SIMT: A Holistic Framework for Embedding Simulation into the Health Care Systems

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Abstract

Simulation and Modelling (S&M) have been proven as very valuable tools in the health care sector. In recent years, the sector has experienced a rapid increase in applications. However, it appears that health care organisations have failed to sustain the use of these powerful techniques.

In this research, an extensive literature review is carried out to identify the main challenges of the use of health care simulation and the underlying barriers of implementing S&M in the sector. In order to address these issues, it identifies the need to fully embed S&M into the sector through a systematic approach. However, the literature in this subject area has not provided such a holistic approach to the use of simulation.

With the view to embed these techniques in health care decision making processes, this research develops a new framework, known as **SIM**ulation **T**hinking (SIMT), to overcome the identified challenges and barriers. SIMT includes five key components: infrastructure, management, culture change, methodology and modelling.

Whilst the SIMT framework presents the important elements that need to be considered to make S&M mainstream tools, this research also presents an implementation framework which transforms SIMT into a practical and applicable approach to embed S&M in health care organisations. The implementation framework includes two main stages: planning stage and action stage.

Questionnaire and case study approach are conducted to validate the usefulness and importance of the SIMT components and the proposed implementation framework. The questionnaire is used to understand how the selected group of experts consider the SIMT components and the planning stage of the implementation framework as a valuable guideline.

To validate the action stage of the implementation framework, this research uses the case study approach which introduces the proposed methodologies and modelling best practices into a local hospital. The feedback received from the hospital is used to evaluate the usefulness and practicable of the proposed approach.

This thesis is dedicated to my beautiful newborn baby girl Molly Sze Ching Hughes, who was born on the 5^{th} August 2010 and become the most important person in my life.

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1 CHAPTER ONE: INTRODUCTION

1.1 Introduction to health care system

Providing high quality and efficient health care services is always the first priority for today's health care organisations. In the United Kingdom (UK), increasing government funding has been allocated to public health care services (the National Health Service (NHS) spent over £80 billion in 2009 to 2010 (DoH, 2009)). The NHS has been providing health care services to millions of potential patients for over 50 years. The aim has never changed - provide excellent and efficient health services under a safe environment. However, today's changing demographics and increasing people expectations are putting much pressure on the NHS along with other such organisations around the world.

Because today's health care system has becoming bigger and more complex, health care organisations are facing many more challenges when trying to meet the increasing standards and demands. In the UK, Department of Health (DH) is responsible for the NHS and to review the performance of its organisations. Official national targets are set in order to develop strategies and directions for guiding these organisations in improving their service performance. The recent targets include a maximum of 26 weeks for inpatient admission, a maximum of 13 weeks for first outpatient appointment following GP referral, a maximum of 4 hours waiting time for patients coming in Accident and Emergency (A&E) department and a maximum of 18 weeks waiting time from general practitioner referral to hospital treatment (DoH, 2008).

Health care organisations are currently meeting all these national targets by frequently reviewing the patient pathways and redesigning the care delivery. In the operational areas, the main responsibilities for them include continuously review and improve the performance of the patient throughput, waiting times and length of stay. These improvements are necessary to achieve improved performance of the patient flow, the effectiveness of the resource allocation and the efficiency of the patient scheduling and admissions.

Health care strategic decision-makers on the other hand need to consider vague, complex and non-routine decisions, such as where to invest capital, where to expand service lines, or whether to start a new surgery centre (Parayitam and Phelps, 2007). The challenges for these health care managers are not only considering the financial viability, quality of care and safety of patient, they have to consider many uncertainty factors such as human behaviour, social factors and political issues during the decision processes.

1.2 Simulation and modelling in health sector

Much of the challenge that health care decision makers face today is how to improve the efficiency of the overall operational systems and to effectively allocate and schedule the available resources. Among most of the operations research techniques, simulation and modelling (S&M) is one of the most suitable analytical tools to evaluate, improve, and optimise these complex systems.

Simulation models can be classified into three main dimensions:

- Static vs. Dynamic simulation models
- Deterministic vs. Stochastic simulation models
- Continuous vs. Discrete simulation models

The full description of their characteristics can be found in Law (2007). In this research, we mainly focus on two types of simulation models: *discrete event simulation (DES) models* and *system dynamics (SD) models*.

Although there are many differences between these two simulation models (Morecroft and Robinson 2005), one of the common characteristics of these two simulation models is their abilities to model uncertainty and complexity of a system. As well as providing a risk-free environment in which to investigate how alternative policies or changes could improve the performance of a system.

According to a recent review of the literature, the interests of applying DES approach for addressing different health care issues are growing rapidly within the last 5 years (Gunal and Pidd, 2010). Figure 1.1 shows the number of papers published in this area from year 2000 to 2008.

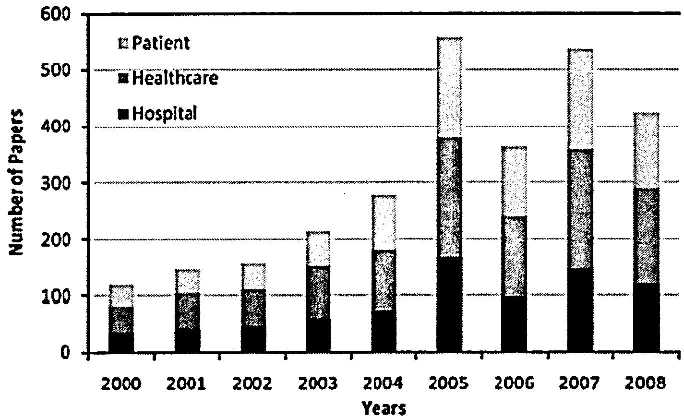


Figure 1-1 Number of papers in health care simulation (adapted from Gunal and Pidd, 2010)

Despite the fact that SD approach is comparatively new to the sector, literature review shows the use of SD is also expanding rapidly within the last few years (Brailsford, 2008). Figure 1.2 shows the number of publications in relation to system dynamics and health care from year 1980 to 2007.

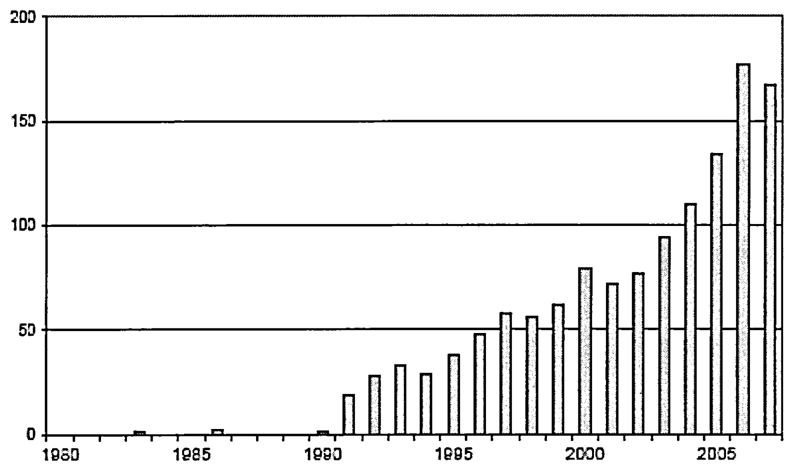


Figure 1-2 Number of papers in the area of system dynamics and health (adapted from Brailsford, 2008)

Eldabi *et al.* (2007) also conducted an extensive review of the literature. The review shows that despite the use of DES and SD models only recently started to gain acceptance in the health sector, these simulation-based approaches have already been used for studying vary decisions in medical, administrative or operational areas.

A similar review has been conducted by Brailsford (2007) which provides excellent case studies which proved S&M has a great potential to address many complicated health care issues. Brailsford classifies them into three main types of models – human models, operational models and strategic models.

1.3 Challenges for health care simulation

Despite the proliferation of publications and studies of health care simulation, it appears that health care industries have failed to sustain the use of these powerful techniques. Many researchers have argued the current approach of using simulation in the sector is not practical.

Pidd (2008) comments that the majority of the simulation based solutions have been produced by academics and/or consultants with a relatively low engagement of clinicians and/or operational managers. This leads to the situation in which the "given" solutions failed to solve the real problems (kulijis *et al.,* 2007).

In addition, Brailsford (2007) identifies the problem of academic simulation studies, which unlikely these models can be implemented or reused by other health care providers. One possible reason is that these models are often developed for a specific hospital.

The problem of getting health care models implemented seems to be becoming a focus for many researchers (Lowery, 1994; Eldabi *et al.*, 2007; Brailsford, 2007). Many authors comment it is difficult to identify the actual value of modelling in health sector because the evidence of implementation was so limited (Fone *et al.*, 2003; Sobolev *et al.,* 2009).

Therefore, to facilitate more effective and efficient use of S&M in the sector, many of these authors argue that there is a need for a more holistic approach to the use of simulation (Gaba, 2004; Eldabi *et al.,* 2007). On the other hand, some others argue that there is a need to develop “generic” health care models (Gunal and Pidd, 2007; Augusto *et al.,* 2007). However, none of these can be achieved unless underlying barriers are identified and addressed.

1.4 Research objectives

A review of relevant literature did not reveal any published work contributed a holistic approach for guiding the implementation of S&M in the sector.

The main aim of this research is to develop a holistic implementation framework for embedding simulation into the health care systems.

The main objectives of this research are:

- examine the current practices of health care simulation
- identify underlying barriers that impede the use of S&M within the sector
- examine the key issues of applying discrete-event simulation and system dynamics approaches within health care environment
- identify key elements required to address the underlying barriers

- investigate the best practices from the other quality and process improvement approaches which has already been embedded within the sector
- validate the proposed framework by questionnaire and case studies

1.5 Thesis structure

A summary of each chapter is listed below:

1. ***Introduction***; introduces the characteristics of today's health care system, and the requirement of today's health care management. Introduces the use of health care simulation and identifies its main challenges. Identifies the key objectives of this research.

2. ***Literature review***; reviews and summarises the current practices and challenges of health care simulation development. Reviews and discusses the main barriers of embedding S&M into the health care systems, and the best practices that have been applied for implementing other world-class management approaches in the health care. Finally, identifies the research gap to be filled.

3. ***Discrete event simulation and System dynamics approaches***; introduces the methodology and discusses the modelling characteristics of discrete event simulation and system dynamics. Provides literature review of the uses of these two simulation models within the health sector. Highlights the limitations of these simulation techniques. Finally introduces and illustrates the most commonly used simulation packages for developing these health care models.

4. ***Framework methodology and critical components;*** presents the development approach and describes the methodology used for validating the proposed framework. Provides an overview of the research approach and the key objectives of each research activity. Presents the initial framework which includes the critical components that are then used as a basis for developing the implementation framework. Finally, maps the proposed critical components with the identified success factors to ensure the initial framework are sustained by sound theory.

5. ***SIMT framework***; introduces the principle and basic structure of the proposed implementation framework. Presents and discusses the proposed approaches for guiding health care practitioners to implement the critical components in order to successfully embed S&M for supporting varies decision making in local or national management level.

6. ***Validation of SIMT implementation framework***; validates the proposed framework components and the implementation framework by questionnaire and case studies. Analyses and discusses the validation results in order to demonstrate the strengths and limitations of the proposed framework.

7. ***Conclusions and recommendations***; summarises the objectives met from this research. Identifies the author's major contributions to the knowledge of health care simulation and modelling. Finally, identifies and presents future recommendations for this research area.

1.6 Summary

This chapter introduced the background of the research, and presented the current challenges for the health care simulation. The research objectives were identified. The thesis structure was included with a brief summary of each chapter.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the previous research and literature relevant to the current practices and examines the existing problems of using S&M within the health care sector. The chapter goes into detail about the existing barriers of embedding simulation into the health care sector, with regard to the research objective of the thesis (mentioned in Chapter one), which highlights the critical issues needed to be overcome by a systematic framework. In addition, a review of three world-class quality and process improvement approaches that have been successfully embedded within most of the health organisations has been conducted. Finally, it examines and discusses the main success factors which have been applied in overcoming the barriers of embedding new management approaches within health care organisations.

2.2 The overview of health care simulation development

Simulation and modelling is one of the most widely used operations research tools which have been used to evaluate, improve, and optimise many types of processes. In general, simulation models have been developed mainly for understanding the behaviour of a system and to practice its control, estimating some variables of interest from the behaviour of the simulation, and in comparing two or more different policies by trying them out in a simulation (Law, 2007).

The review of literature shows that the development of health care simulation applications has been dominated by research organisations and external consultancies (Pidd, 2008). One of the main reasons is this group of researchers are enthusiastic to promulgate simulation in this area. Their applications are commonly used to target problems of a more generic aspect. Therefore, the development time and cost involved in this type of application is usually long and expensive. Managers from the health care organisations on the other hand are typically willing to have simulation models which can effectively support the improvement of care and patient safety, improvement of efficiency, reduction of cost and errors and competition with other organisations (Gaba, 2004). Therefore, these simulation models developed in-house by health care organisations are usually targeted at a more specific area of concern. Additionally, the time scale of the development process is often shorter and is more cost effective.

As computing technology is becoming more advanced and user-friendly, there are many simulation software packages which are available for the non-programmer. This benefits for example health care managers who typically cannot spend too much time on operating complex programming tools. However, it is important to understand that model programming is just part of the overall effort to analyse a complex system by simulation (Law, 2007). In fact, there are other critical processes which are always involved in most of the simulation development. Figure 2-1 shows the steps that are included in a typical simulation study which is originally produced from Law and Kelton (1991).

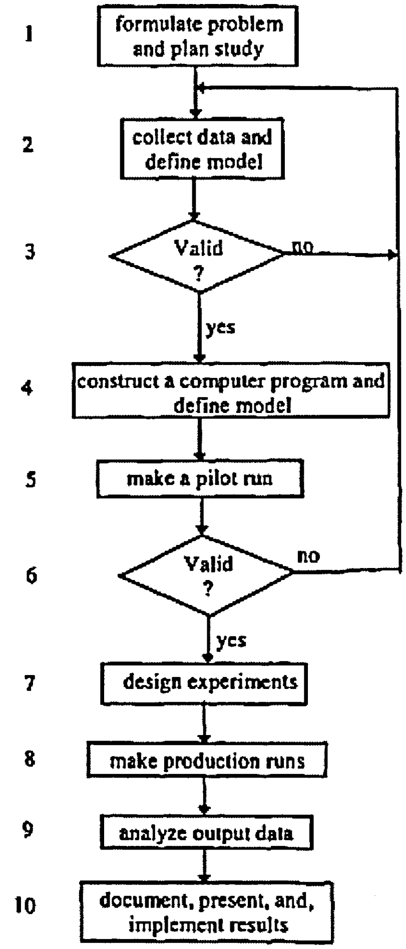


Figure 2-1 Steps in simulation study (Law, 2007)

Although the simulation process shown in Figure 2-1 can be applied to most of the simulation studies, there are particular concerns when applying to health care modelling. The environment within a health sector is very different from most of the other industries, there are many uncertainties, complex scenarios and human issues which are difficult to adjudge before a simulation study. One of the main challenges within the development of health care simulation models is the data collection process (Lowery, 1998). For example there can be thousands of different reports of length of stay within one hospital. Health care modellers can eventually spend months collecting this process data. In addition, a review of the literature shows that health care data is often not reliable enough for a health care model (Baldwin *et al.*, 2004). The main reasons are the changes that may occur in medical technology, policies, and socio-economic values can cause the collected data to become invalid. Secondly, health care professionals may sometimes provide less than accurate data for varying reasons (Eldabi, 2002).

Health care modellers often ignore the importance of the validation process; this issue has been reported in the literature as a major problem (Lowery, 1998). Within Law's simulation process model (Figure 2-1), validation process (i.e. step 6 in Law's model) is a major process which can affect the success of the whole development. For example, if the developing model is found to have failed to represent the real system or situation, it is necessary to return back to the early steps, find out either there is the problem of the collected data or the model structure etc. Without this process, the final model can become useless for problem owners. However, health care modellers often pay less attention to this step, perhaps this is because the uncertainty and different human issues which causes these modellers to be unable to spend too much time and effort on this process.

Similar issues have also been raised within a review of the use and value of simulation in health care (Fone *et al.*, 2003). These authors comment there is lack of evidence of implementation found within the reviewed papers. Without the outcomes of model implementation, this is difficult to judge the actual value of a model. According to a recent review of the health care publications conducted by Sobolev *et al.* (2009), there are still limited studies reporting simulation models that are implemented to address the needs of the health care managers or the problem owners.

2.3 Current status of health care simulation

Over the last two decades, the research and development of health care simulation has in fact become a popular topic within health care literature. A majority of these interests has focused on how simulation modelling can be used for addressing the complex health care issues. Health care simulation models have been employed extensively for assisting a wide range of clinical decision making, such as capacity planning, resource allocation and organisation redesign.

As the development of health care models has grown substantially over recent years, there is increasing concern about the 'true' value of these health care models for the health care communities and managers. Pidd (2008) comments that the health care community and managers are still not ready to operate a simulation software tool. The great majority of these health care models are still developed by commercial consultants and/or research organisations. In fact, reviews of the literature show that the involvement of health care managers and policy makers in these simulation studies are very limited (Sobolev *et al.*, 2009). The current practices of using simulation in the health sector is tool-driven, health care managers are only applying a 'ready-made' solution (Kulijis *et al.*, 2007). In most cases, these simulation solutions could not really address the needs of these health care managers or policy-makers.

Increasingly, studies in literature are addressing the future of health care modelling. Most of this concern focuses on the need to implement S&M within health care systems, so that it can be used on a regular basis by health care managers or policy-makers (Kuljis *et al.*, 2007; Eldabi *et al.*, 2007; Pidd, 2008). Back in the 1990s, Lowery (1994) has already discussed some barriers of implementing simulation in health care. His studies show that in order to reap the full benefit of simulation, implementing this technique within health care system is a necessity. There is still no evidence to show that simulation has been successfully implemented within the health care system.

There is no doubt that implementing simulation techniques into an organisation system is always a big challenge. It is necessary to have some guidelines or toolkits which can provide best practices or procedures for guiding these professionals. For instance, Hughes and Perera (2009) develop a five stage framework which provides manufacturing professionals a systematic guideline to embed simulation into business processes from foundation, introduction, infrastructure, deployment to embedding. However, health care sector has its unique characteristics and different human issues. Therefore, the guidelines which can provide health care professionals to embed simulation into their systems have to be considered all the unique issues and to be able to apply hierarchically.

The following section provides an overview of these unique characteristics and human issues which hinder S&M to be embedded within a typical health care system.

2.4 Barriers of Embedding Simulation into a Health Care System

As stated in the previous section, there is still no evidence to show that S&M has been embedded into health care systems as a routine tool. In fact, embedding simulation techniques into a health care system is not an easy task. Compared to other business sectors, health care systems are characterised by different human issues and unique characteristics. Some of these issues in fact bring a number of problems to modellers when employing simulation to the health care systems. The following sub-sections discuss these barriers in detail.

2.4.1 Health Care Complexity

One of the main barriers for employing simulation extensively within health care systems is their complex nature. In most cases, health care processes involve patients, healthcare professionals and health resources, in which their interactions are too complex to be understood analytically. One of the critical processes within a simulation study is to formulate problem during the beginning stage (Law and Kelton, 1991). Pidd (1998) suggests that this stage is the attempt to take an overlook to the system and to extract from it some agreement about the particular problems which might be amenable to analysts. However, unlike most of the routine manufacturing processes, health care systems involve random events, multiple characteristics of patients and resources. Most of these uncertainties and variables are simply too complicated to be well defined as an assumption.

Many of the simulation studies reported failed because modellers attempt to examine everything at once (Lowery, 1994). In most cases, these studies either failed to focus on the defined problem or were terminated as a result of spending too much effort and time on details. However, these practices in health care modelling are sometimes unavoidable because of its complex nature. For example each patient can go through various patient pathways through the process of care. There is much uncertainty and variability involved such as patient demand, length of stay, treatment times, delays or resources availability. These processes are simply too complicated to be reduced, health care modellers have no choice but to include all these details in a model.

2.4.2 Multiple Stakeholders

Health care systems are mainly composed of patients and health care professionals. These health care professionals can include clinicians, managers and health economists. Eldabi *et al.* (2002) defines this group of professionals as "Stakeholder". These stakeholders are the main decision makers within a health care system, and often they are the problem owners of a simulation study. Since these stakeholders always have their own different objectives and interests, in most cases they can have different views to address the same problem. Therefore, without good communication (Eldabi *et al.*, 2007), modellers always find it frustrating when trying to understand a real problem from each of them.

2.4.3 Cultural resistance

One of the other barriers for the slow acceptance of the use of simulation in the health care sector is cultural resistance. Traditionally, health care managers relied primarily on simpler, deterministic decision making (Lowery, 1994). Simulation might be seen as a complicated tool which requires high level technical skills and complicated procedures. Pidd (2008) comments that health care managers nowadays are just not feeling as ready to operate simulation software tool as they are in currently opening a spreadsheet.

In fact, health care managers always view simulation-based solutions as "black-box" answers to complex problems (Lowery, 1994). They often feel uncomfortable to the validity of the distributions employed in the analyses or the unpredictability of the outcomes. In general, health care clinicians and care providers are the main resources within a health system. They simply do not like being analysed, viewed or treated in the same way as machines within a simulation model. In addition, this group of staff often has less chance to get involved in the model building until a problem is identified. Therefore, simulation might be seen as a management tool which is not welcome by clinicians and other care providers (Eldabi *et al.*, 2007)

2.4.4 Lack of simulation knowledge

Although the time and skill level required for model building is surely decreasing as the power and flexibility of the available simulation software increases. Nevertheless, a level of education and training is still necessary for non-programmers such as health care managers for simulating a relatively simple system. However, this kind of simulation training is apparently absent within the health care culture. There are two reasons. First, there is lack of incentives for health care managers and decision makers to employ simulation within their routine decision making. As today's health care environment is in a state of such rapid change, these decision makers cannot afford to spend too much time developing models of systems which may become outdated as soon as they are completed. Additionally, the actual value of simulation for the health care managers is still not yet been clearly proven. (Sobolev *et al.*, 2009).

Secondly, the health care sector is traditionally responsive and sensitive to political influence and control (Kuljis *et al.*, 2007). However, organisations do not warrant an investment in simulation software and the associated training, instead the allocated funds are usually spent on patient accounting and medical information systems.

2.4.5 Time and Cost

Literature shows that the development of health care simulation is still dominated by external consultancies and/or research organisations (Pidd, 2008). As discussed previously, one of the main reasons for this current practice is due to the lack of simulation knowledge among health care managers and decision makers. However, in most cases, these external modellers simply spend too much time and effort in search of a level of complexity that was totally unwarranted or they were trapped by the temptation to simulate everything in the model.

Because of these reasons, these models were often terminated due to the costing issue, or the finished models were invalid due to the changes in the current situation. This current practice of developing health care models is basically too time-consuming and not cost-effective enough for the health care sector.

2.4.6 Modelling accuracy

The problem of accuracy in health care simulation models is mainly the consequence of most of the issues that have been discussed above. These issues include the complexity and variable nature of health care processes, different views from multiple-stakeholders, no involvement of managers or clinical staff during model building processes, and the domination of external consultancies in simulation development.

Problems of the accuracy in health care modelling mainly focus on model accuracy and data accuracy. Eldabi *et al.* (2002) reports model accuracy highly depends on defining a right ‘problem’ at the initial stage of the development. However within health care systems, problems are often not well defined. Additionally, it is unlikely that external modellers can really understand health care ‘from the inside’ because of the lack of communication between stakeholders and modellers (Eldabi *et al.*, 2007). Data accuracy on the other hand is another important barrier for health care modelling. Because of the rapidly changing and unpredictable nature of health care systems, available data can often become invalid after a short period of time. As a result, health care managers and decision makers generally do not believe modellers can measure and predict for example patient arrive times, patient waiting times or treatment times accurately.

All of these barriers prevent simulation from being used as widely as possible in the health care sector. Some of these barriers can be addressed with changes to simulation products and its delivery to this important sector. Other barriers must be dealt with through changes within the health care organisations.

2.5 World-class quality and process improvement approaches embedded in health care

In order to fully understand the unique characteristics of the health care sector, it is important to investigate how other quality and process improvement approaches were embedded in health care systems and their best practices. The following sub-sections examine and discuss three world-class quality and process improvement approaches which have been extensively studied and applied in the health care sector.

2.5.1 Total Quality Management

Total quality management (TQM) is a management philosophy which aims to improve quality, operations, and productivity on a continuing basis. Within the health sector, TQM is an essential management approach implemented to improve the overall quality of hospital systems, processes and services. Successful implementation of TQM requires a fundamental paradigm shift in health management (Isouard, 1999). Most importantly, quality improvements should not be managed piecemeal, but in concert (Kimberly and Minvielle, 2000). Isouard (1999) suggests a strategy which guides the development of the TQM environment within hospitals. The key elements include a change in the management culture, teamwork development, customer focus and continuous feedback to staff (Table 2-1).

Table 2-1 Organisational framework for the development of TQM environment (Isouard, 1999)

Stage 1: *Management cultural change*
- Commitment towards TQM from senior management
- Quality management plan introduced
- Quality issues on management agendas
- Quality adviser appointed
- TQM training provided for staff

Stage 2: Teamwork developed
- TQM team project introduced
- Quality adviser focused on team building
- Responsibilities identified problems
- Staff empowered to identify problems
- Staff involved in process change
- Trust among team members developed
- Reinforce successes

Stage 3: Focus on customers
- Promoting an attitude that customers come first
- Customers identified and represented on TQM team
- Determine specific customer requirements
- Process improvement strategies developed to meet customer needs
- System to evaluate how customer needs are being met
- Organization responds quickly to changing customer needs

Stage 4: Continuous feedback to staff
- Emphasis placed on continually keeping staff informed of the improvement process
- Feedback in form of progress reports and minutes from TQM meetings
- Recognizing staff value
- Communication successes

Isouard's strategy focuses the importance of ongoing organisational improvement, not a one-time event. Quality has to be integrated into day-to-day management, and it is essential to involve all staff to contribute to the improvement process. In which, the involvement of senior management is especially critical. For example, senior managers should spend time "walking the job" for explicit quality improvement purposes, which can motivate those below through leadership, support and action (Joss, 1994). This action can include adequate employee education and training for quality improvements.

In addition, good communication is also vital to the development of a TQM environment. Isouard (1999) emphases continuous feedback to staff about the changing processes can ensure continued cooperation and minimise resistance to the proposed changes. On the other hand, closer communication between customers (patients) and providers (hospitals) is another success factor to the development of a TQM environment. This is important to determine clear customer needs and requirements, and continuously evaluate how these customer needs were being met through meetings or surveys.

2.5.2 Lean management

Lean management pioneered by Toyota in the 1940s, is to redesign services by removing practices or stages in a process that do not add value to the customer (Ward, 2006). If successfully implemented, Lean in health care organisations can help to improve productivity, reduce waste and lower costs. Lean is an approach that seeks to improve flow in the patient journey and eliminate all forms of waste. It is the process of identifying the least wasteful way to provide value to customers (Westwood and Silvester, 2006). Table 2-2 shows the basic Lean principle when applying to health care.

Table 2-2 Five-step process for guiding the implementation of lean in health care (Westwood and Silvester, 2006)

Theory*:* Improve flow and eliminate waste
Lean principle:
1. **Specify value** – What is important in the eyes of the patients and staff?
2. **Understand demand** – What is the type and frequency of the demand?
3. **Flow** – How will the patient and information flow through the patient journey?
4. **Pull** – How can we create pull in the patient journey rather than pushing patients and information round the system?
5. **Perfection** – How can we optimise the patient journey?

The Lean principle basically includes five main stages – specify value, understand demand, create flow, establish pull and seek perfection. This is not the main purpose of the study to investigate the details of Lean principle. However, it is important that senior leaders fully understand this basic Lean principle and to build the Lean thinking into their management strategies. Similar to the TQM approach, successfully implementing Lean thinking into a health care organisation requires the development of a continuous improvement culture (Atkinson, 2004). This long-term improvement culture should focus on improving flow and eliminates waste from the whole system rather than a short-term reactive culture (Westwood and Silvester, 2006).

However, the challenge of implementing Lean in health care is that it requires people to identify "waste" from their daily tasks. It is particularly difficult for health care professionals to accept their work is wasteful and does not add value. Therefore, senior leaders play an important role to create a set of values and beliefs that guide people to make the right choices, behave differently, and allow them to experience a better set of results. All these changes cannot be done individually, but must be implemented throughout an entire organisation (Miller, 2005).

One of the United States (US) medical centres has been using Lean management since 2002. One of their major precepts is to introduce a "No-Layoff Policy" (Miller, 2005). Therefore, people can fully commit and engage in improvement work without worrying themselves out of a job. Neil Westwood, associate in service transformation at the NHS Institute for innovation and improvement, states "Lean is a long-term strategy which requires expertise to get it started...Lean is not about sacking people...a true Lean organisation would redeploy these staff elsewhere in the organisation to improve that area" (Ward, 2006). Senior leaders are required to be educated initially and then as a leader to guide people to experience the process of improvements. When this process is repeated, a new culture will evolve.

2.5.3 Six-sigma Quality

Six-sigma has been used since the 1980s and was originally developed by Motorola and championed by multinational company General Electric (Chassin, 1998). When implemented in health care, six-sigma uses a powerful project management framework and statistical tools to uncover root causes of a problem. The main principle of six-sigma is about doing things right at the first time, defect-free.

The phases of the six-sigma methodology are represented by DMAIC, or Define, Measure, Analyse, Improve and Control (Antony *et al.*, 2007a). Table 2-3 shows the basic principle of DMAIC methodology for managing a six-sigma project.

Table 2-3 DMAIC methodology for applying a six-sigma project (Westwood and Silvester, 2006)

Theory*:* Eliminate defects and reduce variation
Six-sigma DMAIC methodology:

1. **Define** – What is important?
2. **Measure** – How are we doing?
3. **Analyse** – What is wrong?
4. **Improve** – What needs to be done?
5. **Control** – How do we sustain the improvements?

In which, there are many different analytical tools and techniques that can be used during each DMAIC stages. For example process mapping, brainstorming, root cause analysis, run charts and Pareto analysis (Antony *et al.,* 2007b). Literature shows that six-sigma quality has already been widely accepted and implemented in many health care organisations (Natarajan, 2006; Antony *et al.*, 2007b; Hilton *et al.*, 2008).

Similar to TQM and Lean management approaches, the key success factors for implementing Six-sigma quality within health care organisations is to create the continuous improvement culture. Chassin (1998) explains that priority is to educate public and leading representative organisations about the importance of health care quality improvement. Without customers demanding better performance from their health care systems, health care organisations will not have the motivation to make the kind of investment needed to improve or create new systems of care.

In addition, a key factor of successful implementation of six-sigma is to create the right mindset and attitude of people working within the organisations at all levels towards six-sigma quality improvement (Antony and Banuelas, 2002). This should begin from the top management team. Without senior management support and commitment, six-sigma is impossible to implement within an organisation. Appropriate training about the six-sigma methodology should be provided to all staff, this can make sure everyone in the organisation has the same standard on errors and quality (Antony and Banuelas, 2002).

Finally, competition between health care organisations can become an important motivation in applying quality improvement (Chassin, 1998). For instance, the Baldrige award (Bodinson, 2005) catches the attention of 33 health care organisations on systems thinking, benchmarking, and comparative results. There are many other quality award programs which successfully motivate health providers and managers to implement quality improvement within their organisations (Natarajan, 2006).

2.6 Research Gap

The review of the existing literature and research shows that there are many known challenges and problems when applying simulation modelling within the health care sector. Recent literature focuses mainly on the need to fully embed simulation within the health care sector (Kuljis *et al.*, 2007; Eldabi *et al.*, 2007; Pidd, 2008). However, embedding simulation into this complex environment is always a challenge.

The following issues are absent in relation to the research area:

- There is no clear guideline to show how the underlying barriers of implementing S&M can be addressed

- There is no implementation framework available to guide how health care managers or/and practitioners can embed S&M in the sector for supporting decision making
- There is no specific toolkit to show health care managers or/and practitioners the appropriate skills and techniques for developing in-house simulation models for routine use.

This work will develop a practical and systematic implementation framework, to fill the research gap, which can guide health care managers and practitioners to effectively address the underlying barriers and to successfully embed S&M in the sector.

2.7 Summary

This chapter starts by examining the overall development practices of health care simulation modelling in Section 2.2. A general simulation development process, based on the literature, was presented. Discussion goes on to the common challenges of applying this process flow into health care environment. For example, the difficulties of collecting data and lack of attention to the model validation processes.

Based on the discussions conducted in Section 2.2, the current situations and problems of using health care simulation modelling were examined in more detail in Section 2.3. The discussion was then focused on the future of health care simulation. Attention here was drawn to the fact that health care simulation modelling should be fully embedded within health care organisations, so that simulation can be effectively used on a regular basis.

Section 2.4 reviewed and discussed the main barriers of embedding simulation technology within health care systems. These include: *health care complexity, multiple stakeholders, cultural resistance, lack of simulation knowledge, time and cost, and modelling accuracy*. Section 2.5 presented the three well-known quality and process improvement approaches within the health care sector. Those are: *total quality management, lean management, and six-sigma quality*. The methodology of each approach is briefly discussed. The discussion was then focused on the best practices for overcoming the natural barriers of embedding these approaches within health care organisations. Section 2.6 identified the research gap in the research area and presented the main goal of this study.

3 CHAPTER THREE: DISCRETE EVENT SIMULATION AND SYSTEM DYNAMICS APPROACHES

3.1 Introduction

Among a variety of computer simulation modelling approaches, discrete event simulation (DES) and system dynamics (SD) are the two most widely used simulation approaches for modelling health care systems. The main reasons being that these two approaches have the abilities to model health care systems, with regard to its uncertainty, variability and complexity. In which, DES modelling is known for simulating processes which involve random events and stochastic data or elements. Conversely, SD modelling is known for studying complex systems which include multiple stages and feedback relationships.

The aim of this chapter is to examine the methodology of these two simulation approaches, and to review the use of these two approaches for health care management. Although simulation is known for supporting various health care decisions in many application areas, each of these approaches has its own limitations. This chapter will discuss these potential limitations in detail. As computing technology is becoming more advanced, increasing simulation software packages are available in today's software market. Arena® is one of the popular simulation packages for building DES models. Stella/iThink are specialised for building SD models. The characteristics and functions of these simulation packages will be briefly introduced in this chapter.

3.2 Discrete event simulation in health care

Discrete event simulation is an analytical simulation tool which can be used to model systems that involve a network of queues and activities. Systems to be simulated in DES models are considered to consist of discrete entities, in which the state variables change instantaneously in discrete time. Since DES has the ability to model uncertainty and variability, increasing interest and studies are using DES to model health care systems in many application areas (Brailsford and Hilton, 2000).

3.2.1 Theory and methods

Discrete event simulation models have traditionally been applied to address decision making at a tactical and operational level since the early 1950's. Since then, DES approach has been widely used in manufacturing, health care and public service sectors (Pidd, 2003). Systems operated in these industries are usually stochastic in nature, which require a modelling approach capable of dealing with distinct entities, scheduled activities, queues and decision rules (Brailsford and Hilton, 2000). In comparison to other computing simulation tools, DES is generally the most suitable tool when the system details need to be modelled and individual items need to be tracked (Morecroft and Robinson, 2005).

In general, the aim of DES models is for performing 'what-if' experimentation. Decision makers can use the models to investigate the effects of various scenarios and to predict the performances of different proposed policies. The basic function of a DES model is shown in Figure 3-1.

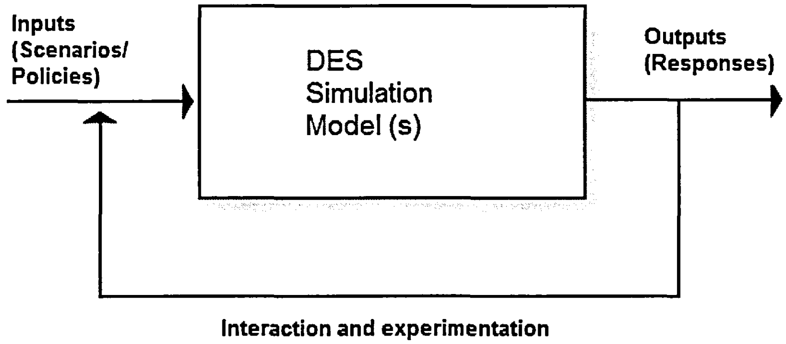


Figure 3-1 Basic function of a discrete event simulation model (adapted from Pidd, 2003)

3.2.2 Objects in a DES model

Within a DES model, there are several system components which need to be identified and defined in the first place. First of all, objects of the system. In a DES model, these objects are usually known as *entities.* An entity can be a dynamic object that moves around, changes status, interacts with other entities and affects the output performance measures (Kelton *et al.,* 2010). In a hospital, this type of entity could be patients. One of the characteristics of a DES model is each entity can have its individual characteristic. For instance, each patient can be modelled with different individual characteristics (for example age, gender, diagnosis, disease status and blood group etc.) which may be used for deciding their pathways throughout a diagnostic process. These individual characteristics are usually called *attributes*.

An entity can also be a tangible *resource* within a DES model. In a hospital, these types of resources might be doctors, nurses or beds. Logically, an entity (patient) seizes resource (doctor) when it is available and releases this resource when an activity is finished. However, in some cases when resource (doctor) is not available, the entity (patient) needs to join a *queue* before the resource becomes available. In DES, this type of queue may be served in a FIFO (first-in, first-out) manner, LIFO (last-in, first-out) manner, or ranked on some attribute in increasing or decreasing order (Law, 2007).

3.2.3 Logics in a DES model

In definition, one of the important mechanisms of a DES model is it consists of discrete entities, in which the state variables change instantaneously in discrete time. Thus, within a DES model each entity can have different *states* in different time. For instance, a patient may include states like "waiting in triage", "being examined" or "waiting for doctor". Similarly, a nurse may include states like "examining a patient", "operating a treatment" or "documenting a case".

Basically, each entity must be in one state or another at any point throughout their time in a simulation. The current state of an entity will only change when an *event* occurs that is associated with it. In DES, an event is something that happens at an instant of time that might cause states to change. An *activity* begins with an event and ends with an event. In Figure 3-2, "t_1" to "t_6" marks the time of an event occurring. Therefore, the state of entity 1 has changed from "State 1" to "State 2" at event time "t_3", and this state has changed from "State 2" to "State 3" at event time "t_4". Logically, each entity has its own life cycle in the simulation, and each of them is called a *process*. A process is basically a collection of events or activities.

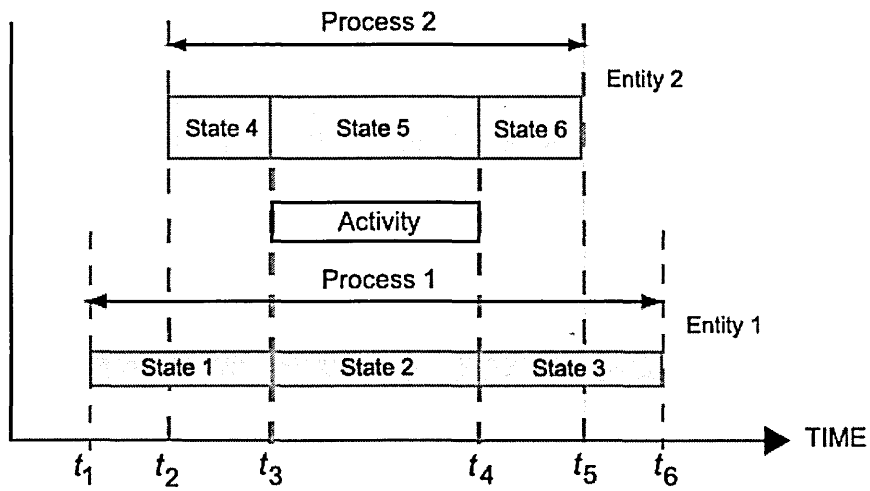


Figure 3-2 Relationship between states, events, activities and processes (Pidd, 2003)

3.2.4 Operations in a DES model

Another key part of a DES system is the time-advance mechanism. In DES, *simulation clock* is a variable that represents the current value of simulated time in a simulation. Time-advance is a mechanism that advances the simulated time from current value to another. There are two basic approaches for controlling the time advance, one is *next-event time advance* and another one is *fixed-increment time advance* (Law, 2007).

With next-event approach, simulation clock is advanced from the time of one event to the time of the most imminent event. The time between these events is ignored. On the other hand, fixed-increment approach advances the simulated time at fixed intervals (e.g. every 5 seconds) even if there is nothing going to happen at that time. As mentioned previously, state changes will only occur at events. Therefore, next-event approach is comparatively more efficient and allows models to be executed more quickly when compared to fixed-increment approach. In fact, next-event time advance is the most commonly used approach by most of the major DES simulation software companies.

Figure 3-3 illustrates the operation flow in a DES model (Law, 2007). In which, next-event time advance approach is used. Technically, simulation begins at time 0 when the main program invokes the initialisation routine to reset simulation clock, system state, event list and statistical counters to their initial status. *Event list* is one of the main components in DES, which holds a record of information for the most imminent event. Once simulation finishes the initialisation routine, main program invokes the timing routine which checks with the event list to determine the next event type. At the same time, simulation clock is advanced to the time of the next event. Main program then invokes the event routine, in which system state, statistical counters and event list will be updated. These two routines will keep repeating until the stopping condition of the simulation is satisfied. Finally, main program invokes the report generator to produce a simulation report.

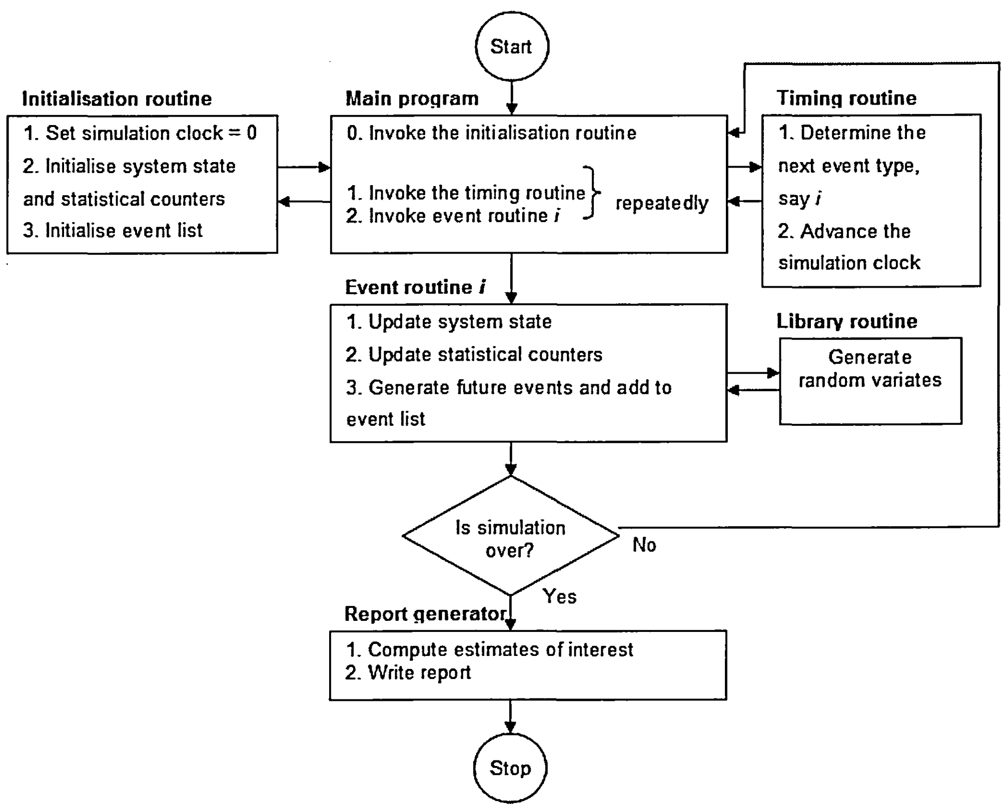


Figure 3-3 Operation flow in discrete event simulation model (Law, 2007)

One of the main advantages of DES is that it can model random events. This is achieved by a method of generating or obtaining numbers that are random. Law (2007) describes this as a process of "*generating random variates*", which to generate random observations from probability distributions. Pidd (2003), Law (2007) and Kelton *et al.* (2010) provide detailed explanation regarding the mechanism of random number and probability distributions that are used in DES.

3.2.5 Use of discrete event simulation for decision making

Literature reports a wide range of areas where DES has been successfully used in the health care sector (Fone *et al.,* 2003; Brailsford, 2007; Gunal and Pidd, 2010). These applications can be classified into two main areas: medical and operational areas.

For instance, to support analysis in *medical* issues, DES has been used to model human health behaviours (Brailsford, 2007) and the spread of infection and communicable disease such as Chlamydia or HIV/AIDS (Fone *et al.,* 2003). These models improve the understanding of the complex issues and help to test different policies in medical practice. The key benefits of these applications are that experiments can be performed without putting patients in inconvenient situations or placing them at risk.

In recent years, increased DES models have been reported for supporting health care decision making and planning in the *operational* areas (Gunal and Pidd, 2010). These models have been widely used for understanding the patient flow and resource allocation within Accident and Emergency (A&E) department, outpatient clinics or/and inpatient areas.

In 2008 the NHS institute launched Scenario generator (NHS, 2008) – a generic simulation tool that allows health care clinicians or/and operational managers to develop scenarios to examine the impact of changes on patient flow, capacity, end-to-end transaction times (including delays and waits) and operating cost across the whole system. Similarly, Gunal and Pidd (2008) develops DGHPSim that allows hospitals to utilise their existing local data or national data set in the DES models. The aim of DGHPSim is to allow operational managers to examine the changes of the whole hospital performance under different circumstances. However, literature shows this type of generic DES models is still not commonly used in the sector (Gunal and Pidd, 2010). One possible reason is the difficulty to represent the complexity of a whole hospital's activities within a simulation model.

Therefore, the majority of simulation models are commonly used to model only a specific aspect, such as A&E department, inpatient areas, outpatient clinics, operating theatres or intensive cares units (Gunal and Pidd, 2010). In which, A&E department is one of the most popular units for health care simulation. The main reason is this unit is relatively self-contained and patient pathways are usually more well-defined.

Kolb *et al* (2008) report a case study to use DES models to examine the potential benefits to an A&E unit if a new proposed buffer concept is implemented. This new buffer concept aims to relieve overcrowding pressure in the Emergency Room (ER) by introducing five buffer areas. The simulation results show that the new buffer concept can successfully reduce the overcrowding pressure in the ER room, also all buffers are managed to run with less resources then in the ER room. Other examples include Ruohonen and Teittinen (2006) and Meng and Spedding (2008) which both present detailed case studies of building A&E simulation models for specific hospitals.

Apart from A&E units, a large number of DES models have been used to model outpatient units. Literature shows these models commonly used on two main areas: scheduling and capacity planning (Guo *et al.,* 2004; Giachetti *et al.,* 2005; Takakuwa and Wijewickrama, 2008).

Guo *et al.,* (2004) and Giachetti *et al.,* (2005) both use DES models to address problems in patient appointment scheduling. Guo *et al.,* (2004) presents a detailed simulation model ("Patient Scheduling Simulation Model –PSSM") for examining the relationship between the current triage rules and resource utilization rates. The study showed that PSSM can provide a good understanding of the current situation and can be used to examine different scheduling strategies. Giachetti *et al.* (2005) presents a new patient appointment scheduling system ("Open Access") for addressing the problem of backlog appointments and high no-show rate. The open access policy is tested in a DES model, and the study showed that patient throughput time could be reduced significantly through better management of the schedule. Other examples include Takakuwa and Wijewickrama (2008) who present a case study that introduced an improved Doctor Scheduling Mix (DSM) policy. A detailed DES model was developed for this specific outpatient unit, by integrating with the optimization technique, the study showed the best scheduling options for reducing the long waiting time and increasing the utilization rates of the current staff.

The literature has many other examples of DES models for addressing various operational issues in other hospital units. For example operating rooms, critical-care units, screening units, surgical units, pharmacies and laboratories. Gunal and Pidd (2010) report a detailed review of these applications.

3.2.6 Limitations

Although discrete event simulation has great potential to support better decision making and planning in the health care sector, some authors have identified several limitations regarding the use of DES in the sector.

First of all, the majority of DES models require large amounts of quantitative, numerical data input to the simulation. Health care modellers often invest a great deal of effort to collect and analyse historical data that may or may not be available within the system (Brailsford and Hilton, 2000). However, without this accurate data, simulation models can only produce "garbage".

Brailsford and Hilton (2000) also argue DES models often produce a vast range of output results, including the whole distribution of possible outcomes and results. This situation often happens when simulation is used within a highly variable environment such as the health care sector. However, special care and necessary statistical skills are often required for analysing these simulation results.

As discussed earlier, in most cases, the development of health care DES models are limited to model specific units, and to address specific problems (Gunal and Pidd, 2010). One possible reason for this limitation is the complexity of modelling a whole hospital in one single DES model. However, this type of unit-specific model usually cannot see a holistic view of the whole system and ignores the importance of what is happening over the other side of the system. In addition, given the specific nature of this type of model, reuse of the model is often restricted.

3.2.7 Discrete event simulation software package: ARENA

Arena is a general-purpose simulation package that supports discrete event simulation model development. Arena has been widely used for modelling manufacturing processes, supply chain systems, health care systems and call centers. Since Arena runs on a Windows Platform, it inherits the advantages of embedding other Windows-based applications [such as Crystal Reports, Microsoft Visual Basic for Applications (VBA) and Microsoft Excel] within a model.

Arena provides users with a number of “templates” for constructing a model. Each template contains different modules (a module contains logic, user interface and options for animation) or SIMAN blocks (a building block contains SIMAN simulation language). The basic templates include for example basic process, advanced process, advanced transfer, flow process, support, blocks and elements. Apart from these given templates, users can create customised modules for representing specific process and store them in a new template (Law, 2007).

An example of General Practitioner (GP) clinic system

A very simple DES model of a general practitioner clinic system is modelled in Figure 3.4, which consists of a registered nurse and a doctor. Figure 3.4 shows the five required SIMAN blocks and the necessary connections to define the entity flow. The "Create" block is used to generate arrivals of patients. The Create block is connected to the "Seize", "Delay" then "Release" blocks, which are the required blocks to represent the processing of a patient with a registered nurse. Once again, this set of blocks is connected to another set of processing blocks to represent the processing of a patient with a doctor. Once a doctor has finished seeing a patient, this patient will exit the model which is represented by the "Dispose" block.

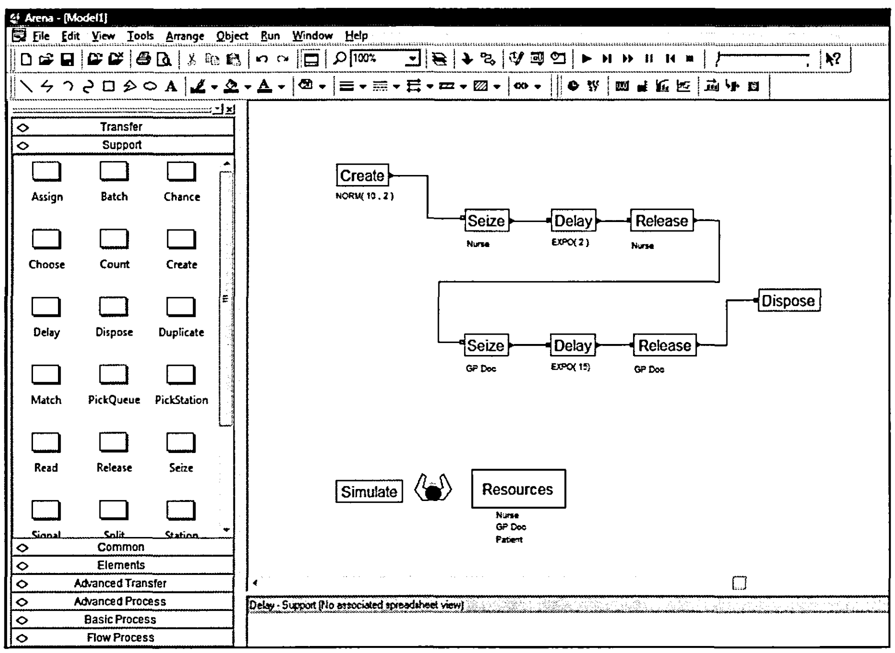


Figure 3-4 Arena model for a GP clinic system

Arena also has the feature to include two-dimensional animation and dynamic graphics. Figure 3.5 shows the animation snapshot of the GP clinic system example.

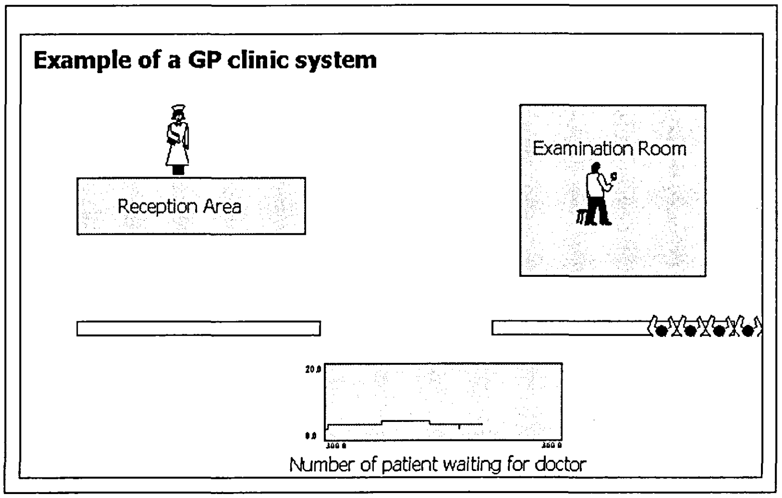


Figure 3-5 Arena animation for the GP clinic system example

3.3 System Dynamics in health care

System Dynamics is an approach to model the dynamic behaviours of a system, such as population, ecological, social and economic systems. It can support the understanding and analysing of the interactions, feedback relationships and the underlying structure between system elements. In health care, applications of SD models are still not widely applied when compared to the DES approach. One of the main reason is SD cannot model the effects of stochastic variation and individual patients within a system (Lane *et al.,* 2000). Nevertheless, increasing studies and research have used SD approach to model health care systems in a more strategic perspective (Lane *et al.,* 2000; Dangerfield, 1999; Lane and husemann, 2008).

3.3.1 Theory and methods

System dynamics was first called “Industrial Dynamics” (Forrester, 1961). The underlying concept of the approach is to combine the power of the human mind with the strengths of today’s computing technology (Keough and Doman, 1992). SD combines two distinct approaches: qualitative and quantitative. Qualitative approach concerns with defining problems, identifying the factors bearing on the problem, and recognising the feedback loops with relate materials, information and decisions. Quantitative approach involves building simulation models which can be used to understand the actual system performance, and to experiment the consequences of different courses of action on system behaviour.

3.3.2 System structure in system dynamics

In order to understand the dynamic behaviours in system dynamics, there are three major system components that need to be identified i.e. levels, rates and delays (Pidd, 2003).

Levels and Rates

Levels (or stocks), are the accumulations of resources within a system. In SD, it is used to represent the current value of a variable, for example the number of patients waiting in triage area or the number of doctors on duty. On the other hand, rates (or flows), are the control variables which determines the levels. It includes inflow rate and outflow rate. In an example of a clinic system, inflow rate may be the patient arrival rate and outflow rate can be the doctor seeing patient rate. Figure 3.6 is an example of a tank which shows the basic relationship between levels and rates.

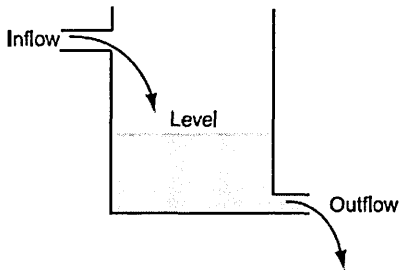


Figure 3-6 Relationships between levels and rates (adapted from Pidd, 2003)

Delays

In system dynamics, there is another important system feature which is necessary to identify - Delays. In most of the human systems, delays occur because of different reasons. Resources and information within a system are rarely transferred instantaneously. For example, after a patient takes medicines, it usually takes a few hours or days before the patient can totally recover. Figure 3.7 shows the patient recovery status over time. Since these delays can directly affect the overall system's behaviour, it becomes one of the key parts when analysing a feedback system.

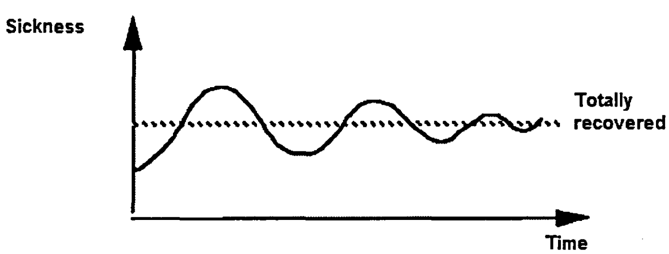


Figure 3-7 Patient recovery status over certain times

3.3.3 Type of diagrams in system dynamics

SD approach provides two main types of diagrams for supporting the qualitative and quantitative analysis of the feedback systems. They are causal loop diagrams and stock and flow diagrams.

Causal loop diagrams

Causal loop diagrams or as they are sometimes referred to, influence diagrams (Coyle, 1977) or cause and effect diagrams (Wolstenholme, 1990) are concerned with analysing the qualitative aspect of feedback systems. Pidd (1998) defines this as an important process to define the "structure" of how each element interact within a system.

To construct a causal loop diagram, the initial step is to identify any system elements which cause effects to the system. Then, the identified system elements are connected by arrows that indicate causality. In addition, the "+" and "-" signs are used to indicate the effect of the causality. Figure 3.8 shows a simple example of a causal loop diagram. That is, as *patient admission rate* increases *the number of patients in ward* increase, therefore a "+" sign is used. Similarly, as *patient discharge rate* increases *the number of patients in ward* decrease, therefore a "-" sign is used.

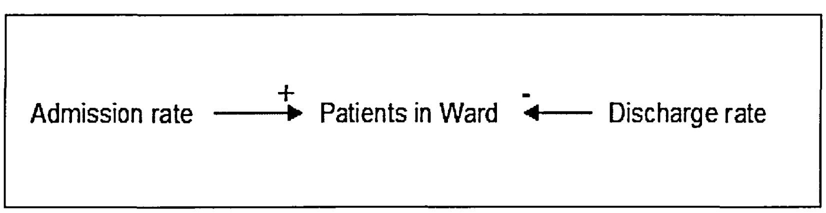


Figure 3-8 an example of a causal loop diagram

Obviously, a real-world system contains more system elements which their interactions are identified as different "loops" (Brailsford, 2000). There are two types of loops: balanced loops and reinforcing loops (Brailsford, 2000) often referred to as negative feedback loops and positive feedback loops (Pidd, 2003). By understanding the nature of these loops within a complex system, the modeller can achieve a better understanding of the system behaviour and it can be a very useful initial diagram for guiding the development of a quantitative system dynamics model.

Stock and flow diagrams

Stock and flow diagrams or as they are sometimes referred to, quantitative diagrams (Wolstenholme, 1990) or flow diagrams (Riachardson and Pugh, 1981) are used to construct system dynamics model that can represent the interactions among levels, rates and delays. The model can be used to gain a better understanding on how these system elements cause changes to the system behaviour. In addition, alternative strategies and system structures can be tested and examined.

There are four well-known software packages which can support the building of system dynamics models. They are Dynamo, iThink/Stella, PowerSim and Vensim. In which, iThink/Stella are the most popular choices for the non-programmer. It is mainly because of their user-friendly interface and good quality graphics developed by the Macintosh computer. A more detailed discussion on iThink/Stella will be described in Section 3.3.4.

Figure 3.9 shows an example of a stock and flow diagram that has been constructed from the causal loop diagram shown in Figure 3.8. The diagram shown in Figure 3.9 consists of four main symbols.

(1) Two "*clouds*" represent a source and a sink, which are the materials (in this case, patient) that flow through the system.

(2) The rectangular "*Patient in Ward*" represents a level (or a stock); in this case the number of patients within the ward.

(3) The circles with the tube lines "*Patient admits to ward*" and "*Patient discharged from ward*" represent the actions that patients flow into and out from the ward.

(4) The number of patient flow into and out of the ward is controlled by the rates, which are represented by "*Patient admission rate*" and *Patient discharge rate*".

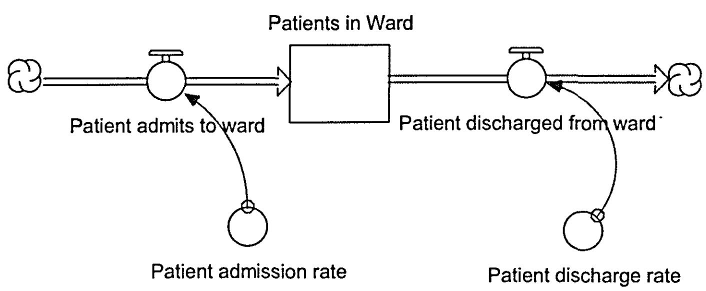


Figure 3-9 Example of a stock and flow diagram

In order to simulate how the system behaviour and variables change over time, modellers can enter relevant numerical data to the model. This data can include integer, equation or graphical format. Nevertheless, compared to DES model, SD models do not required accurate historical data in order to produce valid results. In SD approach, identifying system structure is the priority, in most cases model data is simply anecdotal or estimated data (Sweetser, 1999).

3.3.4 Use of system dynamics for decision making

System dynamic models have the capability to study how different system elements interact to produce influence to the overall system behaviour. These models are often used to support strategic policy analysis, such as strategy development, analysis of policy structures, and analysis of dynamic systems where interactions of flows and information are the key considerations.

In the health care sector, SD has been applied to address complex health care issues which involve large population and resources since the 1980s. In the early years, SD modellers mainly focused on the *use of qualitative SD diagram* to gain a better insight into the health care systems. In which, examining the underlying issues related to the waiting list problems is one of the main application areas.

Wolstenholme (1993) demonstrates the use of qualitative diagrams to evaluate the potential consequences from a new national policy (Figure 3.10). The main target of the new policy is to save public funds by transferring the responsibility of elderly from the community care to the Personal Social Services Directorates in which the department has cash limited budget imposed upon them. Wolstenholme's model shows the new policy could cause a serious problem to the community as limited funding will restrict social services to accept more discharge. Therefore, fewer beds become available for new admission. Because of this feedback effect, more sick and elderly will be waiting for admission and thus community care costs will eventually arise.

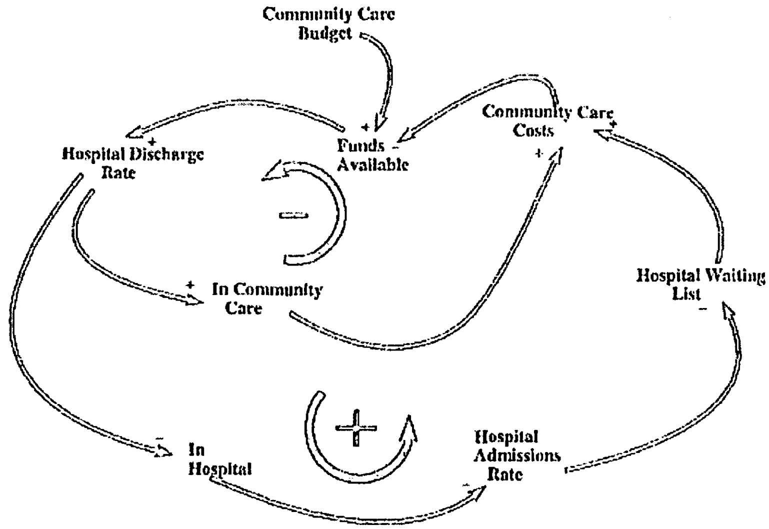


Figure 3-10 Main feedback loops of the community care model (adapted from Wolstenholme, 1993)

A similar study has been conducted by van Ackerre and Smith (1997). The study demonstrates a case study of using causal loop diagrams to study the negative effects from introducing extra public sector health care to target the waiting list problem for the NHS. The diagram demonstrates extra support from private care could only temporary reduce the excessive patient demand. Since by the time the NHS waiting lists are cleared, more people will come back to the NHS thus the problem can reappear.

Since the late 1990's, increased interest and studies have combined the *use of causal loop diagram and stock and flow model* in order to gain a holistic view to analyse the dynamic behaviour of health care systems (Lane *et al.,* 2000; Brailsford *et al.,* 2004; Lane and Husemann, 2008 and Desai *et al.,* 2008). The general approach used in these studies is to apply causal loop diagram to understand the feedback structure of a system, then develop stock and flow models to simulate how various system elements interact as a whole can cause influences to the system behaviour.

In which, A&E department is one of the main focuses for the approach. Brailsford *et al.* (2004) developed SD models to investigate the whole emergency and unscheduled care system in the city of Nottingham, England. Brailsford *et al.* identify the use of SD approach is ideal for the study as the system can involve up to 600 000 patients. Using other analytical tools such as DES, it is difficult to model this volume of people and alternative patient pathways as a whole. Another well-known example is conducted by Lane *et al.* (2000), which the study aims to explore the underlying problems which cause delays in the A&E. Figure 3.11 shows the causal loop diagram (left hand side) and the high-level stock and flow diagram (right hand side) which were developed in the study. It has been argued by policy makers that the underlying problems were mainly caused by bed shortages in hospital wards, and inadequate doctor capability. The key outcome of the study counters the above hypothesises and proves even with increased beds and doctors, there is no significant improvement to the overall performance. Instead, the critical factor to the delays is the cancellation of elective admission which led to more patients present in the A&E department.

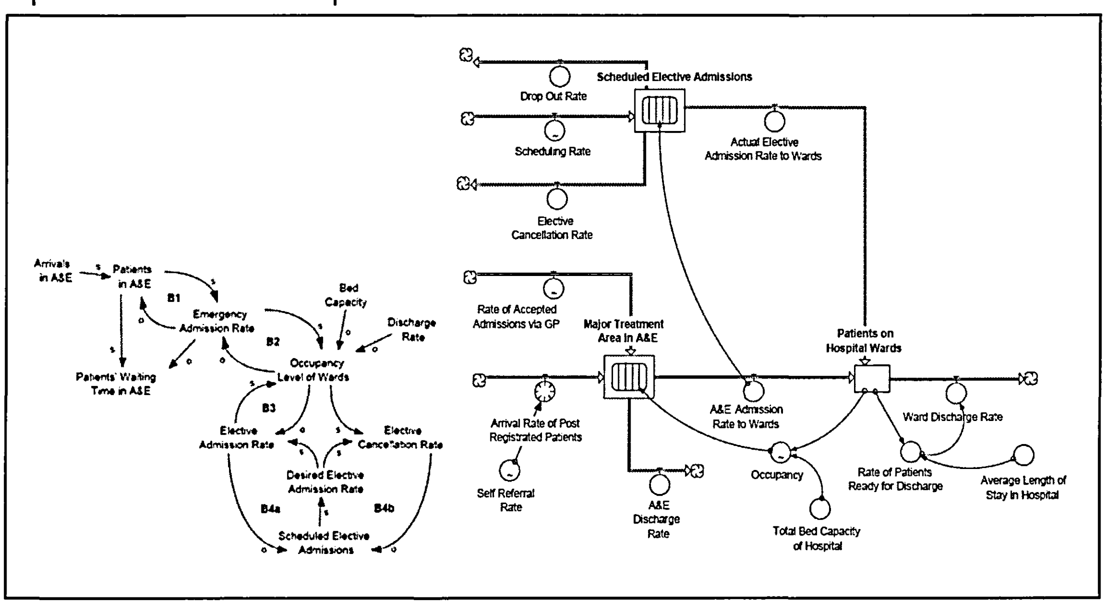


Figure 3-11 Causal loop diagram and stock and flow model from the A&E study (adapted from Lane *et al.*, 2000)

In health care literature, SD approaches have been used to address many other specific health care issues, such as to explore the sensitivity between demand of adult services and ageing population (Desai *et al.,* 2008), to investigate how hospital waste management system can affect the public health (Chaerul *et al.,* 2008), to understand how different human behaviour (e.g. word of mouth) can directly affect the number of users for a new health service centre (Rohleder *et al.,* 2007) and to analyse the spread of HIV/AIDS (Dangerfield,1999) or Chlamydia infection dynamics within a population (Evenden *et al.,* 2005).

3.3.5 Limitations

Given the flexibility of the SD approach, increasing interest and studies have used SD to analysis dynamic processes within the health care sector. However, these studies are often used only in strategic policy analysis. One of the main reasons is SD focus mainly on modelling overall system performance rather than detailed representation of a system. Therefore, when compared to DES approach, SD cannot model how individual patient changes states, where queues or backlogs form, and how a process operates within a system.

On the other hand, the accuracy of SD models is also one of its pitfalls. Since real systems that SD models represent are inherently dynamic, in which intangible variables (such as human behaviour) often play an important role for this dynamic behaviour. However, intangible variables are often difficult to quantify thus modellers have to rely on anecdotal data or experiences from relative health care experts.

3.3.6 System dynamics software package: Stella/iThink

The key principle of system dynamics software is to provide a user-friendly interface for modellers, which enable users to clearly visualise how each system components and processes works in relation to the other. As mentioned in Section 3.3.1, Stella/iThink is perhaps the most widely known SD software for building stock and flow model within the recent years.

Stella/iThink was originally developed for the Apple MacIntosh environment, but it is also able to run on Microsoft Windows-based systems. When the use of Stella is usually targeted on education and research, iThink is usually targeted on the commercial users. This research will focus on the use of Stella software.

Figure 3.12 shows a snapshot of the interface of Stella, together with the example discussed in Figure 3.9. Each icon from the top toolbar represents individual functions, for example level, inflows/outflows and rates. In addition, there are some graphical functions which enable modellers to show how variables change over time by using flow charts or tables.

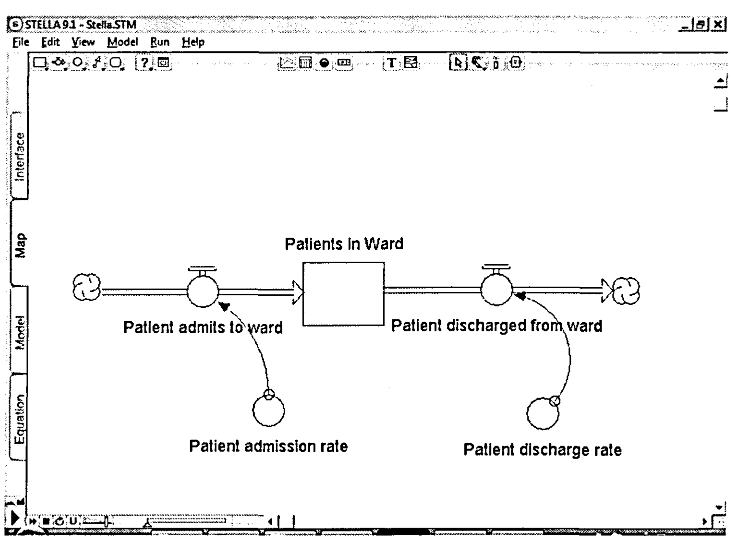


Figure 3-12 Snapshot of Stella interface

In order to execute a model, data must be inputted into the model after a diagram map is finished. This data can be integer, equation or in graphical formats (Figure 3.13 and Figure 3.14 show the appearances of the data input interfaces)

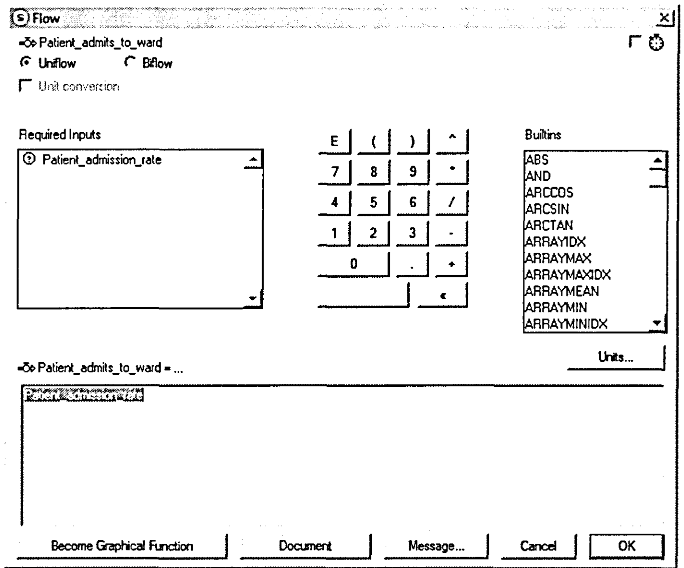


Figure 3-13 STELLA data input interface (integer/equation format)

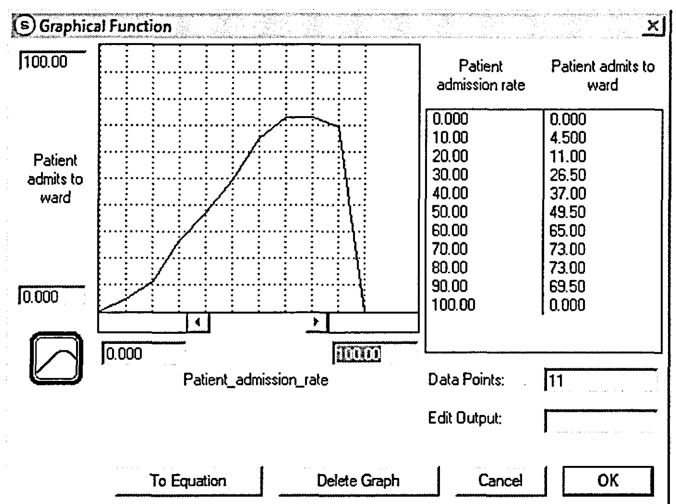


Figure 3-14 STELLA data input interface (graphical function format)

The Stella system is able to read the diagram and can generate some of the equations automatically. Figure 3.15 shows the interface of the equation module.

Figure 3-15 STELLA equation interface

Once modellers confirm the diagram and the input data, the model is ready to "Run". The Stella system bases on the specifications (e.g. the run time unit, run time period etc.) and starts the simulation. Figure 3.16 shows the simulation result of the example.

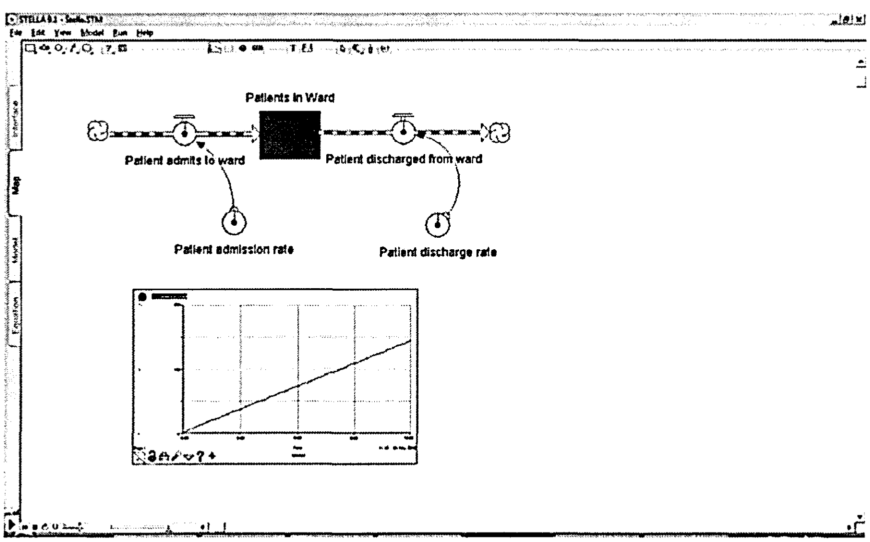


Figure 3-16 STELLA interface - after simulation run

3.4 Summary

This chapter introduced the main principles of DES and SD, and detailed how these two approaches have been used for supporting decision making in the health sector. Section 3.2 presented the methodology related to DES modelling including theory, objects, logics and operations. This section reviewed the literature and discussed examples of using DES for supporting various health care decision making. Limitations of using DES models in the health sector were also discussed. A general-purpose simulation package that supports DES model development was introduced and demonstrated with an example.

Section 3.3 presented the methodology related to SD modelling which included theory, system structure and two types of SD diagrams. This section reviewed the literature and discussed examples of using SD approach for addressing various health care decision making. Limitations of using SD approach within the health sector were discussed. One of the widely used SD software was introduced and demonstrated with an example.

The understanding of the principles and applications of these two simulation approaches forms the basis for the development of the proposed framework.

4 CHAPTER FOUR: FRAMEWORK METHODOLOGY AND CRITICAL COMPONENTS

4.1 Introduction

Chapter two presented a number of underlying barriers for embedding S&M in the health sector. The chapter concluded by proposing a holistic implementation framework to guide health care managers and practitioners to address the underlying barriers in order to fully embed S&M within their organisations. This chapter presents the development approach of the proposed implementation framework and describes the methodology used for validating the proposed framework. The overall structure of the research approach is presented in Section 4.4 which summarises the main research activities and the key objectives of each research activity.

Additionally, this chapter presents an initial framework which includes the five critical components that are then used as a basis for developing the implementation framework. This chapter also presents the findings from the literature review, the author's experience and interviews that relate to the success factors for embedding S&M in the health sector. These identified success factors are then mapped with the five proposed components to ensure the proposed framework components are sustained by sound theory.

4.2 Framework development

As the review of literature shows, there was no evidence found that simulation and modelling (S&M) has been embedded in the health sector. Some of the literature identifies elements that should be present to successfully develop a health care model; however no holistic framework exists to help health care managers and practitioners embed S&M as a routine tool for decision making.

This research proposes the development of an implementation framework that can be used by health care managers and practitioners to guide them in successfully embedding S&M. The author developed an initial framework called SIMT (**SIM**ulation **T**hinking) based on the literature review, author's knowledge and experience in embedding simulation techniques in the manufacturing sector, and interviews with appropriate experts from the health care sector (See Figure 4.1). The SIMT framework is used as a guideline that presents the important elements required to be considered to make S&M as a mainstream tool. Further work developed the SIMT framework into a structural implementation framework (called "SIMT implementation framework").

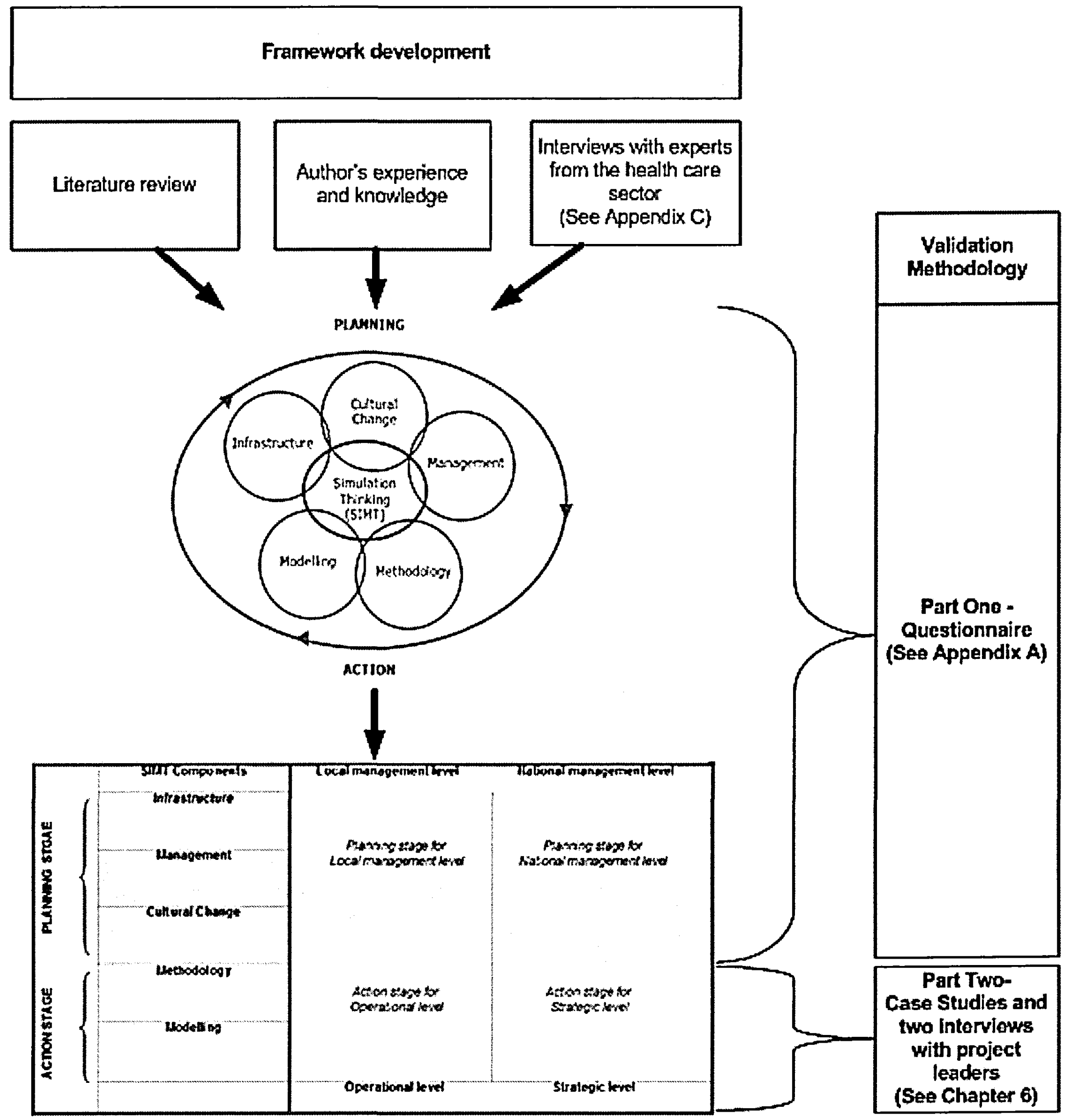


Figure 4-1 Framework development and validation methodology diagram

The SIMT implementation framework is used to prescribe how S&M can be embedded for supporting various clinical decision making at national or local management level. The proposed implementation framework includes the SIMT components, with a detailed roadmap for guiding the initial planning (planning stage) and the methodologies and activities (action stage) required to successfully embed S&M within the sector.

4.3 Framework validation methodology

In order to validate the proposed framework in a holistic approach, this research adopted a mixed-methods approach (Johnson and Turner, 2003), through the use of questionnaire to collect quantitative data, and case study techniques to collect qualitative data.

The validation includes two parts. The first part validates the initial framework components together with the planning stage of the implementation framework by a questionnaire. The second part validates the action stage of the implementation framework by applying it to a local hospital. A combination of semi-structured interviews and questionnaires was followed to collect relevant feedback (See Figure 4.1).

4.3.1 Part one validation

The main aim of the SIMT implementation framework is to help health care managers or/and practitioners to successfully embed S&M. A successful implementation framework should be concise and user-friendly. On the first part of the validation, a questionnaire is used to validate the usefulness and importance towards the basic structure and the essential components of the proposed implementation framework. The questionnaire was sent to health care managers, practitioners and simulation modellers. This demonstrated how the proposed framework can be understood and accepted by this group of experts. **Appendix A** includes a sample of the questionnaire together with a brief description of the content of the SIMT implementation framework.

According to Yin (2003), the layout of a good questionnaire should be clear, and easy to follow. This questionnaire organises along five sections:

(A) *Background*

(B) *Basic Structure of the SIMT framework*

(C) *Infrastructure element*

(D) *Management element*

(E) *Cultural change element*

In order to avoid inconsistent answers and to obtain significant analysis, all the questions are designed to collect opinions from respondents utilising a five point rating scale, where 5 = *Very useful* and 1 = *No use* or 5 = *Very important* or 1 = *Not important at all*.

Data analysis

The author used one of the most widely used software packages for analysing the data collected from the questionnaire, which is called Statistical Products and Service Solution (SPSS). There are two important steps for processing data in SPSS. The first is to transform the collected data into the SPSS database, and the second is to identify statistical relationships between the answers.

In this research, author obtained the "descriptive statistics" (Leech *et al*, 2005) to summarise the collected data by using SPSS. Validation of the usefulness and importance for the proposed framework was achieved by the percentage of each rating. As all the questions in the questionnaire are using five point rating scale, the average percentage gain for each rate will indicate the levels of significance of that question.

4.3.2 Part two validation

The second part of the validation validates the action stage of the proposed implementation framework by case study approach. This part of the framework aims to provide methodologies and activities required to successfully embed S&M. The author applied the proposed framework to a local hospital as pilot project. This demonstrated how the proposed S&M approach can be used to model and analyse the existing problems in a local hospital.

Two individual pilot projects were conducted during the validation. The first one worked with the A&E team by using the DES approach to investigate the high-level operational processes within the A&E department. And the second one worked with the administration team by using the SD approach to analyse alternative strategies for targeting one of the latest national target (the 18-week waiting time target).

Data collection and analysis

Following the pilot projects, the author collected feedback from each of the team leaders. A simple evaluation form is used to collect their opinions towards the usefulness and importance of the proposed methodologies and activities. A sample of the evaluation form is attached in **Appendix B**. Two interviews were conducted with each of the team leaders (one with the DES project's leader, and the other one with the SD project's leader). These interviews aim to collect additional feedback regarding the pilot projects.

4.4 Research approach summary

Figure 4.2 provides a summary of the research approach. It identifies the research activities that are performed within the research, and the aims and objectives for each activity.

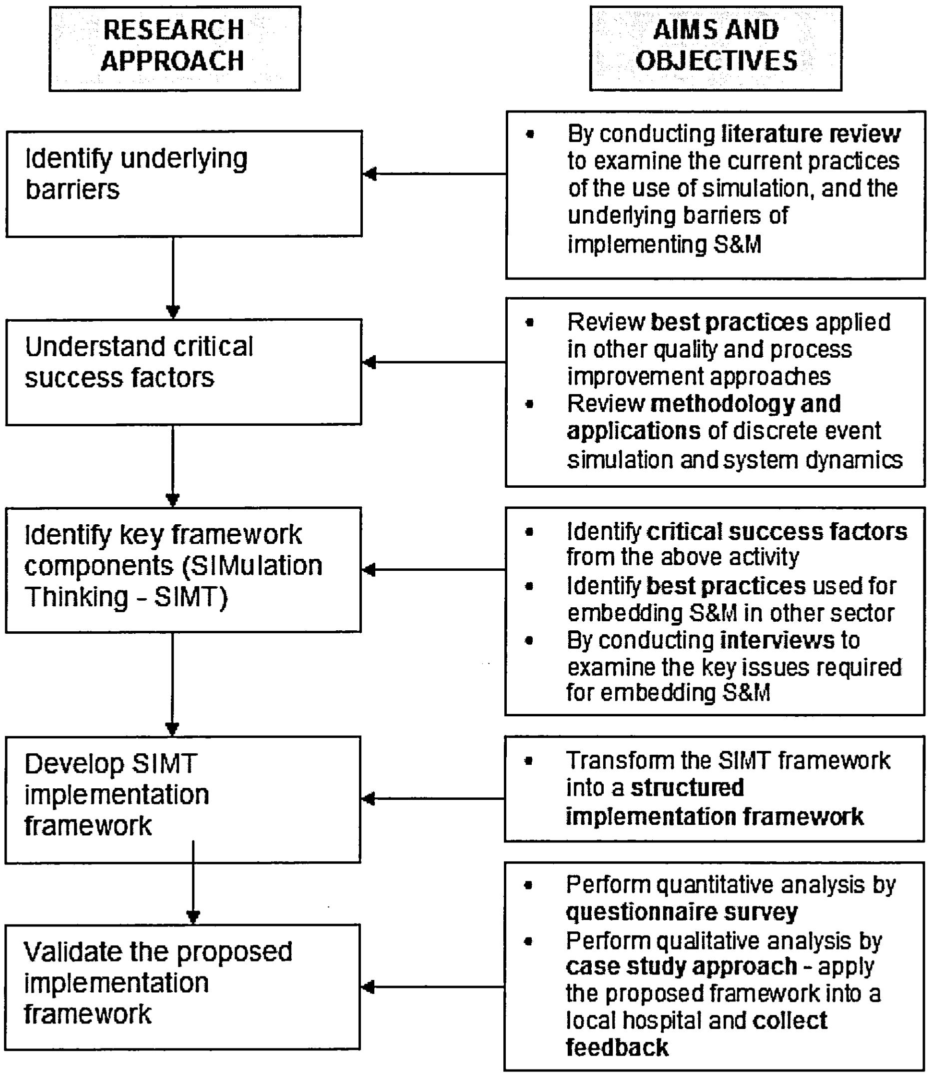


Figure 4-2 Research methodology

4.5 Initial framework components

The main purpose of this section is to present the five critical components that create the infrastructure of the SIMT implementation framework (Figure 4.3). The author identifies the critical components based on three sources: the success factors for embedding other quality and process improvement approaches in health sector, the best practices for embedding S&M in other sectors, the critical issues for embedding new systems in the NHS. All the identified success factors are mapped against the proposed five framework components to ensure they are sustained by sound theory.

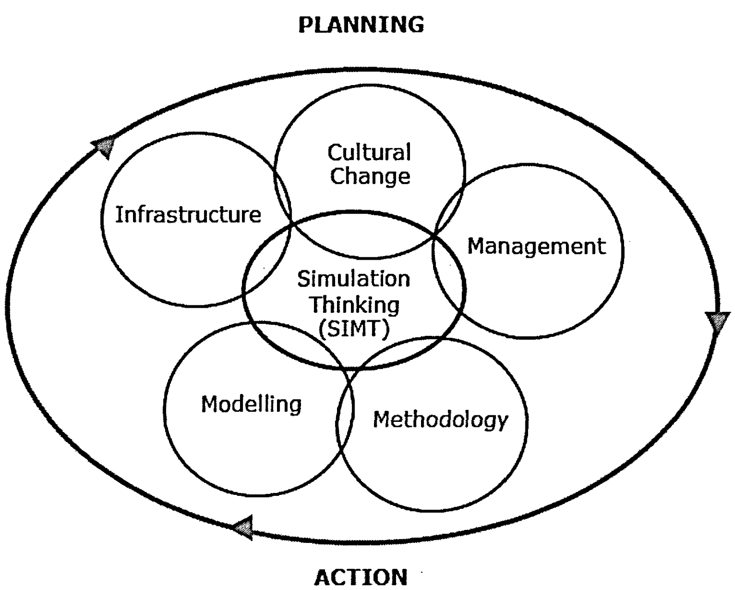


Figure 4-3 SIMT (SIMulation Thinking) framework components

Figure 4.3 shows the proposed five components which combined from the SIMT (SIMulation Thinking) framework: *infrastructure, cultural change, management, methodology and modelling*. The concept of SIMT presents the most important components required for addressing the underlying barriers of embedding S&M in the health sector (refer Chapter two – Section 2.4 for the underlying barriers). As shown in Figure 4.3, the outer circle of the framework represents the motion of the implementation approach, this motion includes two stages: *planning stage and action stage.* As Isouard (1999) states a successful implementation approach often includes a "fundamental paradigm shift". This fundamental shift is particularly vital for embedding S&M in the health sector. As discussed in Section 2.4, some of the barriers of embedding S&M in the sector are mainly due to the poor communication between modellers and the stakeholders, cultural resistance and lack of management for simulation projects. The main aim of the SIMT planning stage is to address these fundamental barriers to ensure simulation thinking can be understood, established and accepted from top to bottom management within an organisation. The planning stage of the SIMT framework includes the three critical components: *infrastructure, cultural change and management.*

The other important stage within the motion circle is the action stage. The action stage of the SIMT framework includes two components: *methodology and modelling*. As discussed, some other underlying barriers of embedding S&M in the sector are due to the difficulties of defining a 'right' problem within a complex process and lack of experience for applying the 'right' simulation approach. These issues often cause the problems of model accuracy or the model includes too much detail that no one can understand or cannot be used for future analysis. The SIMT action stage focuses on addressing these barriers which introduces the appropriate simulation approaches and skill sets in order to guide health care professionals to put the 'right' simulation into action.

4.5.1 SIMT Components

The following is a description of each SIMT component:

Infrastructure

The infrastructure component provides the fundamental elements which are essential for supporting the routine use of simulation. It includes identifying a simulation leader who can plan and communicate the missions, goals, objectives and progresses of simulation projects with different stakeholders. It includes the development of teamwork within a complex environment, which ensures simulation projects can be effectively supported by appropriate teams. This component also includes the establishment of the necessary knowledge and skill for performing simulation, which builds confidence in the use of simulation.

Management

The management component focuses on the establishment of commitment and support from the top management team (which can include finance administrators, project managers, department managers or senior doctors). This component includes strategy to identify a clear achievement plan details the missions, visions, objectives, goals, schedules, resources and roles of simulation projects. Also it includes strategy to maintain continuous communication between simulation team and management team. All these elements are essential to ensure simulation projects are well understood by the management team and to ensure that projects can successfully deliver the 'right' solution in a timely manner.

Cultural Change

The cultural change component includes developing a strategy that addresses how to develop a 'new' culture in order to embed S&M for supporting decision making. Many quality and process improvement approaches such as TQM, Lean management and Six-Sigma highlight the difficulties of changing the management culture within the health sector. This component therefore focuses on developing a strategy that can help the people becomes less resistance to S&M approach.

One of the important elements is to involve the decision makers and the affected group of staff in the processes of simulation projects. First, it can improve the model accuracy with continuous communication between simulation team and this group of staff. Second, it can help to improve their confidence on S&M by experiencing the whole process. The strategy also includes developing pilot projects in order to allow them to experience the abilities of S&M. Furthermore, it emphases the importance to clarify with health care managers and practitioners the key changes needed from the traditional management approach to a simulation approach. Therefore, a clear and consistent vision can be understood and spread out to the entire organisation.

Methodology

The methodology component provides a structural approach to support health care managers and/or practitioners to identify a suitable S&M approach for supporting various decision making. It includes the best practices for identifying simulation project objectives, defining the possible causes of a target problem. Modelling complex systems is always a challenging task, thus a well-defined problem and objectives are a key for successful simulation projects. This component also provides the key methodologies and approaches on how to carry out simulation projects for addressing clinical decisions at both operational and strategic management level.

Modelling

The modelling component provides structural guidelines for developing health care models that address decision making at both operational and strategic management level. This component includes well-organised techniques for defining patient pathway, model components and model data. Also it includes the necessary techniques for minimising the development time and effort in modelling. This includes the use of customised templates and excel-spreadsheets.

4.6 Critical success factors

The following sub-sections present the critical success factors and best practices that contributed to the proposed five components of SIMT. These critical success factors are identified from the literature review, the author's experience in embedding S&M in manufacturing sector and interviews with experts from the health care sector.

4.6.1 Success factors for embedding world-class quality and process improvement approaches in the health sector

As discussed in Chapter two (Section 2.5), many authors have identified the success factors for implementing quality and process improvement approaches such as TQM, Lean management and six-sigma quality in the health sector. A summary of these identified success factors are presented as follows:

- Manage cultural change for long-term improvement
- Establish teamwork
- Ensure customer focus
- Maintain continuous feedback to staff
- Involve senior management support
- Maintain good communication
- Senior leaders have to understand the principle of the methodology
- Create value and belief
- Secure staff morale
- Provide staff training
- Increase public awareness
- Introduce reward scheme

4.6.2 Best practices for embedding S&M in manufacturing sector

It is not the purpose for this study to investigate how S&M can be embedded in the other sectors such as the manufacturing sector. Nevertheless, literature shows that S&M has been successfully used for modelling manufacturing processes as a mainstream tool. Therefore, it is important to consider the best practices that have been identified for guiding the success of these implementations. Hughes and Perera (2009) present a five-stage implementation framework which includes the best practices to guide these professionals to embed S&M from foundation, introduction, infrastructure, deployment, to embedding. Figure 4.4 shows the basic structure of this implementation framework.

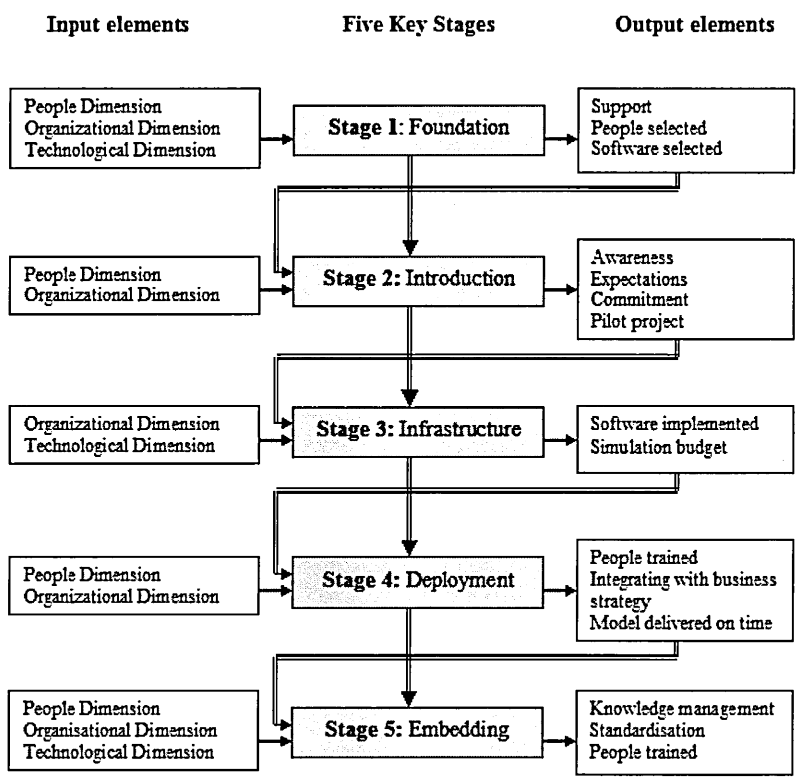


Figure 4-4 Framework for embedding simulation in manufacturing (Hughes and Perera, 2009)

The main components and the best practices are summarised as follow:

(1) People dimension

- Develop simulation team with appropriate skills
- Include simulation champion for leading the development of simulation

- Maintain good communication between team members
- Involve support from external consultants
- Involve future users during model development processes
- Provide user training on simulation experimentation and execution
- Provide user training on modelling building
- Attend simulation conference
- Share simulation knowledge

(2) Organisational dimension

- Involve senior management support
- Maintain good communication between modellers and problem owners
- Spread out the benefits of simulation across the organisation
- Involve pilot project
- Manage project time with schedule plan
- Maintain documentation for each simulation project
- Link simulation projects to the business strategy
- Standardise simulation project procedures

(3) Technological dimension

- Select and install appropriate simulation software in-house
- Develop standardised model data input and output interface
- Re-use existing simulation model

4.6.3 Critical issues for embedding new systems in the NHS

During this research, interviews were conducted with appropriate personnel from the Department of Health, the NHS and software vendors. Full details of the interviews and the analysis can be found in **Appendix C**. One of the areas from the interviews focused on the critical issues for embedding new systems in the NHS. Following is a summary of these critical issues that were identified from the interviews:

- Maintain good communication
- Integrate front-line staff to involve in new system
- Embed complex system from small area and expands to other area
- Balancing cost, time and resources
- Increase public awareness
- Provide training and seminar
- Provide accessibility to the new system
- Involve pilot project
- Introduce leadership
- Introduce punishment or/and reward system
- Ensure visibility of the benefit

4.7 Framework components to success factors mapping

This section highlights the relevant success factors and best practices for embedding S&M in the health sector. Table 4.1 maps these identified critical success factors with the proposed five components of the SIMT framework. This mapping table sustains the proposed SIMT components are based on sound theory.

Table 4-1 Framework components and success factors mapping table

SIMT Framework components	Success factors/Best practices
Infrastructure	• Develop simulation team with appropriate skills • Include simulation champion for leading the development of simulation • Involve support from external consultants • Introduce pilot project • Select and install appropriate simulation software in-house • Provide accessibility to the new system
Cultural change	• Manage cultural change for long-term improvement • Ensure customer focus • Maintain continuous feedback to staff • Create value and belief • Secure staff morale • Increase public awareness • Introduce punishment or/and reward system • Integrate front-line staff to involve in new system • development processes • Spread out the benefits of simulation across the organisation • Embed complex system from small area and expands to other area
Management	• Involve senior management support • Maintain good communication between team members • Share simulation knowledge

	• Manage project time with schedule plan • Link simulation projects to the business strategy • Balancing cost, time and resources • Ensure visibility of the benefit
Methodology	• Senior leaders have to understand the principle of the methodology • Provide staff training • Attend simulation conference
Modelling	• Provide user training on modelling building • Maintain documentation for each simulation project • Standardise simulation project procedures • Develop standardised model data input and output interface • Re-use existing simulation model

4.8 Summary

This chapter presented the development approach of the proposed implementation framework, and described the methodology used for validating the proposed framework. Figure 4.2 provided a summary of the research approach, It identified the activities that are preformed within the research, and the aims and objectives of each activity.

Section 4.5 introduced the five framework components that are the infrastructure of the SIMT implementation framework. Section 4.6 presented the findings from the literature review, the author's experience and interviews that relate to the success factors for embedding S&M in the health sector. The author then mapped the framework components to the critical success factors to ensure that the components are based on a sound theory. The mapping table has been presented in Table 4.1.

5 CHAPTER FIVE: SIMT IMPLEMENTATION FRAMEWORK

5.1 Introduction

Chapter four presented the five critical SIMT components that demonstrate the essential elements required to address the barriers for implementing simulation in the health sector. In this chapter, the author transforms these five SIMT components into a practical and holistic implementation framework – "SIMT Implementation framework". This proposed implementation framework includes flexible ways to guide health care managers and practitioners to understand how they can implement these critical components in order to successfully embed S&M in their organisations for supporting various decision making.

This chapter begins by discussing the basic structure and principle of the proposed implementation framework. Section 5.3 presents a brief description of the key activities, tools, strategies and best practices that are proposed for achieving the five critical SIMT components. The section goes into details of the approaches to implement these proposed components for guiding health care professionals to successfully embedded S&M within their organisations. The approaches include planning stage for local and national management level, action stage for modelling health care system at operational level and action stage for modelling health care system at strategic level.

5.2 SIMT Implementation framework overview

The main goal of the proposed SIMT implementation framework is to provide a practical and holistic framework that can enable health care managers and practitioners to understand how S&M can be successfully embedded in their organisations. The author's approach to develop the implementation framework is to integrate the identified five SIMT components, the major activities, tools and strategies for achieving each component and the best practices of the appropriate simulation methodologies within the framework. In which, the simulation methodologies are based on the two simulation approaches that have been discussed in Chapter three.

Figure 5.1 presents the basic structure of the SIMT implementation framework. The left table column identified as "SIMT Components" represents the framework components, which include infrastructure, management, cultural change, methodology and modelling. As discussed in Chapter four, these framework components are grouped into two main stages. First, the planning stage which for guiding the initial planning of the implementation. Second, the action stage for providing the methodologies and best practices for guiding the development of health care models.

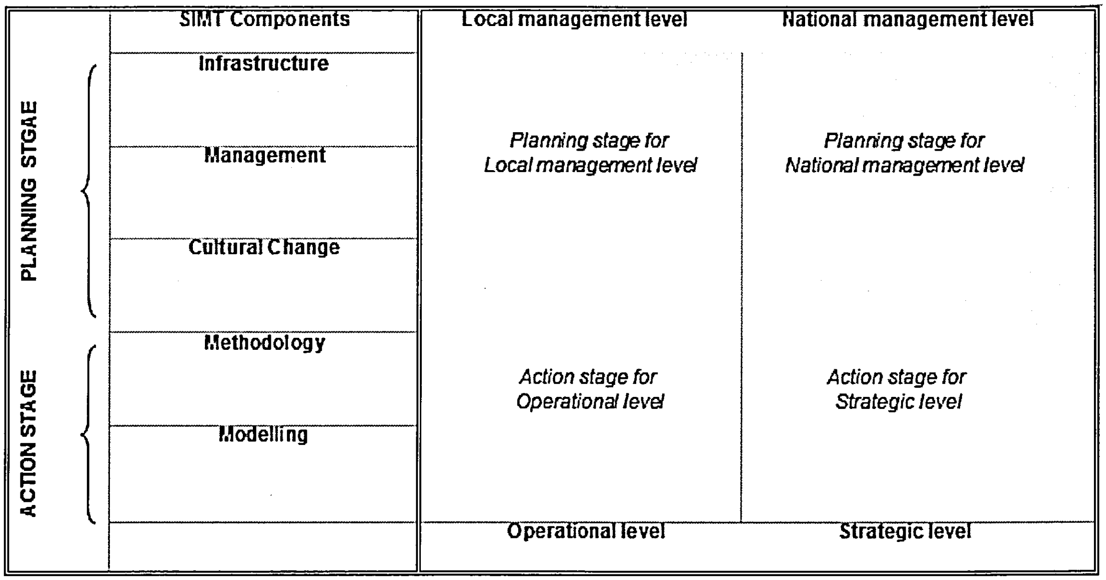


Figure 5-1 Basic structure of the SIMT Implementation framework

As presented in Chapter two (Section 2.4), the major barriers of embedding simulation into health care systems involve complexity, multifaceted structure and multiple stakeholders. Therefore, the main objective of this proposed implementation framework is to provide flexible approaches for applying the SIMT components in resolving these issues. To achieve such an objective the planning stage of the implementation framework is designed to be able to apply into local management level or national management level. On the other hand, the action stage of the implementation framework is also designed to be able to apply for handling decision making at operational level or strategic level (see Figure 5.1).

5.3 SIMT Implementation framework description

The author's approach to develop the SIMT implementation framework is to integrate the identified five SIMT components, the major activities, tools and strategies for achieving each component and the best practices of the appropriate simulation methodologies within the framework. Based on the basic structure presented in Figure 5.1, Figure 5.2 includes the highlights of the major activities, tools, strategies and best practices for each SIMT components. Details on how to apply each SIMT component for addressing issues in the planning stage and the action stage are presented in the following sub-sections.

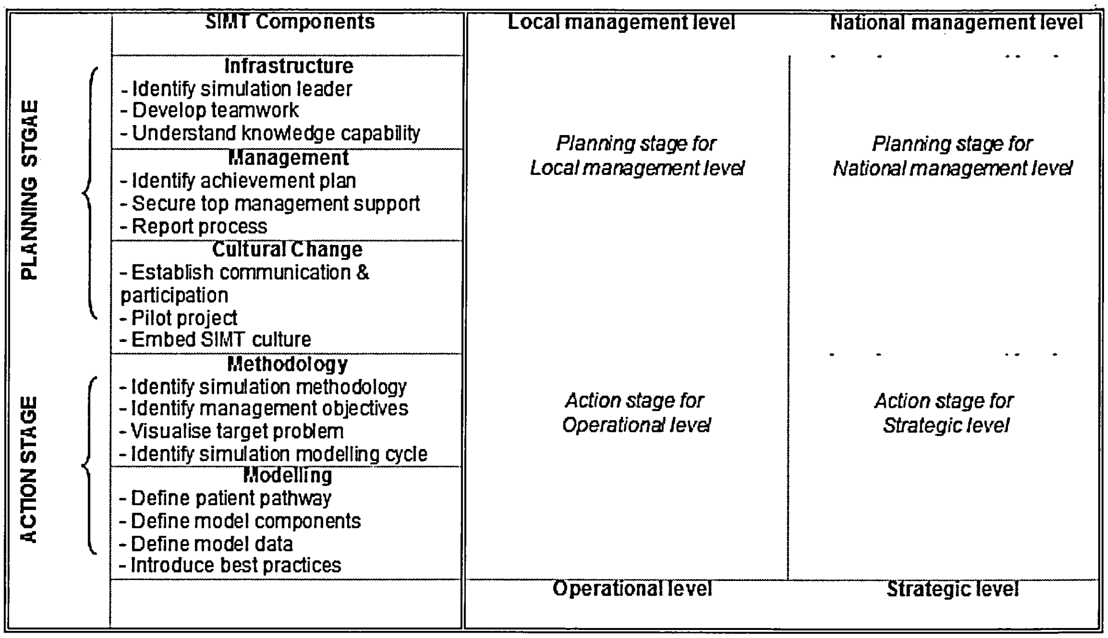


Figure 5-2 Detailed SIMT Implementation framework

5.3.1 Planning stage for local management level and national management level

5.3.1.1 <u>Infrastructure Component</u>

The goal of the infrastructure component is to ensure necessary resources are available for supporting the development of simulation projects in a long term basis. As discussed in Chapter two (Section 2.4), the majority of the health care modelling is dominated by external consultancies and/or research organisations.

Health care organisations are becoming less motivated to invest in building their own simulation models. Firstly, because they have a misconception that simulation is a complicated tool which only model experts can operate. Secondly, these health care models provided by external parties often involve expensive resources and long development time. Health care managers and practitioners are becoming less confident in the use of simulation tools.

The infrastructure components provide the following major activities and strategies that address these issues:

(1) Identify simulation leader

(2) Develop teamwork

(3) Understand knowledge capability

(1) Identify simulation leader

Most of the successful implementation frameworks include the role of leadership. Bennis (1994) explains the role of a leader is to make sure things can be done correctly. Many authors have identified the major requirements for a leader. Peck (2006) states a good leader should include some special personal characteristics for example being decisive, being honest and consistent and to be able to resolve complex problems. A good leader should also be able to lead the changes within an organisation and guide other people to follow the changes. Table 5.1 presents some basic requirements for a good leader.

Table 5-1 Leadership characteristics (Peck, 2006)

Leading and developing others	Personal qualities	Leading the organisation
• Showing genuine concern • Enabling • Being accessible • Encouraging change	• Being honest and consistent • Acting with integrity • Being decisive • Inspiring others • Resolving complex problems	• Networking and achieving • Focusing effort • Building shared vision • Supporting a developmental culture • Facilitating change sensitively

One of the other major requirements is to identify a leader within the organisation (Shacklady-Smith, 2006), not from the external parties. The main reason for this requirement is a successful leader should already understand the organisational structure, culture and management. He or she should be able to coordinate and communicate with people from the top to the bottom level.

Apart from the above basic requirements, a good leader who supports the implementation of S&M has to have sufficient knowledge of health care modelling. Although a simulation leader should not necessarily be the one who develops the model, he or she is required to have the appropriate skills to manage simulation projects from start to finish, and to make sure simulation projects can achieve the right objectives. Table 5.2 presents four key skills that are essential for a simulation leader for managing simulation projects in local management level and national management level.

Table 5-2 Key skills for a simulation leader

Key skills for a simulation leader	For local management level	For national management level
1. Achievement – oriented	- to be able to identify a well-defined problem within a complex environment - make sure simulation projects can achieve the objectives on time	- to be able to identify a well-defined problem within a complex environment that include political issues and multifaceted structure - to be able to handle large scale simulation projects and make sure simulation projects can achieve the objectives on time
2. Directive	- to be able to identify roles and responsibilities within the organisation - maintain good communication between problem owners and simulation team during projects - make sure appropriate simulation software is installed and accessible by all local users	- to be able to provide clear guidelines on identify roles and responsibilities within national level - maintain good communicate with all related decision makers, staff and simulation team during projects - make sure appropriate simulation software is selected and installed across national level
3. Participative	- to be able to spend time in the workspace to observe changes - to be sensitive in current targets and bottlenecks - participate in simulation societies and/or conferences	- to be able to review project status and make decisions on major schedule changes - to be sensitive in current national targets - participate in simulation societies and/or conferences
4. Supportive	- to be able to participate in project development and reviews - to be able to provide trainings and guidelines on the use of simulation within organisation	- to be able to participate and provide opinion in project reviews and presentations - to be able to provide trainings or guidelines on the use of simulation for national level

(2) Develop teamwork

The major problems of embedding health care simulation are the complexity of health care systems and lack of simulation experiences. In order to address these issues, identifying appropriate teams is necessary. This ensures appropriate team members are available for performing certain tasks. It can also help them to share experiences and knowledge so that the confidence of using simulation can be built up within the organisation.

There are four types of teams that are essential for supporting simulation development within a health care organisation.

- Simulation team
- Management team
- Problem solving team
- Data-supporting team

Simulation team includes the key team members for supporting the development of health care simulation models. A good simulation team should include simulation leader and simulation modellers. The size of a simulation team can be flexible, depending on the scale of the organisation.

Management team includes members from the top management, which can include finance administrators, project managers, department managers and/or senior doctors. These members are often the key decision makers from an organisation. It is important for the simulation leader to communicate with this team, in order to obtain a consistent idea of the current organisational targets, bottlenecks and future plans.

Problem-solving team includes members assembled to solve specific problem and then disbanded. These members are usually the problem-owners. Their roles are providing support and information to the simulation team for identifying, analysing and solving problems. Figure 5.3 presents the key activities within a typical problem-solving approach.

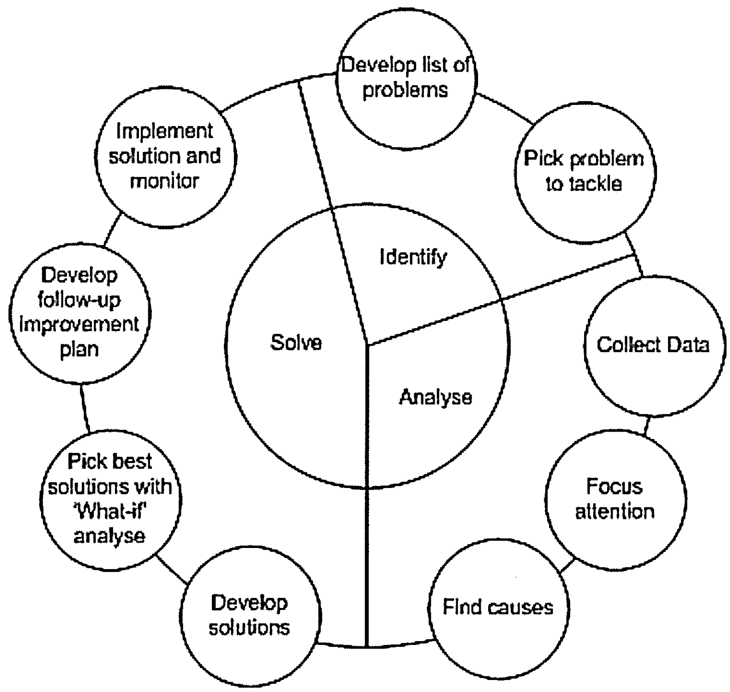


Figure 5-3 Problem solving approach (adapted from Evans and Lindsay, 2005)

Data supporting team includes members to support the data collection for simulation projects. This team is especially important if DES approach is selected for a simulation project due to the amount of quality data required for this type of models (see chapter three for details). Comparatively, since SD approach does not require accurate data, the management team or problem-solving team can often provide valuable data without the help of the data supporting team.

The four teams are the key resources for supporting the development of simulation models within a health care organisation. Table 5.3 presents the key characteristics of these teams when applying to local and national management level.

Table 5-3 Key characteristics of the proposed teams

Teams	For local management level	For national management level
1. Simulation team	- Both simulation leader and simulation modellers should be identified within the organisation, thus simulation knowledge can be maintained. - Internal trainings should be available for health care managers and internal staff	- Simulation leader should be identified within the organisation - Helps from external modellers are sometimes unavoidable due to the scale of projects. However simulation leader should maintain the control of the whole project
2. Management team	- Members usually include finance administrators, project managers, department managers and/or senior doctors within an organisation - These team members usually have similar views on the organisational structure, processes and problems - This team plays an important role to provide commitment to the simulation projects	- Members usually include health care managers and/or senior doctors from different organisations - These team members usually have different views and opinions on the organisational structure, processes and problems
3. Problem-solving team	- Good communication between this team and the simulation team is very important, in order to identify problems, provide information and alternative solutions for 'what-if' analysis	- Good communication between this team and the management team is particularly important, in order to identify underlying problems in a high-level structure - Good communication between this team and the simulation team is important, in order to provide supportive information and alternative solutions for 'what-if' analysis
4. Data collecting team	- These team members usually include front-line staff who are relevant to the project objectives within an organisation	- This team usually involve large-scale data collection processes (collect timely data, analyse collected data & validate collected data) - e.g. The information centre (IC) of the NHS

(3) Understand knowledge capability

As discussed, in order to embed S&M within the health care sector to support decision making on a long-term basis, the fundamental requirement is to ensure adequate resources and support is available within an organisation. Apart from identifying a good simulation leader and appropriate teams, the knowledge of developing simulation models and performing simulation experiments is also important to be developed within an organisation. These issues can be addressed by training or pilot projects, the benefits of these activities will be further discussed in the SIMT "cultural change" component.

Two types of simulation skills are important for supporting a successful simulation project. They are *descriptive analysis skills* and *prescriptive analysis skills*. Descriptive analysis skills include problem identification, data collection and analysis, modelling development, validation and verification, and performance evaluation. Prescriptive analysis skills mainly focus on the skills for performing sensitivity testing or 'what-if' analysis.

Within a complex organisation, these simulation skills are required to be developed and maintained by appropriate teams. As proposed in the previous "develop teamwork" element, there are four fundamental teams for supporting simulation development (simulation team, management team, problem-solving team and data collecting team). Table 5.4 presents the specific simulation skills required for different teams in supporting simulation development for local and national management level.

Table 5-4 Key simulation skills for supporting simulation development

Teams	For local management level	For national management level
1. Simulation team	- Simulation modellers should have the appropriate skills in model building - Simulation team are necessary to have the skills to validate and verify a proposed model	- Simulation modellers should have the appropriate skills in developing different types of simulation models. Usually supports from external modellers are necessary - Simulation team are necessary to have the skills to validate and verify a proposed model
2. Management team	- Management team members should have the skills to support problem identification process	- Simulation leader should have the skills to support the management team members to identify a well-defined problem
3. Problem-solving team	- Problem-solving team members should have the skills to support problem identification process - These team members should have the skills to perform sensitivity testing and 'what if' analysis - Performance evaluation skills are essential	- Problem-solving team members should have the skills to support problem identification process - Simulation leader should have the skills to support the problem-solving team to perform sensitivity testing and 'what if' analysis - Performance evaluation skills are essential
4. Data collecting team	- Simulation modellers should have the skills to identify the appropriate requirements for the model data - Data collection and analysis skills are essential	- Simulation modellers should have the skills to identify the appropriate requirements for the model data - data analysis skills are important for analysing a bulk of data

5.3.1.2 Management Component

The goal of the management component is to ensure top management support and commit to the implementation of S&M. This issue is considered to be one of the most important success factors of any implementation framework.

The SIMT management component provides the following activities and strategies for supporting this issue:

(1) Identify achievement plan

(2) Secure top management support

(3) Report progress

(1) Identify achievement plan

Given that the health care environment is naturally complex and involves many changeable factors, simulation modelling is the most suitable analytical tool for supporting decision making in the sector. However, if simulation models fail to identify the right problems or simulation projects fail to deliver the right solutions on time, health care management and practitioners would no longer be interested in the use of simulation modelling. Therefore it is important to have good planning on any simulation project. It is suggested that the simulation management and problem-solving teams can all be involved within the planning process. It can help to ensure a well-defined problem can be identified and understood by each team member. Additionally, it can ensure project objectives and schedules are well-communicated between these teams.

The following are the key elements that an achievement plan should include:

- Well-defined problems
- Project objectives and goals
- Details for each project stage
- Time plan for each project stage
- Resources require for each project stage

A well-established achievement plan is a success factor for managing simulation projects at both local and national management level. However, national projects usually involve longer development time, more resources and multiple stakeholders, regular reviews of the achievement plan are necessary. It can help to ensure the project objectives, goals and schedules are still appropriate towards the overall organisational strategies.

(2) Secure top management support

As mentioned previously, top management support and commitment is one of the most critical success factors to the implementation of S&M in the health sector. First, it can ensure sufficient *funding* is available to support appropriate trainings and resources. Second, by securing top management commitment, it can help to release the barrier of *clinician resistance* towards the use of simulation. In health care, a top-down approach is traditionally the most effective approach for change management. Therefore, if management wants simulation to become part of the culture, this idea has to be clearly communicated down to all the staff.

In order to strategically secure top management support for embedding S&M in the sector, there are key activities that address in this issue at both local and national management level.

Secure top management support at Local Management Level

Health care management at local level mainly focuses on dealing with clinical aspects of care. This includes providing and improving health services and integrating national priorities into local health delivery plans. It is important that a clear concept of how simulation can help to support decision making in these issues can be clearly communicated to this group of management. The following are the key issues that are suggested:

- Provide some successful case studies of the use of health care simulation
- Provide proposals on how simulation could possibly help on addressing the decision making at the local level
- Provide a clear strategic plan to identify the funding, resources that may required

Secure top management support at National Management Level

At national level, management mainly focuses on dealing with strategy, policy and managerial issues. This can include creating policy and legislation for primary, secondary, community and social care, developing strategies for improving public services and safety and responsible for finance, personal, planning and performance management etc. Given that simulation has the ability to include variability, complexity and human issues within a model for supporting decision making in these areas, it is important to clearly communicate this benefit to the top management level in order to gain the support from them. Following are the key issues that are suggested:

- Provide simulation demo on how simulation can support decision making for national management level
- Provide sound proposals on how simulation can support decision making for the current strategy or policy.
- Provide a clear strategic plan to identify the funding and resources may required

(3) Report process

SIMT management component highlights the importance of reporting simulation project processes to team members that include management team and problem-solving team. As discussed previously, the barriers for implementing health care simulation include the problem of model accuracy and data accuracy. These issues mainly caused by the rapidly changing and unpredictable nature of the system and the relatively low engagement of clinicians and/or health care managers. In order to address these issues, the simulation team is required to review project status and findings with the appropriate teams as soon as new progress is identified.

Although reporting project progress seems to be a very basic element for any project management, for managing health care simulation project in particular, this practice is necessary to be developed and maintained. First it can help to enhance the understanding for management and problem-solving teams about the on-going projects. Second, it can ensure models are still accurately reflecting the current systems and the identified model data is still applicable.

Following list suggests the key practices that should be developed for managing simulation projects at both local level and national level.

- Involve management team and problem-solving team in review meetings to ensure on-going projects are applicable
- For large scale project in particular, simulation team should communicate with data-collecting team to ensure identified data is up-to-date
- Collect feedback from appropriate teams about the project status and findings

- Maintain good communicate between simulation team and the appropriate teams

5.3.1.3 Cultural Change Component

The goal of the cultural change component is to develop a 'new' culture that would guide people from the organisation to believe S&M is a suitable tool for supporting health care decision making, so that people can become less resistant to the implementation of S&M. As discussed previously, one of the major success factors for implementing quality and process improvement approaches in the health sector is to guide everyone within an organisation to make the right choice, behave differently, and to experience a better set of results, so that necessary changes can be implemented throughout an entire organisation.

This component focuses on these success factors, and aims to provide a strategic approach that helps to create this new culture for supporting the implementation of S&M. The following are the activities provided for addressing this issue:

(1) Establish communication and participation

(2) Pilot project

(3) Embed SIMT culture

(1) Establish communication and participation

Resistance to change is identified to be one of the major barriers for implementing S&M in the health sector. Literature shows that there is still a lack of incentive for health care managers and practitioners to apply S&M to support decision making. Also, health care clinicians simply do not like to be analysed by computing models. To help in these issues, it is important to enhance the understanding of these professionals about the benefits of health care simulation and encourage them to participate in simulation project development.

This component highlights the importance of creating a clear vision statement that includes a clear direction and consistent managerial 'mind-sets' for guiding the implementation of S&M. The vision statement must be clearly communicated to all levels of staff to make sure everyone within the organisation can understand how simulation will be used to support decision making; how simulation projects will be controlled and managed; and how the success of simulation projects will be measured.

The key components that should be included within vision statements are as follows:

- Top management commitment and support to the implementation of S&M
- Encourage communications among individuals and simulation team for applying S&M
- Encourage staff participation and maintain staff feedback
- Involve front-line staff in decision making
- Motivate staff with reward system

(2) Pilot project

Implementing a new system or technique in the health care management is always a challenge. One of the main reasons is 'change' within a health care organisation can involve long procedure, multiple stakeholders, human issues, culture issues and political issues. In fact, many researchers found that proving the substantial value of a new system or technique within the sector is often impractical.

In order to address these issues, the use of a pilot project or program is especially accepted in this sector. First, it can enhance the understanding for health care management on how a new system or technique would apply and affect the existing practices. Second, it can help to release the barriers and worries for applying the new system or technique in future stages.

This component includes the importance of applying pilot project in the early stage of the S&M implementation. Therefore, health care managers and practitioners can experience how simulation can be used for supporting decision making. The following describes the key success factors for performing a simulation pilot project.

- **Team size**: A pilot project should not involve too many staff members. It is suggested three to four staff are ideal for managing a local level project while six to eight staff are suitable for managing a national level project.

- **Length and time**: A pilot project should be scheduled to finish within two to four weeks. It is found that the longer the time spent on a pilot project, the higher the chance the project would fail. The key success factor is to involve the top management members in the project from start to finish so that they can experience how simulation can be used for supporting decision making.

- **Staff profile**: Members involved in a simulation pilot project should include a simulation leader, simulation modellers and members from the top management. In some cases, the involvement of front-line staff is also important. For example, modelling operational processes often require information of the process flows and the actual data collected from the processes.

- **Importance and complexity:** Another key success factor for a pilot project is to select the right project objective and appropriate level of detail. First, the simulation leader should consult with top management members in order to identify a sound project objective. Otherwise, no one will be interested in the pilot project and the related results. Second, it is important to keep the pilot project as simple as possible. High level of detail can cause a high risk of failure and often involve long modelling time.

(3) Embed SIMT Culture

As mentioned previously, in order to successfully embed S&M within the health sector, it is important to define a 'new' culture. This new culture will guide people within the organisation to behave differently, experience differently and learn differently throughout an on-going journey.

This component presents a new culture named "SIMT Culture". The SIMT culture includes the key changes from a traditional decision making approach to a simulation-based decision making approach. The main key changes are presented in Table 5.5.

Table 5-5 Key differences between traditional culture and SIMT culture in health care management

Traditional Culture	SIMT Culture
Managers direct	Managers direct, key staff involve
Blame people	Root cause analysis
Test with real implementation	Test before real implementation
Increase resource and capacity based on available budget and expected demand	Seek the optimise resource and capacity based on expected demand
Higher costs with failure	Lower costs with pre-testing in models

Traditionally, health care decision making is the responsibility of top management team. The involvement of front-line staff is often limited. This often means that practice causes health care managers do not get the full picture of a problem. On the other hand, when the Plan-Do-Study-Act (PDSA) cycle is used by health care decision makers, new policies or strategies are tested with real implementation. This practice often involves the problem of high cost and high risk.

Given the benefits that simulation can offer, SIMT culture emphases the importance of people involvement, root cause analysis, risk-free and low cost approaches. All these issues need to be clearly understood and communicated through a top-down and on-going management approach. It is important that everyone within the organisation can participate and experience this new approach, so that SIMT culture can be developed and maintained.

5.3.2 Action stage for modelling health care system at operational level

The action stage of the SIMT implementation framework focuses on the importance of providing the most suitable methodology and approach for guiding health care professionals to understand and develop health care simulation models. Although simulation training and support is available in the market, specific guideline for helping these professionals in the use of simulation is limited. Because of this reason, health care professionals always find simulation tools are complicated to operate.

The goal of this action stage is to provide a specific guideline that includes the most suitable simulation approach for modelling health care operational systems and the best practices for developing this type of simulation models.

5.3.2.1 Methodology Component

The first component provided within this action stage is methodology. This component includes the following four key activities:

(1) Identify simulation methodology

(2) Identify management objectives

(3) Visualise target problem

(4) Identify simulation modelling cycle

(1) Identify simulation methodology

Discrete event simulation (DES) is identified to be the most suitable simulation approach for modelling health care operational systems. There are two main reasons. First, DES has the ability to model complex systems which may include multiple events, queues, resources and attitudes. In health care management, this level of complexity is required during decision making. In DES model, patients can be modelled as individual entity that flows around a network of waiting queues, of which each patient can have different characteristics (e.g. age, gender, diagnosis, disease status) for determining their patient pathways. Therefore, DES model can enable health care managers and practitioners to have a clear understanding of the existing system, and to examine the existing systems performance without interrupting the live system.

The second advantage of using DES for modelling health care operational system is the ability of handling randomness. Health care systems are characterised by uncertainty and variability, for example patient arrival time and doctor examination time are highly random. With the distribution technique of DES approach, this randomness can be flexibly modelled.

(2) Identify management objectives

The key objectives for operational health care management often involve improving the performance of patient flows and the utilisation of resources. In order to develop an effective simulation model for supporting the decision making at this level, it is important to first identify a sound simulation objective which can target one of the key management objectives. Table 5.6 identifies the key management objectives for an operational health care system, which includes A&E, Outpatient, and Inpatient departments.

Table 5-6 Key management objectives for an operational health care system

	Key management objectives
A&E	***Patient Flow*** - Reduce long patient waiting times - Increase patient throughput ***Allocation of Resources*** - Increase staff utilisation rates
Outpatient	***Patient Flow*** - Reduce waiting times for appointments - Reduce waiting times in the consultation rooms - Increase patient throughput ***Allocation of Resources*** - Increase staff utilisation rates
Inpatient	***Patient Flow*** - Increase patient throughput - Reduce patient length of stay - Reduce patient waiting times for surgery ***Allocation of Resources*** - Increase staff utilisation rates - Increase bed utilisation rates - Increase operating room utilisation rates

(3) Visualise target problem

Literature shows that a well-defined problem is one of the key success factors for a simulation project. This component puts emphasis on the importance of identifying a sound objective and to identify the underlying causes based on the identified problem. As health care operational systems often involve complex processes and complicated issues, it is important to have a good understanding of the target system before developing a simulation model.

This component identifies an effective approach to help in these issues. The cause and effect diagram is chosen to be the most suitable analytical tool for supporting this analysis. Following is an example of an A&E department in which long patient waiting time is the target problem.

Step 1 – identify the effect

The first step is to identify the target problem (the effect). Figure 5.4 shows the cause and effect diagram with the main effect at the arrow's end.

Figure 5-4 Cause and effect diagram - with effect

Step 2 – identify the main categories of the causes

The second step of this approach is to identify the main categories of the underlying causes. Four categories of causes are identified for this example (People, Equipment, Environment and Procedures).

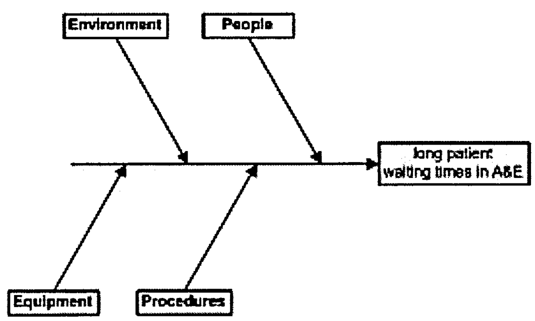


Figure 5-5 Cause and effect diagram - with main categories of causes

Step 3 – identify the causes of each cause

The final step of this approach is to explore each main category and to find out the 'causes of each cause'. Figure 5.6 shows the complete cause and effect diagram which presents all the possible underlying causes for this example.

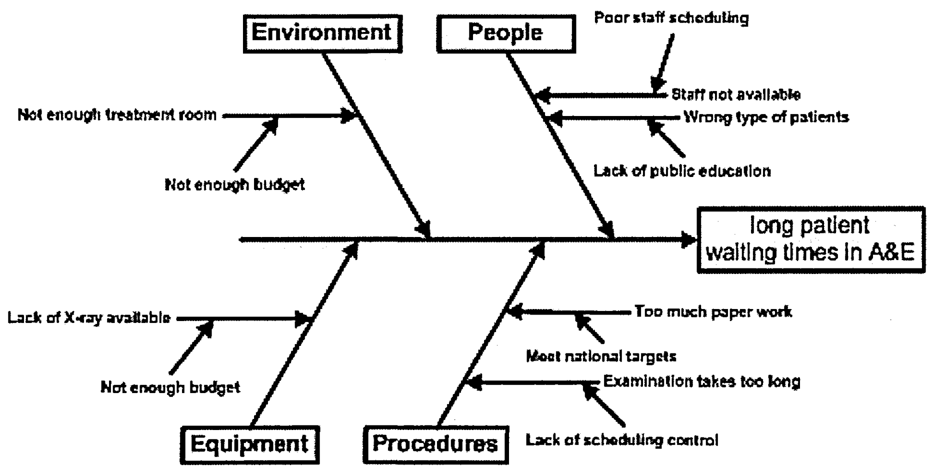


Figure 5-6 Cause and effect diagram - with all the possible underlying causes

(4) Identify simulation modelling cycle

A clear and well-organised simulation modelling cycle is a key success factor for managing a simulation project. First, it can help to ensure simulation projects can follow a standardised approach so that project failure can be minimised. Second, it can provide a good guideline in project scheduling, so that project time and cost can be more effectively managed.

This component proposes a simulation modelling cycle for supporting health care modelling with DES approach. Figure 5.7 shows the overview of this proposed modelling cycle. The modelling cycle include six topics (*problem structuring, model coding, data inputs, results and experimentation, validation and verification, and continuous improvement*) and four stages (*starting stage, middle stage, final stage, and improvement stage*). The following discussion provides details on how this proposed modelling cycle can be used to guide the development of health care simulation models.

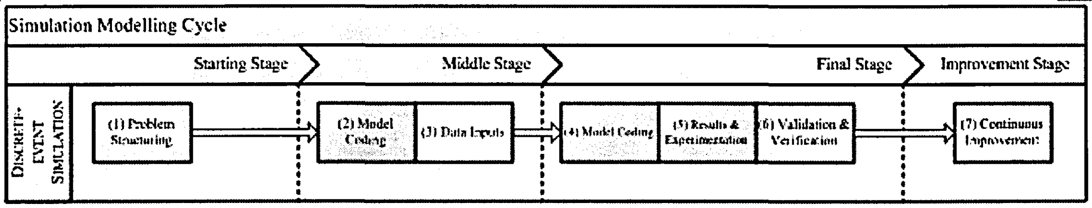


Figure 5-7 Proposed discrete event simulation modelling cycle

Problem structuring is the key topic within the *starting stage*. As discussed previously, a well-defined problem is one of the key success factors for a simulation project. According to the identified management objective and the underlying causes identified from the cause and effect approach, problem structuring focuses on identifying the project objectives for a simulation project. Three main issues are commonly targeted within a health care operational system, they are: reviewing existing system, testing new operational process and optimising resource utilisation. Table 5.7 shows some examples of these issues within the A&E, Outpatient and Inpatient departments.

Table 5-7 Simulation project objectives for health care operational system

	Health care model objectives
A&E	***Review Existing A&E System*** - Review patient routing and flow - Review scheduling and availability of resources ***Test New A&E Operational Processes*** - Introduce fast track lane in minor care - Ordering tests while in triage - Placing patients in the treatment area instead of sending them back to the waiting room - Introduce new triage system ***Optimise Resource Utilisation*** - Finding the optimal amount of nurses and doctors are needed to ensure that no patient spends more than 4 hours.
Outpatient	***Review Existing Outpatient System*** - Review patient routing and flow - Review scheduling and availability of resources ***Test New Outpatient Operational processes*** - Apply new appointment booking scheduling system - Evenly distribute patient demand with alternative scheduling rules - Increase doctor appointment slots ***Optimise Resource Utilisation*** - Find the optimal amount of capacity is needed to ensure that no patient spends more than 3 months for an outpatient appointment.
Inpatient	***Review Existing Inpatient System*** - Review patient routing and flow - Review patient scheduling and admission processes - Review scheduling and availability of resources - Assess the efficiency of existing healthcare delivery systems ***Test New Inpatient Operational Processes*** - Apply new patient scheduling and admission scheduling system - Apply new bed planning rule ***Optimise Resource Utilisation*** - Find the optimal number of beds needed for different operating timetable scenarios - Find the optimal amount of capacity is needed to ensure that no patient spends more than 3 months for an inpatient treatment.

Model Coding included in both *middle stage* and *final stage* of the proposed modelling cycle. This topic focuses on the development of the “model logic”. Model logic is the basic structure of a simulation model which represents how a system would operate in the real system. For instance, in order to model a new triage system and to examine how the new system would affect the performance of an A&E department, modellers need to create a model logic which includes patient pathway from patient arrival, triage and to examination or treatment.

In order to accurately develop a model logic that represents a target system, a process flow diagram is recommended to be created before starting the model coding. Details on how to use process flow diagrams to define patient pathway is discussed in the next component (modelling component).
In the proposed simulation modelling cycle, model coding occurs in the beginning of middle stage and the beginning of final stage. Since accurate model logic is the key for a successful simulation model, modellers have to make sure there is no missing processes or mistakes from the initial model logic before running a simulation.

Data Inputs includes collecting model data and analysing the collected data for inputting to a simulation model. This process resides within the *middle stage* of the modelling cycle.

Literature shows that data collection is often the most time-consuming process within a DES modelling. Within health care operational systems, this process can be even more challenging. In order to resolve in this issue, it is suggested that the simulation team should design a standard data collection sheet or database to capture all the real-time data during patient visits. This practice can help to ensure the right model data can be efficiently obtained from the real system without going through a bulk of files or paper work. Details on how to identify the right model data for particular health care models are discussed in the next component (modelling component).

Results and experimentation is proposed within the final stage of the modelling cycle. The main purpose of this process is to obtain the necessary simulation results from the finished model. If the objective of a simulation project is to review performance of an existing system or a new proposed system over a certain time, modellers can execute the simulation according to the time period in order to obtain the desired results.
However, if the objective of a simulation project is to test alternative scenarios or to perform 'what-if' analysis, modellers have to change the relevant model data in order to obtain the desired simulation results. The involvement of the management team or problem-solving team during this type of experimentation is often critical.

Validation and verification is the last process within the final stage. The main purpose of this process is to make sure the finished model and simulation results can accurately represent the real situation. Firstly, it is suggested that modellers are required to verify the model with problem-solving team or affected staff in order to make sure the model is understood and trusted. Secondly, modellers are required to compare the model results with some relevant historical data in order to test and validate the accuracy of the simulation model.

Continuous Improvement a key process within the improvement stage. Improvement within health care operational systems is an on-going journey, often health care decision makers would like to apply simulation in the same area but with different objectives. Therefore, it is worthwhile to reuse an existing model either with changes on the model logic or with a different set of input data.

5.3.2.2 Modelling Component

The second component provided within the action stage is the modelling component. The goal of this component is to provide effective guidelines for health care professionals to develop health care simulation models with DES approach. This component includes four key issues:

(1) Define patient pathway

(2) Define model components

(3) Define model data

(4) Introduce best practices

(1) Define patient pathway

Defining a clear patient pathway in the initial stage is a key for developing a successful DES health care model. As mentioned in the methodology component, it is a good practice for understanding the target system and it can provide a clear structure for supporting the model coding process.

The principle of defining patient pathway is by drawing a simple process flow diagram which can show all the relevant procedures within the target system. The following examples use simple process flow diagram to describe a typical health care operational system which includes the patient pathways within A&E, Outpatient and Inpatient departments.

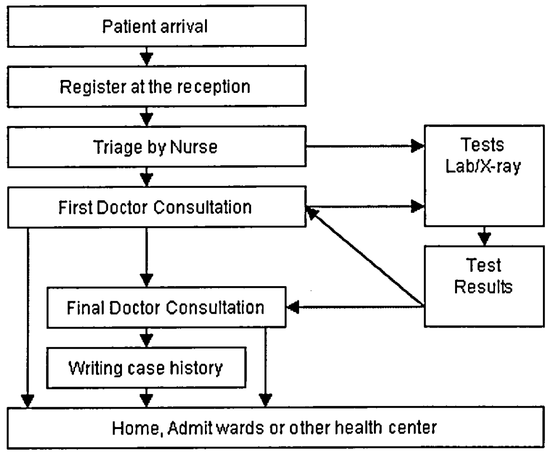


Figure 5-8 Example of patient pathway in A&E department

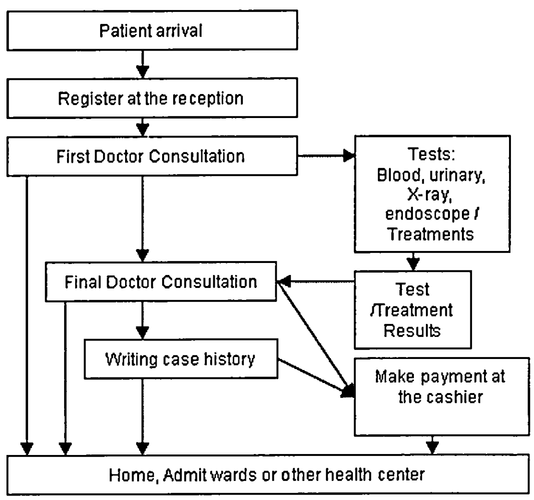


Figure 5-9 Example of patient pathway in Outpatient department

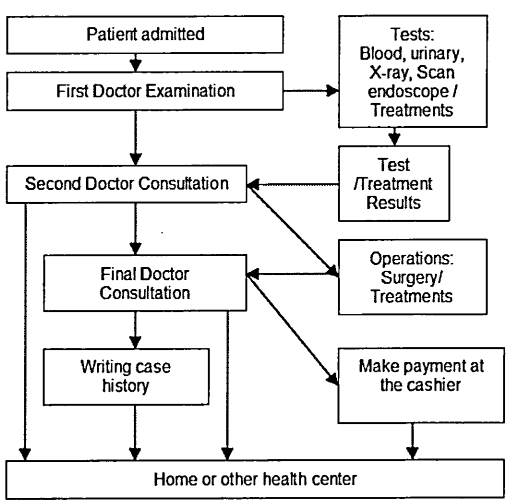


Figure 5-10 Example of patient pathway in Inpatient department

(2) Define model components

Model logic, model entities and resources are the main modelling components within a DES model. Therefore, during the starting stage for a model development, it is important to clearly define the type of entities and resources that will be included in a simulation model.

Table 5.8 shows some examples of the model entities and resources which are typically included within A&E, Inpatient and Outpatient simulation models.

Table 5-8 Example of model entities and resources in health care models

	Simulation model entities	Simulation model Resources
A&E	Patients	Receptionist Nurse Doctor Test machines X-ray
Outpatient	Patient	Receptionist Nurse Doctor Test machines X-ray Cashier Lab test Other hospital facilities
Inpatient	Patient	Nurse Doctor Bed Test machines X-ray surgery room treatment room

(3) Define model data

As described within the methodology component, data collection is often one of the most challenging processes for health care modelling. In order to address this issue, it is suggested that the simulation team should design a standard data collection sheet or database for collecting real-time data during patient visits. Modellers should clearly define what type of data is required for the simulation model. Table 5.9 shows some examples of the model data which are typically includes within A&E, Outpatient and Inpatient health care models.

Table 5-9 Example of model data for health care models

	Simulation model – Information on Entities	Simulation model – Information on Resources	Simulation model – Login Definition
A&E	- Patient arrival time - Patient type (ambulance patients, walk-in patients)	- Number of nurse on-duty - Number of doctor on-duty - Number of consultants on-duty - Number of X-ray	- Service Time for each procedure along patient path - Pathway or sequence of actions - Resources required to perform each action
Outpatient	- Patient arrival time - Patient type (appointment patients, same day appointment patients, new patients)	- Number of nurse on-duty - Number of doctor on-duty for each consultation service - Number of X-ray	- Service Time for each procedure along patient path - Pathway or sequence of actions - Resources required to perform each action
Inpatient	- - Patient (emergency patients, scheduled patients, patients on waiting lists)	- Number of nurse on-duty - Number of doctor on-duty for each consultation service - Number of operating rooms - Number of beds	- Service Time for each procedure along patient path - Pathway or sequence of actions - Resources required to perform each action - Staff scheduling

(4) Introduce best practices

One of the best practices in DES modelling is to build customised template is for specific business sectors. The author creates a customised template in order to guide health care practitioners to develop health care models in a more effective and efficient way. The proposed customised template is called 'Healthcare OR Template' (Figure 5.11). It is built with the simulation software Arena. 'Healthcare OR Template' provides customised building blocks which can be re-used for developing different operational health care models and with different model logics and objectives.

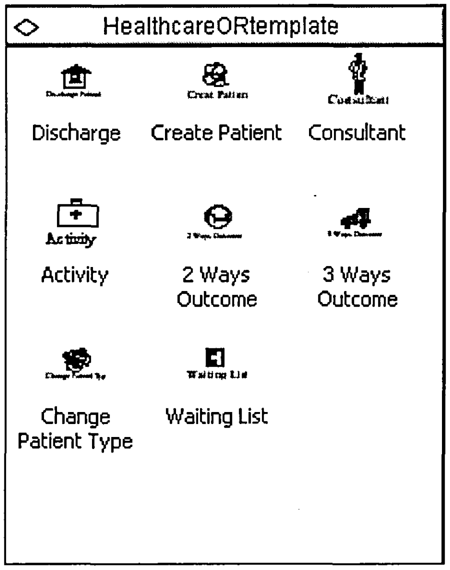


Figure 5-11 Proposed customised template for developing operational health care models

For example, the 'Healthcare OR Template' can build simulation models to simulate and review any existing health care operational processes, patient pathways, or testing of new health care procedures. **Appendix D** illustrates how an A&E operational process model is built with the 'Healthcare OR template'.

5.3.3 Action stage for modelling health care system at strategic level

The goal of the action stage is to provide a specific guideline that includes the most suitable simulation approach for modelling health care system at a strategic level and the best practices for developing this type of simulation model.

5.3.3.1 Methodology Component

The first component within this action stage is methodology. This component includes the following four key activities:

(1) Identify simulation methodology

(2) Identify management objectives

(3) Visualise target problem

(4) Identify simulation modelling cycle

(1) Identify simulation methodology

System dynamics (SD) modelling is identified to be the most suitable simulation approach for supporting clinical decision making at a strategic level. SD models can be used for helping health care managers and practitioners to understand how strategies can affect a system over time, or how changes can improve the overall performance. Also it can provide a better insight for these professionals to understand the dynamic structure of a target system.

There are three main reasons for using SD approach to support strategic decision making in this sector. First, the nature of health care system is dynamic. It includes many changeable variables for which SD approach is ideal to model how the changes of these variables can affect the overall system performance. The second reason is the importance of understanding the feedback effect within a health care system. The qualitative aspect of the SD approach can provide a better insight to understanding how feedback relationships between the system variables would affect the overall system behaviour. Finally, SD approach can quantify a system structure. The quantitative aspect of the SD approach allows health care practitioners not only to have a better understanding of the system structure; it also allows them to test alternative strategies and scenarios with SD simulation models.

(2) Identify management objectives

As with most of the simulation approaches, it is important to first identify a clear management objective for a SD simulation project. This practice can help to ensure a simulation project can target the right strategic goal and at the right time.

In the UK, the Department of Health (DH) is responsible for developing strategies and directions for guiding its organisations in improving their service performance. SD approach is found to be well-suited to support this level of decision making which it can use to understand the current problems of a target system and allowing new strategies to be tested before implementation. Table 5.10 highlights some recent management objectives from the UK health care system.

Table 5-10 Strategic targets for the UK health care system (DoH, 2008)

NHS National Targets	Target Information (Year of launch)
18 weeks target	a maximum of 18 weeks from the time they are referred for a hospital operation by their GP until the time they have that operation (2004)
Primary care target	Guaranteed access to a primary care professional within 24 hours (2004)
Outpatient and Inpatient target	No patient will wait more than 3 months for an outpatient appointment and a further 3 months for any inpatient or day-case treatment (2004)
A&E access target	4 hours the maximum wait in A&E from arrival to admission, transfer or discharge (2005)
Choose and Book scheme	Ensure every hospital appointment is booked for the convenience of the patient, making it easier for patients and their GPs to choose the hospital and consultant that best meets their needs (2005)

(3) Visualise target problem

Once a sound strategic objective is identified for a SD project, it is crucial to first visualise the target system in order to identify the system elements and variables that are relevant to the target system. This practice is especially important when modelling a health care system which includes a high level of complexity and variability elements.

In order to visualise a target system for this purpose, this component suggests the use of Cause and effect diagrams. The following is an example to show how a Cause and effect diagram can be used to identify the relevant system elements and system variables within an A&E system. The management objective for this example is to target the 4 hours maximum wait within an A&E department.

Step 1- Identify the target

The first step of building a Cause and effect diagram is to identify the strategic target. In this example, "A&E seen patients within 4 hours" is the identified target. Figure 5.12 shows the Cause and effect diagram with the main target at the arrow's end.

Figure 5-12 Cause and effect diagram - with main target (Effect)

Step 2 – Identify the main strategies

The second step is to identify the key strategies which may be possible to be applied for addressing the identified target. In this example, eight possible strategies are suggested for targeting the A&E 4-hours target. They are connected to the body of the arrow as shown in Figure 5.13. In order to identify the right strategies, the key success factor for this step is to involve the problem-solving team and affected staff in the discussion.

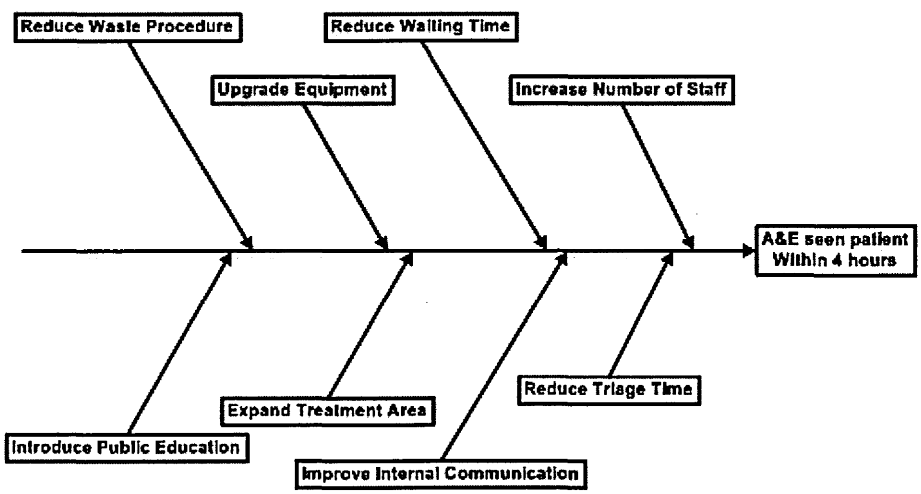


Figure 5-13 Cause and effect diagram - with the key possible strategies

Step 3 – Identify the key system elements and variables

By referring to the key strategies that identified in Figure 5.13, the main purpose of this step is to identify the key system elements and variables which may influence these strategies within the system. Table 5.11 shows the mapping of the key identified strategies and the relevant system elements and/or variables.

Table 5-11 Mapping of key strategies and relevant system elements/variables

Key identified strategies	Key system elements/ variables
Increase number of staff	Number of nurse, number of doctor
Reduce waiting time	Number of demand, number of referral
Upgrade equipment	Available funding, number of equipment
Reduce waste procedure	Key processes within the system
Reduce triage time	Number of triage nurse
Improve internal communication	Trainings
Expand treatment area	Available funding, number of doctor
Introduce public education	Public awareness

These key system elements and variables are the critical underlying factors which can influence the performance of the target system. However, in order to understand how these system elements and variables can influence the performance of the target system as a whole, it is important to investigate the feedback relationships between these variables. The next component (modelling component) will discuss how to use SD modelling to understand the interconnection between these variables and to use SD models to analyse the dynamic behaviour of the system.

(4) Identify simulation modelling cycle

A clear and well-organised simulation modelling cycle is one of the key success factors for managing the development of a simulation project. This component proposes a simulation modelling cycle for guiding the development of SD health care models.

A number of authors have contributed on this issue (Richardson and Pugh, 1981; Roberts *et al.*, 1983; Coyle, 1996). All of these authors share a similar approach to the SD modelling process, which includes problem identification, system conceptualisation, formulating the model both qualitatively and quantitatively, and sensitivity testing. A recent study from Tako and Robinson (2007) comments the modelling process for SD should not follow a sequential order. A similar issue has also been discussed by Forrester (Keough and Doman, 1992) in which he states refinement is a critical step in a SD approach for improving the final model adequacy.

Based on the author's experience on the development of SD models and the critical issues suggested in the literature, a proposed simulation modelling cycle is developed for guiding the development of SD health care models (see Figure 5.14). The proposed SD simulation modelling cycle includes three main stages, conceptual stage, modelling stage, and strategic stage.

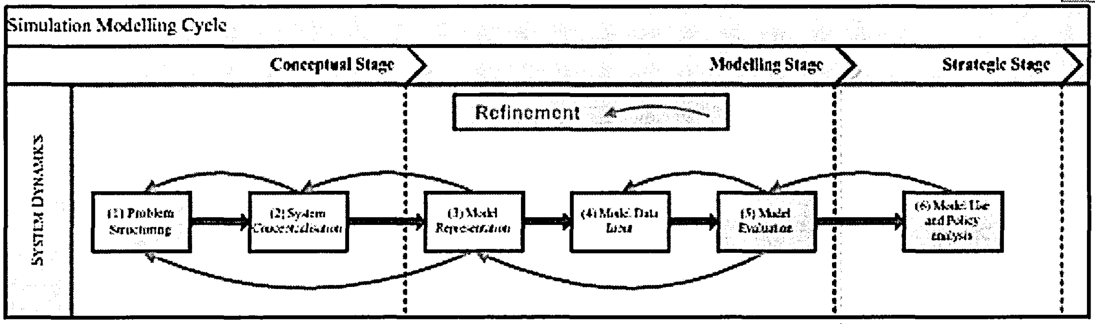


Figure 5-14 Proposed system dynamics modelling cycle

Stage 1: Conceptual Stage

The aim of the conceptual stage is to identify a well-defined project objective and target problems. Also it includes the identification of the key system elements and variables. Two steps are included within the conceptual stage: problem structuring and system conceptualisation.

Problem structuring – once a management objective is selected for a SD project, it is important to identify the key process involved within the identified target. Since the health care system includes complex processes and complicated patient pathways, modellers have to clearly identify which parts of the systems and/or processes should be included within the SD project.

For example, in order to achieve the 4-hours maximum target within an A&E system, the modeller should clearly identify the patient pathways from patient arrival, patient admission, and to patient transfer or discharge. Therefore, a structural map can be produced in order to provide a clear guideline for further development. Also, it can enhance the communication between modellers and problem-owners in this early stage. The next component (modelling component) will suggest some examples of using process flow diagram to develop a structural map for this purpose.

System Conceptualisation – There are two main system components that are necessary to be identified during this stage, they are ***levels*** and ***rates***.

Levels

The level, which is referred to as stock, is the accumulations within an organisation system. For example within a typical A&E system, the total number of patient waiting in triage is one of the key levels. Within a SD model, it represents the current state of the target system. Decision makers can measure these levels over time within a SD model in order to understand how changes happen within the target system.

Rates

The rate, which is referred to as flow rate, is the activities within an organisation system. In General, the rates are represented as control variables which directly increase or drain stocks. In the example of an A&E system, referral rate (inflow rate) and nurse seeing patient rate (outflow rate) are the variables which influence the total number of patient waiting in triage (level).

Within a SD model, it is important that all these variables are clearly defined, and none defined more than once (Keough and Doman, 1992).

Refinement – As mentioned previously, refinement is a critical practice within SD modelling cycle. During this stage, modellers should review the problem structuring process in order to make sure the identified target is clearly represented (see Figure 5.14).

Stage 2: Modelling Stage

The aim of the modelling stage is to transform the identified system levels and rates into SD diagrams. There are two main types of SD diagrams, they are Causal loop diagram and Stock and flow diagram. Three modelling steps are suggested within the modelling stage: model representation, model data input and model evaluation.

Model representation – SD approach provides two main types of diagrams for supporting the qualitative (Causal loop diagram) and quantitative (Stock and flow diagram) analysis of a system (see Section 3.3.1 for more details).

Causal loop diagram (influence diagram)

This type of SD diagram focuses on representing the interconnections between system variables. This involves identifying the feedback relationships among the system variables in order to provide a better insight to the feedback structure of a system. Following is an example to explain how a causal loop diagram can be built to show the demand and capacity relationship within a health care system.

The first step is to connect all the identified system elements by arrows that indicate causality. Then apply "+" and/or "-" signs to indicate the effect of the causality.

In Figure 5.15, Budget, capacity and waiting lists are the key system elements that can cause effects to the system. And as *Budget* increases, *Capacity* increases, shown by a "+" sign; and as *Capacity* increases, *Waiting list* decreases, shown by a "-" sign.

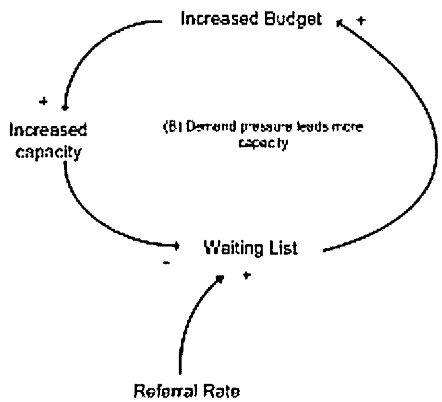


Figure 5-15 Causal loop diagram to demonstrate demand and capacity feedback relationship within a health care system

Once the basic structure of a causal loop diagram is developed, the next step is to identify the feedback loop. Feedback loop represents the dynamic nature of a system. There are two types of feedback loops: balanced loops and reinforcing loops.

The mechanism of identifying these loops is counting the number of "+" or "-" signs within an identified loop. For instance, if there is odd number of "-" signs, it is a balanced loop; otherwise, if there is even number of "-" signs, it is a reinforcing loop. In the example of Figure 5.15, it shows a balanced loop which the system regulated itself (i.e. when more patient in waiting list, the more budget and capacity the system is required, in order to reduce the waiting list problem).

Stock and flow diagram (flow diagram)

The second type of the SD diagrams is the Stock and flow diagram. This SD diagram focuses on simulating the dynamic behaviours of a system quantitatively. Levels and rates are the key components within this type of SD diagram.

The following example shows how to convert a causal loop diagram into a stock and flow diagram (Figure 5.16). The diagram is developed in Stella® software and it is based on the causal loop diagram example used in Figure 5.15.

In Figure 5.16, the two "clouds" represent a source and a sink, in other words infinite amounts of material (in this case, patient) that flows through the system. The *waiting list* is modelled as a stock. *Referral* and *capacity* are defined as rates, which represents patient flows into and out of the waiting list system. *Budget* is defined as a soft variable, it influences the *capacity* rate. Additionally, the level of waiting list can influence the budget rate, which completes the system cycle.

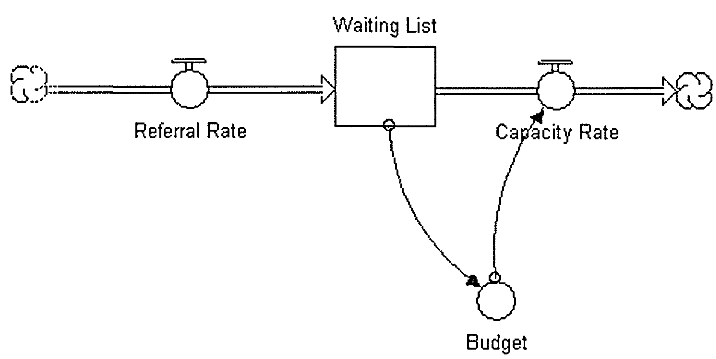


Figure 5-16 Example of a stock and flow diagram using STELLA® software

Model data input – Model data is required only with the stock and flow diagram in order to execute the simulation. As discussed, the main components of a stock and flow diagram are levels and rates. Modellers need to collect relevant data to represent these components. For example, Stella® provides a user-friendly interface which allows modellers or model users input this numerical data in integer, equation or graphical format.

Based on the stock and flow model example in Figure 5.16, the following stock equation represents the 'physics' of the system and describes how a level will rise or fall, depending on the values of its inflows and outflows.

$$Waiting\_List\ (t) = Waiting\_List\ (t\text{-}dt) + (Referral\_rate - Capacity\_rate) * dt$$

Therefore, modellers need to collect the following data:

- The initial number of the waiting list
- Value of the referral rate
- Value of the capacity rate

Model Evaluation – model evaluation is the final stage of the proposed modelling stage. The aim of this step is to ensure the finished SD model can reflect the real behaviour of the target system. It is suggested that modellers should review the model structure and model data with problem owners or decision makers. Also, it suggests comparing the simulation results with the relevant organisational report or data.

Refinement – Once again, refinement during this stage is essential by reviewing the model structure, components or model data (see Figure 5.14).

Step 3: Strategic Stage

The main aim of the strategic stage within the proposed SD modelling cycle is to apply the SD models for supporting decision making. The key steps included within this stage are policy analysis and model use.

First, modellers or/and decision makers can execute the SD models with the current value in order to understand how the overall system performance will change over time. These professionals can test alterative strategic decisions by changing the value of the system variables. For example, they can simulate how a 10% decreased of the patient referral rate can affect the overall waiting list problem or how a 2% increase in the capacity rate can improve the overall performance of the system.

5.3.3.2 Modelling Component

The second component provided within the action stage is the modelling component. The goal of this component is to provide effective guidelines for health care professionals to develop health care simulation models with SD approach. This component includes four key issues:

(1) Define patient pathway
(2) Define model components
(3) Define model data
(4) Introduce best practices

(1) Define patient pathway

As discussed in the proposed SD modelling cycle, it is important to first identify a clear and well-defined system target. Health care system often involves complex processes and multiple patient pathways, modellers should clearly identify and simplify the target system with the use of process flow mapping.

It is suggested that process flow mapping is a suitable tool for helping this issue. The main reason is the use of process flow mapping is not a new technique in the sector. It can help to enhance the communication between modellers and problem owners during the problem structuring process. Following is an example of a process flow mapping which includes the key patient pathways within an A&E system.

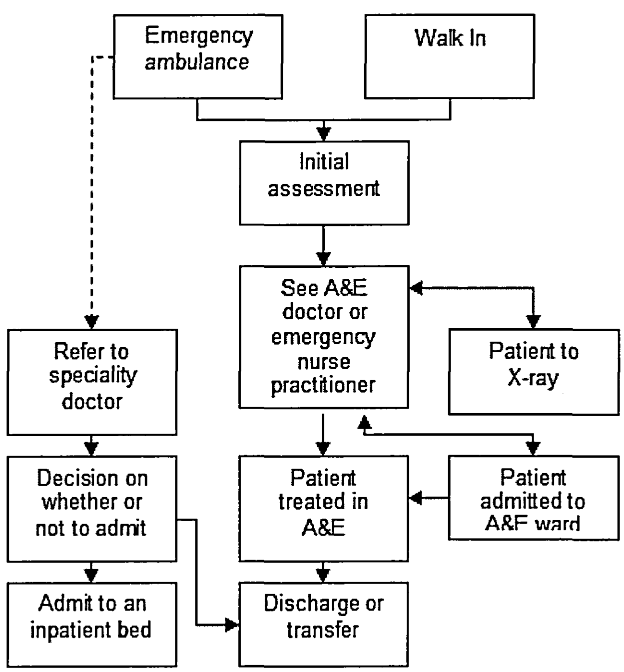


Figure 5-17 Process flow mapping of an A&E system

(2) Define model components

There are two key system components that are necessary to be clearly defined within a SD model. They are levels and rates. This component suggests the best practices to guide health care practitioners to identify these system components more efficiently.

Identify system levels

In order to clearly define the system levels, it is recommended to create a simple 'process flow diagram' which lists out the key patient statuses within a target patient pathway. These patient statuses are the accumulation within the patient pathway, in other word, the system levels. Figure 5.18 shows an example of a process flow diagram which lists out the four key patient statuses involved within an A&E system.

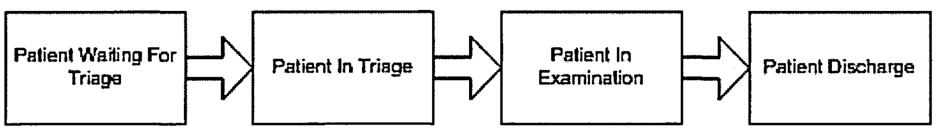


Figure 5-18 Process flow diagram with the key patient statuses in an A&E system

Identify system rates

System rates are the activities or strategic policies which cause changes to the related patient status. Based on the key patient statuses identified in Figure 5.18, the following example identifies the related system rates which cause the value of these patient statuses to rise or fall.

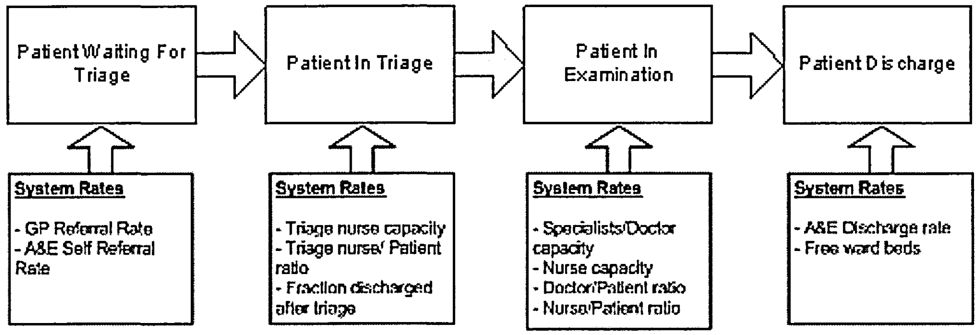


Figure 5-19 System rates that can cause changes within an A&E system

(3) Define model data

As discussed in Chapter three, compared to DES approach, SD models do not require a bulk of model data, thus data collection is comparatively less time-consuming. The key within an SD modelling approach is to define the right system components, levels and rates, and to collect relevant data to define these variables within a model.

Based on the above A&E system example, this step develops a stock and flow model which includes the identified levels and rates from Figure 5.19. The key of this example is to show the model data would be required for this SD model. Stella® software is used in this example.

Figure 5.20 shows a snapshot of the stock and flow model of the A&E system. In order to execute the model, Stella® requires relevant numerical data to represent the variables. This numerical data can include constant number, equation, graph or variables. The "?" signs represent the missing model data which required to execute the model. For example GP referral rate, A&E self referral rate, triage nurse capacity etc.

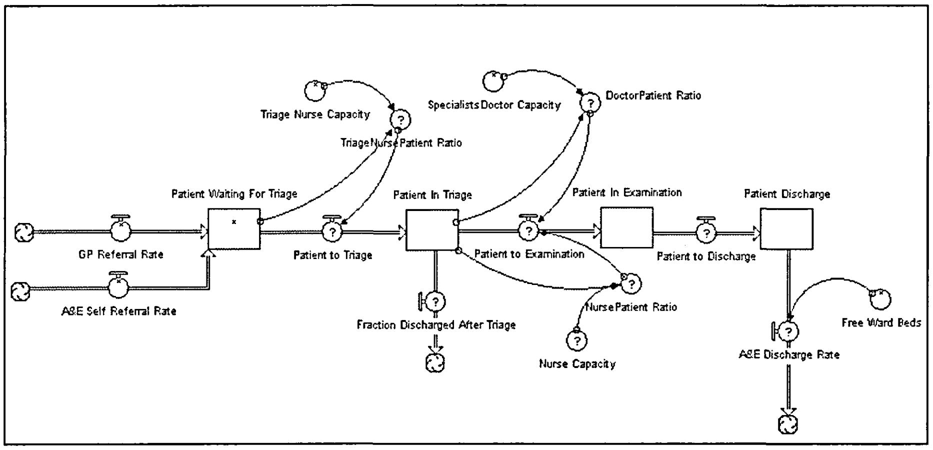


Figure 5-20 An example of stock and flow model built in Stella® software

(4) Introduce best practices

As discussed in Chapter three, generic health care simulation models are not commonly used in the sector. One of the key reasons is modellers often create specific simulation models for a specific purpose. However, health care organisations such as the NHS typically run many hospitals with similar practices. If health care models can be built based on this general practice, these health care models should be easily reused for supporting various decision making.

However, if decision makers are not familiar with the modelling environment, it can still be very time-consuming for them to modify input data in a SD model. In order to resolve in this issue, this component proposes to embed Excel spreadsheets to a generic simulation model so that data entry can become easier for this group of professionals. **Appendix E** includes an example to illustrate how to use the Stella® built-in function to embed Excel spreadsheet with a SD model.

5.4 Summary

This chapter presented the proposed SIMT implementation framework, and described the approaches to implement the framework for guiding health care professionals to embed S&M within their organisations. The overview of the SIMT implementation framework was presented in Figure 5.2. The approaches of applying each SIMT component for addressing issues in the planning and the action stage of the implementation have been discussed.

6 CHAPTER SIX: SIMT IMPLEMENTATION FRAMEWORK VALIDATION

6.1 Introduction

Chapter five presented the proposed SIMT implementation framework for guiding health care managers or practitioners through the essential approaches to successfully embed S&M within their organisations. This chapter validates the proposed implementation framework by questionnaire and case studies. The validation process includes two main parts. First, validation of its basic structure and planning stage which was achieved by questionnaire. The purpose of the questionnaire is to demonstrate how the proposed SIMT components and the key issues proposed within the planning stage can be understood and accepted by a selected group of professionals.

The second part of the validation focuses on the action stage of the proposed implementation framework. This was achieved by applying the selected methodologies and best practices for guiding the development of health care models within a local children hospital. Two pilot projects have been developed within the case study. The first pilot project applied DES approach for modelling the operational processes within the A&E department. The second pilot project applied SD approach for modelling the patient pathways within the 18-week waiting time target system. Evaluation of these pilot projects was then carried out in order to examine if the proposed key issues within the action stage are useful and important during their experiences.

6.2 Validation of the framework components and the planning stage

The first part of the validation aims to validate the SIMT framework components and the planning stage of the proposed implementation framework. A questionnaire is used. The questionnaire was sent to a group of professionals (which includes health care mangers, health care practitioners, academic professionals and simulation modellers). A sample of the questionnaire can be found in **Appendix A**.

The aim of the questionnaire is to demonstrate how the framework components and the proposed framework can be understood and accepted by this group of professionals. The questionnaire includes 20 questions which grouped into 5 main parts (A- background, B- basic structure of the SIMT framework, C-infrastructure element, D- management element and E-cultural change element).

Fifteen respondents participated in the questionnaire, Table 6.1 summarises the background of these respondents. Among this group of respondents, ten of them have experience of developing simulation models (see Figure 6.1).

Since the target respondents are the health care professionals from the top management level and the experts with health care simulation experience, this group of professionals was carefully selected to ensure quality feedback can be collected. Therefore, the author considered fifteen respondents to be acceptable in this case.

Table 6-1 Respondents background

Respondents background	**Number of respondents**
Academic professionals	4
Healthcare practitioners	1
Local healthcare managers	7
National healthcare authorities	2
Software vendors	1
Total	15

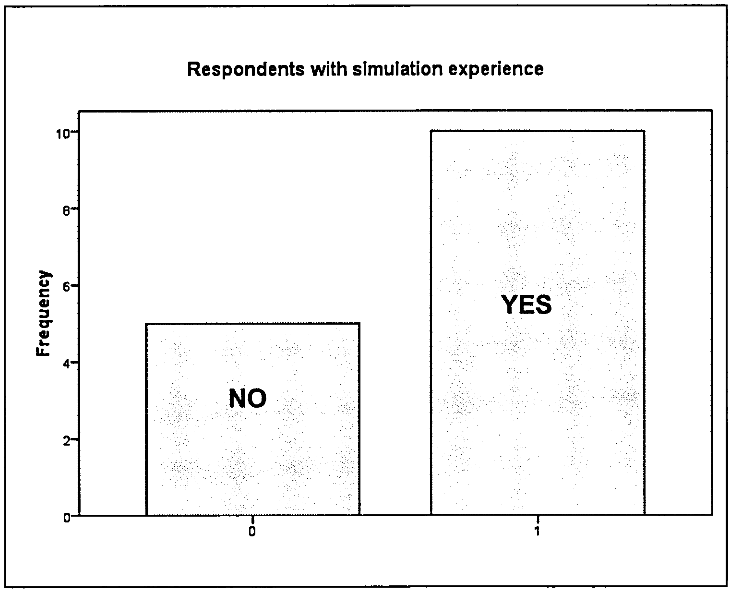


Figure 6-1 Respondents with simulation experience

6.2.1 SPSS Output

As discussed in the framework validation methodology (Chapter four - Section 4.3), the questionnaire data is analysed by Statistical Products and Service Solution (SPSS) software. Collected answers from these respondents are transformed into the SPSS database, which includes the answers from part B to part E. The aim of the analysis is to examine the distribution of the responses with the SPSS frequencies procedure, so to look at how these respondents rank each question or statement. Five point rating scale is used in the questionnaire.

In SPSS, each question or statement is represented by a “variable”. For instance, question ‘B1’ includes five statements (*a. Infrastructure, b. Management, c. Cultural Change, d. Methodology, e. Modelling*) which are represented as ‘B1a’, ‘B1b’, ‘B1c’, ‘B1d’ and ‘B1e’. In total, 33 variables are identified from the questionnaire.

Appendix F shows the output from the SPSS analysis based on the collected data. The statistics show the total number of responses for each variable. The frequency table shows the counts and percentages of each rating.

6.2.2 Output analysis

Based on the SPSS output, this section aims to identify the level of significance of each question and statement. Thus, to demonstrate how the proposed framework and components are understood and accepted by this group of professionals and to identify the strengths and limitations of the proposed framework.

Appendix G presents the most accepted rank based on the highest percentage of each variable, which are mapped with the appropriate questions and statements.

Based on this analysis, the author identified the following strengths and limitations of the proposed implementation framework and the components.

Strengths

1. The *five SIMT components* are essential for guiding the successful implementation of S&M in the health sector.
2. The proposed *planning stage and action stage* are both critical to the implementation process.
3. The proposed guidelines for establishing necessary resources to support health care modelling within the *infrastructure component* are considered to be useful at both local and national management level.
4. The teamwork approach (*which includes simulation team, management team, problem-solving team and data supporting team*) is considered to be very important for supporting simulation development in a long term basis.
5. The proposed best practices for guiding the *simulation team and management team* are considered to be useful at only the national management level.
6. The proposed best practices for guiding the *problem-solving team and data supporting team* are considered to be useful at both local and national management level.
7. The proposed *key knowledge* for guiding the teams to support simulation development is considered to be important at both local and national management level.
8. The proposed achievement plan within the *management component* is considered to be very important.
9. *Top management support in project funding* is considered to be very important
10. The proposed best practices for *securing top management support* for simulation development is considered to be useful.

11. The proposed best practices for *ensuring on-going project progress* can report to appropriate teams are considered to be very important.
12. The main issues highlighted in the proposed vision statement are considered to be very important for helping the problems of *resistance to change.*
13. The respondents are strongly agreed on the proposed *key differences between traditional culture and SIMT culture* in health care management.

Limitations

(With reference to Appendix G, any statements with a ranking lower than 4 is considered to be a limitation of the proposed framework)

1. The *mapping concept within the planning stage* of SIMT implementation framework is considered to be 'quite clear'.
2. The proposed best practices for guiding the *simulation team and management team* for local management level are considered to be 'not very useful'.
3. *Top management support for addressing the clinician resistance* issue is considered only 'fairly important'.
4. The four best practices (which include team size, length and time, staff profile and importance and complexity) suggested for guiding *simulation pilot project* are considered to be 'not very useful'.

The validation proved the five SIMT components and the planning stage of the implementation framework are valuable and useful for guiding this group of professionals for embedding simulation within the sector. Although the validation showed some proposed issues are considered not very useful, it was determined that the success of embedding simulation within the sector should follow a holistic approach. Therefore best practices for guiding simulation team and management team, top management support and best practices for guiding simulation pilot project are remain as important issues within the implementation framework.

6.3 Framework validation through application of case study

The second part of the validation developed two case studies to validate the proposed action stage of the SIMT implementation framework. The action stage of the proposed framework includes two main targets, first is to model the health care system at operational level, while the second target is to model health care system at strategic level.

The author developed two case studies in a local children's hospital in order to validate the guidelines and best practices proposed within the action stage. The first case study focuses on the validation of the modelling approach for developing health care models at operational level. The second case study focuses on the validation of the modelling approach for developing health care models for addressing strategic decisions.

6.3.1 Case study for validating the modelling approach at operational level

The purpose of the case study was to apply discrete-event simulation (DES) approach and the proposed best practices to model health care system at the operational level. The Accident & Emergency (A&E) department of the local children's hospital was selected in the case study as a pilot project.
One of the consultants from this A&E department was participated as a project champion, who has over 30 years experience in this environment. The author was the simulation modeller who supports the problem structuring and the model building processes.

The A&E department open 24 hours, 7 days a week. Their main target is to provide trauma (minor or major) service for the children of this local area. In the UK, national targets have been putting pressure on most of these A&E departments which includes the "4 hours maximum wait" target. Health care managers and practitioners are eagerly seeking the most effective and efficient way to improve their performances.

The main objective of the pilot project was to apply DES approach to model the existing A&E operational processes. Health care managers and practitioners from the department can have a better understanding of the existing system, in terms of the impact of increasing demand and different capacity levels.

First phase of the pilot project

The first phase of the pilot project was to identify the main process flows within the A&E department. Figure 6.2 shows the main patient pathways within the A&E department. Patients are classified into five main types (i.e. AA, BB, CC, DD and EE), which to identify the level of illness or injury of a patient.

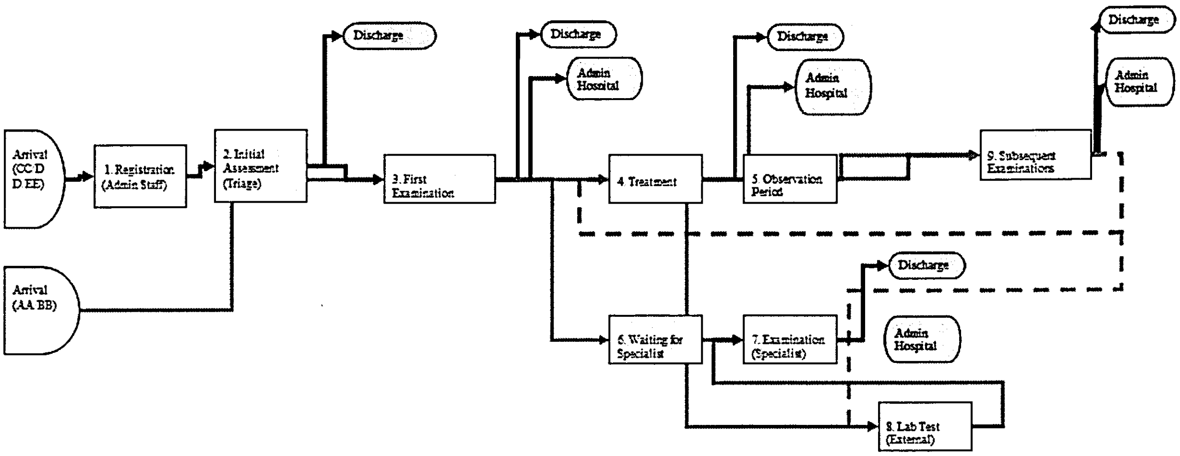


Figure 6-2 Process flow diagram of the A&E department

Second phase of the pilot project

During the second phase, several meetings had been arranged with the simulation champion and the related front-line staff to ensure the accuracy of the process flow diagram. The author then transformed the identified process flows into DES model logic with the use of Arena software. Figure 6.3 shows a snapshot of the DES model logic.

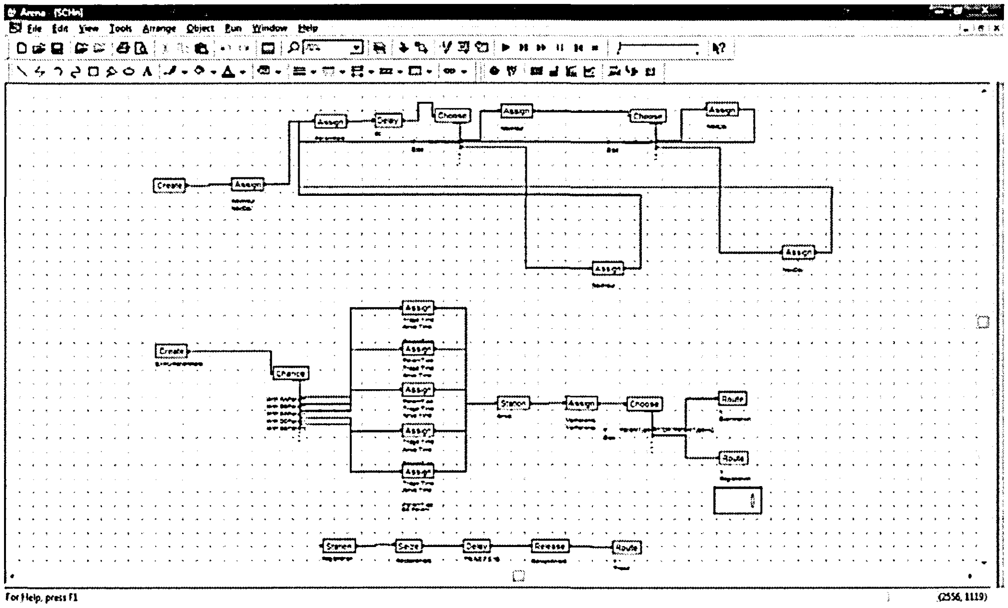


Figure 6-3 Snapshot of the DES model logic

Model data was collected by the simulation champion. The model data includes patient arrival pattern in terms of arrival time, day and patient type. Also, it includes staff capacity in terms of number of staff on duty and their working schedule.

The author embedded Excel spreadsheet into the DES model, so that the identified model data is stored within the Excel spreadsheet instead of the actual model. This practice can ensure health care managers and practitioners can easily modify the model data without any programming skill. Figure 6.4 and Figure 6.5 show the snapshots of these Excel spreadsheets with the data of patient arrival pattern and staff capacity.

Accident & Emergency Department - Patient Arrivals

	MON	TUE	WED	THU	FRI	SAT	SUN
00-01	1.31	1.17	0.92	0.69	1.17	1.37	1.40
01-02	1.52	1.02	1.19	0.83	1.19	1.63	1.60
02-03	1.21	0.79	0.77	0.75	0.92	1.06	1.08
03-04	0.73	0.44	0.42	0.69	0.56	0.73	0.73
04-05	0.81	0.63	0.52	0.40	0.35	0.76	0.65
05-06	0.56	0.40	0.27	0.44	0.54	0.43	0.54
06-07	0.69	0.52	0.33	0.48	0.63	0.76	0.62
07-08	0.81	0.75	0.87	0.60	0.79	1.12	0.90
08-09	1.90	1.79	1.67	1.87	1.71	2.18	2.13
09-10	5.17	4.96	4.50	4.87	5.12	4.43	5.19
10-11	6.79	6.13	5.67	6.60	6.27	6.49	6.52
11-12	7.50	7.29	7.15	7.42	6.54	7.29	8.02
12-13	8.37	6.44	7.46	8.00	6.56	7.57	9.04
13-14	6.73	7.29	6.58	7.06	6.62	8.02	9.02
14-15	7.90	6.71	6.19	7.37	5.81	7.16	8.35
15-16	5.87	5.88	5.65	6.62	5.54	8.45	8.29
16-17	8.31	6.48	6.71	7.37	7.50	7.80	8.21
17-18	7.81	7.31	7.31	7.50	7.48	6.78	8.10
18-19	10.62	9.65	10.73	9.52	9.92	7.02	8.54
19-20	10.69	9.81	9.54	10.04	9.98	7.59	9.33
20-21	7.69	7.87	8.06	8.52	6.67	7.10	7.73
21-22	5.69	5.88	6.00	5.90	5.44	6.00	6.15
22-23	5.35	4.23	4.21	4.56	5.10	4.45	4.21
23-24	2.92	3.06	2.63	2.65	3.65	3.02	2.65

Type	Percentage
AA	0.20
BB	0.50
CC	6.00
DD	93.00
EE	0.30
	100.00

Figure 6-4 Model data within excel spreadsheet (Patient arrival pattern)

Accident & Emergency Department - Staff Rota

Triage	T	T	T	T		T	T	T	T	T	T	T			T	T	T	T	T	T
	NR1	NR2	NR3	NR4	NR5	NR6	NR7	NR8	NR9	NR10	NR11	NR12	NR13	NR14	NR15	NR16	NR17	NR18	NR19	NR20
00-01	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
01-02	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
02-03	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
03-04	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
04-05	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
05-06	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
06-07	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
07-08	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
08-09	0	0	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
09-10	0	0	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
10-11	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0
11-12	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0
12-13	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0
13-14	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0
14-15	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
15-16	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	0	0
16-17	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0
17-18	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0
18-19	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0
19-20	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0
20-21	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0
21-22	0	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0
22-23	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1
23-24	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1

NR	Nurses
NP	Practitioner Nurse
CN	Consultant
T	Triage Nurse
FT	Full Time Triage

Figure 6-5 Model data within Excel spreadsheet (staff capacity)

Third phase of the pilot project

The third phase of the pilot project involves the presentation of the DES model and model execution. In order to present the DES model in a user-friendly interface, the author created the 2D animation for the A&E department model. Therefore, health care managers and practitioners can see how the system operates through the dynamic animation. Figure 6.6 shows the snapshot of the animation.

The main objective of this DES model is to provide a better understanding of the existing A&E system, which can help the health care managers and practitioners to identify the underlying bottlenecks and to support decision making. One of the simulation experiments in this project involved the analysis of the waiting times. Figure 6.7 is one of the simulation results generated from the existing A&E system model which indicates the waiting times involved in each key process.

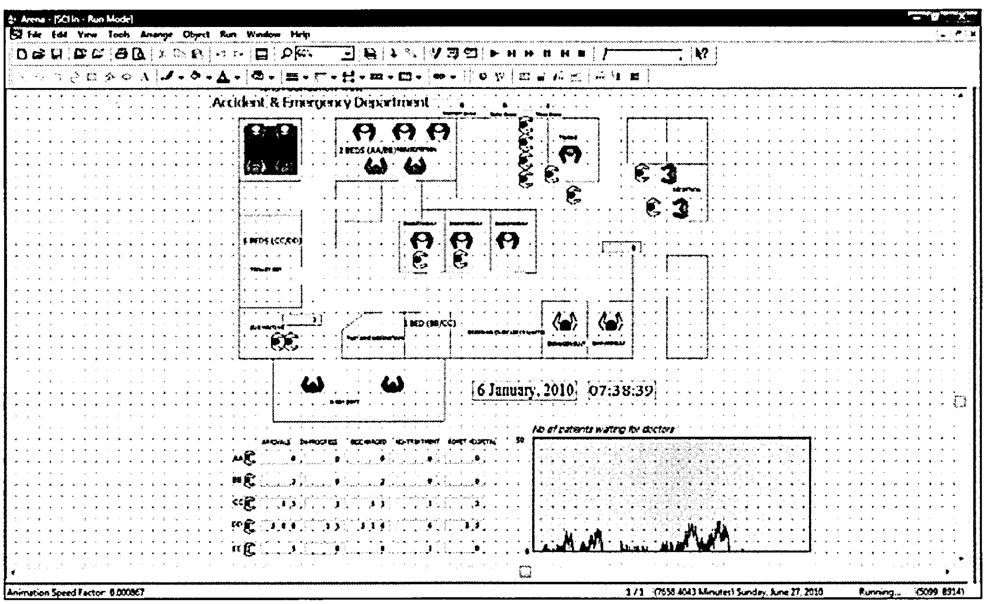
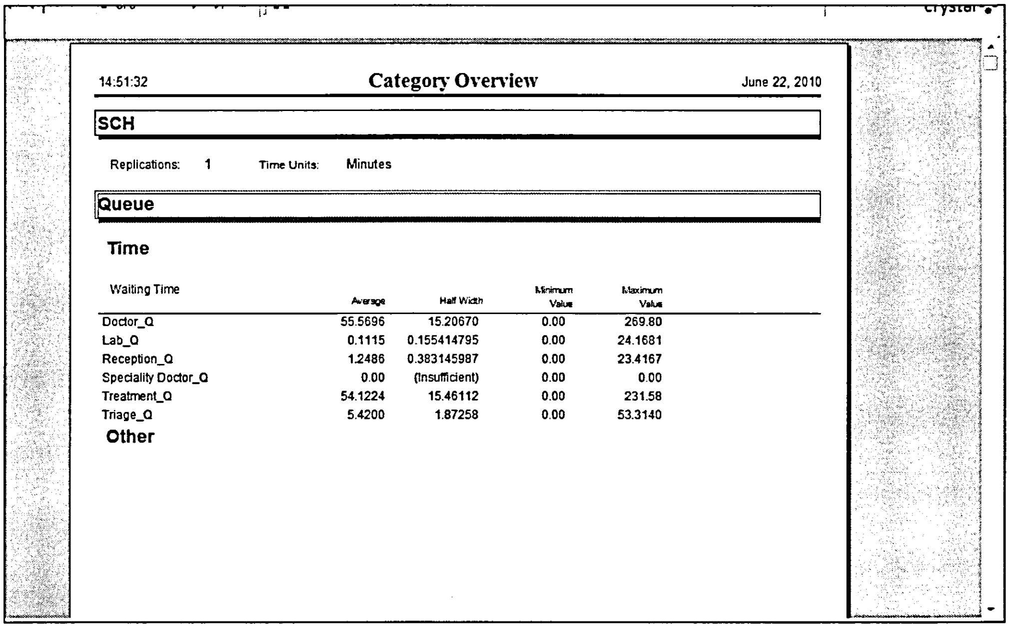


Figure 6-6 2D animation of the A&E simulation model


14:51:32 Category Overview June 22, 2010

SCH

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Doctor_Q	55.5696	15.20670	0.00	269.80
Lab_Q	0.1115	0.155414795	0.00	24.1681
Reception_Q	1.2486	0.383145987	0.00	23.4167
Speciality Doctor_Q	0.00	(Insufficient)	0.00	0.00
Treatment_Q	54.1224	15.46112	0.00	231.58
Triage_Q	5.4200	1.87258	0.00	53.3140

Other

Figure 6-7 Simulation results with waiting time

6.3.1.1 Feedback from the pilot project

The goal of the pilot project was to apply the suggested DES approach and the proposed best practices to model the operational process within the A&E department. Overall, the simulation champion and health care managers from the department were impressed by the results of the simulation model.

In order to examine their experiences during the pilot project, the author prepared an evaluation form which collected opinions from the simulation champion about the key components proposed within the action stage. A sample of the evaluation form is attached in **Appendix B**. Following are the key issues summarised from the results of the evaluation.

1. It is agreed that DES approach is a suitable tool for modelling operational processes in the health sector.

2. It is strongly agreed that identify management objective during the early stage of the project is important.
3. It is strongly agreed that the proposed simulation modelling cycle is easy to follow.
4. It is agreed that the proposed simulation modelling cycle is practical.
5. It is agreed that the team will apply the proposed methodology and guidelines in the future.
6. It is strongly agreed that defining patient pathway is important for identifying the main processes within a target problem.
7. It is agreed that suggested guidelines for defining model components and model data are useful.
8. It is strongly agreed that the best practice introduced for this simulation method is easy to follow and is practical.
9. It is strongly agreed that the team will apply the proposed modelling best practices in the future.

One additional comment had been made by the simulation champion which is the importance to get people to "believe" that simulation is related to the real world. So that people will take the risk to change from traditional management to this new approach.

6.3.2 Case study for validating the modelling approach at strategic level

The methodology component of the action stage suggested System Dynamics (SD) is the most suitable tool for modelling health care system at strategic level. The goal of the case study was to apply the SD approach and the best practices proposed within the modelling component to develop SD health care model for this purpose.

The case study project includes health care managers from the administration team, simulation champion and simulation modeller. After numerous meetings with this group of members, one of the latest national targets of the NHS – "the 18- week waiting time target" was selected to be the key objective of this pilot project.

First phase of the pilot project

The main goal of the 18-week waiting time target is to set a maximum wait of 18 weeks from the time of referral to a hospital consultant or to a start of a treatment.

The first phase of the pilot project was to identify the patient pathways involve within the 18-week target. Figure 6.8 shows the identified patient pathways from referral to a hospital consultant or a treatment start.

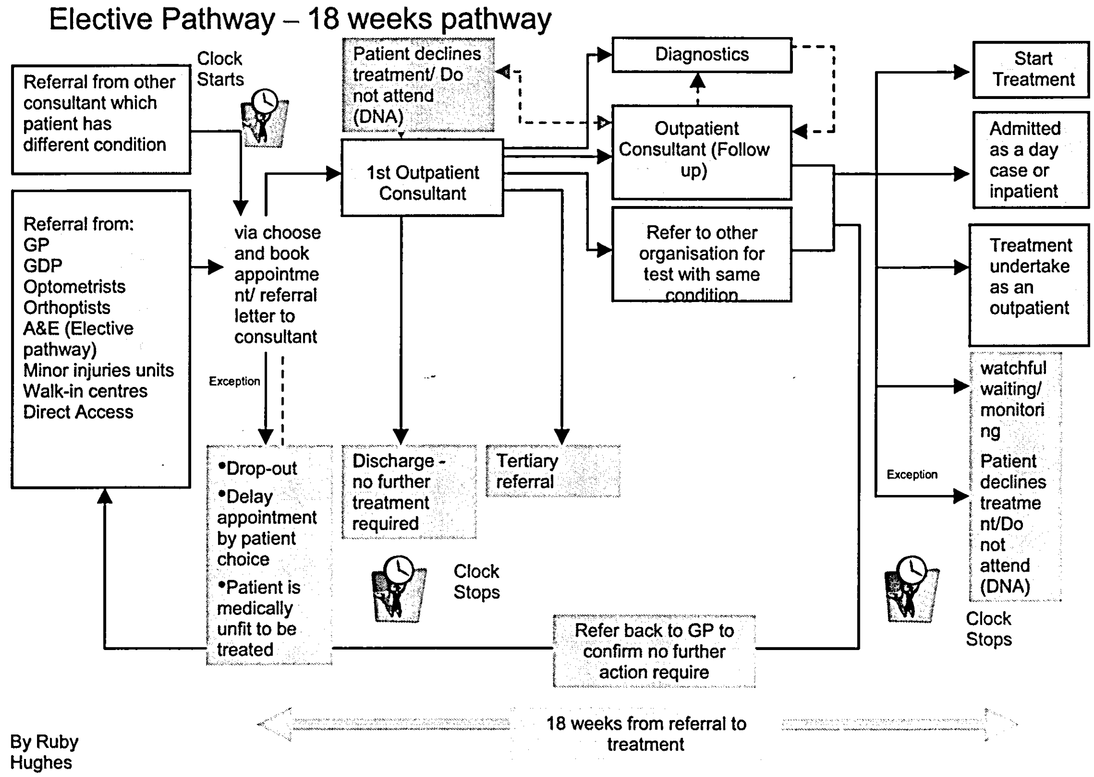


Figure 6-8 18-week pathway diagram

Second phase of the pilot project

The next phase of the pilot project was to identify the critical system elements that could influence the performance of the target system. Information had been collected from the group of health care managers and the 18-week project manager regarding the strategies which were considered to be applied for meeting the target. A cause and effect diagram was created which includes these identified strategies (Figure 6.9).

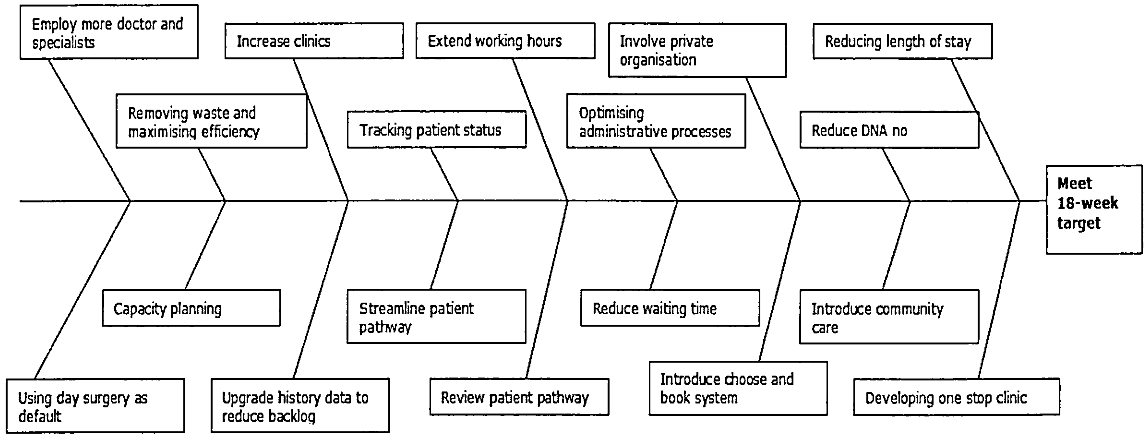


Figure 6-9 Cause and effect diagram - proposed strategies for meeting the 18-week target

Based on the proposed strategies identified by this group of professionals, the following mapping table highlights the critical key system elements which could influence the performance of the target system.

Table 6-2 Mapping of the identified strategies and key system elements

The identified strategies	**Key system elements**
Employ more doctor and specialists	Staff capacity
Extend working hours	Staff capacity
Optimising administrative processes	Staff capacity
Capacity planning	Staff capacity
Introduce community care	Resource
Increase clinics	Resource
Involve private organisation	Resource
Using day surgery as default	Resource
Developing one stop clinic	Resource
Reducing length of stay	Demand
Reduce DNA number	Demand
Streamline patient pathway	Demand
Upgrade history data to reduce backlog	Demand
Removing waste and maximising efficiency	Waiting time
Tracking patient status	Waiting time
Reduce waiting time	Waiting time
Review patient pathway	Waiting time
Introduce choose and book system	Waiting time

Third phase of the pilot project

During this phase, the simulation modeller based on the identified patient pathways and the key system elements developed a SD model which can represent the existing target system. The SD model was built with Stella® software. Snapshots of the SD model are shown in Figure 6.10, Figure 6.11 and Figure 6.12.

Figure 6.10 shows how the total capacity level can be affected by alternative system elements (such as consultant capacity, actual capacity in 1st outpatient and actual capacity in follow-up etc.). This module aims to represent the total capacity that is available for the target system.

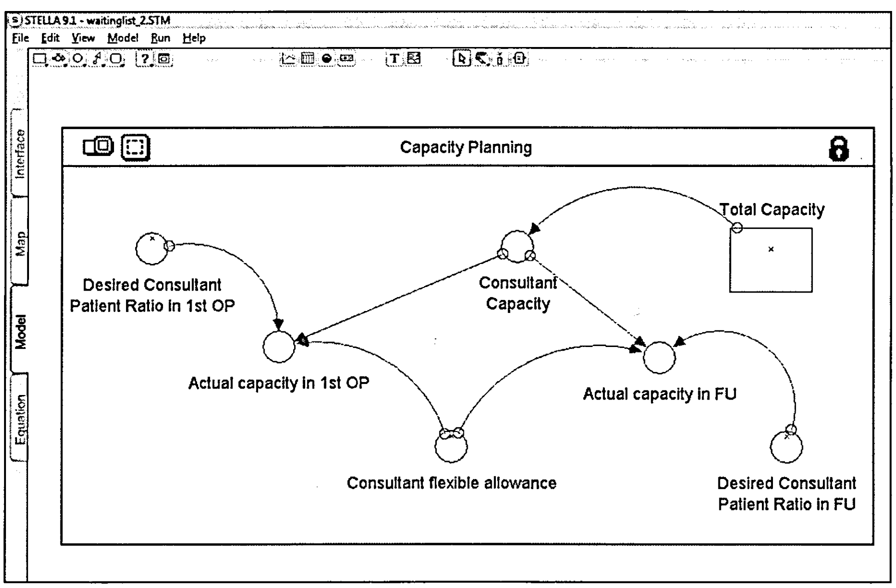


Figure 6-10 SD model - capacity planning module

Figure 6.11 shows the patient pathway within the 1st outpatient journey. In which, the level of patient waiting for 1st outpatient referral and the level of patient finished 1st outpatient are included within this module. Different system elements (such as fraction DNA in 1st outpatient, rate of patient being seen in 1st outpatient, fraction of patient transfer etc.) are all considered within this module.

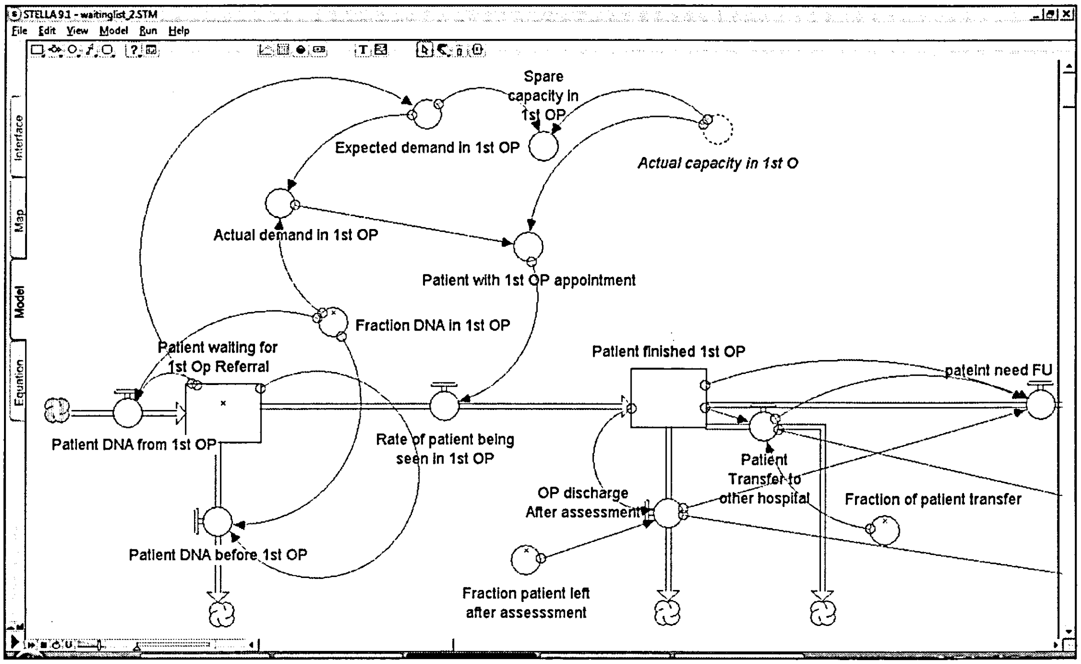


Figure 6-11 SD model - 1st outpatient journey module

Figure 6.12 shows the follow-up outpatient journey within the 18-week pathway, in which the level of patient waiting for follow-up, level of patient finished follow-up and level of patient finished the pathway are included within this module. System elements (such as actual capacity in follow-up, rate of patient being seen in follow-up and fraction patient discharge after follow-up etc.) are identified within this module in order to show how these variables can influence the performance of the target system.

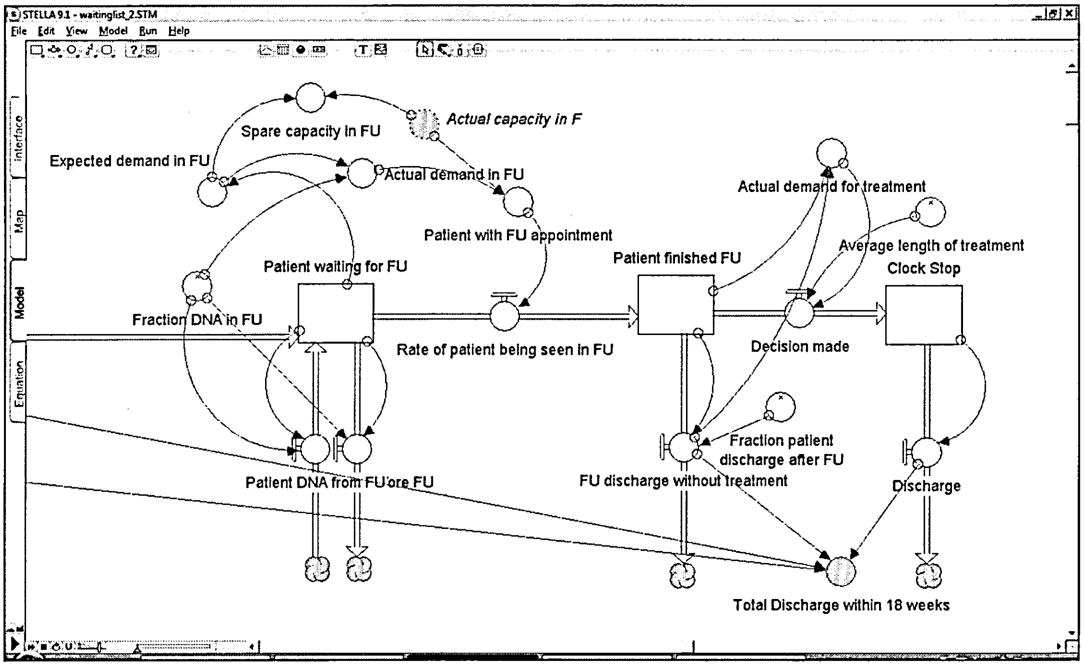


Figure 6-12 SD model - follow up outpatient journey module

Model data was collected from the 18-week project manager who is responsible for the performance of the 18-week target for this local hospital. The first column from Table 6.3 presents the type of model data required for this SD model, which includes capacity, demand and process data. The second column of the table presents the value of these model data.

Table 6-3 SD model data for the 18-week target project

Capacity	**Per Week**	
Total Capacity	5	(consultants)
Desired Consultant Patient Ratio in 1st OP	2.58	(per consultants)
Desired Consultant Patient Ratio in FU	7	(per consultants)
Consultant flexible allowance	0	(empty slot)
Demand		
Patient waiting for 1st Op Referral	80	
Fraction DNA in 1st OP	0.11	(1st Op Appointment)
Fraction patient left after assessment	0.34	(1st Op Appointment)
Fraction of patient transfer	0.1	(1st Op Appointment)
Fraction DNA in FU	0.1	(Follow-up)
Fraction patient discharge after FU	0.17	(Follow-up)
Process		
Average length of treatment	2	(Weeks)

In this pilot project, all the model data was stored within an Excel spreadsheet which is embedded with in the actual SD model. Therefore, further "what-if" analysis and simulation experiments can be easily operated by health care managers or practitioners.

Fourth phase of the pilot project

The main objective of the pilot project was to provide a better understanding on how the existing system performance is affecting by the level of demand, capacity and other critical system elements, thus to support the decision making on meeting the 18-week target.

The main goal of this phase was to execute simulation experiments in order to analysis the target system. One of the simulation experiments applied the existing model data provided by the 18-week project manager (Table 6.3), to look at the current performance on discharging the referral patients. Following graphs show the SD simulation results of the total discharge figures and the total discharge within 18 weeks.

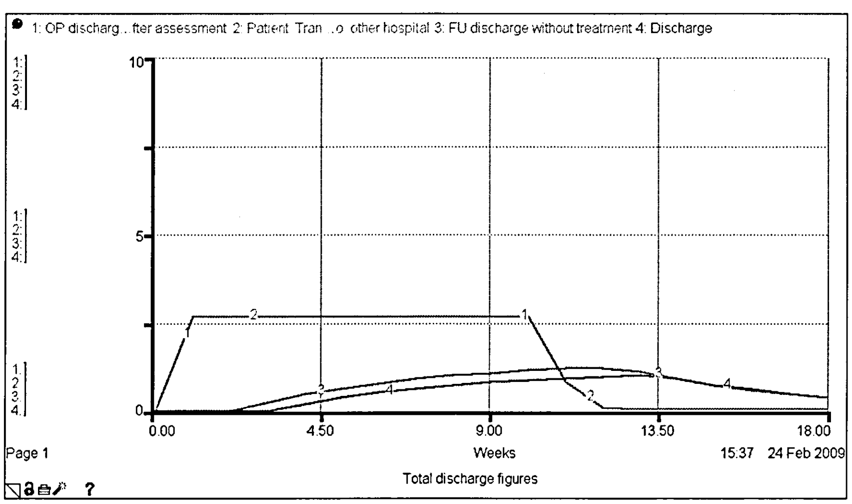


Figure 6-13 SD simulation results of the total discharge figures

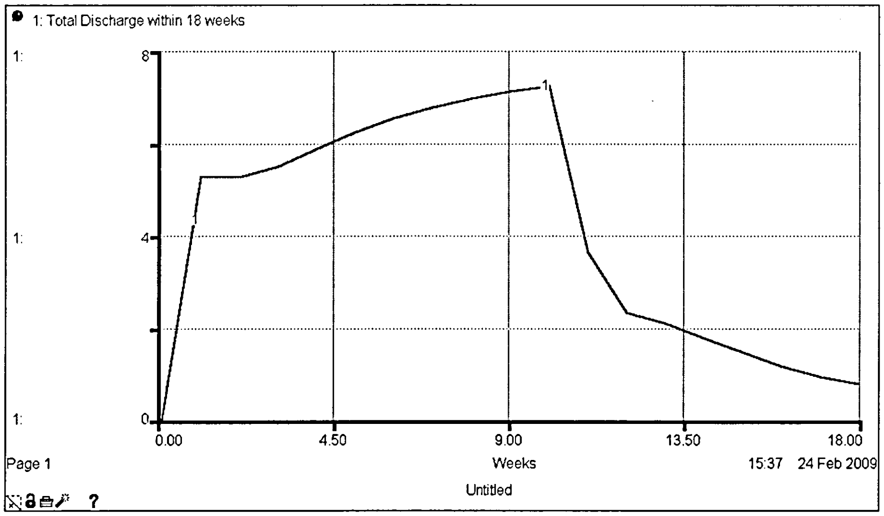


Figure 6-14 SD simulation results of the total discharge within 18 weeks

6.3.2.1 Feedback from the pilot project

In order to examine how the proposed simulation methodology and modelling components within the action stage can help on guiding the development of the pilot project, the author prepared the evaluation form to collect feedback from the 18-week project manager. A sample of the evaluation form is attached in **Appendix B**. Following are the key issues summarised from the results of the evaluation.

1. It is agreed that system dynamics is a suitable tool for modelling health care system at strategic level.
2. It is strongly agreed that identifying management objective in the early stage is important.
3. It is strongly agreed that the use of cause and effect diagram is useful for visualising a target system.
4. It is agreed that the proposed SD simulation modelling cycle is easy to follow and is practical.

5. It is strongly agreed that defining patient pathway is important for identifying the main processes within a target system.
6. It is strongly agreed that the suggested guidelines for defining model components and model data are very useful.
7. It is strongly agreed that the proposed best practices for developing SD model are easy to follow and is practical.

Additional comments had been made by the 18-week project manager on the data collection stage during the pilot project. It was suggested that model data should somehow match the available data from the hospital database, so that additional data analysis processes can be eliminated during the modelling cycle.

6.4 Summary

The proposed SIMT components and implementation framework were shown to be valuable for guiding health care managers and practitioners for embedding S&M in the health care sector. The first part of the validation proved the five SIMT components are the critical factors for addressing the underlying barriers of embedding health care modelling. Additionally it demonstrated that key issues proposed within the planning stage of the implementation framework are useful and important for guiding this group of professionals on how these critical factors can be embedded within their organisations.

The second part of the validation proved the key components proposed within the action stage of the implementation framework are useful and practical. The proposed methodology and modelling components were both shown to be valuable for guiding the development of health care models for supporting decision making at both operational and strategic management level.

7 CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The main aim of this research was to develop a practical and holistic implementation framework for guiding health care managers or/and practitioners to successfully embed S&M in the health sector. The key objectives of this research were clearly defined in Chapter one. This study has achieved its objectives through the proposed research approach which was presented in Chapter four (Figure 4.2).

A summary of its achievements are listed as follows:

- The current practices and existing problems of using S&M within the health care sector were identified. It has identified that the majority of the health care models were developed by commercial consultants or research organisations. The involvement of health care managers in the simulation study was very limited. Therefore, problems such as model accuracy, lack of communication, lack of evidence of model implementation are evident (see Chapter two).

- The underlying barriers that impede S&M embedding into the health sector were clearly identified in Chapter two. These include health care complexity, multiple stakeholders, cultural resistance, lack of simulation knowledge, time and cost, and modelling accuracy.

- The methodologies, current practices and limitations of applying DES and SD approaches within the health care sector were examined and discussed in Chapter three.

- Five key elements were proposed in order to address the underlying barriers of embedding S&M in the sector. These elements include infrastructure, cultural change, management, methodology and modelling. These elements were used as a basis for developing the implementation framework (see Chapter four).

- Three well-known quality and process improvement approaches were examined. These approaches include total quality management, lean management, and six-sigma quality. The methodology and best practices of embedding these approaches within the health care sector were discussed in Chapter two.

- The SIMT implementation framework was developed that provides a detailed roadmap for guiding the initial planning and the methodologies and activities required to successfully embed S&M within the sector (see Chapter five).

- The SIMT implementation framework was validated as valuable approach for guiding health care managers and practitioners to embed S&M within the health sector. The planning stage of the SIMT implementation framework was shown to be useful and important for guiding this group of professionals how to embed the essential components for supporting simulation development in a long-term basis. The action stage of the SIMT framework was proved to be practical and useful for guiding the development of health care models for supporting various decision making (see Chapter six).

7.2 Contributions to knowledge

The literature review (Chapter two) identified gaps in the knowledge of this research area. The following summarises the author's major contributions to the knowledge of health care simulation and modelling:

- Performed a literature review to understand the need for developing an implementation framework for guiding health care manager and practitioners to fully embed S&M within the health sector. Additionally, to understand the critical success factors and best practices for implementing quality and process improvement approaches within the sector (see Chapter two).

- Based on the findings from the literature and the author's experiences, it identified five key framework components in order to address the underlying barriers of implementing S&M within the sector (see Chapter two and Chapter four).

- Developed the SIMT implementation framework which proved to be valuable for guiding health care managers and practitioners to embed S&M in the sector for supporting varies decision making (see Chapter five and Chapter six).

- The planning stage of the SIMT implementation framework provided the best practices and success factors for addressing the barriers of embedding S&M. These barriers include health care complexity, multiple stakeholder, cultural resistance, time and cost and model accuracy (see Chapter five).

- The action stage of the SIMT implementation framework provided specific toolkits to guide health care managers and practitioners the appropriate methodologies and techniques for developing in-house simulation models for supporting routine decision making processes (see Chapter five).

7.3 Recommendations for further work

There is a great deal of areas for further work using the SIMT implementation framework. These include applying the planning stage of the framework in a real-world organisation and introducing the action stage of the framework at the national level.

7.3.1 Continuous improvement in a real-world organisation

Embedding S&M into the health sector is not a one-time event. The key components proposed within the planning stage of the SIMT implementation framework are recommended to be implemented through an on-going organisational improvement. This research proved these key components are useful and important for guiding health care managers or/and practitioners for addressing the underlying barriers of embedding S&M in the sector. However, further confidence in the proposed components could be built if they can be introduced and implemented within a real world organisation. Therefore, it will help to ensure whether the planning stage of the SIMT implementation framework can successfully guide the organisation to establish a fundamental environment and changed culture for supporting the S&M.

7.3.2 Additional case studies at national level

This research applied the action stage of the SIMT implementation framework into a local children's hospital, which proved to be a useful and practical guideline for supporting the development of health care models at both operational and strategic management level. Nevertheless, the key components included within the action stage could also be adapted for supporting simulation development at the national level.

As managers within the NHS claim they are going to face "an extremely challenging financial outlook… the NHS in England is going to face a real-term reduction of between £8bn to and £10bn over the three years after 2011" (Jeffreys, 2009). Additional research should target these challenges, introduces the proposed methodologies and guidelines to support the use of S&M within the NHS. For example, examine the underlying factors causing the inflation in the health service and analyse innovative ways of making the service more efficient.

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Appendix A

Questionnaire for evaluating SIMT implementation framework

Research Title: Embedding Modelling and Simulation Methods into Healthcare System

Dear Sir/Madam,

The purpose of this questionnaire is to evaluate the SIMT framework roadmap that is proposed in this research for guiding healthcare practitioners to embed the 5-elements simulation thinking (SIMT) into healthcare systems. SIMT framework roadmap includes two main parts - planning stage and action stage. Planning stage includes *Infrastructure, Management and Cultural Change*; and Action stage includes *Methodology and Modelling*.

This questionnaire contains five parts:

Part A of this questionnaire aims to understand the background of the respondent.

Part B of this questionnaire aims to evaluate the basic structure of the SIMT framework roadmap.

Part C to Part E of this questionnaire aims to evaluate the planning stage of the SIMT framework roadmap.

Please read the attached PowerPoint presentation before doing this questionnaire. The PowerPoint presentation will give you necessary information about the simulation thinking (SIMT) and the SIMT framework roadmap.

If you have any queries about this questionnaire or would like more information about the research, please contact Ruby Hughes at r.w.lau @shu.ac.uk or Terrence Perera at t.d.perera@shu.ac.uk

Please return your completed questionnaire by email to r.w.lau@shu.ac.uk no later than **30 August 2009 (New deadline 30 September 2009).**

Thank you for your valuable feedback!

Thanks and Best Regards,
Ruby Hughes

Part A. Background

A1. Please mark an "x" from one of the groups below that best describes your role

a. Academic professionals	( )
b. Healthcare practitioners	( )
c. Local healthcare managers	( )
d. National healthcare authorities	( )
e. Software vendors	( )
f. Other (please describe)	( )

A2. Have you ever participated with any simulation model development for supporting decision-making or system analysis?

Yes	( )
No	( )

Part B. Basic Structure of the SIMT framework roadmap (Slide 2 & Slide 3)

B1. How would you rate the importance of the 5 elements within the SIMT thinking? Refer Slide 2

SIMT 5-elements	1 Not important at all	2	3 Fairly Important	4	5 Very Important
a. Infrastructure	( )	( )	( )	( )	( )
b. Management	( )	( )	( )	( )	( )
c. Cultural Change	( )	( )	( )	( )	( )
d. Methodology	( )	( )	( )	( )	( )
e. Modelling	( )	( )	( )	( )	( )

B2. How would you rate the importance of the two main stages within the SIMT Framework roadmap? Refer Slide 2

SIMT Framework roadmap - two main stages	1 Not important at all	2	3 Fairly Important	4	5 Very Important
a. Planning stage	( )	( )	( )	( )	( )
b. Action stage	( )	( )	( )	( )	( )

B3. The "Planning Stage" of the SIMT framework roadmap is to guide healthcare practitioners to understand three of the necessary SIMT elements when embedding simulation in both the local level and national level.

How would you rate the clarity of the mapping concept within the SIMT framework roadmap? <u>Refer to Slide 3</u>

1 Not at all	2	3 Quite Clear	4	5 Very Clear
()	()	()	()	()

<u>Part C.</u>  **<u>(A) Infrastructure element (Slide 4)</u>**

C1. How would you rate the usefulness of the main issues and best practices suggested in the Infrastructure element in the local healthcare level? <u>Refer to Slide 4 – (A1)</u>

1 No use	2	3 Not very useful	4	5 Very Useful
()	()	()	()	()

C2. How would you rate the usefulness of the main issues and best practices suggested in the Infrastructure element in the national healthcare level? <u>Refer to Slide 4 – (A2)</u>

1 No use	2	3 Not very useful	4	5 Very Useful
()	()	()	()	()

C3. How would you rate the importance of each team suggested in SIMT infrastructure for supporting the evolvement of simulation? <u>Refer to Slide 4 – (A2) and (A5)</u>

SIMT Infrastructure - develop teamwork	1 Not important at all	2	3 Fairly Important	4	5 Very Important
a. Simulation team	()	()	()	()	()
b. Management team	()	()	()	()	()
c. Problem-solving team	()	()	()	()	()
d. Data supporting team	()	()	()	()	()

C4. How would you rate the usefulness of the best practices suggested for each team within a local healthcare level? Refer to Slide 4 – (A2)

SIMT Infrastructure - teamwork best practices	1 No use	2	3 Not very useful	4	5 Very Useful
a. Simulation team	( )	( )	( )	( )	( )
b. Management team	( )	( )	( )	( )	( )
c. Problem-solving team	( )	( )	( )	( )	( )
d. Data supporting team	( )	( )	( )	( )	( )

C5. How would you rate the usefulness of the best practices suggested for each team within a national healthcare level? Refer to Slide 4 – (A5)

SIMT Infrastructure - teamwork best practices	1 No use	2	3 Not very useful	4	5 Very Useful
a. Simulation team	( )	( )	( )	( )	( )
b. Management team	( )	( )	( )	( )	( )
c. Problem-solving team	( )	( )	( )	( )	( )
d. Data supporting team	( )	( )	( )	( )	( )

C6. How would you rate the importance of the proposed key knowledge for guiding the teams to support simulation development in local healthcare environment? Refer to Slide 4 – (A3)

1 Not important at all	2	3 Fairly Important	4	5 Very Important
( )	( )	( )	( )	( )

C7. How would you rate the importance of the proposed key knowledge for guiding the teams to support simulation development in national healthcare environment? Refer to Slide 4 – (A6)

1 Not important at all	2	3 Fairly Important	4	5 Very Important
( )	( )	( )	( )	( )

Part D.  **(B) Management element (Slide 5)**

D1. How would you rate the importance of the suggested simulation achievement plan in guiding a simulation project? Refer to Slide 5 – (B1)

1 Not important at all	2	3 Fairly Important	4	5 Very Important
( )	( )	( )	( )	( )

D2. How would you rate the importance of top management support in the following two main issues? Refer to Slide 5 – (B2)

SIMT Management - top management support	1 Not important at all	2	3 Fairly Important	4	5 Very Important
a. Funding	( )	( )	( )	( )	( )
b. Clinician resistant	( )	( )	( )	( )	( )

D3. How would you rate the usefulness of the best practices suggested for securing top management support? Refer to Slide 5 – (B2)

1 No use	2	3 Not very useful	4	5 Very Useful
( )	( )	( )	( )	( )

D4. How would you rate the importance of ensuring a good practice to report progress at short intervals during any simulation project development? Refer to Slide 5 – (B3)

1 Not important at all	2	3 Fairly Important	4	5 Very Important
( )	( )	( )	( )	( )

D5. How would you rate the usefulness of the best practices suggested for simulation team to report progress to management team? Refer to Slide 5 – (B3)

1 No use	2	3 Not very useful	4	5 Very Useful
( )	( )	( )	( )	( )

Part E. (C) Cultural change element (Slide 6)

E1. SIMT Cultural change element suggested that one of the key best practices to break down the barrier of resistance is to establish communication and participation. In which, a clear vision statement is suggested to be a vital practice.
How would you rate the importance of the main issues highlighted in the proposed vision statement? Refer to Slide 6 – (C1)

1 Not important at all	2	3 Fairly Important	4	5 Very Important
( )	( )	( )	( )	( )

E2. How would you rate the usefulness of four important issues suggested for a simulation pilot project? Refer to Slide 6 – (C2)

1 No use	2	3 Not very useful	4	5 Very Useful
( )	( )	( )	( )	( )

E3. SIMT Cultural change highlights the five main important differences between a traditional culture and SIMT culture for healthcare decision-making. How would you agree on these five main issues? Refer to Slide 6– (C3)

1 No Agree	2	3 Partly Agree	4	5 Strongly Agree
( )	( )	( )	( )	( )

END of the questionnaire

Sheffield Hallam University

Simulation Thinking (SIMT)

SIMT components & SIMT implementation framework ...

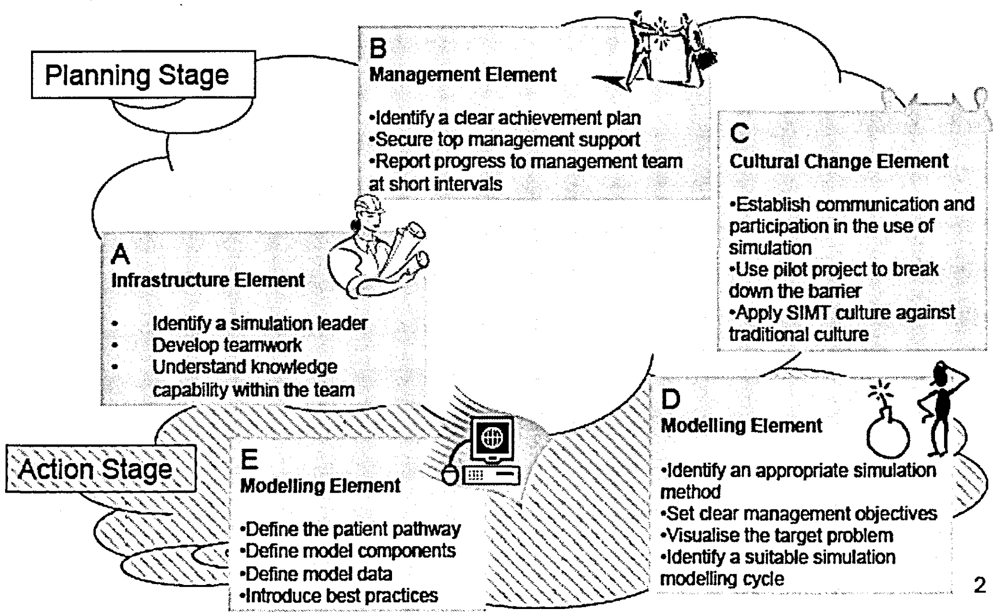
- *This document describes the SIMulation Thinking (SIMT) components – that presents the important elements required to be considered to make simulation and modelling (S&M) as a mainstream tool*

- *It also presents a implementation framework which includes the SIMT components, with a detailed roadmap for guiding the initial planning and methodologies required to embed S&M within the health sector*

By Ruby Hughes

1

- ***Simulation thinking (SIMT)** includes five elements (as shown below "A to E")*
- *These elements are grouped into: Planning and Action stages*
- *The questionnaire evaluation only focuses on "Planning Stage"*



2

• *To implement SIMT elements [A, B, C] to planning stage, we have developed an implementation framework (as shown below)*

• *For each element, guidelines and best practices are proposed to guide healthcare practitioners to understand the important issues when implementing simulation*

• *Guidelines are provided for two different levels: (a) Local management level and (b) National management level*

	SIMT Elements in Planning	Local level	National level
PLANNING	(A)Infrastructure 		
	(B)Management 		
	(C)Cultural Change 		

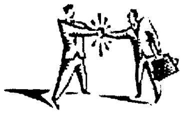
Implementation framework to embed SIMT elements into healthcare systems 3

(A) Infrastructure Element

This table summarises the important issues and guidelines when embedding SIMT Infrastructure element in local and national management level

In Local Healthcare Level	In National Healthcare Level
(A1) Identity a simulation leader • **Achievement-oriented:** able to identify right target for simulation • **Directive:** able to establish good communication and direct the use of simulation • **Participative:** able to understand current local targets and problems • **Supportive:** able to provide internal support in the use of simulation	(A4) Identity a simulation leader • **Achievement-oriented:** able to consider the political issues and procedures strategically in national level when applying simulation • **Directive:** able to set a clear guidelines, boundaries and objectives in national level simulation projects • **Participative:** have to highly involve in all simulation development project and participate national conferences • **Supportive:** able to provide simulation trainings and supports to local organisations and able to spread out the benefit of using simulation.
(A2) Develop teamwork • **Simulation team:** simulation leader, simulation specialist/modellers • **Management team:** management staff who can provide supportive information to simulation team • **Problem-solving team:** decision-makers who can perform 'what-if' analysis • **Data supporting team:** internal staff who can support data collection	(A5) Develop teamwork • **Simulation team:** simulation champion, simulation specialist/modellers, external consultants support may be required • **Management team:** management staff who can provide supportive information and support data collection process • **Problem-solving team:** decision-makers who can perform 'what-if' analysis • **Data supporting team:** internal department who can support data collection
(A3) Understand knowledge capability •**Simulation team:** skills for model building, skills to validate and verify a proposed model •**Management team:** skills to support problem identification process •**Problem-solving team:** skills to support problem identification process, skills to perform sensitivity testing and 'what if' analysis, and skills for performance evaluation •**Data supporting team:** skills to identify the appropriate requirements for the model data, and skills for data collection and analysis	(A6) Understand knowledge capability •**Simulation team:** skills in developing different types of simulation models, skills to validate and verify a proposed model •**Management team:** skills to support the management team members to identify a well-defined problem •**Problem-solving team:** skills to support problem identification process, skills to support the problem-solving team to perform sensitivity testing and 'what if' analysis, and skills for performance evaluation •**Data supporting team:** skills to identify the appropriate requirements for the model data, and skills for data collection and analysis

4



(B) Management Element

- *Management element is an critical element affecting the success of implementing simulation in healthcare*
- *This table summarises the best practices and main issues when embedding SIMT management element into local and national healthcare levels*

Local healthcare level & National healthcare level

(B1) Identify achievement plan

Achievement plan for a simulation project should have:
- Well-defined problems
- Project objectives and goals
- Details for each project stage
- Time plan for each project stage
- Resources require for each project stage

(B2) Secure top management

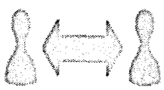
Funding: sufficient financial support is essential for a long-term success.
Clinician resistance: top management is always the power of encouragement.

Issues to achieve top management support:
- Provide some successful case studies of the use of health care simulation
- Provide proposals on how simulation could possibly help on addressing the decision makings at the local level
- Provide a clear strategic plan to identify the funding, resources that may required

(B3) Report progress

- Ensure on-going simulation project provides timely simulation results
- Report management team the latest development progress
- Ensure collected model data is up-to-dated
- Listen to feedback
- Maintain good communication between simulation team members

5



(C) Cultural Change Element

- *Cultural change element is one of the success factor when embedding simulation into healthcare systems*
- *This table summarises the best practices and main issues when embedding SIMT cultural change element into local and national healthcare levels.*

Local healthcare level & National healthcare level

(C1) Establish communication and participation

Simulation leader and healthcare managers **should create a clear vision statement which includes:**
- Top management commitment and support to the implementation of S&M
- Encourage communications among individuals and simulation team for applying S&M
- Encourage staff participation and maintain staff feedback
- Involve front-line staff in decision makings
- Motivate staff with reward system

(C2) Pilot project

Pilot project can start from a really small scale, the main point is to involve healthcare practitioners in the simulation development cycle. There are four important issues:
1. **Team Size:** 3 to 4 staff for local level project/ 6 to 8 staff for national level project
2. **Length and time:** 2 to 4 weeks is ideal, depends on the level of the healthcare simulation model
3. **Staff profile:** staff involved should have both the willingness and the ability to learn and apply simulation within their departments in the future
4. **Importance and complexity:** pilot project should be built for a real target and problem, and avoid too complex structure

(C3) Apply SIMT Culture

Main differences from a traditional culture to SIMT culture for process improvement:
1. SIMT culture involve both managers and key staff in decision-making process
2. SIMT culture focuses on root cause analysis instead of blaming people
3. SIMT thinking emphasises "testing" before real implementation
4. SIMT seeks the optimize resource and capacity based on expected demand
5. SIMT culture can lower the costs with pre-testing new strategy

8

THE END

Full details of the SIMT Implementation framework are available upon request please contact me at r.w.lau@shu.ac.uk

By Ruby Hughes, August 2009

7

Appendix B

Evaluation form for SIMT implementation framework (Action Stage)

Research Title: Embedding Modelling and Simulation Methods into Healthcare System

This evaluation form is for completing after finishing the simulation model development, with the guidance from the 'Action Stage' of the proposed SIMT framework roadmap.

Part 1 - Methodology Element

Please tick the appropriate box	1 Strongly Disagree	2 Disagree	3 Don't know	4 Agree	5 Strongly Agree
1a. The selected simulation method (DES/SD) is suitable for the project.	☐	☐	☐	☐	☐
1b. Identified management objective in the early stage is important.	☐	☐	☐	☐	☐
1c. Cause and Effect diagram is useful for visualise a target problem.	☐	☐	☐	☐	☐
1d. The proposed simulation modelling cycle is easy to follow.	☐	☐	☐	☐	☐
1e. The proposed simulation modelling cycle is practical.	☐	☐	☐	☐	☐
1f. I/ My team will apply these methodology best practices and guidelines in the future.	☐	☐	☐	☐	☐

Part 2 - Modelling Element

Please tick the appropriate box	1 Strongly Disagree	2 Disagree	3 Don't know	4 Agree	5 Strongly Agree
2a. Defined patient pathway is important for identifying the main processes within a target problem.	☐	☐	☐	☐	☐
2b. Model components are clearly defined based on the examples provided.	☐	☐	☐	☐	☐
2c. Model data are clearly defined based on the examples provided.	☐	☐	☐	☐	☐

2d. The best practice (template/ excel spreadsheet) introduced for this simulation method is easy to follow	☐	☐	☐	☐	☐
2e. The best practice (template/excel spreadsheet) introduced for this simulation method is practical.	☐	☐	☐	☐	☐
2f. I/ My team will apply these modelling best practices and guidelines in the future.	☐	☐	☐	☐	☐

Other comments or any other issues you think are essential for the 'Action stage' of the SIMT framework roadmap.

End of this evaluation form

Thank you for your participation!

Thanks and Best Regards,
Ruby Hughes

Appendix C

Interview questions and analysis

Interviews with personnel from the Department of Health, the NHS and software vendors

(A) Interview questions:

PERSONAL DETAILS

1. Which area/department in healthcare are you working in?
2. What are your main duties?
3. How many years have you been working in the healthcare sector?

CURRENT CHALLENGES/TARGETS IN YOUR AREA

4. What are the key challenges/targets that you are aware of in your area/department/NHS? (bed management, patient flow, waiting time, lack of resources)
5. Personally, in which ways do you think these issues/challenges may be solved?
6. Are there any ongoing projects in your area/department/NHS for handling these issues/challenges?
7. In terms of process management, are there any projects in your area/department/NHS?
8. What is the progress of these particular projects/targets?
9. If any, how successful are these projects/targets?

18-WEEKS TARGET

10. Is your department related to the18-weeks target?
11. If so, how far can your department achieve 18-weeks target?

12. What are the key factors/challenges for your department to overcome in order to achieve 18-weeks target?
13. Which approach is your department targeting during this 18-weeks project?
14. In your opinion, what do you think about the current approach?
15. How successful is this approach?

EMBEDDING A NEW SYSTEM (e.g. Lean system)

16. What is the approach to make a new system/technique become an everyday tool in NHS?
17. Is it always a challenge?
18. What you think is the most important issues to bring a new system into NHS and become a daily tool?

SIMULATION & MODELLING

19. Are you aware of simulation and modelling used in the NHS
20. Are there any simulation tools that have been used in the past in your area/department? (either operational/ strategic model)
21. How has simulation been considered as a solution?
22. What type of simulation has been used?
23. If known, what was the key objective of this simulation project?
24. If any, who was involved in the simulation projects?
25. Were internal staff involved in the project?
26. Were external consultants involved in the project?
27. Can the simulation project achieve the objectives?
28. What type of problems have been resolved using simulation?

29. Were there any major challenges during the projects?

30. Are simulation projects still ongoing in your area/department?

31. Does your area/department have a strategy to further develop the use of simulation?

32. <u>If no, what kind of process improvement tools have been used in the past?</u>

33. <u>How successful are these process improvement tools?</u>

(B) Interview sample size

Department/organisation	Number of interviewee(s)
Department of Health (DOH)	1
NHS institute	1
Primary Care Trust	1
18 week target project manager	1
Secondary Care - NHS Trusts	10
Software vendor	1
Total:	15

(c) Interview analysis

	Secondary Care (Consultants, Doctors)	Secondary Care (Management Level)	Department Of Health	Primary Care Trust	Simulation Modeller
NHS challenge:	- Financial challenge - Sufficient funding - Performance - Patient safety - Managing resources - Improving waiting time - To handle emergency patients	- Financial and budget challenge - Patient safety - Maintain performance - Meet target - Space requirement - Predict amount of activity	- Costing - Complex behaviour/ Patient choice in healthcare system	- Financial and budget challenge - Patient safety - Maintain performance - Meet target	- Use basic process improvement tools to reduce waiting time - There are many educational-research in simulation but none of them really help NHS to improve efficiency - Complexity of healthcare system - political issues in NHS - Balance budget and cost effectiveness
Recent Target:	- Reduce MRSA disease - Patients need to see in 4 hours @ A&E - 18 weeks target	- 18 weeks target	- 18 weeks target - Patients need to see in 4 hours @ A&E	- 18 weeks target	- 18 weeks target

Issues in launching new target:	- Communication problem - Long procedure	- Long procedure (can take couple of years) - embed complex system is always from small then expands to the other area - Always have to balance : Cost, Time and Resources - Communication via team brief, notice board, intranet - Training and Seminar	- by punishment and award - by pilot project (not very common)		- Better to "involve" new system to existing process by training or integrate front-line staff to involve to new system - Training - Increase accessibility - Time-consuming - Pilot project - Leadership - visibility of the benefit - Increase public awareness
Main Target:	- Meet new target - Reduce transit time - Minimise resource with high efficiency - Enhance environment safety	- Meet new target - Predict amount of activity - Pay extra money for extra activity - Control backlog - Review pathway - Apply change management - Balance of the	- Review the whole NHS system then setup new targets and ideas in order to improve the overall UK healthcare system - Advise target to SHA	- PCT give out contracts annually, and make sure organisation can meet the required targets - Delivery performance: Reviewing activities	- Provide model for PCT, local organisation to achieve target and solve demand and capacity activities - Use DES to model details flow within hospitals (NHS

		budget - Capacities planning - Maintain patient safety - Reduce waiting time - Improve effectiveness and efficiency	- monitor PCT performance with monthly report	and patient experiences - Supporting internal booking system - Review current challenges and target with organisation	institute)
Process reengineering Tools:	- Lean technique - Discrete event simulation (in-house) - Excel statistics	- Simplify data - statistical data control (to understand demand, queue, DNA) - Tracking system (witness the whole process) - Capacity planning - Identify bottleneck - Lean - Ad-hoc meeting - Data mapping - Process mapping	- Stock and flow model in Excel/ Scenario planning - Discrete Event Simulation		- Discrete event simulation (in Good hope hospital) to predict system how to work with different scenario - Test different scheduling - Validation new design and design solution - Introduce Just in Time schedule - Scenario Generator Model (SGM): Redesign PCT pathway and provide scenario to be discussed

Opinion on simulation modelling technique:	- Very useful to understand the queuing problem and resources allocation issues.	- Modelling capacity is difficult - Difficult to get quality data - Specialist level is important	- very useful to understand different scenario testing - organisation don't trust the number from simulation		- High-level modelling tool to answer strategic questions - Answer what-if questions - Collect data can be difficult - data is easier to collect nowadays - Difficult to educate staff - Time - Simulation is good to predict variation - simple is important
Why organisation can't achieve 18-weeks target:	- Waiting Time problem (Paper work, Referral) - Poor planning in capacities and resources with waste resources	- Managing capacity is difficult (lack of efficient booking system) - high demand in outpatient referral, thus long waiting time	- Patient delay the process - Not enough resources (Budget problem) - Lack of specialist - Lack of documentation system	- Complexity in healthcare - Data IS system - Capacity (limited resource) - Difficult to track patient pathway - Back log problem	

	- Poor processes design - Pathway is too complicate for some patients - Resources shortage - Demand growth	- Efficiency problem - Specialist Resources are limited - Long training time for specialists			
Solution in 18 weeks target:	- Control and build flexibility on the use of resources - Increase resources (not a good idea for organisation) - Review pathway - Increase efficiency (Introduce day care service in A&E) - Tracking patient status - Extend working hours - Involve private organisations - Invest training in process improvement (in-house)	- Capacity planning - Review/streamline patient pathway - Problem oriented - Reduce waiting time by redesign pathway - Review public processes e.g. introduce day care service - Reorganise internal processes e.g. internal booking system - Collect clean data - Employ new staff - Negotiate with staff to meet target - Educate staff - Upgrade history data - productivity		- Support organisation: increase capacity, give alternative solution and bring expertise in. - Design care pathway - Reduce waste procedures	- Process mapping - Process improvement - Value stream design - Use simulation to reduce resources by streamlining - Culture change - use high-level simulation model to redesign processes - use strategic model to look at higher level consultation - use generic pathway

		measurement - Reduce number of DNA - understand the referral situation		
Problem of existing solution:	- NHS solve problem is problem-oriented - Not much prediction for future change - Lack of educational training within NHS - Difficult to see patient in time (patient need longer treatment) - NHS is not good at standardised process - Difficult to capture time of the every procedure - Patient case is complex then longer time is require for investigation - Limited specialists	- Difficult to get quality data - Difficult to change existing procedures - Difficult to measure patients status - Difficult to identify fixed pathway - Difficult to predict demand for specialist theatre - Difficult to calculate pathway		- Healthcare system is very complex, it is very difficult to use System Dynamics to solve the operational problems - Manager has lack of understand in simulation - Lack of training in systematic thinking - Lack of systematic thinking - Accessibility of simulation - Not 100% accurate - Lack of support for future development - Cost effectiveness: Need to match

	resources still can't cope with the increasing demand				budget - Healthcare system in England is political
Opinion on 18-weeks target:	- Important to ensure quality service while achieving the 18 week target - 18 weeks target increase cost and increase waste in resources if they don't solve the roof problem	- Good systematic target - Rule are simple - Not just a temporary solution compare to the past target	- Good target as it can review exciting problems - Reduce waste procedure - Redesign pathway to become more efficient and effective	- Good target as it can review exciting problems - Reduce waste procedure - Redesign pathway to become more efficient and effective	- Other organisation just/maybe throwing capacity/resources - NHS always solve the short team problem but not a long term solution - Manger training is very important - Lack of process improvement in NHS - Important to reengineering the whole NHS system, not just focus on individual organisation

Appendix D

Example of building simulation model with
Healthcare OR Template

Example of Building Simulation Model with Healthcare OR Template

This example describes the steps of using the Healthcare OR Template (Figure 1) with Arena ® Software to build an A&E operational process model. Figure 2 shows a process flow of a simple A&E patient pathway. The simulation model will follow this process flow as a structure during the development cycle.

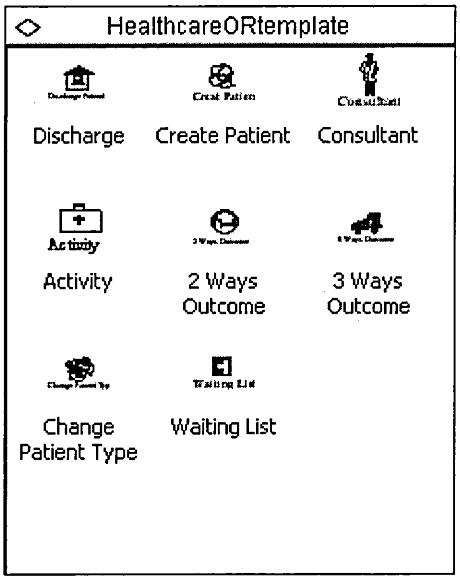


Figure 1- Healthcare OR Template with Arena® Software

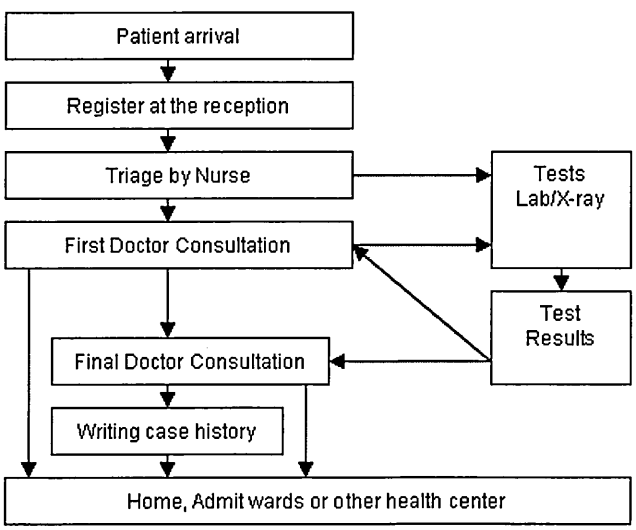


Figure 2- Simple A&E patient pathway example

Start a new simulation model

Within Arena® model logic view, from the left hand side, there is a list of model templates which content different building blocks for developing a simulation model. Figure 3 shows the model logic view of this example - A&E Operational Processes Model. From the list of the model templates, there is one called "Healthcare OR Template" which is the customised template for the example.

In the right hand side of the model logic view, there is where the actual simulation model is located. The following steps from this example will guide user to build this model with only the building blocks from the Healthcare OR Template (Figure 1).

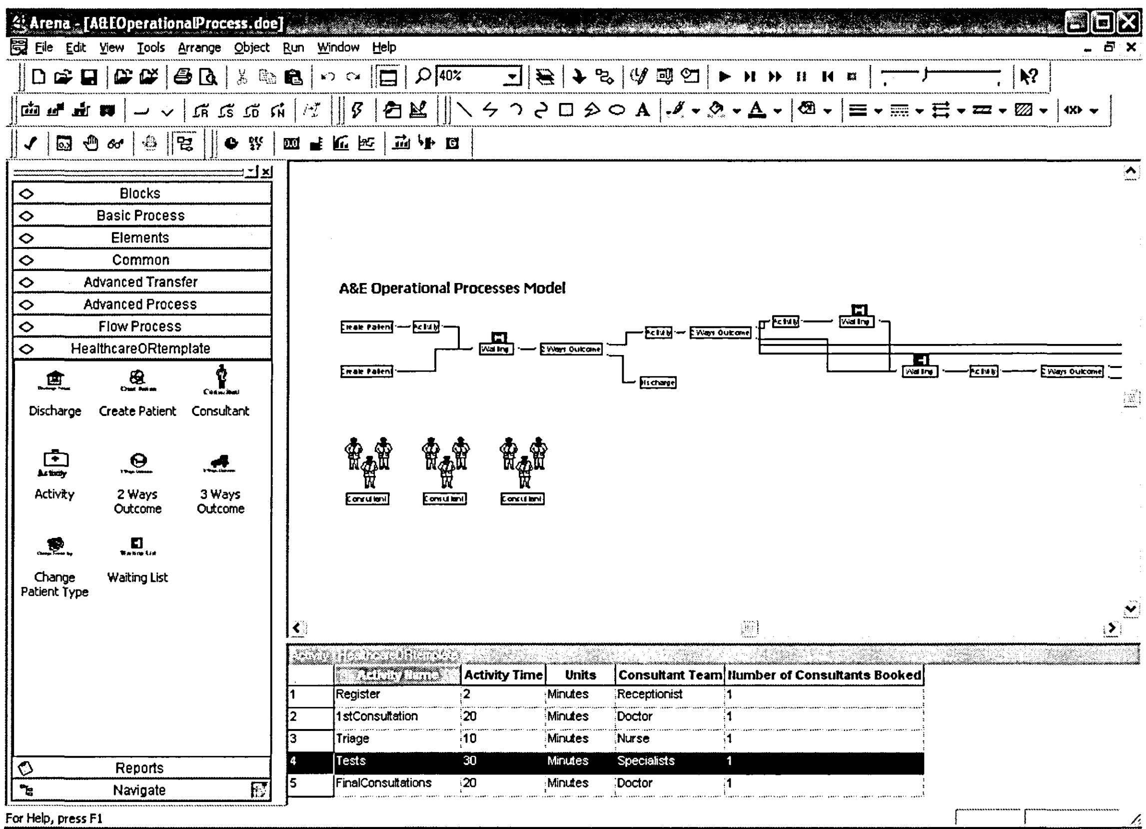


Figure 3 - Model login view in Arena® Software

Step 1: Patient Arrival

To create "Patients", first select the  Create Patient block from the Healthcare OR Template and paste it to the model logic page. Double-click the Create Patient from the logic page. Figure 4 and Figure 5 show the model details which are required. There are two types of patients coming to the system, Type1 - Ambulance patient, Type 2- Walk-In patient.

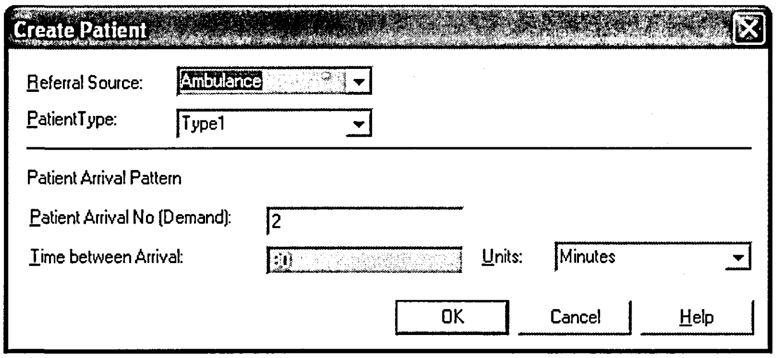


Figure 4 Create Ambulance Patient Block

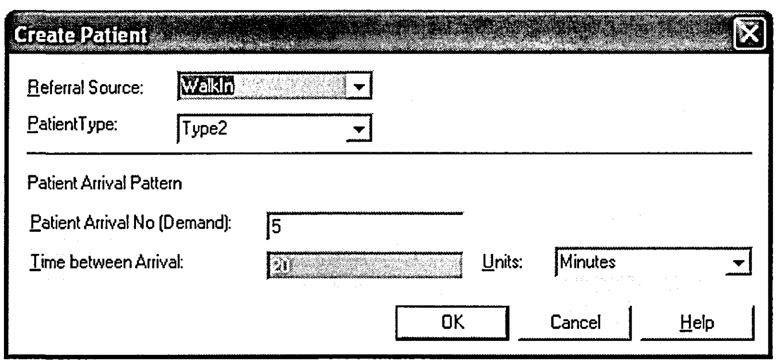


Figure 5 -Create Walk-In Patient Block

Step 2: Register at the Reception

To create an "Activity", first select the  Activity block from the Healthcare OR template and paste it to the model logic page. Double-click the Activity from the logic page. Figure 6 shows the model details which are required from the patient registration.

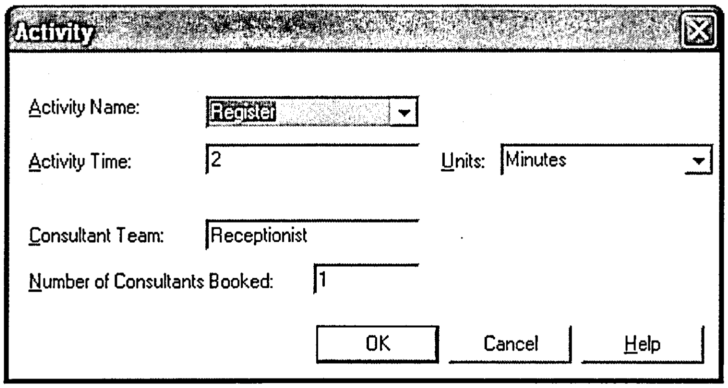
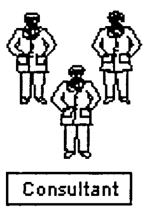


Figure 6 -Activity 1: Patient Registration

Within a simulation model, resource is required to allocate to an activity. In this case, we need receptionist to perform the patient registration. To simulate the "Resource", first select the 

block, then double click the 

from the logic view page, Figure 7 shows the required model details for this building block.

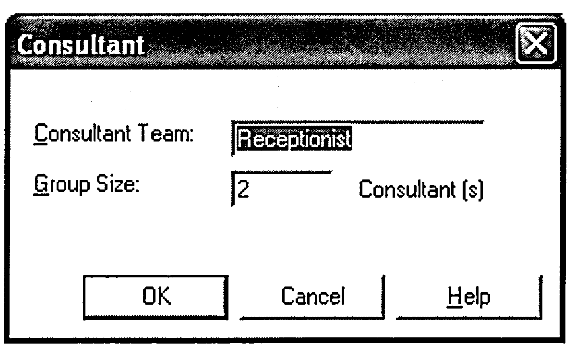


Figure 7- Resource: Receptionist

Step 3: Waiting before Triage

Since there is a "Waiting" before the triage, user can use the Waiting List block to simulate this. First of all, select the waiting list icon to the model logic page, then double-click the Waiting from the logic page. Figure 8 shows the model details required for this waiting activity.

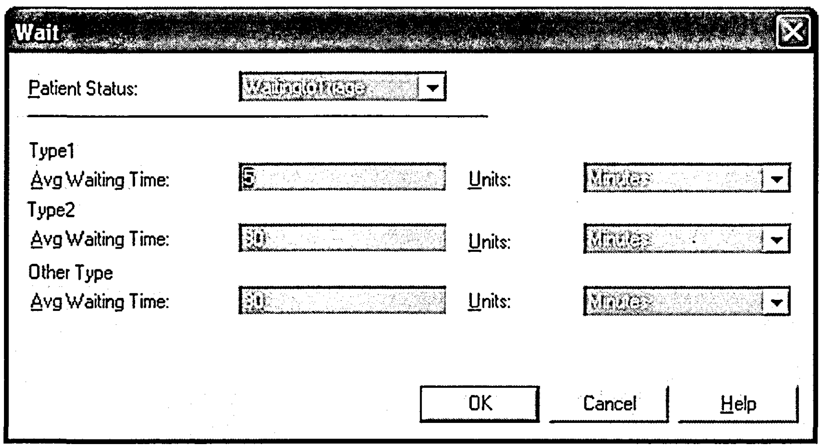


Figure 8- Waiting1: Waiting before triage

Step 4: 2 Ways Outcome

Within the Healthcare OR Template, there is 2 Ways Outcome block to simulate a 2 ways decision outcome after a waiting or an activity. In this case, after the waiting for triage, patient may send back home before triage. We use 2 ways outcome to simulate these two outcomes, one to home (20%); another one to triage (80%). Figure 9 shows the model logic details.

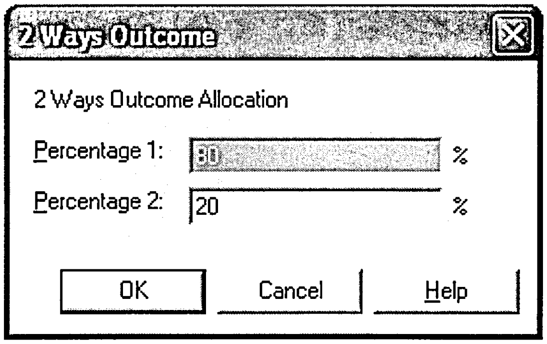


Figure 9- 2 Ways Outcome

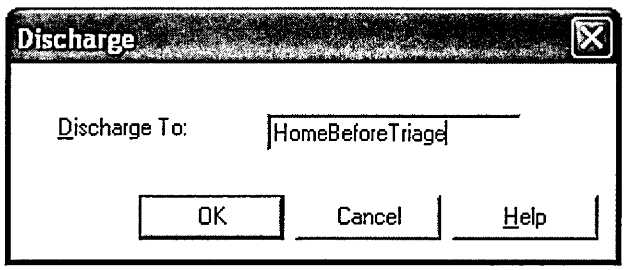


Figure 10- Patient Discharge

Step 5: Triage by Nurse

Since triage is an activity, therefore select the activity block and paste it to the model logic page. Double-click the activity icon to fill-in the activity details as in Figure 11.

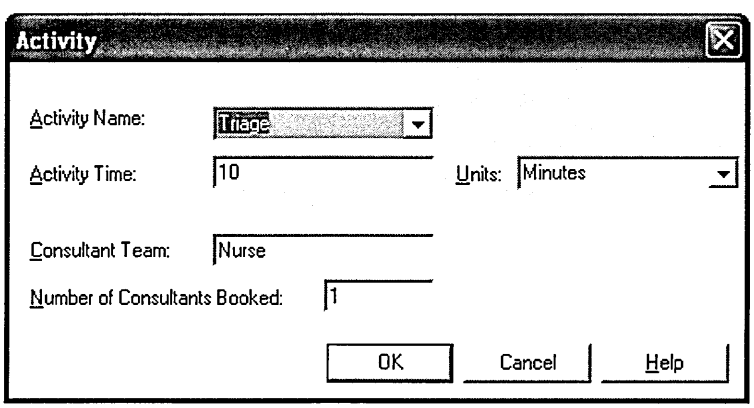


Figure 11- Activity2: Triage by Nurse

We need a 2 ways outcome to simulate the outcome after the triage activity. Therefore, we use the 2 ways outcome block with 50% send to Tests and 50% send to waiting for examination (First Doctor Consultation) as shown in Figure 12.

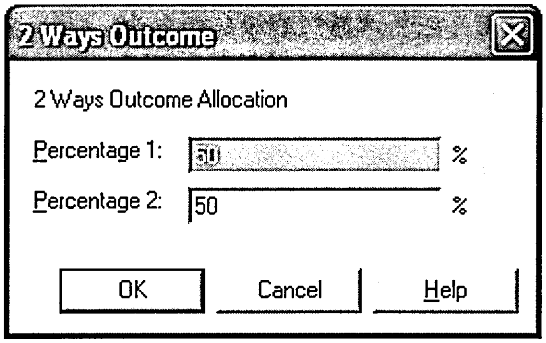


Figure 12 - 2 ways Outcome after Triage

Step 6: Tests - Lab/X-ray

Tests are activity, therefore we use the activity block and fill-in the required model details as shown in Figure 13.

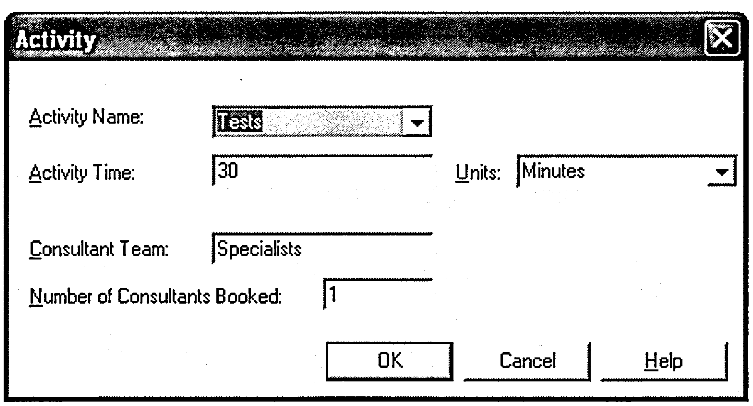


Figure 13- Activity3: Tests in Lab/X-ray

Since this is an activity, we need resource allocated to this activity. In which, specialists are required for this activity (Figure 14).

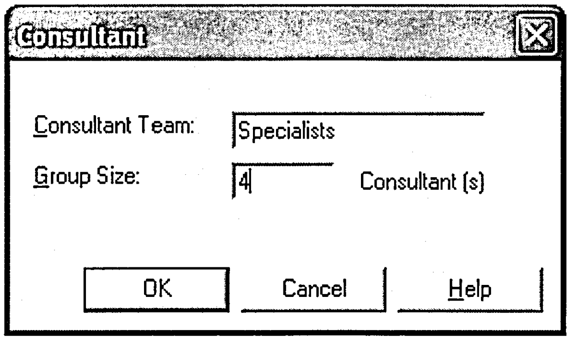


Figure 14- Resource: Specialists

If patient is sent to the do the Tests, waiting is required after the testing is done. We use the Waiting Block to simulate this event as shown in Figure 15.

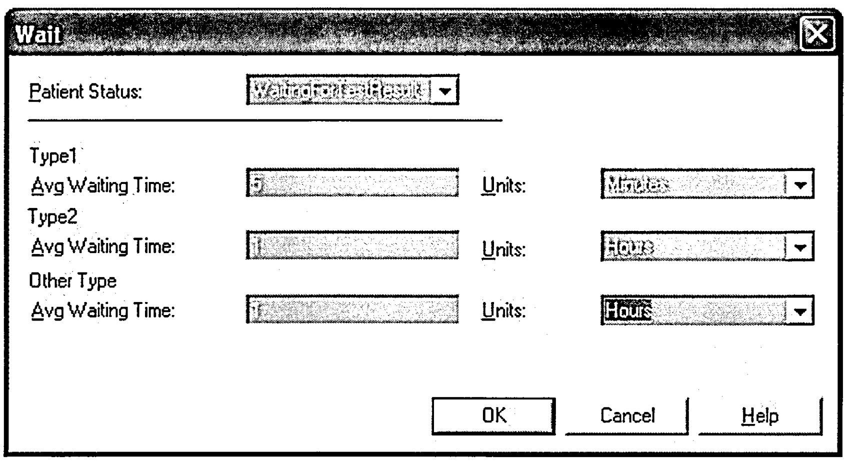


Figure 15: Waiting for Test Results

Step 7: Waiting For Examination

Both patients from Triage or after Testing need to wait for the first doctor consultant. Therefore, a Wait is required. We use the Waiting Block to simulate this waiting event as shown in Figure 16.

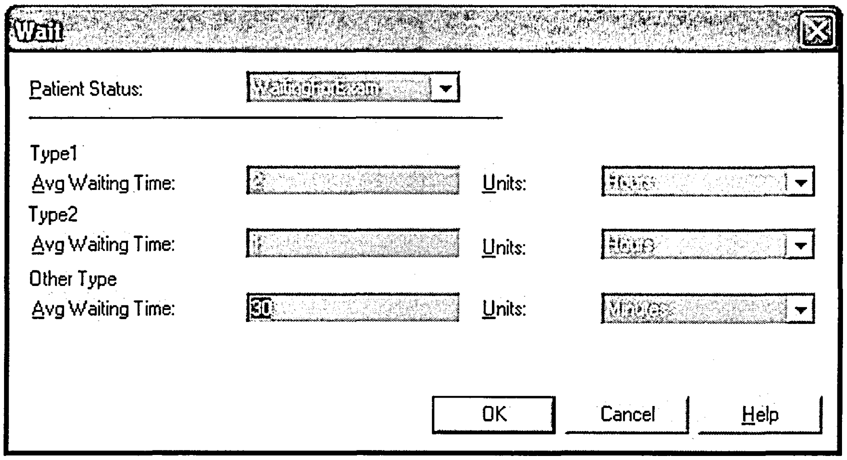


Figure 16- Waiting for Examination

Step 8: First Doctor Consultation

First doctor consultation is an activity. We need to use the Activity Block to simulate this event. Figure 17 shows the required model details within this Block.

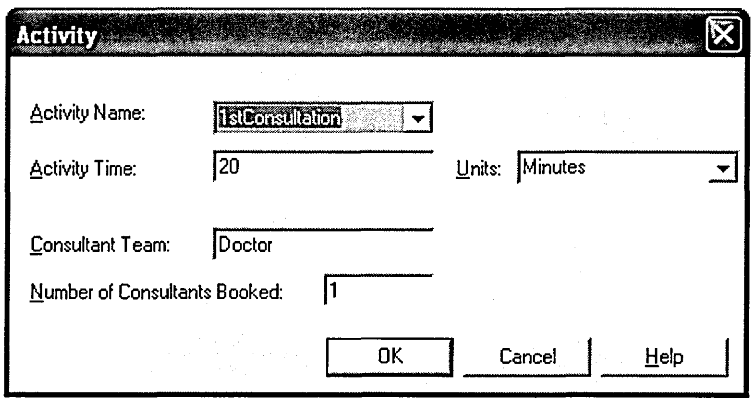


Figure 17-Activity 4: First Doctor Consultation

Then, we have to create resources for this activity. Figure 18 shows the Consultant Block which we need for this activity.

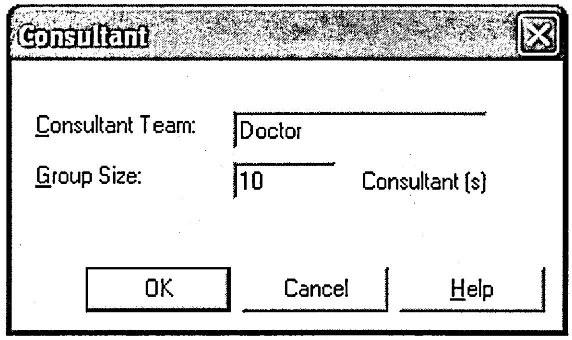


Figure 18-Resource: Doctor

After the first doctor consultation, there are 2 ways outcome. 50% of the patients need to send back for more testing; another 50% of the patients send to wait for the final examinations. (Figure 19)

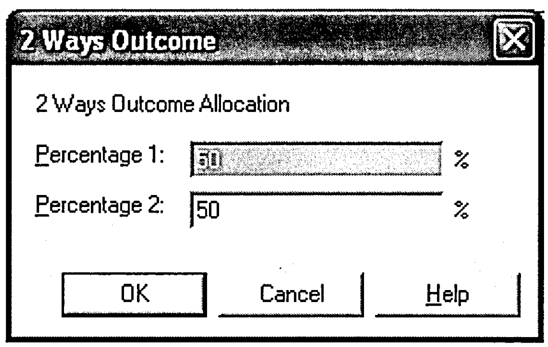


Figure 19- 2 Ways Outcome after 1st Consultation

Step 9: Final Doctor Consultation

Waiting is happened before the final doctor consultation. Therefore, we use a Waiting Block to simulate this waiting event. Figure 20 shows the model details required for this waiting event.

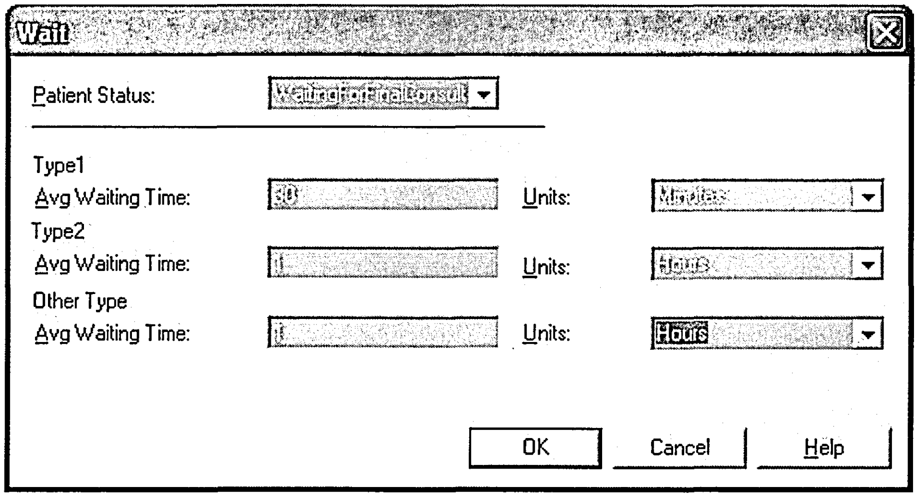


Figure 20- Waiting before Final Doctor Consultation

Final Doctor Consultation is an activity. Therefore, we used an Activity Block to simulate this activity event. Figure 21 shows the model details required for this activity even. Since only doctor (Resource) is required for this activity and doctor is already created for the Activity 4 (First Doctor Consultation). Therefore, this is no need to create another Consultation resource Block.

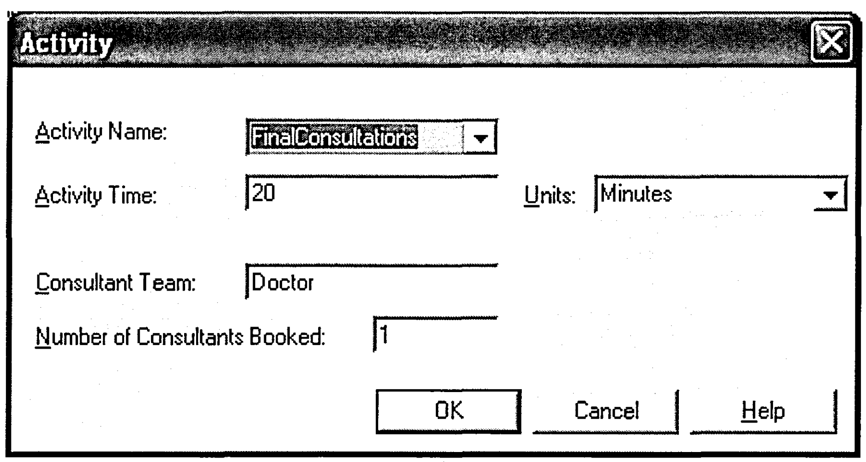


Figure 21- Activity5: Final Doctor Consultation

After the final doctor consultation, there are three outcomes which we need to simulate. One is patient discharge to home (50%), the other one is patient admit to wards (30%), the last one is patient need to send back for more testing (20%). In which,  3 Ways Outcome Block is used to simulate these multi outcomes. Figure 22 shows the model details required in the model logic.

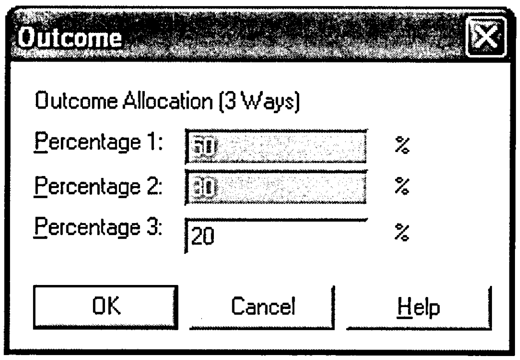


Figure 22- 3 Ways Outcomes after Final Doctor Consultation

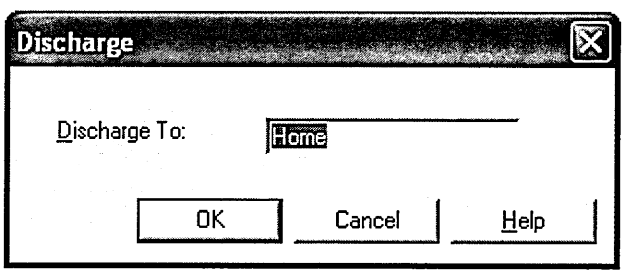


Figure 23- Patient Discharge Home after Final Doctor Consultation

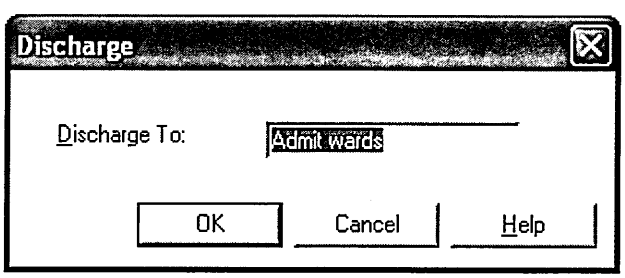


Figure 24- Patient Admit Wards after Final Doctor Consultation

Step 10: Connect all model logic events

Before running the A&E healthcare operational process model, it is important that all the model logic events are logically connected based on the process flow structure prepared in Figure 2. Figure 25 shows a snapshot of this model connection.

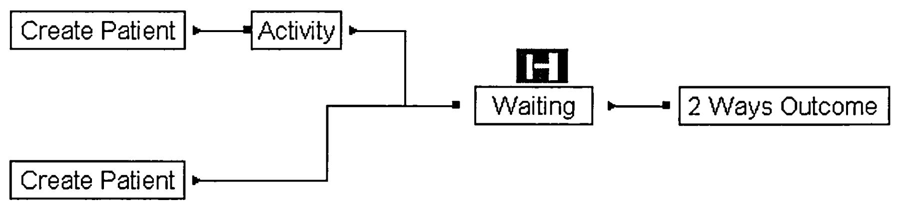


Figure 25- Model Logic View Example

Step 11: Change the simulation Run-time Setup

To finish the simulation model, it is important to change the simulation run-time setup. This function can find from the Run menu> Setup (Figure 26). In which, user can change the Replication Length (e.g. 6 Hours) and Number of Replications (e.g. 1)

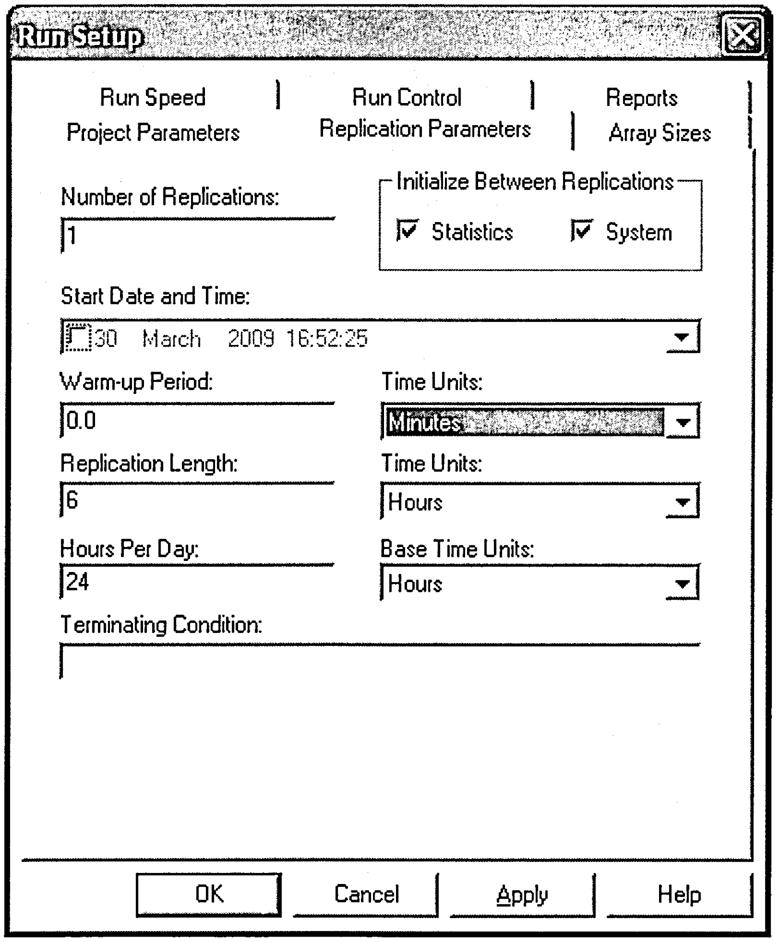


Figure 26- Simulation Run Setup

Step 12: Animation (Queues)

After finishing the model logic, there is something we can do for the simulation animation. One of the popular animations is to model the waiting queue.

In this example, we can select the Queue Icon from the animation toolbar  and paste it to the model logic window. Then double-click the queue and select which patient queue need to be shown in the animation. Figure 27 shows all the patient queues created within this example. Simply select the one which is required (e.g. Triage_Q), this animation queue will be showing during the simulation runs (Figure 28).

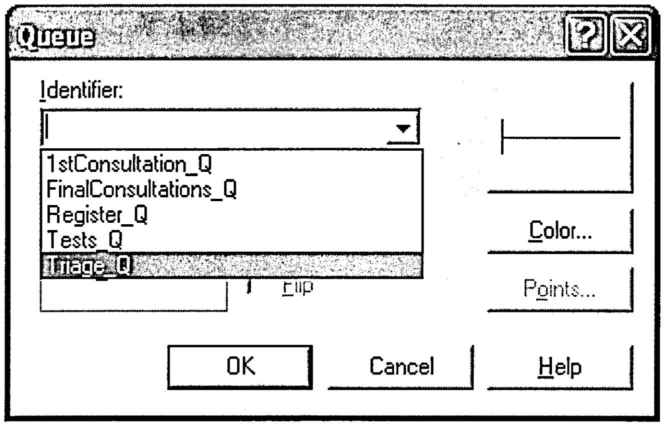


Figure 27- Queue Animation Window

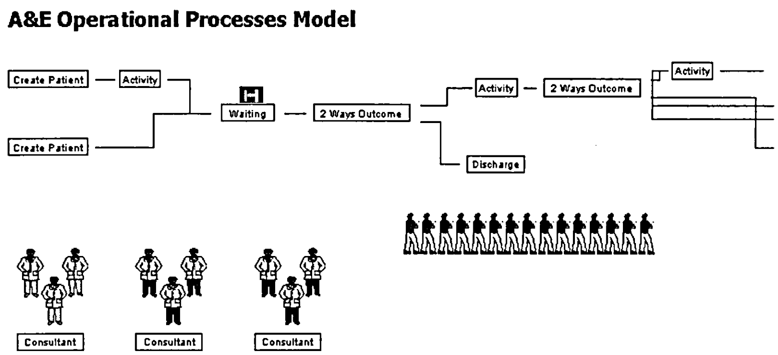


Figure 28- Animation Queue during simulation run

Step 13: Simulation Report

Arena ® automatically creates simulation summary report after each simulation run. Figure 29 and Figure 30 show the simulation reports from this A&E operational processes model.

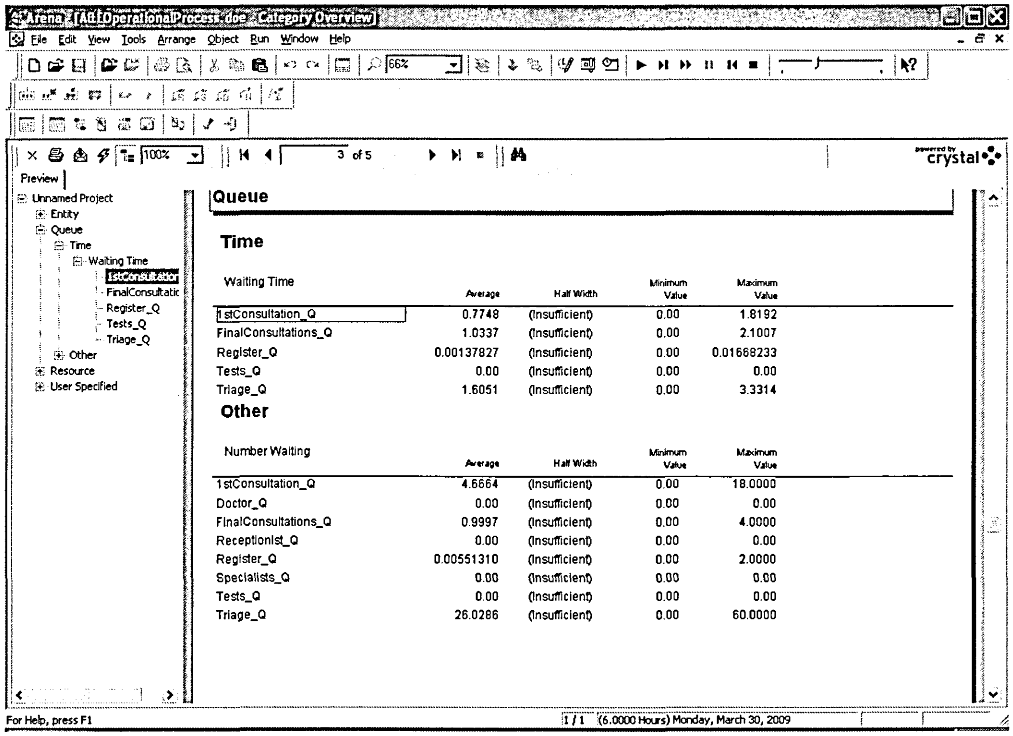


Figure 29- Simulation Report (Patient Queue Number)

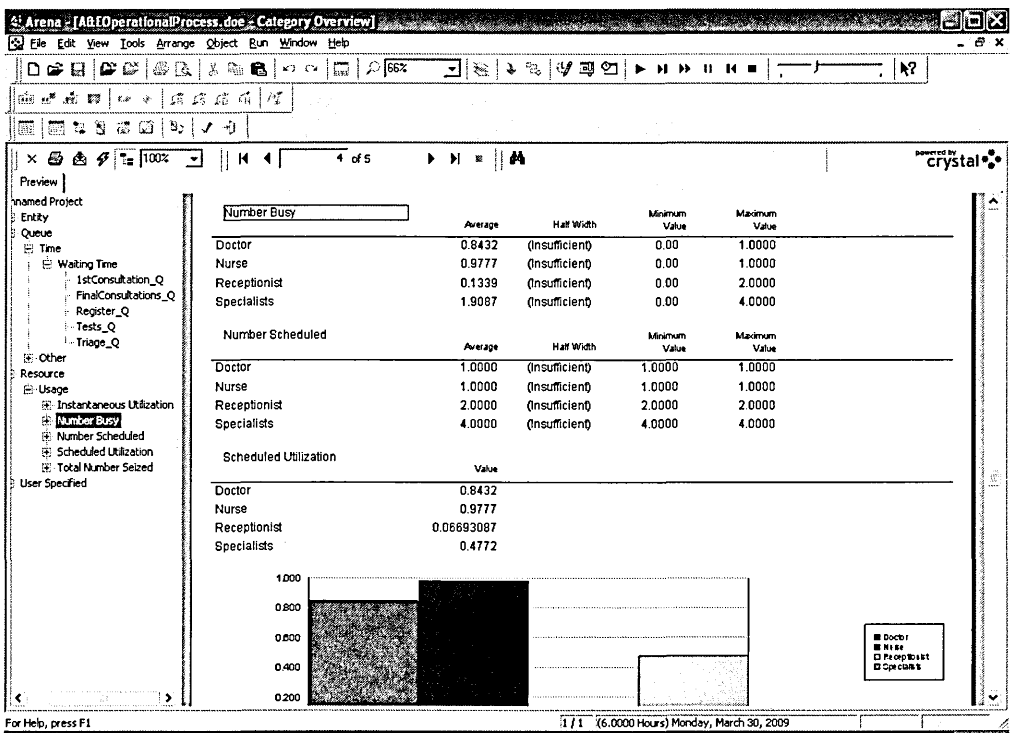


Figure 30- Simulation Result (Consultant Utilisation)

Appendix E

Example of embedding Excel spreadsheet to a SD model in Stella®

Example of Embedding Excel Spreadsheet to a SD model in STELLA®

This example describes the steps of using the STELLA "Input data" function to embed Excel Spreadsheet to a SD model. Figure 1 shows a stock and flow model built in STELLA of a typical A&E system.

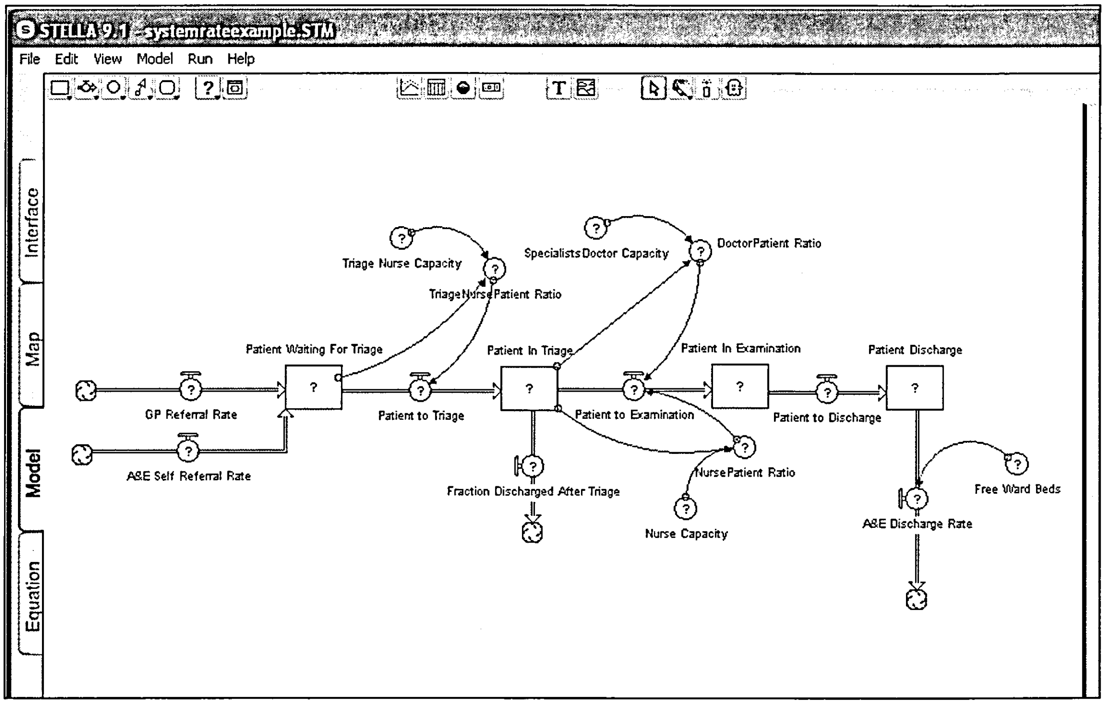


Figure 1 - Stock and flow model for a generic A&E system built in STELLA®

Step 1 - Create input data in Excel spreadsheet

The first step is to create an Excel spreadsheet with all the input data for running the model. Two columns are required: (1) variable name, (2) model data. Variable names are the system rates and system stocks defined in the SD model, for example *GP Referral Rate* and *Patient Waiting for Triage*. The important point is all the variable name can only define once within the model. Figure 2 shows the example of the excel spreadsheet (which saved as *'InputData.xls'*)

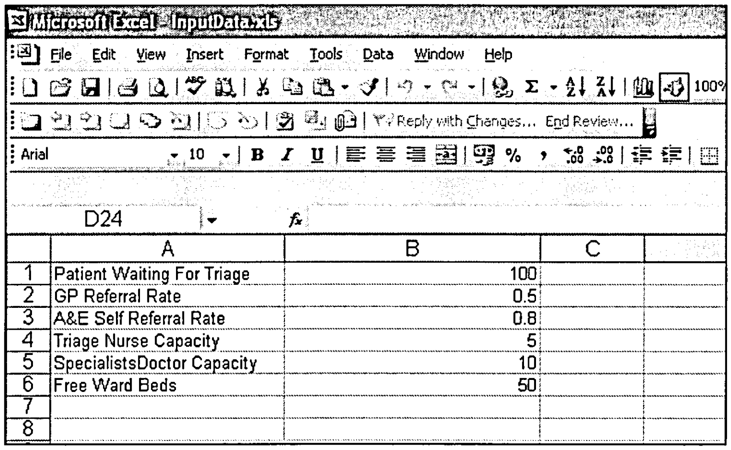


Figure 2 - Excel spreadsheet for model data entry

Step 2 - Embed 'InputData.xls' into the SD model

The next step is to embed 'InputData.xls' into the SD model so that the model data can be input automatically into the model environment. Select 'Import Data' from the STELLA menu toolbar: Edit> Import Data, dialog box shows in Figure 3.

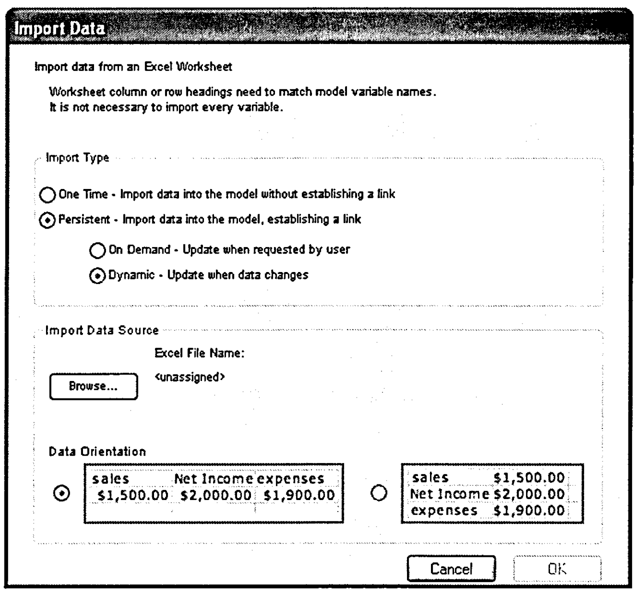


Figure 3 - Import Data dialog box in STELLA

Then select '*Dynamic - Update when data changes*' under the Import Type section, this option makes sure any changes in 'InputData.xls' will automatically change in the SD model.

In the Import Data Source section, select 'Browse' button to select the Excel spreadsheet which needs to embed into the SD model (*in this case - InputData.xls*).

Then, select the data orientation, either vertical or horizontal as shown in Figure 4.

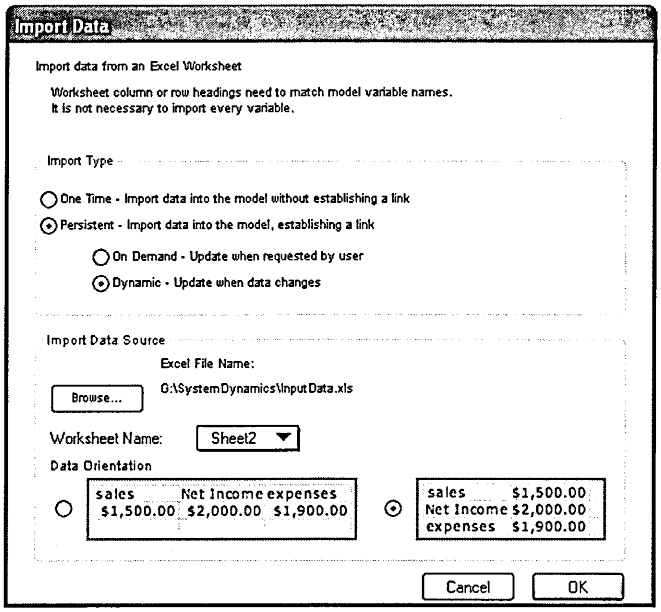


Figure 4 - Import Data dialog box options

Step 3 - Confirm the input data

After Step 2 is done, input data should be input successfully into the SD model if there is no error. Figure 5 is a confirmation message from STELLA if no error is found. However, if there is some error, error message will pop-up until error is clear.

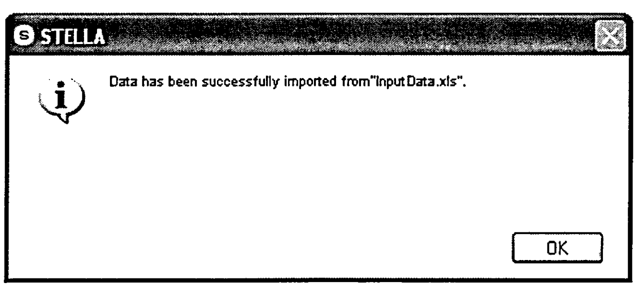


Figure 5 - Confirmation message with no error

To confirm the dynamic data is input into the model, double check the variable name, the data should be shown within the input box. For example 0.5 is input to the GP Referral Rate correctly as shown in Figure 6.

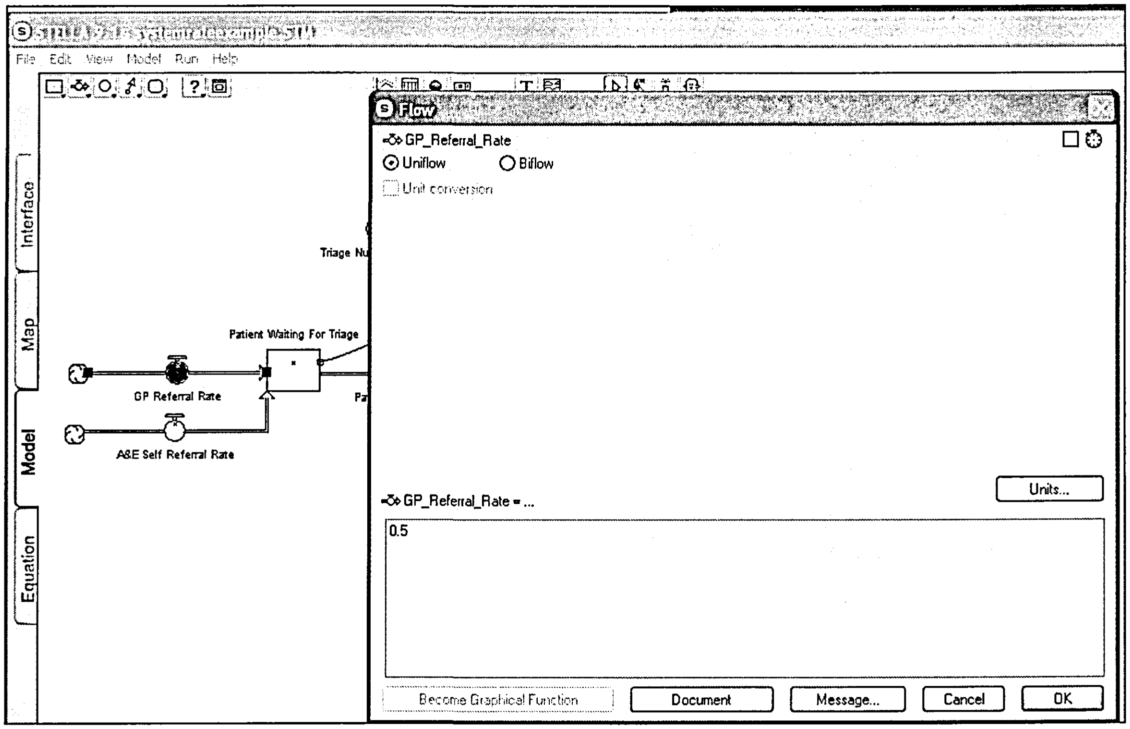


Figure 6 - Example of model data input in a variable from embedded spreadsheet

```
FREQUENCIES VARIABLES=B1a B1b B1c B1d B1e B2a B2b B3 C1 C2 C3a C3b C3c C3d C4a C4b C4c C4
d C5a C5b C5c C5d C6 C7 D1 D2a D2b D3 D4 D5
    E1 E2 E3
  /ORDER=ANALYSIS.
```

Frequencies

[DataSet1] G:\Phd\PhD documents\Framework Validation\Validation.sav

Statistics

		B1a	B1b	B1c	B1d	B1e	B2a	B2b	B3	C1
N	Valid	15	15	15	15	15	15	15	15	15
	Missing	0	0	0	0	0	0	0	0	0

Statistics

		C2	C3a	C3b	C3c	C3d	C4a	C4b	C4c	C4d
N	Valid	15	15	15	15	15	15	15	15	15
	Missing	0	0	0	0	0	0	0	0	0

Statistics

		C5a	C5b	C5c	C5d	C6	C7	D1	D2a	D2b
N	Valid	15	15	15	15	15	15	15	15	15
	Missing	0	0	0	0	0	0	0	0	0

Statistics

		D3	D4	D5	E1	E2	E3
N	Valid	15	15	15	15	15	15
	Missing	0	0	0	0	0	0

Frequency Table

B1a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	2	13.3	13.3	13.3
	5	13	86.7	86.7	100.0
	Total	15	100.0	100.0	

B1b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	1	6.7	6.7	6.7

B1b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	14	93.3	93.3	100.0
	Total	15	100.0	100.0	

B1c

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	1	6.7	6.7	6.7
	5	14	93.3	93.3	100.0
	Total	15	100.0	100.0	

B1d

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	5	33.3	33.3	33.3
	4	6	40.0	40.0	73.3
	5	4	26.7	26.7	100.0
	Total	15	100.0	100.0	

B1e

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	4	26.7	26.7	26.7
	4	5	33.3	33.3	60.0
	5	6	40.0	40.0	100.0
	Total	15	100.0	100.0	

B2a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	6.7	6.7	6.7
	4	3	20.0	20.0	26.7
	5	11	73.3	73.3	100.0
	Total	15	100.0	100.0	

B2b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	4	26.7	26.7	26.7
	5	11	73.3	73.3	100.0
	Total	15	100.0	100.0	

B3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	4	26.7	26.7	26.7
	3	6	40.0	40.0	66.7
	4	4	26.7	26.7	93.3
	5	1	6.7	6.7	100.0
	Total	15	100.0	100.0	

C1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	20.0	20.0	20.0
	4	6	40.0	40.0	60.0
	5	6	40.0	40.0	100.0
	Total	15	100.0	100.0	

C2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	6.7	6.7	6.7
	3	2	13.3	13.3	20.0
	4	9	60.0	60.0	80.0
	5	3	20.0	20.0	100.0
	Total	15	100.0	100.0	

C3a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	20.0	20.0	20.0
	4	5	33.3	33.3	53.3
	5	7	46.7	46.7	100.0
	Total	15	100.0	100.0	

C3b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	6.7	6.7	6.7
	4	6	40.0	40.0	46.7
	5	8	53.3	53.3	100.0
	Total	15	100.0	100.0	

C3c

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	3	20.0	20.0	20.0
	5	12	80.0	80.0	100.0
	Total	15	100.0	100.0	

C3d

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	6.7	6.7	6.7
	4	5	33.3	33.3	40.0
	5	9	60.0	60.0	100.0
	Total	15	100.0	100.0	

C4a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	2	13.3	13.3	13.3
	2	3	20.0	20.0	33.3
	3	4	26.7	26.7	60.0
	4	3	20.0	20.0	80.0
	5	3	20.0	20.0	100.0
	Total	15	100.0	100.0	

C4b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	6.7	6.7	6.7
	2	1	6.7	6.7	13.3
	3	6	40.0	40.0	53.3
	4	4	26.7	26.7	80.0
	5	3	20.0	20.0	100.0
	Total	15	100.0	100.0	

C4c

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	6.7	6.7	6.7
	3	4	26.7	26.7	33.3
	4	6	40.0	40.0	73.3
	5	4	26.7	26.7	100.0
	Total	15	100.0	100.0	

C4d

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	6.7	6.7	6.7
	3	3	20.0	20.0	26.7
	4	8	53.3	53.3	80.0
	5	3	20.0	20.0	100.0
	Total	15	100.0	100.0	

C5a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	6.7	6.7	6.7
	3	2	13.3	13.3	20.0
	4	6	40.0	40.0	60.0
	5	6	40.0	40.0	100.0
	Total	15	100.0	100.0	

C5b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	6.7	6.7	6.7
	2	2	13.3	13.3	20.0
	3	3	20.0	20.0	40.0
	4	3	20.0	20.0	60.0
	5	6	40.0	40.0	100.0
	Total	15	100.0	100.0	

C5c

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	6.7	6.7	6.7
	3	4	26.7	26.7	33.3
	4	5	33.3	33.3	66.7
	5	5	33.3	33.3	100.0
	Total	15	100.0	100.0	

C5d

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	2	13.3	13.3	13.3
	3	3	20.0	20.0	33.3
	4	8	53.3	53.3	86.7

C5d

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	2	13.3	13.3	100.0
	Total	15	100.0	100.0	

C6

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	20.0	20.0	20.0
	4	9	60.0	60.0	80.0
	5	3	20.0	20.0	100.0
	Total	15	100.0	100.0	

C7

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	20.0	20.0	20.0
	4	7	46.7	46.7	66.7
	5	5	33.3	33.3	100.0
	Total	15	100.0	100.0	

D1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	6.7	6.7	6.7
	4	7	46.7	46.7	53.3
	5	7	46.7	46.7	100.0
	Total	15	100.0	100.0	

D2a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	6.7	6.7	6.7
	4	3	20.0	20.0	26.7
	5	11	73.3	73.3	100.0
	Total	15	100.0	100.0	

D2b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	6	40.0	40.0	40.0
	4	4	26.7	26.7	66.7

D2b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	5	33.3	33.3	100.0
	Total	15	100.0	100.0	

D3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	20.0	20.0	20.0
	4	7	46.7	46.7	66.7
	5	5	33.3	33.3	100.0
	Total	15	100.0	100.0	

D4

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	4	26.7	26.7	26.7
	4	5	33.3	33.3	60.0
	5	6	40.0	40.0	100.0
	Total	15	100.0	100.0	

D5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	4	26.7	26.7	26.7
	4	7	46.7	46.7	73.3
	5	4	26.7	26.7	100.0
	Total	15	100.0	100.0	

E1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	20.0	20.0	20.0
	4	5	33.3	33.3	53.3
	5	7	46.7	46.7	100.0
	Total	15	100.0	100.0	

E2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	6.7	6.7	6.7
	3	6	40.0	40.0	46.7
	4	4	26.7	26.7	73.3

E2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	4	26.7	26.7	100.0
	Total	15	100.0	100.0	

E3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	6.7	6.7	6.7
	4	6	40.0	40.0	46.7
	5	8	53.3	53.3	100.0
	Total	15	100.0	100.0	

Appendix G

Mapping of questionnaire questions with SPSS output

Mapping of questionnaire questions/statements with the SPSS output

(The highlighted rank represents the most accepted rank for the question or/and statement)

B1. How would you rate the importance of the 5 elements within the SIMT thinking?
a. Infrastructure – 5 very important
b. Management – 5 very important
c. Cultural change – 5 very important
d. Methodology – 4 Important
e. Modelling – 5 very important

B2. How would you rate the importance of the two main stages within the SIMT framework roadmap?
a. Planning stage – 5 very important
b. Action stage – 5 – very important

B3. How would you rate the clarity of the mapping concept within the SIMT framework roadmap?
*3 – Quite clear

C1. How would you rate the usefulness of the main issues and best practices suggested in the infrastructure element in the local healthcare level?
4/ 5 –Useful to very useful

C2. How would you rate the usefulness of the main issues and best practices suggested in the infrastructure element in the national healthcare level?
4 – Useful

C3. How would you rate the importance of each team suggested in SIMT infrastructure for supporting the evolvement of simulation?

a. Simulation team – 5 very important
b. Management team – 5 very important
c. Problem solving team – 5 very important
d. Data supporting team – 5 very important

C4. How would you rate the usefulness of the best practices suggested for each team within a local healthcare level?

a. Simulation team – *3 not very important
b. Management team – *3 not very important
c. Problem solving team – 4 Important
d. Data supporting team – 4 Important

C5. How would you rate the usefulness of the best practices suggested for each team within a national healthcare level?

a. Simulation team – 4/5 Important to very important
b. Management team – 5 Very important
c. Problem solving team – 4/5 Important to very important
d. Data supporting team – 4 Important

C6. How would you rate the importance of the proposed key knowledge for guiding the teams to support simulation development in local healthcare environment?

4 - Important

C7. How would you rate the importance of the proposed key knowledge for guiding the teams to support simulation development in national healthcare environment?

4 - Important

D1. How would you rate the importance of the suggested simulation achievement plan in guiding a simulation project?

4/5 – Important to very important

D2. How would you rate the importance of top management support in the following two main issues?

a. Funding – 5-very important
b. Clinician resistance – *3- fairly important

D3. How would you rate the usefulness of the best practices suggested for securing top management support?

4 - Useful

D4. How would you rate the importance of ensuring a good practice to report progress at short intervals during any simulation project development?

5 – Very important

D5. How would you rate the usefulness of the best practices suggested for simulation team to report progress to management team?

4 – Useful

E1. How would you rate the importance of the main issues highlighted in the proposed vision statement?

5 – Very important

E2. How would you rate the usefulness of four important issues suggested for a simulation pilot project?

*3 – not very useful

E3. SIMT Cultural change highlights the five main important differences between a traditional culture and SIMT culture for healthcare decision-making. How would you agree on these five main issues?

5 – Strongly agree