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.

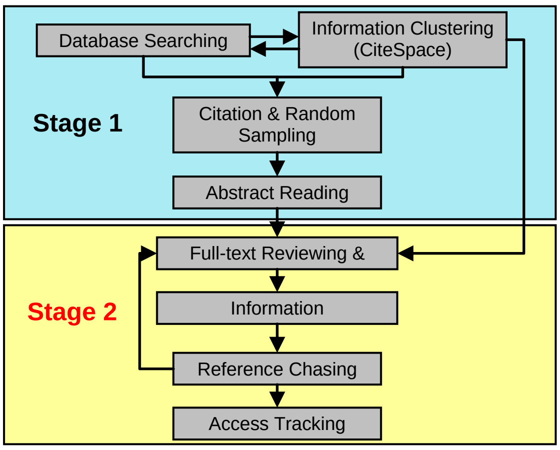

Figure 1: The systematic literature review framework

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.

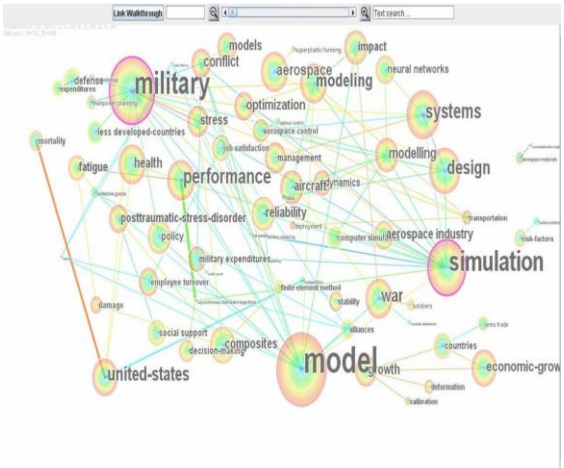

Figure 2: A snapshot of CiteSpace results for ‘Simulation in Military and Aerospace’

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
System Dynamics (SD)	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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