of information and resources for example, and that is something we are currently investigating.

As the simulation progresses, the actors, although constrained by their overall intents (as described above), are highly interactive, as captured by the screenshots at Figures 5 and 6 of actor locations part way through one of the simulations. The different colours show the four different agent types (Peacekeepers are shown as Blue, Insurgents as Red, NGOs as Green and Civilians as White).

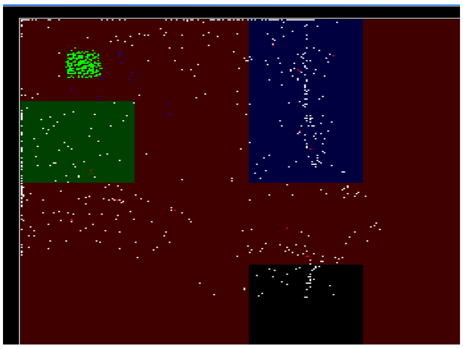

Figure 5: Example screenshot of the Three-Block War Testbed near the beginning of a simulation.

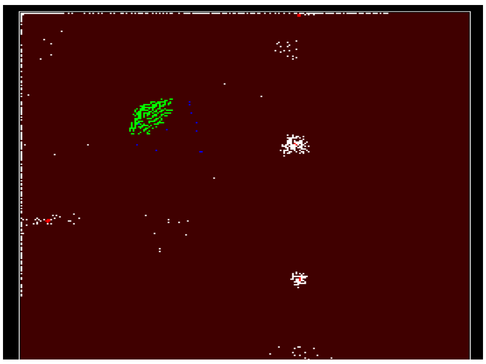

Figure 6: Further evolution of the Three-Block War Testbed.

4.2 SKIRMISHES

We define a 'skirmish' as a continuing series of interactions between peacekeepers and insurgents. A skirmish is started by the insurgents through a single interaction. This can result in anything from no response to an exchange of fire involving the whole set of peacekeepers. A skirmish continues until it peters out with no interaction from either side for at least one timestep. Two metrics are used; the number of interactions (the *size* of the skirmish), and the length of the skirmish in model timesteps (the *duration* of the skirmish).

A number of scenarios of increasing complexity have been modelled. In each case, the scenario is run 50 times, and the results pooled as a 'cloud'.

Figures 7 and 8 show the result for the most complex scenario modelled. This is plotted on a log-log scale to test the hypothesis that it approximates to a power –law distribution. (The reasons for expecting such power-law behaviour are discussed later). A power-law distribution would form a straight line on such a plot, and the best fit straight line is shown on each plot.

These results (and the others obtained from the model) indicate a wide spectrum of skirmish sizes and durations ranging from small to very long durations of interaction. However the evidence for power-law behaviour is still inconclusive.

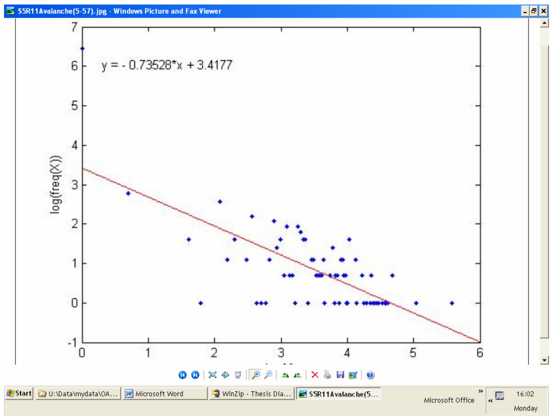

Figure 7: Statistics of distribution of size of skirmishes for the most complex scenario (log-log plot with straight line of best fit).

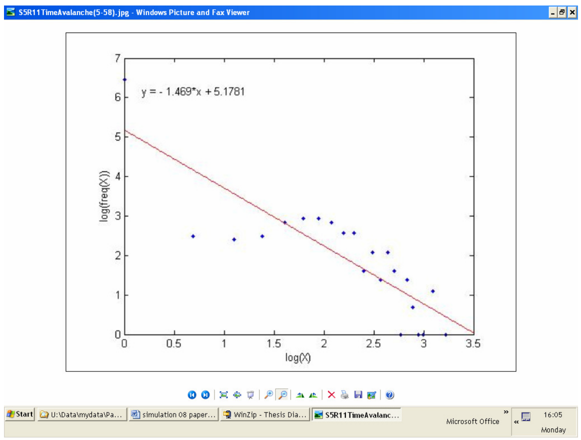

Figure 8: Statistics of distribution of duration of skirmishes for the most complex scenario (log-log plot with straight line of best fit).

5. THE RODGERS-D'HULST MECHANISM OF DYNAMIC CLUSTERING

Evidence from the modelling above is still tentative for power-law behaviour in terms of the size and duration of interactions (although there is good evidence of a large spectrum of skirmish sizes and durations). Academic studies of real world data appear to show this power-law effect strongly (Johnson et al, 2005, 2006), and explain it on the basis of the *Rodgers'D'Hulst mechanism*, which was originally developed to explain the behaviour of stock market traders (D'Hulst and Rodgers, 2000), who form transitory groupings to make trades, and then disaggregate dynamically in order to form further adaptive groupings. Working with Prof. Rodgers (Brunel University), we have taken this idea further, and investigated the self-organising behaviour of actors who have information rich tasks to perform, and who can share information in various ways to achieve those tasks. These actors also cluster and disaggregate dynamically using the Rodgers-D'Hulst mechanism. An example of the simulation of their emergent behaviour in terms of the resultant cluster size distribution is shown at Figure 9, exhibiting strong power-law behaviour. The red, green and blue colours represent increasing numbers of actors involved in the simulation, and the superimposed plots show power law behaviour as the limiting case. The index of the power law (2.5) is also consistent with the results of (Johnson et al, 2005, 2006).

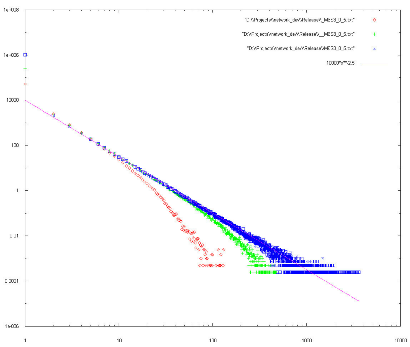

Figure 9: Emergent cluster size distribution

6. CONCLUSIONS

In this paper we describe the concept of *Agility*, as applied to our future defence force structures, Agility starts with the creation of informal adaptive networks across the organisation. We show that such 'Complex Adaptive Networks' can be classified and studied at a number of different levels. At the top level of this classification, we illustrate this with innovative and exploratory simulation modelling of 'actors' interacting in self-organising ways within a dynamic environment, and introduce the idea of the Rodgers-D'Hulst mechanism of dynamic clustering.

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A SURVEY OF SIMULATION TECHNIQUES IN COMMERCE AND DEFENCE

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ABSTRACT:
Despite the developments in Modelling and Simulation (M&S) tools and techniques over the past years, there has been a gap in the M&S research and practice in healthcare on developing a toolkit to assist the modellers and simulation practitioners with selecting an appropriate set of techniques. This study is a preliminary step towards this goal. This paper presents some results from a systematic literature survey on applications of M&S in the commerce and defence domains that could inspire some improvements in the healthcare. Interim results show that in the commercial sector Discrete-Event Simulation (DES) has been the most widely used technique with System Dynamics (SD) in second place. However in the defence sector, SD has gained relatively more attention. SD has been found quite useful for qualitative and soft factors analysis. From both the surveys it becomes clear that there is a growing trend towards using hybrid M&S approaches.

1 INTRODUCTION

Simulation and Modelling (M&S) has been applied to various sectors of life, ranging from management and business to defence and government, one can see a wide spectrum of successful M&S applications. However, addressing the management aspect of healthcare through simulation is an interesting challenge. A critical problem in the modelling and simulation of large systems, such as public organizations, is that changes to one part of the system would impact unexpectedly to other areas. For instance, traffic simulations in which any changes to one part of the system, e.g., the traffic light timing at one junction, would have potential effects on the traffic conditions within larger vicinity. Moreover, in order to convert best local practice into national policy, one must understand the impact that changes at one level of management will have on other levels. Clearly, there are tools that could be used at every level, but there is no systematic way of selecting the best tool, and crucially, there is no means of connecting up tools to understand the inter-relations between the different layers of the systems. The RIGHT project (Research into Global Healthcare Tools) [see www.right.org.uk for more details] aims at addressing such challenges by providing a framework toolkit, that would ultimately enable users to assess their scenarios and resources in accordance to the available (M&S) methods in order to select an appropriate method which would best suit their needs.

As an initial phase for this project, several literature surveys have been conducted to analyse an overlap or gap in the application of M&S techniques in various domains. This was to assess the applicability of the M&S techniques used in non-healthcare to the healthcare domain. Out of the several literature surveys conducted in various domains/sectors, two are discussed in this paper namely simulation and modelling in commerce and defence. This paper presents initial findings of a systematic literature search that aims to identify individual capabilities of different simulation techniques and tools used in these sectors. The research ultimately aims to identify simulation methods that may be implemented for healthcare improvements by discovering problem-oriented patterns of use from other mainstream application domains, such as business, manufacturing, and military (a useful discussion on this possibility can be found in (Young et al., 2004)). The hypothesis under investigation is that, despite the apparent complexity and uniqueness of healthcare and the inherent difficulties in making meaningful comparisons, sensible analogies can be made with various types of systems implemented in other domains such as commerce and defence.

2 LITERATURE REVIEW METHODOLOGY

An extensive, systematic literature survey of the use of modelling and simulation has been carried out, which consists of two stages as depicted in figure 1. The survey covers peer-reviewed general research as well as review articles, followed by analysis and classification through analogy.

This literature review covered publications on the applications of simulation in manufacturing, business, military and aerospace fields over the past seventeen years (1990-2007). The Scopus citation database (http://www.scopus.com) was searched to identify academic general research as well as review papers. Scopus is arguably the largest citation database and indexes approximately 15,000 peer-reviewed journals from more than 4000 publishers (Elsevier, 2007).

A visualization software tool called 'CiteSpace' (Chen, 2006) was applied for several purposes during our study, for instance to exclude some irrelevant set of articles that take a 'Physical Design' approach to the simulation application. Figure 2 illustrates one snapshot of the CiteSpace result that demonstrates a number of chunks of articles each of which using the same keywords. As a result, the literature will be visually organized based on the authors' keywords enabling us to distinguish between the relevant and irrelevant chunks of academic articles.

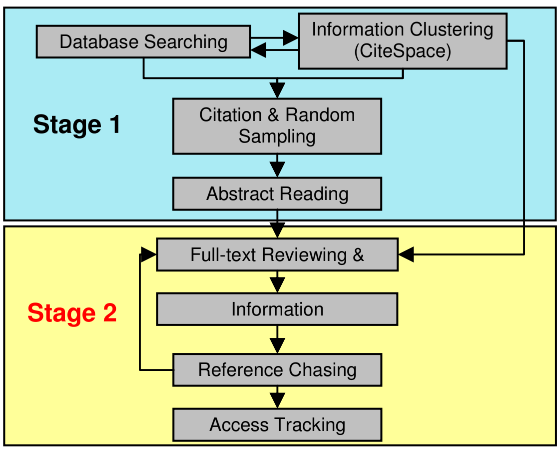

Figure 1: The systematic literature review framework

A sampling mechanism using the citation count as well as the random method narrowed down the search to the highly cited articles. Reading the abstracts was the next step of the process in order to sift the irrelevant articles using the reviewer's personal judgment.

The remaining subset of the papers was then subjected to full-text reviewing during which final screening and some analysis and classification of the articles were carried out. Information captured and extracted from full-text reviewing were fed into an information template form for further use and analysis. Reference chasing, which is claimed to be a very effective as well as efficient search mechanism (Greenhalgh and Peacock, 2007), was also done while reviewing the full-text, and the relevant references were added to the list of articles to be analysed. 'Access Tracking' is to tag the articles with the method they have been accessed, e.g., a) formal search, b) reference chasing, or c) personal contacts and knowledge. It was regarded as a means to measure the effectiveness of different access methods.

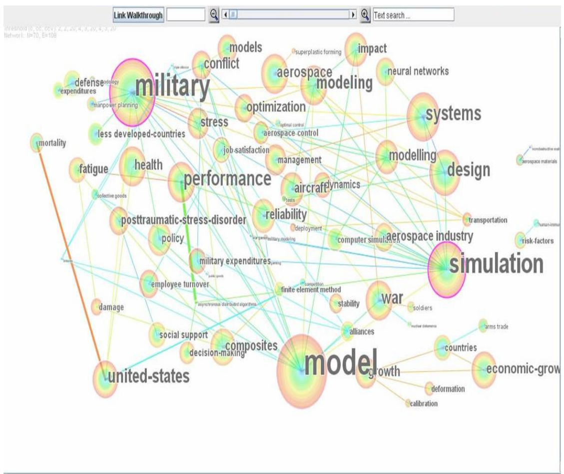

Figure 2: A snapshot of CiteSpace results for 'Simulation in Military and Aerospace'

3 MANUFACTURING AND BUSINESS

3.1. LITERATURE SURVEY METHOD

The search in this area was conducted with the Boolean keyword combination "(simulat* OR 'system dynamics') AND (manufacturing OR business)" and was further refined using the Scopus searching tools such as 'Limit to' as well as CiteSpace tool.

The sampling task using the citation count and random method returned around 1000 articles at the end of this stage. A similar process was carried out in parallel for the articles identified as 'survey papers' as well, and ended up with around 300 articles. The abstracts of all these 1300 papers were read and 398 abstracts were found suitable for inclusion in the literature review. The abstracts were read with the aim to extract three specific information attributes, namely, the simulation technique that was used, the industry sector where simulation was applied and the purpose of applying simulation. A detailed description of the literature review methodology can be found in (RIGHT, 2007). Table 1 shows a subset of this categorization, covering the simulation and modelling techniques, industry sectors and purposes of simulation that were identified to be important in this initial phase of literature review.

3.2. PRELIMINARY RESULTS

Based on impact and frequency of applications, a relatively small number of simulation techniques were identified as important, mainly comprising of mainstream simulation methods as well as emerging techniques and hybrid approaches:

Table 1: Simulation techniques applied in manufacturing and business

Technique	Industry sector	Purpose of application
Discrete-Event Simulation (DES)	Semi-conductor Manufacturing	Scheduling, Process Improvements, inventory management,
	Automobile	Buffer size optimization, Business process improvement*, inventory management
	Job Shops & FMS	Production Planning, Scheduling, Batch Sizing, Inventory Management
	Transportation	Truck dispatching
Continuous Simulation	Aluminium	Production and Inventory Management
	Software Development	Knowledge Management
	Semi-conductor Manufacturing	Supply Chain Management,, Industrial Development
	Generic Part Manufacturing	Strategy Development, Organizational Design, Production & Inventory Management, Innovation & Knowledge Creation, Supply Chain Management
	Pharmaceutical	Organizational Performance Improvement
	Consulting	Organizational Learning
	Automotive	Process Improvement, Industrial Development
	Electricity Generation	Asset Management Strategy
	Financial & Insurance	Performance Measurement
	Software Development	Project Management
	Information & communication	Strategy Development, Knowledge Management
Agent-Based Simulation (ABS)	Generic Part Manufacturing	Mass Customization, Supply Chain Management, Organizational Design, Process Improvement
Simulation Gaming	Financial & Insurance	Strategic Management, Capacity Adjustment
	Wholesale & Retail Trade	Supply Chain Management
	Education	Teaching Management courses
Hybrid Approaches (DES and SD)	Semi-conductor Manufacturing	Resource Allocation,
	Generic Part Manufacturing	Production Planning
Hybrid Approaches (Simulation and other Analytical Techniques)	Airline	Dynamic Resource Allocation
	Software Development	Multi-Project Management
	Generic Part Manufacturing	Resource Allocation, Logistics System Design, Assembly Line Balancing, Inventory Management, Supply Chain Management

The preliminary results of our survey show that the **Discrete-Event Simulation** (DES) has been applied in 45% of the articles reviewed and therefore it is considered as the most widely used technique in the manufacturing area mainly for testing different strategies for scheduling industrial machines (see Van Der Zee, 2007, Elleuch et al., 2007, Kumar and Rajotia, 2006, Gupta and Sivakumar, 2005, Barua et al., 2005 as the examples of the most recent articles), improving the business processes (see Rhee, 2004, Volkner, 2002), increasing the resource efficiency (see Masmoudi et al., 2006,), increasing the supply chain performance and decreasing the inventory costs (see Chan and Chan, 2006, Byrne and Heavey, 2006, Marseguerra and Podofillini, 2005), and enhancing the production plans (see Moon and Phatak, 2005). DES has also gained a good amount of attention from the transportation industry in domains such as efficiency improvement by balancing the schedule of dispatching trucks (see Feng and Wu, 2006, Shi et al., 2005).

Continuous Simulation is used for production and inventory management in aluminium industry, and also to study knowledge flow in a visualized network and to develop strategies for adapting networks to changing conditions in software development industry (see Zhuge, 2006, Arer and Ozdemirel, 1999).

System Dynamics (SD) has been the second most widely simulation technique being applied in the manufacturing and business fields, based on our survey that assigns 21% popularity rate to the SD. Its use has mainly centred around policy and strategy development (see Davis et al., 2007, Wenzler, 2005, Jan and Chen, 2005, Yim et al., 2004), although there have been other applications in such domains as Supply Chain Management (SCM) (see Fiala, 2005, Georgiadis and Vlachos, 2004, Anderson et al., 2000), organizational design (see Schwaninger et al., 2006), knowledge management and organizational learning (see Galanakis, 2006, Eskinasi and Fokkema, 2006, Yim et al., 2004), process improvements (see Chatha and Weston, 2005), as well as project management (see Eden et al., 2005, Alexandre and Rodrigues, 2005, Lee and Miller, 2004). A wide range of industries have adopted SD, including semi-conductor manufacturing, Automotive, Pharmaceuticals, Utility companies, as well as some service industries such as Insurance, Consulting, Software Development, and Telecommunications. It's clear from the literature that SD has been found quite useful for qualitative and soft factors analysis.

In this pilot literature survey of simulation methods in manufacturing and business, it has been found that **Agent-Based Simulation (ABS**) has been applied in the generic part manufacturing industry to develop some agent-based concepts and models such as the concept of 'Smart Product' in a mass-customized manufacturing environment where different types of products need to compete for the limited resources (Simao et al., 2006). Another concept is the 'autonomous agents embedded with a trust mechanism' which models and assesses trustworthiness of the partners in a supply-chain (Lin et al., 2005). ABS is also appropriate for organizational design and behavioural modelling in the organizations (see Hill et al., 2005, Rivkin and Siggelkow, 2003).

Simulation Gaming is another technique that is receiving an increasing amount of attention particularly from the education industry and has been applied for such areas as management training (see Arunachalam and Sadeh 2005) and strategy development (see Hoogeweegen et al., 2006). Simulation gaming has also shown its practical use where there are some pre-developed simulation games for specific industries such as insurance, financial services, or supply chains.

There is a growing trend towards the development of **Hybrid Simulation** techniques whether by bringing together various simulation techniques (e.g. DES and SD) or by combining simulation with other approaches (e.g. Expert Systems, meta-heuristics, or other analytical techniques). We put an emphasis on the DES/SD hybrid approach based on the complementary potential they could have, aiming to address the healthcare systems. However, the literature exhibits few cases of such combination meaning the concept is still in its infancy. The existing research has focused on the concept of 'Enterprise Modelling & Simulation' where the impact of production decisions, evaluated using discrete-event-simulation (DES) models, will be investigated on enterprise-level performance measures. The SD simulation captures long-term effects of these decisions, in overall terms that are appropriate for higher management levels, while DES provides detailed analyses of the shorter-term decisions and actions (Rabelo et al., 2005). Another example of such integration can be seen in the form of a hierarchical production planning architecture consisting of system dynamics (SD) components for the enterprise level planning, and discrete event simulation (DES) components for the shop-level scheduling (Venkateswaran, et al. 2004). We believe this line of research will hold promise during the next decade.

The combination of simulation and other analytical approaches seems more widespread throughout the literature. Such techniques as Inventory Control Models, Meta-heuristics, Critical Path Method (CPM), Expert Systems, and Artificial Neural

Networks (ANN) have been used in conjunction with simulation mainly to address the optimality.

4 MILITARY AND AEROSPACE

4.1. LITERATURE SURVEY METHOD

In order to conduct literature search in the area of aerospace and military, the Boolean keyword combination of "(simulat* OR 'system dynamics') AND (aerospace OR military)" was used. The search results were further refined using the Scopus searching tools such as 'Limit to' as well as the 'CiteSpace'. In literature search for military and aerospace, CiteSpace was used for a purpose similar to that mentioned in section 3. As mentioned earlier, Figure 2 illustrates one snapshot of the results from CiteSpace that shows cluster of rings joined together representing the keywords, the frequency of their occurrence and their respective links to other keywords. Consequently, this visualization helps us to distinguish between the relevant and irrelevant chunks of academic articles based on the authors' keywords.

The search process for military and aerospace returned around 900 (approx.) articles. As number of the resulted articles did not exceed 1000, therefore no further systematic filtering was employed. The abstracts of all these 900 papers (approx.) were read and out of these, 300 abstracts were found suitable to be passed on to the next stage of full-text reading of literature review. Similar to the case of manufacturing and business, these abstracts were read with an aim to extract three specific pieces of information (attributes) namely, the simulation technique used, the industry sector where simulation was applied and the purpose of applying simulation. Table 2 shows a subset of this categorization, covering the simulation and modelling techniques, industry sectors and purposes of simulation that were identified to be important in this initial phase of literature review.

4.2. PRELIMINARY RESULTS

Based on the real-world problems with stakeholders' engagements only a few direct implementations of simulation techniques were found as significant, mainly comprising of the contemporary simulation methods as well as emerging techniques and hybrid approaches:

Table 2: Simulation techniques applied for various purposes in aerospace and military

Technique	Industry sector	Purpose of application
System Dynamics (SD)	Military	Weapon System Development, Non-real and Real-time Dynamic Simulations, rapid assessment of the outcome of major Land and/or Air conflicts, train leaders to make effective decisions in turbulent environments
	Aerospace /Aviation	Free Flight Simulations, Human-in-the-Loop simulation experiments
Discrete-Event Simulation (DES)	Military	Improving border control and security system, providing insights into the geomatics division workflow process and to estimate the system performance measures, estimating availability of the weapon systems
Advanced Distributed Simulation (ADS)	Military	Simulation Based Training (SBT), Semi-automated Forces (SAFs), defense training applications such as training commanders in a given battlefield scenario
Agent-Based Simulation (ABS) or Agent Directed Simulation (ADS)	Aerospace / Aviation	Examining pilot retention issues
	Military	Management of military missions that utilize intelligent munitions, solving dynamic teaming and task allocation problems
War Gaming (WG)	Military	Virtuous War, Designing Military Simulations to depict an actual or assumed real life situation, Combat Planning
Real-time Simulation (RT)	Military	Behavior modelling and representation of military objects to sense, reason and act in virtual environments
	Aerospace / Aviation	Free Flight Simulations, Human-in-the-Loop simulation experiments
Stochastic Petri Nets	Military	Policy distribution and network provisioning to maintain a logically centralized control of the network as a whole, while allowing a physically decentralized and self-managing implementation
Hybrid Approach (RT and SD)	Aerospace / Aviation	Support for the development, verification and operation of the space station robotic systems, Free Flight Simulations, Human-in-the-Loop simulation experiments
Hybrid Approach (SD and War Gaming)	Military	Land and/or Air modelling for future warfare, Combat Planning
Hybrid Approach (RT and War Gaming)	Military	Free Flight Simulations, Human-in-the-Loop simulation experiments

System Dynamics (SD) has been applied in both areas of defense (military and aerospace). However, this technique is most widely used in the military domain as compared to that of the aerospace and aviation. It has been used mainly for rapid assessment of the outcome of major land and/or air conflicts (Moffat, 1996), train leaders to make effective decisions in turbulent environments (Hunsaker, 2007), weapon system development (Jan and Jan, 2000). SD has also been used in the non-real and real-time dynamic simulations. In aerospace and aviation, SD has been used for free flight simulations and human-in-the-loop simulation experiments.

Discrete-Event Simulation (DES) has been used in military for improving border control and security system (Celik and Sabuncuoglu, 2007), for providing insights into the geomatics division workflow process and to estimate the system performance measures (Ghanmi, 2006). DES has also been used for estimating the availability of weapon systems to the military and for modelling the progress of a complex design project (Cho and Eppinger, 2005).

Advanced Distributed Simulation (ADS) is one of the simulation techniques applied quite frequently in military simulation such as for Simulation Based Training (SBT), Semi-automated Forces (SAFs), defense training applications such as training commanders in a given battlefield scenario, etc. (Wilcox et al., 2000).

Agent-Based Simulation or Agent Directed Simulation (ADS) has been used in aerospace/aviation for the examining pilot retention issues. In military it has been used for the management of military missions that utilize intelligent munitions, multi-agent simulations are carried out for solving dynamic teaming and task allocation problems (Altenburg et al., 2002). Agent-based simulation has not been applied heavily in any of the aerospace or military domains.

War Gaming is one of the most popular techniques used in the military domain for conducting / organizing virtuous wars, designing military simulations to depict an actual or assumed real life situation and for combat planning (Power, 2007).

Real-time Simulation has been applied in the military for behavior modelling and representation of military objects to sense, reason and act in virtual environments (Shen and Zhou, 2006). Also in the aerospace / aviation domain it has been used for conducting free flight and human-in-the-loop simulation experiments (Ruigrok and Hoekstra, 2007).

Stochastic Petri Nets have been rarely used in the military. They have been used for limited operations such as for policy distribution and network provisioning to maintain a logically centralized control of the network as a whole, while allowing a physically decentralized and self-managing implementation (Phanse et al., 2006).

There has been an interesting trend in terms of merging two or more simulation techniques to carry integrated or hybrid simulations. Both in aerospace and military, the hybrid simulation approaches have been successfully deployed to carryout customized simulations. Few of those are further listed:

RT & SD Hybrid Approach (Real-time Simulation and System Dynamics) have been applied in the aerospace / aviation industry for supporting the development, verification and operation of the space station robotic systems. The hybrid of real-time simulation and SD has also been applied to free flight simulations and human-in-the-loop simulation experiments (MacLean and Carr, 1997).

SD & WG Hybrid Approach (System Dynamics and War Gaming) has been a popular integration. It is a relatively new approach for land and/or air modelling for future warfare and also for combat planning based on the use of System Dynamics and War gaming. These techniques have been often used in conjunction implicitly (Moffat, 1996), (Hunsaker, 2007), but not explicitly mentioned.

RT & WG Hybrid Approach (Real-time Simulation and War Gaming) has been another popular merger. These have been used in the military for free flight and human-in-the-loop simulation experiments. Similar to the SD & WG hybrid approach these two techniques are also quite often used in a hybrid manner (Power, 2007), but not mentioned explicitly.

5 CONCLUSIONS

Addressing the management aspect of healthcare through simulation is an interesting challenge. A critical problem in the M&S of large systems, such as public organizations, is that changes to one part of the system would impact unexpectedly to other areas. Despite a relatively rich set of computer simulation tools and techniques developed over the past 60-70 years, there is currently a lag in the modelling and simulation research and practice in healthcare on developing a toolkit to assist the modellers and simulation practitioners with selecting the appropriate set of techniques. We also believe that the applications of M&S in other areas such as in commercial and defence sectors make inspirations for improvements in the healthcare domain.

The first survey of simulation and modelling in the areas of business and manufacturing showed that the Discrete-Event Simulation (DES) has been the most widely used technique with System Dynamics (SD) in the second place. It's clear from the literature that SD has been found quite useful for qualitative and soft factors analysis. The preliminary survey in this domain also exhibits some evidence to prove that there is a growing trend towards using and development of SD, Agent-Based Simulation (ABS), Simulation Gaming, and Hybrid Simulation techniques.

The second survey in the area of military and aerospace showed that System Dynamics (SD) has been one of the most widely used technique. It has been applied in both areas of military & aerospace. However, the evidence of SD being used in aerospace is relatively lesser than that of its applicability in the military domain. In aerospace it has been used for free flight and human-in-the-loop simulation experiments, etc. Whereas, in military it has been used for a variety of purposes such as military trainings of soldiers, war design, development of weapon system, predicting outcomes of war, train leaders to make effective decisions in turbulent environments, etc. Also other techniques such as Discrete Event Simulation (DES), Advanced Distributed Simulation (ADS), Agent-Based Simulation (ABS), War Gaming (WG), Real-time Simulation (RT) and Petri Nets have been applied in the defence sector. However, the interesting trend that emerged through this survey was the implementation of these techniques in combination with each other, i.e. the Hybrid approaches. It has been seen that SD has been used both with RT and WG. Moreover, Real-Time simulation (RT) technique has been used in conjunction to the War Gaming (WG) technique for several purposes.

From both the surveys in different areas it has been seen that there is a potential and growing trend towards using hybrid approaches as compared to the application of stand-alone (M&S) techniques. Final results from these surveys are expected to hold a promise to setup a milestone for future research into the applicability of these techniques into healthcare domain that would ultimately facilitate the formulation of the framework toolkit.

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MODELLING THE MILITARY OPERATIONAL FUTURE

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ABSTRACT:
The UK military force structure comprises many force elements which each offer one or more capabilities. The force structure is not static, and there is a need to plan ahead and to compare anticipated future capability with potential future operational demands.
A model has been developed to generate multiple versions of a possible 20-year future operational picture, based on probabilities drawn from historical operational data. Rules are applied to prevent unrealistic sets of concurrent operations occurring. These rules may be based on defence policy or on the practical limitations of the force structure. In each timestep decisions are taken regarding the initiation of new operations and the continuation of ongoing operations.
The output is used in subsequent modelling to generate a consolidated estimate of future activity. Force elements in shortfall or surplus can be identified and recommendations are made that will help shape the force structure of the future.

Keywords: Defence, Force Structure, Concurrency

1. INTRODUCTION

"***Our work to date has been conducted against a changing strategic and operational backdrop…but there are no doubt more twists and turns to come to which we must be ready to respond***"
Rt Hon Geoff Hoon, Secretary of State for Defence, July 2002

The Armed Forces are made up of the three services, and each can be subdivided into force elements: the lowest deployable element of a capability. For the Royal Air Force and Royal Navy these elements are usually individual hulls (carrier, frigate, tanker, submarine) or airframes (fighter plane, attack helicopter, transport aircraft), with an Army force element being a single sub-unit (infantry company, tank squadron). Each force element provides one or more required capabilities. The force structure is the collective name for all of the force elements in the Armed Forces.

The force structure is not static however. Force elements may enter and leave service creating potential capability gaps, and budgetary considerations mean that certain force elements may be cut. New equipments, whether intended to replace existing equipments or provide an entirely new capability, can take years to come into service, so planning cannot simply be reactive. There is a need to plan ahead and to consider what capabilities will be necessary to meet potential military commitments in the future.

In order to do this, some idea of what the operational 'future history', the number and nature of operations in the future, will look like is required.

2. METHODOLOGY

It is assumed that the occurrence of current and past operations will have a bearing on the probability of operations occurring in the future. This assumption relies on the strategic environment remaining broadly constant in the next 20 years, with no 'strategic shocks'. If this is the case, then the question becomes one of timescale: how far back do we need to go? Current commitments could be considered stretching, and it is tempting to judge any future force structure amendments against this and simply maintain our current capabilities. However, a more balanced view can be obtained by considering the numbers and types of operations that have occurred in the recent past.

The current 'operational climate' has been in evidence as far back as 1991, before which activity levels and patterns were significantly different to those of the more recent past, due to the end of the Cold War and the shift to expeditionary operations as a "force for good in the world". This means that there are 16 years of operational data from which probabilities can be extracted. If a large number of different versions of the future operational picture are produced using probabilities drawn from historical data, the mean historical activity level should lie at the centre of the distribution (as illustrated in Figure 1). Any activity below this level is clearly possible, and a certain amount of activity above the historical level will also be possible, as the

force structure has not been consistently stretched to its maximum extent in the last 16 years.
However there will be a level of activity above which the force structure cannot meet its commitments, and this is the risk any proposed force structure must accept.

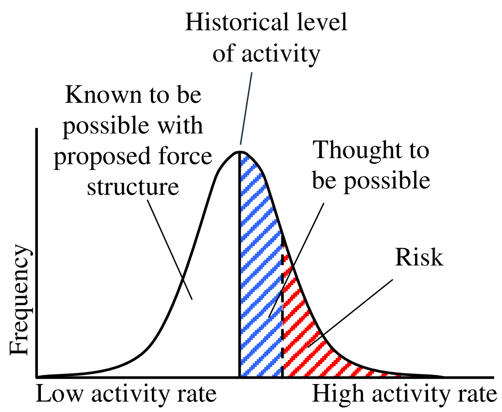

Figure 1: Distribution of activity rates

In order to quantify this risk, simulation of a future event stream can be employed using empirical data on the frequency of historical operations as input (Robinson 2004, Chapter 7). It is necessary to generate a large number of these streams to achieve the required granularity. For this purpose the model DIDO (Demand in Deployed Operations) was developed.

3. INPUT DATA

3.1 HISTORICAL DATA

Each military operation can be classified by scale (minor, small, medium or large) and type. Operational type depends on the task military assets are deployed to conduct, for example peace-keeping or evacuation of civilians. There were 16 major UK military operations between 1991 and 2006, including deployments to Iraq, Bosnia, Kosovo, Sierra Leone and Afghanistan. There were also many minor operations not included for reasons of short duration or because very few force elements were deployed (e.g. the evacuation of British citizens from Lebanon).

The Ministry of Defence has developed a series of scenarios which are intended to be illustrative examples of the types of operation that the UK may wish to conduct in the future. By linking these scenarios with probabilities drawn from historical operational activity a future operational picture can be generated. Each scenario has an associated campaign plan which may be developed into a list of required activities. By assigning force elements to these activities, the overall requirement for each force element may be calculated.

3.2 MIGRATION OF OPERATIONS

An operation initiates at a given scale and type, for example a medium-scale peace-keeping operation. An operation may also be considered either 'enduring' or 'non-enduring', which relates to whether or not the activity endures beyond an initial deployment, with non-enduring operations therefore having a fixed length and enduring operations likely to continue for some time.

Whatever its duration, an operation is unlikely to simply stop after its initial duration. Most operations will change type or 'draw down' to a smaller scale during their lifetime, and the typical migration pattern of each type/scale combination has been mapped out in a series of flow diagrams, an example of which is shown in Figure 2. In this example, a medium-scale peace-keeping operation has a 60% chance of enduring unchanged in each timestep, a 30% chance of changing type (to a peace enforcement operation) or scale (to a small-scale operation), and a 10% chance of stopping altogether.

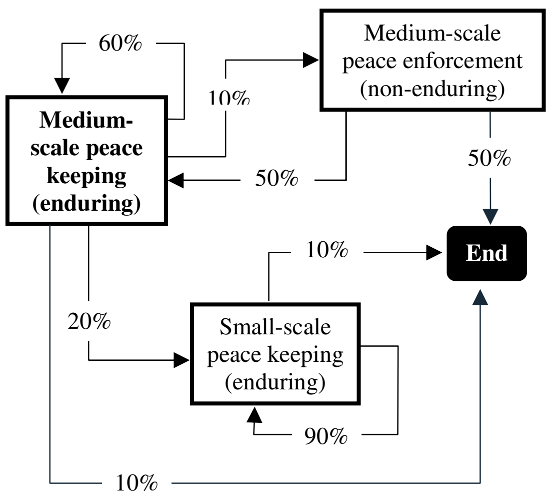

Figure 2: Illustrative flow diagram of operational migration

3.3 CONCURRENCY RULES

Rules must be imposed on the model's decision-making process to prevent unrealistic sets of concurrent operations occurring. The definition of an 'unrealistic' concurrency set depends on the point of view, and for this reason the model can be run in one of two modes. Undertaking a large number of operations at the same time may be technically possible in terms of the force elements available but undesirable due to disruption to such activities as post-operational leave and training. To capture this, defence policy identifies certain combinations of operations which are acceptable as a basis for planning. Despite this policy, the force structure is occasionally stretched beyond these limits in order to meet politically important commitments. To represent this, two different sets of 'rules' have been developed for the model. One set is said to be 'policy constrained' and the other to be 'force structure constrained'.

3.4 STANDING COMMITMENTS

Those military operational activities which are both long-term and low-level in terms of force elements deployed are deemed to be standing commitments, examples of which include the UK presence in Cyprus and the Falkland Islands, and the defence of UK waters and airspace. At any one time a significant proportion of the force structure is engaged in activity relating to standing commitments which, together with activities such as training and maintenance, remove force elements from the pool available to deploy on operational commitments.

4. MODELLING PROCESSES

The model generates a large number of versions of an operational picture spanning 20 years. The principle reason a time-slicing approach was chosen over discrete event simulation is due to the requirement for the model output to provide a time-based event list in order to feed subsequent modelling. A further factor was the interdependent nature of operations: an operation with a pre-determined duration may, for example, end earlier than expected depending on the concurrency conditions. Although there is a trade-off in the efficiency of the time-slicing approach (Robinson 2004, Chapter 2), due to the high frequency of events being modelled the proportion of redundant timesteps is limited to 16%.

The duration of each timestep has been set at 30 days, this being the standard unit of consideration for military deployments, and within each timestep a number of decisions are made. The initiation of a new operation is determined by the probabilities drawn from historical data, and by the application of the concurrency rules. Once an operation has begun, its duration and migration are controlled by the probabilities within the relevant flow diagram.

5. OUTPUT

A large amount of information can be drawn from the spread of possible future operational pictures output by the model, such as the mean and distribution of activity levels, the frequency of operations, the duration of operations and the number of operations 'missed' due to the concurrency rules. Further post-processing can produce analysis of the time spent in each of the various concurrency states, for example the length of time spent with no commitments at all, or the amount of time spent above and below the activity levels specified in defence policy.

6. CONCLUSIONS

The distribution of activity levels is not necessarily symmetrical around the historical level, as the concurrency rules will selectively disallow activity at the top end of the scale. The position of the cut-off point shown in Figure 3 will depend on the rule set used.

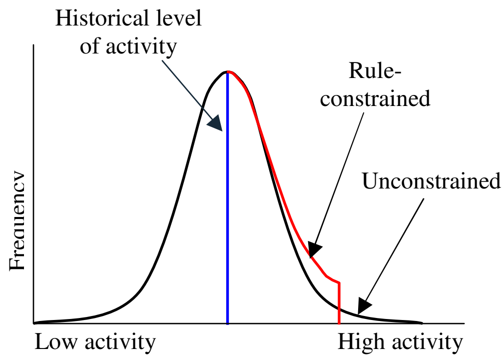

Figure 3: Distribution of rule-constrained activity levels

Given the uncertainty involved in this analysis, the future force structure must be optimised to enable it to meet as many of its potential future operational commitments as possible. This output is taken on into subsequent modelling where the requirement generated by this operational future is compared with the force structure, and force elements in surplus and in shortfall are identified. The costs to develop, acquire, maintain and dispose of equipments and capabilities are introduced to allow optimisation over cost and capability. In this way the force structure of the future is shaped.

REFERENCES

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AUTHOR BIOGRAPHY

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