POTENTIAL APPLICATIONS OF SIMULATION MODELLING TECHNIQUES IN HEALTHCARE: LESSONS LEARNED FROM AEROSPACE & MILITARY

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Abstract

The Aerospace and Military areas are to do with complex missions and situations. Modelling and Simulation (M&S) has been applied in many areas of defence ranging from space sciences, satellite engineering to multi-warfare (air warfare, undersea warfare), air & missile defence, acquisition, tactical military trainings & exercises, national security analysis and strategic decision making & planning, etc. The application of simulation modelling techniques in healthcare would improve the provision of healthcare services; however, their application has been much relatively feeble in the healthcare sector as compared to the defence sector. This paper presents results from a systematic literature survey on applications of modelling simulation techniques in the Aerospace & Military. The knowledge gained or lessons learned from the survey were finally used to analyze the potential applications of the simulation modelling techniques to the healthcare sector. Results show that in the defence sector, Distributed Simulation has now become a widely adopted technique. However, System Dynamics (SD) and Discrete Event Simulation (DSE) have also gained relative attention. From this survey it becomes clear that various simulation modelling techniques are useful for specific purposes and have potential applications in the healthcare sector.

Keywords: Aerospace, Military, Simulation, Modelling, Healthcare, Survey.

1 INTRODUCTION

Modelling and Simulation has around 60 years of history of applications in various fields/sectors of life. It is the 2nd most widely used technique in operations and process management (Eldabi et al., 2008). Although Modelling and Simulation (M&S) has been defined many times, it generally refers to imitating an object or process and its working in an environment, i.e. manipulating with real data and actual events in an environment that is not real (it is simulated) but imitates (represents) the real world. The main purpose of applying simulation technology is to analyze and evaluate the 'what-if scenarios', this means to predict the outcome or after-effects of a change in a process or any input parameter to the system under study by setting-up a simulated environment. This helps in reducing costs and unnecessary human efforts if experienced in reality. For example, simulator operating costs are one-tenth to one-third the cost of operating the actual weapons system (Gordon, 2001). The potential benefits of applying simulation modelling techniques in terms of reducing costs are found in both the physical and logical models. Moreover, there are benefits of utilizing M&S in making production decisions (Componation, 2003).

This study has been carried out as part of the RIGHT project (RIGHT, 2008). RIGHT (Research into Global Healthcare Tools) aims at addressing challenges to the adequate provision of healthcare by providing a framework toolkit that would facilitate the users to assess their scenarios, resources and problems in accordance to the available simulation modelling methods, thus selecting an appropriate method that best suit their needs.

Gordon states that: “M&S is proving to be a valuable training tool in many other fields, including medicine. New systems with interactive ‘dummies’ train soldiers and physicians to treat wounds on the battlefield and conduct patient care in hospitals. New virtual reality systems allow trainee surgeons to feel and see their knife-work. They can see high-resolution three-dimensional images of the human body and feel the pressure of the instrument as it ’cuts‘ through tissue” (Gordon, 2001).

As an initial phase for the RIGHT project, several literature surveys were conducted in order to analyse an overlap or gap in the applications of simulation modelling techniques in various domains such as business, industry, aerospace, military and healthcare, etc. This was to assess the applications of the simulation modelling techniques in both the non-healthcare and healthcare sectors. Out of the many literature surveys conducted in various domains/sectors, one is discussed in this paper namely Simulation and Modelling in Aerospace & Military. As massive literature was found on simulation modelling in defense, therefore in order to conduct this survey feasibly a systematic literature review methodology was devised, which is later described in this paper. This paper not only discusses lessons learned from the survey but also assess the potential applications of these lessons to the healthcare sector.

This review would be of interest to various communities including the defence communities, simulation modelling communities and other communities who wish to learn from the transferrable knowledge relevant to business and process environments such as healthcare and other industries, etc. The motivation of this study (survey) was to discover if the valuable knowledge and lessons learned, from the applications of simulation modelling techniques, within Aerospace & Military **(Defense)** are transferable to the **Healthcare** sector.

This paper has four sections. Section 1 is introduction, Section 2 briefly describes the literature review methodology (and its stages) adopted for this survey. Section 3 talks about the results of this survey, the lessons learned from aerospace & military and their potential applications to the healthcare sector. Finally, Section 4 draws conclusions of this paper.

2 THE LITERATURE REVIEW METHODOLOGY

An extensive, systematic literature survey for the applications of simulation modelling in aerospace & military was conducted (Eldabi et al., 2008). As mentioned earlier, massive literature was found about simulation modelling in defense, therefore, it was necessary to devise a systematic literature review methodology in order to reduce or minimize the result set (by filtration) and to make the survey feasible. The methodology consisted of two stages (Stage-I and Stage-II). Each of these stages is divided into further steps. Figure 1 depicts a consolidated version of this methodology. Stage-I constitutes of two main steps namely, database searching and abstract reading. Similarly, Stage-II constitutes of two main steps namely, full-text reading and filling the RIGHT information template (RIT).

The survey considered not only general research articles but also other literature survey articles already published in this area/field. Publications about the use of simulation modelling techniques in aerospace & military over the past seventeen years (1990-2007) were covered.

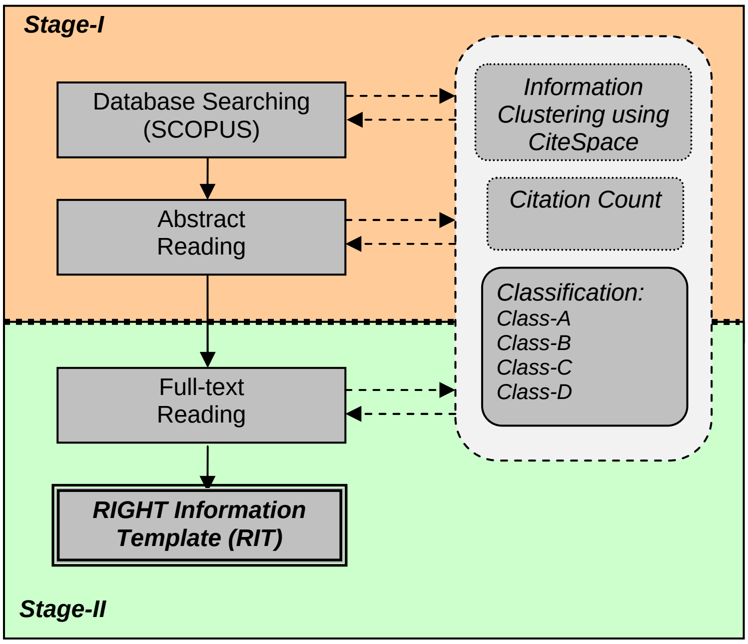

Figure 1. Consolidated Literature Review Methodology for Simulation Modelling in Aerospace & Military

The database used for searching was SCOPUS and the search results were further refined by using the Scopus searching tools such as 'Limit to', etc. Moreover, a visualization software tool called 'CiteSpace'(Chen, 2006) was used that helped to distinguish between the relevant and irrelevant chunks of academic articles based on the authors' keywords, thus minimizing the result set size by filtration. Moreover, Citation Count was also used for this purpose. The most cited articles were definitely included in the results.

The search process for military and aerospace returned around 900 (approx.) articles. Then the abstracts of all these 900 papers (approx.) were read with an aim to extract three specific pieces of information (attributes) namely, the applied simulation technique or method, the industry sector such as aerospace or military where simulation was applied and the problem area or purpose of applying simulation (application domain). Out of these, 300 papers were found suitable to be passed on to the next stage of full-text reading. This was based on the classification of articles. The articles were classified as follows:

- ***Class – A:*** articles addressing a real-world problem with stakeholder's engagement
- ***Class – B:*** articles addressing a real-world problem without stakeholder's engagement
- ***Class – C:*** articles not addressing any real-world problem, just suggested ideas or tips
- ***Class – D:*** articles addressing physical design problems

All Class-A papers were selected. Figure 2 illustrates this classification of articles.

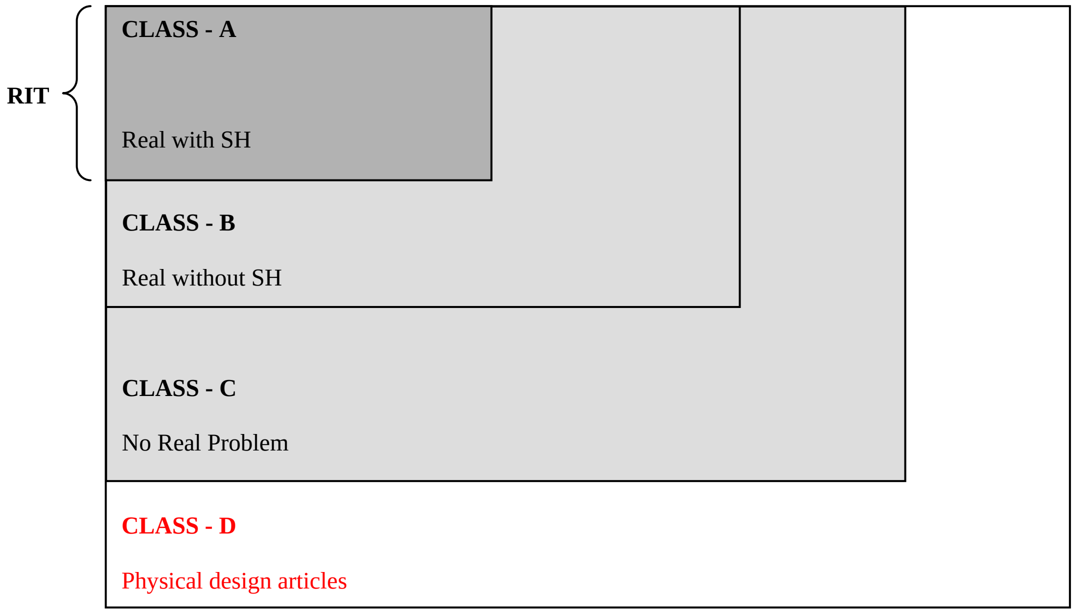

Figure 2: Classification of Articles

Based on the above classifications, the information collected was filled into the RIT (RIGHT Information Template) Figure 3. This template has many fields that are categorized based on the dimensions and attribute value they would contain. As seen in Figure 3, few of the dimensions are not applicable (N/A) for the Aerospace and Military domain. The third category in the RIT named as Method Details shows the *classification of articles* as the *level of implementation* with three attributes. These three attributes namely Real with SH, Real without SH and Not Real refer to Class-A, Class-B and Class-C respectively. This RIT was filled for each of the paper selected finally after the full-text reading and was used for further analysis.

RIGHT Research Into Global Healthcare Tools

RIGHT Information Template (RIT Version 1.2)

(to be filled for full paper reading)

These dimensions are neither fixed nor complete. These could be changed or adapted as reviewers proceed to read full papers. Any changes and adaptations are recommended to be shared with other reviewers as early as possible.

All the dimensions are optional in a sense that reviewers can fill out dimensions only when information is provided by papers/articles. Blank dimensions will be considered that no relevant information is found in papers/articles.

Categories	No	Dimensions	Attributes	Comments
Deliverables	1	Deliverables	D1.3/ D1.4/ D1.5/ D1.6/ D1.7	To be copied and pasted from the original file. No need to re-type.
Paper/ Article details		Article Code	One digit for deliverable, one digit for article type(review, general or grey), 3 digits for serial number	
	2	Paper/Article reference		To be copied and pasted from the original file. No need to re-type.
	3	Source	Journals/ Grey literature	To be copied and pasted from the original file. No need to re-type.
Method details	4	Method(s)/Methodology(ies)		Name of the Simulation method used
	5	Method initiator (project initiator) (N/A for D1.4)	Academia/ Consulting firms/ Authorities/ Hospitals/ Hybrid (specify) [for healthcare] Academia/ Consulting firms/ Authorities/ beneficiaries/ Hybrid (specify) [for non-healthcare]	Authorities: government (national, local), regulators, policy makers, government agencies Hospitals: Trusts, private hospitals
	6	Level of implementation	☐ Real with SH ☐ Real without SH ☐ Not Real	Real with SH: a real-world problem with stakeholder engagement Real without SH: a real-world problem without stakeholder engagement Not real: Not a real-world problem, just suggested ideas or tips
Problem details	7	Industries [only for non-healthcare]	Aircraft/ Aerospace/ Military/ Food/ Pharmaceutical/ Software, etc.	The Harvard industry categorization as a baseline (http://hbswk.hbs.edu/industries)
	8	Problem(s) and/or Purpose(s) of using the method(s)		The definition of the problem and how the method(s) help to solve it
	9	Problem layers (N/A for D1.4)	Policy & Regulation/ Facilitation & Commissioning/ Operation [for healthcare] Strategy/ Managerial/ Operational [for non-healthcare]	
Review Papers Details		How many studies/models?		
		Publication year range		
		Comparison/Analysis methodology?	Yes/No. If yes, explain.	
Others	10	Author's conclusions		Including future works, excluding strengths and weaknesses
	11	Reviewer's comments (optional at this stage)		e.g. proposed applications for healthcare ()
	12	Funding source for studies (N/A for D1.4)		e.g. primary and secondary source

Note: The RIT is fully customizable according to the particular deliverable requirements (D1.1 - D1.7)

RIT (V1.2)
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Figure 3. RIGHT Information Template (RIT)

3 LESSORNS LEARNED FROM AEROSPACE & MILITARY SURVEY

This section is divided into three sub-sections. It first briefly describes the lessons learnt from the survey of Simulation Modelling in Aerospace & Military and then discusses the potential applications of these simulation techniques to the healthcare domain/sector. Results from the survey suggest that knowledge gained from the Defence industry has many potential applications to the Healthcare industry.

3.1 Defence Application Areas where Simulation Modelling is applied

As a result of the survey conducted, it has been seen that there are many application areas in defence (aerospace & military) where simulation techniques have been successfully applied. Figure 4 shows a distribution of the use of simulation modelling techniques in the defence application areas/domains.

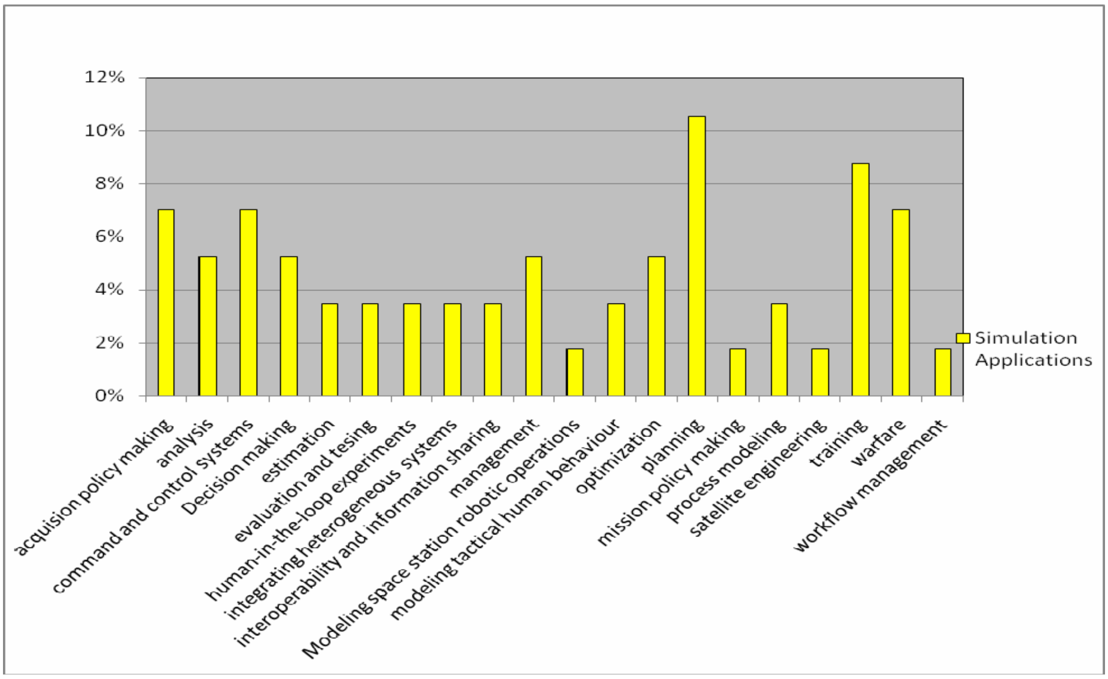

Figure 4. Application Domains in Defence

It can be clearly seen from the chart in Figure 4 that simulation techniques have been heavily applied for Planning in the Aerospace and Military. This kind of planning could include combat planning, strategic planning, network planning, operations planning, trajectory planning, mission planning, and distributed production planning, etc. The second application area where simulation techniques are popular is Training. It includes SBTs (Simulation-Based Trainings), tactical military trainings & exercises, defence training applications, live training, team training, mission training, and mission-level training systems which are used to train soldiers/commanders in a simulated battlefield, etc. The third popular application area is Warfare, which includes virtual warfare, future warfare, tactical warfare, and multi-warfare such as air warfare, undersea or underwater warfare and ground warfare, etc. Then Acquisition Policy Making and Command & Control Systems are the areas that have high implementation of simulation techniques.

3.2 Application of Simulation Modelling Techniques in Defence

The application of simulation modelling technology in defence (aerospace & military) is not new. It has been applied in many areas ranging from space sciences, satellite engineering to the multi-warfare (air warfare, undersea warfare), air & missile defence, acquisition, tactical military trainings & exercises, national security analysis and strategic decision making & planning, etc. Aerospace and military are complicated areas dealing with complex missions and situations. M&S is growing in use for mission-level training systems, which provide improved individual and team training in environments and scenarios that are impossible to create in live training outside of combat (Gordon, 2001). The various military missions include reconnaissance, close air support, battle damage assessment, interdiction, air defence, ground attack, fighter escort, fighter sweep, forward air control, etc. Estimates for the availability of resources such as weapons in these missions cannot be obtained analytically and therefore require detailed modelling of the system which then could be simulated to obtain estimates (Upadhya and Srinivasan, 2005).

One of the most difficult decisions faced by military professionals is the tactical combat decision made on ground during battle. A military battle is ideally suited to analysis by simulation since the military tactical course of action development is a complex and difficult task with which even the most experienced military professionals have difficulties (Kewley and Embrechts, 2002). Simulation modelling techniques have been applied in a variety of sectors in defence including not only military training but also mission planning and decision making because simulation allows ‘what-if’ analysis & evaluation, i.e. one can foresee the impact of changes made to a system’s process, such as to analyse the impact of modification in an acquisition policy, ‘what’ would happen ‘if’ the acquisition is based on air warfare and not the undersea warfare, etc.

The ease with which an analyst can modify the system under review is one of the biggest advantages of using M&S technology. By simply changing model parameters the behaviour of a system can be examined, i.e. same task can be repeated with different parameters in order to examine the system output (Gregg et al., 2002). In this way a system or process could be modified to obtain improved throughput or results, hence improving efficiency of the system under study, therefore the U.S. Navy rely more on modelling and simulation rather than on an actual field testing for both the acceptance and demonstration tests of new or upgraded systems (Dockery, 1998). Moreover, M&S can provide a good environment to support managers in solving aerospace problems and help them in taking decisions about range safety, future vehicles or events (Rabelo et al., 2006). For training, analysis and warfare experimentation the U.S. military relies on simulation and a key element within these simulations is their ability to accurately represent human behaviour, including emulating realistic military decisions (Sokolowski, 2003). Also for routing problems, the simulation technology has proven to be a very useful tool. A study (Grob, 2006) uses event-driven stochastic simulation model for routing problem of maritime surface surveillance operations.

Table 1 shows a subset of findings from the literature survey. It lists the contemporary or mainstream simulation modelling techniques applied for various purposes in defence (Aerospace & Military). It contains three main fields, that were mainly identified to be important in the initial phase of literature review and are a subset of the RIT (Figure 3), namely simulation techniques or methods, industry sectors, and purposes of applying simulation.

As a result of this study it was found that the Distributed Simulation (DS) technique has been most widely adopted as it has long been used in military applications for simulated battlefield training and strategic planning (Prasithsangaree et al., 2004). There has been numerous application of Distributed Interactive Simulation (DIS) technology within the department of defense (Shiflett et al., 1995). Moreover, it can be used for battlefield representations in a distributed manner.

Table 1: Contemporary Simulation Techniques Applied for various purposes in Aerospace & Military (A subset of findings from the literature survey)

Techniques	Industry Sectors	Purposes of Application
Agent-Based Simulation (ABS)	Aerospace / Aviation	examining pilot retention issues, decision making (Sokolowski, 2003)
	Military	management of military missions, modeling tactical human behavior, making decisions (Fernlund et al., 2006)
Contact Dynamic Simulation	Aerospace	modeling space station robotic operations (Xia et al., 1995)
Discrete-Event Simulation (DES)	Aerospace	training of both pilots and navigators, modelling the command and control problem, solving small optimization problems of military airlift (Powell et al., 2004)
	Military	analysis, command & control systems, estimation, optimization, process modelling, training, workflow management (Çelik and Sabuncuoglu, 2007)
Distributed Simulation (DS)	Aerospace	predicting dynamic behavior of aerospace & underwater vehicles, command, control and monitoring systems (Prasad et al., 2004)
	Military	training, evaluation & testing (Boukerche and Dzermajko, 2006), optimization (Bruzzone et al., 2005), planning, trainnig, warfare, integrating heterogeneous systems, interoperability and information sharing (Broadstock, 2004)
Monte Carlo	Aerospace	modelling the physical design of objects such as modeling of NASA space shuttle (Rabelo et al., 2006)
	Military	analyzing network reliability and incorporating uncertainty into reliability calculations, estimation (Cook and Ramirez-Marquez, 2007)
Numerical Simulation	Military	Optimization (Levy, 2007)
Real-time Simulation (RT)	Aerospace / Aviation	evaluation & testing, training for ground-to-air & air-to-air engagements (Wedzinga, 2006), human-in-the-loop simulation experiments (Ruigrok and Hoekstra, 2007), modelling space station robotic operations, satellite engineering
	Military	human behavior modeling, planning (Warren et al., 2004), training (Shen and Zhou, 2006)
System Dynamics (SD)	Aerospace / Aviation	free flight simulations and human-in-the-loop simulation experiments, trajectory planning (Faiz et al., 2001)
	Military	acquisition policy making, management, planning, mission policy making, warfare, decision making (Hunsaker, 2007)
War Gaming (WG)	Military	virtuous war, designing military simulations to depict an actual or assumed real life situation, combat planning (Power, 2007)

3.3 Potential Applications of Simulation Techniques to Healthcare

The various simulation techniques applied successfully in defence (Aerospace & Military), as described in Table 1, have many potential applications to the healthcare sector. Table 2 lists few suggestions about the applicability of these simulation techniques to the healthcare domain.

Table 2. Applicability of Simulation Techniques to Healthcare (Some suggestions)

Simulation Techniques	***Potential Applications to Healthcare (suggestions)***
Agent-Based Simulation (ABS)	management of surgical operations, treatment management, modelling physicians, patients or bio-substances such as antigens or anti-bodies, making treatment decisions
Contact Dynamic Simulation	modelling robotic surgeries
Discrete-Event Simulation (DES)	analysing and designing clinical pathways, clinical workflow management
Distributed Simulation (DS)	training doctors, surgeons, healthcare educational programmes, evaluation and testing of healthcare scenarios both at the strategic and operational level, integration & interoperability of helathcare systems, healthcare information sharing, planning treatment or surgeries, optimization
Monte Carlo	analysing healthcare process reliability and estimation
Numerical Simulation	optimization of resource usage
Real-time Simulation (RT)	designing clinical surgeries, designing experiments to train consultants or physicians, evaluation & testing of treatments or surgeries, planning treatments or strategies
System Dynamics (SD)	designing healthcare service delivery process as a whole, designing clinical surgeries experiments to train consultants, management, policy and decision making about healthcare operations at the strategic, tactical or operational levels
War Gaming (WG)	designing surgical scenarios in a tactical healthcare environment

4 CONCLUSIONS

M&S refers to imitating an object or process and its working in an environment, i.e. manipulating with real data and actual events in an environment that is not real (it is simulated) but imitates (represents) the real world. The main purpose of applying simulation technology is to analyze and evaluate the 'what-if scenarios', this means to predict the outcome or after-effects of a change in a process or any input parameter to the system under study by setting-up a simulated environment. This helps in reducing costs and unnecessary human efforts if experienced in reality. Addressing various problems in the healthcare through simulation is an interesting challenge. 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. The applications of M&S in other areas such as in aerospace and military sectors make inspirations for improvements in the healthcare domain. From this survey it becomes clear that various simulation modelling techniques applied in the aerospace & military are useful for specific purposes and have some potential applications in the healthcare domain.

It has been seen from the literature surveys that Distributed Simulation has proved to be a very useful tool in the analysis, planning and evaluation of military operations and/or missions. Moreover, it has been found from this study (Table 1) that there is a growing trend towards using hybrid M&S approaches, i.e. merging two or more simulation techniques and applying them to solve the problem, as compared to the application of stand-alone simulation modelling techniques.

Almost for each successfully applied simulation technique in defence, there are a number of potential applications to the healthcare domain (Table 2). End results from the RIGHT surveys are expected to set a milestone for future research into the applicability of these techniques into healthcare domain, which would ultimately lead to the development of a framework toolkit for Modelling & Simulation in Healthcare, thus facilitating a better quality of healthcare provision.

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