A THEORETICAL FRAMEWORK FOR HYBRID SIMULATION IN MODELLING COMPLEX PATIENT PATHWAYS

By

JAFRI ZULKEPLI

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ABSTRACT

Providing care services across several departments and care givers creates the complexity of the patient pathways, as it deals with different departments, policies, professionals, regulations and many more. One example of complex patient pathways (CPP) is one that exists in integrated care, which most literature relates to health and social care integration. The world population and demand for care services have increased. Therefore, necessary actions need to be taken in order to improve the services given to patients in maintaining their quality of life. As the complexity arises due to different needs of stakeholders, it creates many problems especially when it involves complex patient pathways (CPP). To reduce the problems, many researchers tried using several decision tools such as Discrete Event Simulation (DES), System Dynamic (SD), Markov Model and Tree Diagram. This also includes Direct Experimentation, one of techniques in Lean Thinking/Techniques, in their efforts to help simplify the system complexity and provide decision support tools. However, the CPP models were developed using a single tools which makes the models have some limitations and not capable in covering the entire needs and features of the CPP system. For example, lack of individual analysis, feedback loop as well as lack of experimentation prior to the real implementation. As a result, ineffective and inefficient decision making was made. The researcher also argues that by combining the DES and SD techniques, named the hybrid simulation, the CPP model would be enhanced and in turn will help to provide decision support tools and consequently, will reduce the problems in CPP to the minimum level. As there is no standard framework, a framework of a hybrid simulation for modelling the CPP system is proposed in this research. The researcher is much concerned with the framework development rather than the CPP model itself, as there is no standard model that can represent any type of CPP since it is different in term of its regulations, policies, governance and many more. The framework is developed based on several literatures, selected among developed framework/models that have used combinations of DES and SD techniques simultaneously, applied in a large system or in healthcare sectors. This is due to the condition of the CPP system which is a large healthcare system. The proposed framework is divided into three phases, which are Conceptual, Modelling and Models Communication Phase, and each phase is decomposed into several steps. To validate the suitability of the proposed framework that provides guidance in developing CPP models using hybrid simulation, the inductive research methodology will be used with the help of case studies as a research strategy. Two approaches are used to test the suitability of the framework – practical and theoretical. The practical approach involves developing a CPP model (within health and social care settings) assisted by the SD and DES simulation software which was based on several case studies in health and social care systems that used single modelling techniques. The theoretical approach involves applying several case studies within different care settings without developing the model. Four case studies with different areas and care settings have been selected and applied towards the framework. Based on suitability tests, the framework will be modified accordingly. As this framework provides guidance on how to develop CPP models using hybrid simulation, it is argued that it will be a benchmark to researchers and academicians, as well as decision and policy makers to develop a CPP model using hybrid simulation.

Keywords: integration model, social care, health care, system dynamics model, discrete event simulation model.

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DECLARATION

This is to declare that:

- I am responsible for the work submitted in this thesis.
- This work has been written by me.
- All verbatim extracts have been distinguished and the sources specifically acknowledged.
- During the preparation of this thesis, some papers were prepared as listed below. The remaining parts of the thesis have not yet been published.

Conference Proceedings – Refereed

1. Zulkepli, J. and Eldabi, T. (2011) Technique for improving care integration model. European, Mediterranean & Middle Eastern Conference on Information Systems 2011 (EMCIS 2011), May 30 – 31, 2011, Athens, Greece.

Abstract

1. Zulkepli, J. and Eldabi, T. (2010) Hybrid techniques for improving care integration model. 6th IMA International Conference on Qualitative Modelling in the Management of Health Care, 29 – 31 March 2010. London, UK.
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Doctoral Symposium (Extended Abstract)

1. Zulkepli, J. and Eldabi, T. (2008) Bridging the gap between health and social care. Brunel Business School PhD Symposium, 21 – 22 May, 2008, Brunel University, London.
2. Zulkepli, J. and Eldabi, T. (2009) Information systems integration for health and social care. Brunel Business School PhD Symposium, 24 – 25 March, 2009, Brunel University, London.

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4. Zulkepli, J. and Eldabi, T. (2011) Framework for hybrid techniques for modelling integrated care systems. Brunel Business School PhD Symposium, 29 – 30 March, 2011, Brunel University, London.

Posters

1. Zulkepli, J. and Eldabi, T. (2010) Framework for modelling integrated care (IC) models, Brunel Graduate Research Poster Conference 2010, May 05-06, 2010, Brunel University, United Kingdom.

2. Zulkepli J. and Eldabi, T. (2009) Developed IC models and criteria of a viable integrated care models, Brunel Graduate Research Poster Conference 2009, May 06-07, 2009, Brunel University, United Kingdom.

- This work has not been submitted within a degree programme at this or any other institutions.

Signature: ______________________________

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CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

The world's population is increasing rapidly. Data from the US Census Bureau reported that in 2008 the total world population was 6.68 billion, with the mean of male and female population almost the same. Developments in science and technology have contributed to the improvement and quality of life, and, consequently, the life expectancy for humans has increased dramatically (International Data Base, 2008). These changes are the result of a combination of factors including nutrition, public health, and medicine. Hence, the need for improved and efficient care delivery systems is also overwhelming. This is true in terms of provision of health services, especially to patients who have multiple and complex needs across different departments and care settings. The complexity of patient pathways across several departments of care setting has caused certain problems to healthcare professionals, such as bed blocking and late transfer to another care provider or other departments. Specifically, a clear and direct example of complex patient pathways (CPP) is one that exists in an integrated care in the settings of health and social care, which involves transferring patients from one department or care givers to another department or care givers.

1.2 RESEARCH CONTEXT

Problems with the complex patient pathways (CPP) such as in an integrated care have been discussed in much of the literature, whereby they involve late transfer of patients to the other department or care setting and bed blocking, among others. In respect of these problems, many researchers and policymakers have used various approaches to facilitate the decision making process. Two types of decision making tools used are direct experimentation and simulation modelling methods. Direct experimentation is one of the tools or techniques in lean thinking/technique, while simulation modelling methods involve Discrete Event Simulation (DES), System Dynamics (SD), Markov Model and Tree Diagram. Several CPP models have been developed using direct experimentation and modelling techniques. Such models are Desai et al. (2008), McClean and Millard (2007), and Katsaliaki et al. (2005). Because these models use a single modelling technique, they are not viable enough to represent the real system due to the limited single techniques' capabilities. For example, some of the developed models cannot mimic the feedback loop, cannot represent individuality analysis as well as a lack of capability to conduct experiments prior to the real world implementation.

In the healthcare sector, most decisions are based on individual analysis (Chahal et al., 2009). This is because care service is a human based service (Baker and Bates, 2010), which means that every patient is a unique case. For example, the patient's time to complete treatment depends on several factors, such as type and level of illness, the experience of the professionals, knowledge and more. Therefore, the model should be considered on an individual analysis rather than aggregated analysis as this will affect the decision making process.

The CPP in healthcare system is dynamic in nature, which means that it is very sensitive to changes in the surrounding environment and that it keeps changing (Chahal et al., 2009). Any changes to the system (for example, adding a new resource) will have an impact in the short- and long-term (Baker and Bates, 2010), which should be identified before it is too late. Some of the developed models use a direct experimentation method. But this method takes a long time to produce a result and as the CPP system keeps changing, this method is impractical and dangerous (Wolstenholme et al., 2004). Consequently, every developed model should have the ability to conduct experiments prior to real implementation to ensure that the changes made to the system are worthwhile and can reduce the problems appropriately.

Any feedback from an intervention which is done to the CCP needs to be considered and implored. Some of these impacts however could not directly be observed but must be taken into consideration. For example, human emotions have a direct impact on the system but cannot be observed (Chahal et al., 2009). This can be seen in the situation where because of a long queue, the patient gets bored and decides to exit from the system. Furthermore, professionals have limited time to assess the patient, which leads to inadequate assessment of some patients. As a result, the patient will be readmitted to healthcare. These are some of the examples for which certain modelling techniques cannot capture the characteristics. These characteristics are important and should be in the modellers' consideration in order to select suitable technique(s) to support the decision making process.

Described above are some of the criteria for a viable CPP model that have been identified by the researcher. Viable CPP models in this research context mean that patient pathways models must closely mimic the characteristics of an existing system. Further explanations of these criteria will be discussed in Chapter Two. As the developed integrated care patient pathways models do not closely mimic the real system due to the limited capabilities of a single technique, the decision making is inefficient and unreliable. Figure 1.1 illustrates the researcher's argument.

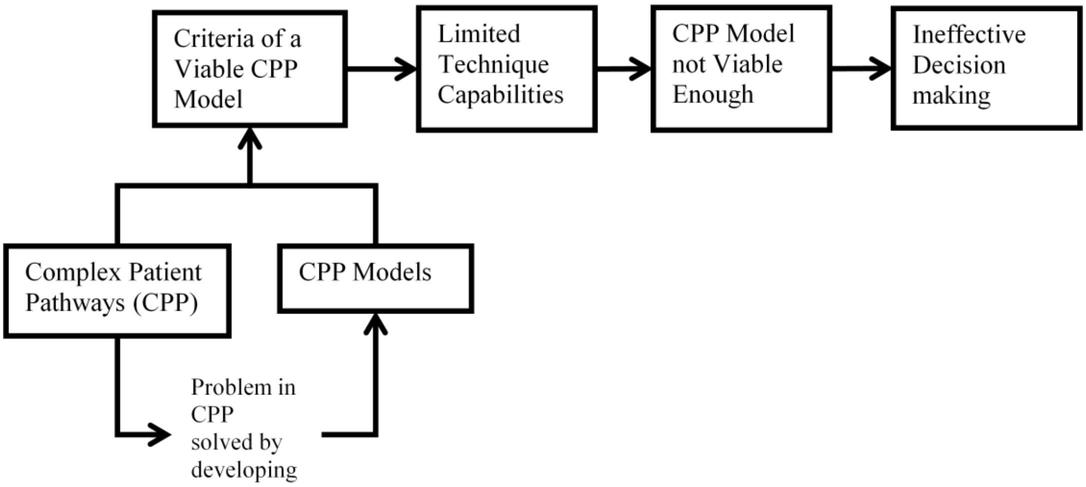


Figure 1.1: The researcher's Argument

Several problems in the CPP system are solved by developing a number of models to support the decision making process. CPP systems have their own criteria, and the developed models are based on these and the problem of patient pathways. However, due to the limited capabilities of techniques, the developed model is not viable enough to represent and mimic the real system. As the decision making process is based on these developed models (Miller et al., 2004; Miller et al., 2003), an ineffective decision will be made.

Following a search of the literature, the researcher suggests a combination of two simulation modelling techniques, i. e. Discrete Event Simulation (DES) and System Dynamics (SD), named as hybrid simulation. These two modelling techniques are selected because of their capabilities in covering all the criteria of a viable CPP model. A thorough analysis and discussion about how the researcher selects these two techniques will be presented in Chapter Two.

1.3 PROBLEM STATEMENT

There is limited literature that discusses combining the DES and SD into hybrid techniques. The hybrid simulation (combining DES and SD) has been applied in several areas including healthcare and supply chain management. However, there is limited literature that discusses combining the DES and SD into a hybrid simulation. Furthermore, there is no hybrid simulation model that has been explored in a CPP system such as in integrated care across different departments and care givers. The hybrid simulation model is argued to improve decision making process, as it would enhance the viability of the model to mimic the real system of patient pathways. In this research, the researcher will only focus on developing the framework for hybrid simulation in modelling the CPP model as there is no standard framework or procedure to develop complex patient pathways (CPP) model using hybrid simulation.

There are several reasons why the researcher is more concerned about developing a framework rather than developing a model. A standard framework is important as it will ensure that the processes of model development so that the developed model runs smoothly like a real system (Mingers and Brocklesby, 1997). It will also help the modellers not to overlook important steps in the development of models as the patient pathways between one care giver or department to another care giver are large, complex, complicated and vary from one system to another. As the framework provides guidelines concerning how to develop CPP models using a scientific method, it will ensure that policymakers, who are not simulation modelling experts, can be actively involved in the model development. Based on these arguments, the critical research question that can be put forward is:

> *"How could a CPP model be developed using a hybrid simulation that combines Discrete Event Simulation (DES) and System Dynamic (SD) that would reduce the existing problems in a CPP system?"*

1.4 AIM AND OBJECTIVES

As highlighted in the previous section, a hybrid simulation is thought to be able to help ensure decision making is more reliable. This is because the developed models that use a hybrid simulation will cover all the criteria for a viable complex patient pathways model. As argued by MacAdam (2008), there is no specific model that will represent any CPP models due to different dimensions, stakeholders and objectives of the model development. Therefore, the researcher argues that instead of developing a model of CPP system itself, it is more essential to have a framework that will facilitate the model development, especially if a hybrid simulation is needed. The framework would eventually include and involve stakeholders to take part in the modelling activities. Therefore, the aim of this research is:

'To develop a framework for hybrid simulation (combining DES and SD) in developing a CPP model (involving transferring patients from one department to other department).'

In order to achieve the aim, the objectives of this research are as follows:

Objective One: To capture information about the CPP systems, their problems, previously developed CPP models, decision tools that have been used, advantages and limitations.

Consequently, this objective is to gain existing knowledge that has been identified by other researchers in terms of patient pathways and the effort that has been put into continuing care services across several departments and care givers, named as integrated care, especially in the UK. The modelling techniques that have been used to model complex patient pathways problem as a decision tools, will be reviewed. The review will include information about the advantages and disadvantages of the modelling techniques used as well as the developed models of CPP. The information concerning CPP system will help the researcher to develop criteria for a viable complex patient pathways model. These criteria will be used to identify why the problems in CPP systems, especially in integrated care, are still persistent, which has also been discussed by several researchers. The criteria for a viable CPP model will be mapped with the capabilities of the techniques. The best techniques that cover most of the criteria will be selected, thus, suggesting alternative modelling methods for the CPP system.

Objective Two: To propose a framework of hybrid simulation for modelling CPP system.

As stated in the previous section, there is no framework for specifically modelling a CPP system using hybrid simulation. Therefore, based on the information in the literature, various frameworks or researches that have adopted hybrid simulation (DES + SD) will be reviewed. This review intends to identify the best framework as a reference for developing a framework for hybrid simulation for modelling a CPP system.

Objective Three: To verify and modify the proposed framework by practical assessment.

The development of the proposed framework for hybrid simulation in modelling the CPP system, which involves transferring patient from one care givers or departments to another, is based on various literatures that have adopted hybrid simulation in certain areas. Therefore, to verify the framework, a practical assessment was done. A patient pathways model which involves transferring patients across healthcare and social care was developed practically using previous case studies, based on the proposed framework. It was then followed by several modifications on the framework to suit the process of the CPP system's model development. The framework that has been developed and tested serves as a roof as it almost completes the aim.

Objective Four: To verify and modify the framework by theoretical assessment

The framework still has to be refined. Therefore, a theoretical assessment will be made on the framework. This theoretical assessment will use four case studies adapted from the NHS Institute for Improvement and Innovation document; however, it does not involve modelling activities because of certain limitations. After assessment, several amendments have been done to the framework. Only after this stage that the final proposed framework is established. This objective ensures that the aim of the research, which is a framework for development of hybrid simulation model for CPP system, can be used in different care settings.

1.5 RESEARCH METHODOLOGY

The importance of having a research methodology was emphasized by Irani et al. (1999). The research methodology will also enhance the capability of understanding the process of doing the research and can serve as a set of rules for reasoning from which a scientific conclusion can be drawn (Eldabi, 1999). The two types of research methodology that have been used are inductive and deductive. The main difference of these two approaches is whether the research starts from specific to general, which is the inductive approach, or from the general to specific conclusion, which is the deductive approach (Chahal, 2009).

There are three main scenarios that can employ a case study as a research strategy: for discovery and theory building; for theory testing; and for discovery, building and theory testing. As this research intends to establish the framework and apply it into the patient pathways system especially in integrated care system setting, the case study method is used as it provides systematic means of observing all the processes that are involved. This method also allows the researcher to study the phenomenon in its context and has the ability to not explicitly control or manipulate variables (Weick, 1984). Based on the brief explanation above, this research will follow the inductive methodology, with the help of a case study strategy. This type of research method and strategy has successfully been used by Eldabi (1999) and Chahal (2009).

In this study, the inductive research methodology will be used with the help of case study as a research strategy. The inductive approach starts with a specific observation, identifying patterns, formulating hypotheses from the observation and pattern, evaluating, and finishes with conclusions or theories (Chahal, 2009). This research starts by looking at the current state of the CPP system, which involves transferring patient from one care givers or departments to another (integrated care), and the methods and tools that have been used to support decision making process to identify the gap in the literature concerning the modelling processes (specific observation and identify pattern). Once the gap between the modelling processes and the CPP system is found, the problem of the modelling is discussed (formulate hypothesis). Based on the hypotheses, the framework of the hybrid simulation for the CPP system will be developed and tested using several case studies (identify pattern and evaluation). The final product, which is the hybrid simulation framework, will be established once the modification step is complete (conclusion or theories).

Figure 1.2 provides a schematic diagram of the whole process involved in this research. The steps in conducting this research will help the researcher to answer all the research questions which will achieve the objectives and aim of the research. To organize the explanation, these steps will be explained in the next section, which will briefly explain the content of each chapter. To ensure that the framework can be used as the CPP modelling of a hybrid simulation's guideline, a selection of criteria of case studies have been drawn up:

- The CPP system has at least an 'integrated' manner, which is at least two systems, or sub-systems combined together becoming one system.
- The main problem in the CPP system should be solved using hybrid modelling as the proposed framework is for the hybrid modelling of the CPP system.

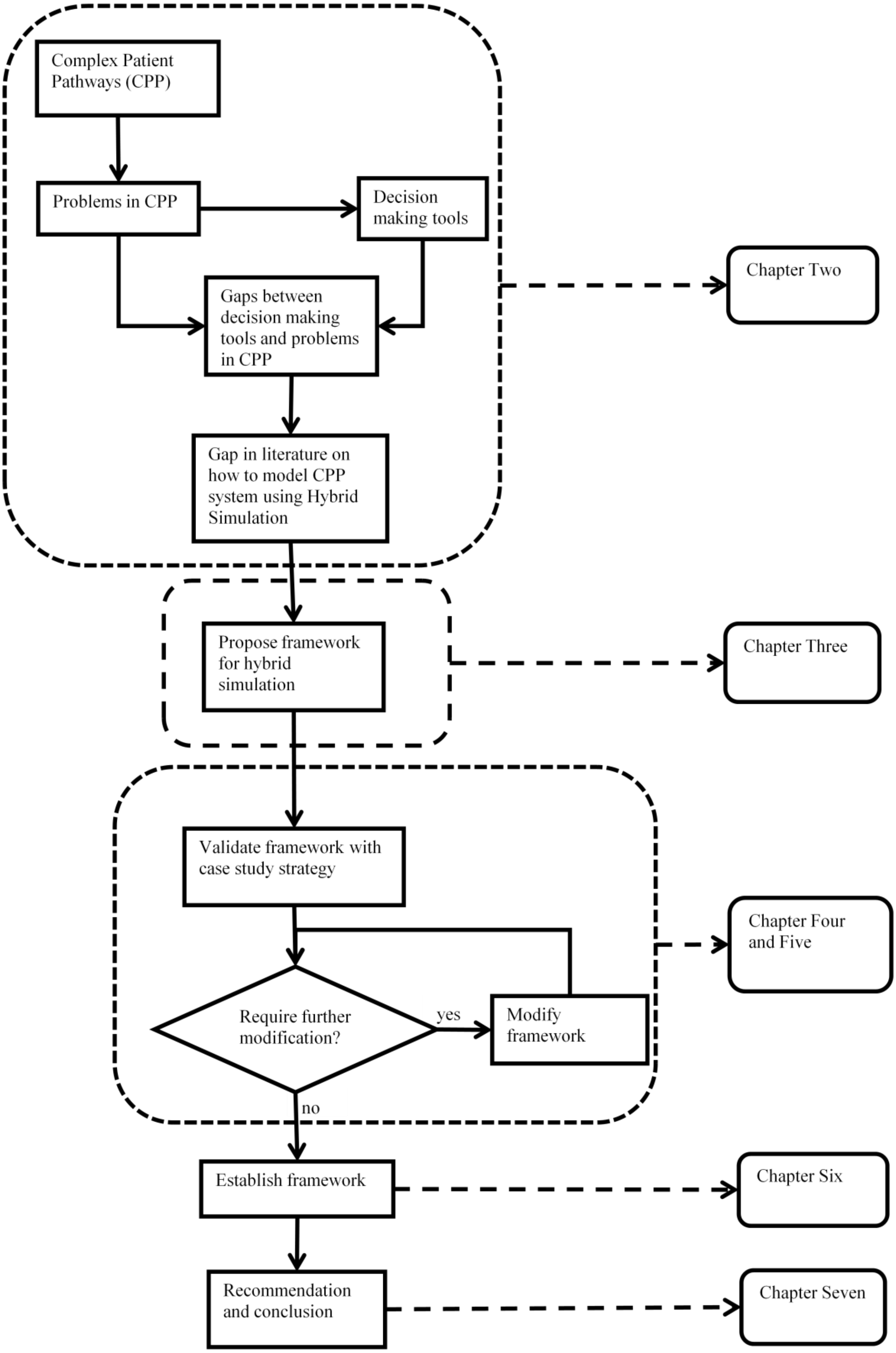


Figure 1.2: Flowchart of Research Methodology

1.6 THESIS ROADMAP

This thesis will be divided into seven chapters and this subsection will provide a brief outline of the whole thesis.

Chapter Two

Chapter Two in this thesis discusses the literatures on the topic, which covers the complex patient pathways (CPP) system within and across several departments or care givers, as well as CPP models that have been used in different types of modelling methods to see the models' and tools' capabilities. Chapter Two expands the problems faced by the researchers, academicians, as well as the policymakers and the tools that were used by them to overcome challenges of the techniques used to model CPP systems. A conclusion to Chapter Two will include suggestions for what should be done to improve the developed CPP model.

Chapter Three

Chapter Three continues with discussions of various hybrid simulations that have been applied in several areas from an operational research (OR) perspective. As the proposed framework of hybrid simulation model for the complex patient pathways is not yet in existence, the framework is then developed based on various references, i.e. framework of hybrid simulation, specifically, in combining DES and SD, which has been applied in large or in healthcare systems, that are easy and simple to be used. Using some modifications that suit the CPP system from the literatures, a framework of a hybrid simulation for modelling CPP system will then be proposed.

Chapter Four

The objective of Chapter Four is to assess the proposed framework in terms of the practicality of the approach. The proposed framework will be assessed using case studies that have been developed using a single technique. Several case studies and literatures will be selected to be the references for use in developing the CPP model using a hybrid simulation. The CPP models will include the healthcare, intermediate care, as well as social care. Criteria for the selected case study will be included in this chapter. These cases are also combined and redeveloped using a hybrid simulation. Technically, the development of the model was done separately but was integrated using the variables (inputs and outputs). Reflecting on the practical assessment, the proposed framework will be modified accordingly.

Chapter Five

From the output of Chapter Four, the modified framework will be theoretically tested and assessed against different case studies in different areas and settings. This chapter does not involve developing the model due to time constraints and the availability of data. The test and assessment is to ensure that the framework can be applied to other cases, especially in integrated care, when the patient transfers to and from one care giver to another in different care settings. Based on this theoretical assessment, the framework will be modified again to suit all types of CPP systems.

Chapter Six

The output from Chapter Five (after framework amendments) is the final proposed framework for modelling the CPP system. This chapter covers all discussions related to the framework. Besides the framework itself, the discussion will also include the reflection on the gap that has been identified in Chapter Two. The discussion will look at whether the model that has been developed using the framework and the framework itself could cover all the needs of a viable of a complex patient pathways model.

Chapter Seven

In Chapter Seven, the researcher will list several advantages and contributions of the framework, as well as future works. The final conclusion will discuss, in detail, every process from where the researcher starts the research until the findings of the research.

1.7 SUMMARY

This chapter has presented an overview of this research which focuses on developing a framework for hybrid simulation for modelling a CPP model. The framework is essential as each model of patient pathways differs depending on the stakeholders, objectives, as well as dimensions. There are many reasons why the development of patient pathways model needs hybrid simulation. All of this information will be included in the next chapter which focuses on the literature review of this research.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This research has been discussed briefly by the researcher in Chapter One. The discussion has included problems such as late patients transfer to the social care (patient pathways), and professionals and communication problems between the professionals within complex patient pathways (CPP) across several departments and care givers, which motivated the researcher to further investigate the issues. The researcher argues that the modelling techniques used to model the CPP is not viable enough to represent the real system as the single modelling techniques have some limitations to capture the needs and requirements of the real system. Thus, combining Discrete Event Simulation (DES) and System Dynamics (SD) as hybrid simulation as an alternative tool to model the CPP is suggested. Based on this motivation, argument and suggestion, the researcher developed s research question which is – 'How could a CPP model be developed using a hybrid simulation that combines Discrete Event Simulation (DES) and System Dynamic (SD) that would reduce the existing problems in a CPP system' leading to the research aim – to develop a framework for hybrid simulation (combining DES and SD) in developing a CPP model (involving transferring patients from one department to other department, and a series of research objectives that leads to achieving the aim of this research. This research will use inductive methodology and case studies as the research strategy. The methodology of how this research should be conducted has been discussed thoroughly in Chapter One.

Chapter Two discusses thoroughly how the researcher developed the research question, aims and objectives. Figure 2.1 illustrates the structure of this chapter. This chapter aims to search for more information and knowledge concerning the CPP system, as well as the developed CPP models and it is divided into two main sections: (i) Complex patient pathways (CPP) in the Integrated Care System and (ii) Modelling methods and developed CPP models. Under CPP in integrated care systems, the definition of CPP will be briefly discussed, problems that associate with the patient pathways and system arrangement followed by CPP in health and social care setting in the UK. From this subsection, the characteristics of CPP systems will be deduced. Upon reviewing the literature, the researcher found that many researchers have discussed the problems in the CPP system. To minimize these problems, many researchers developed various CPP models, using various decision making tools.

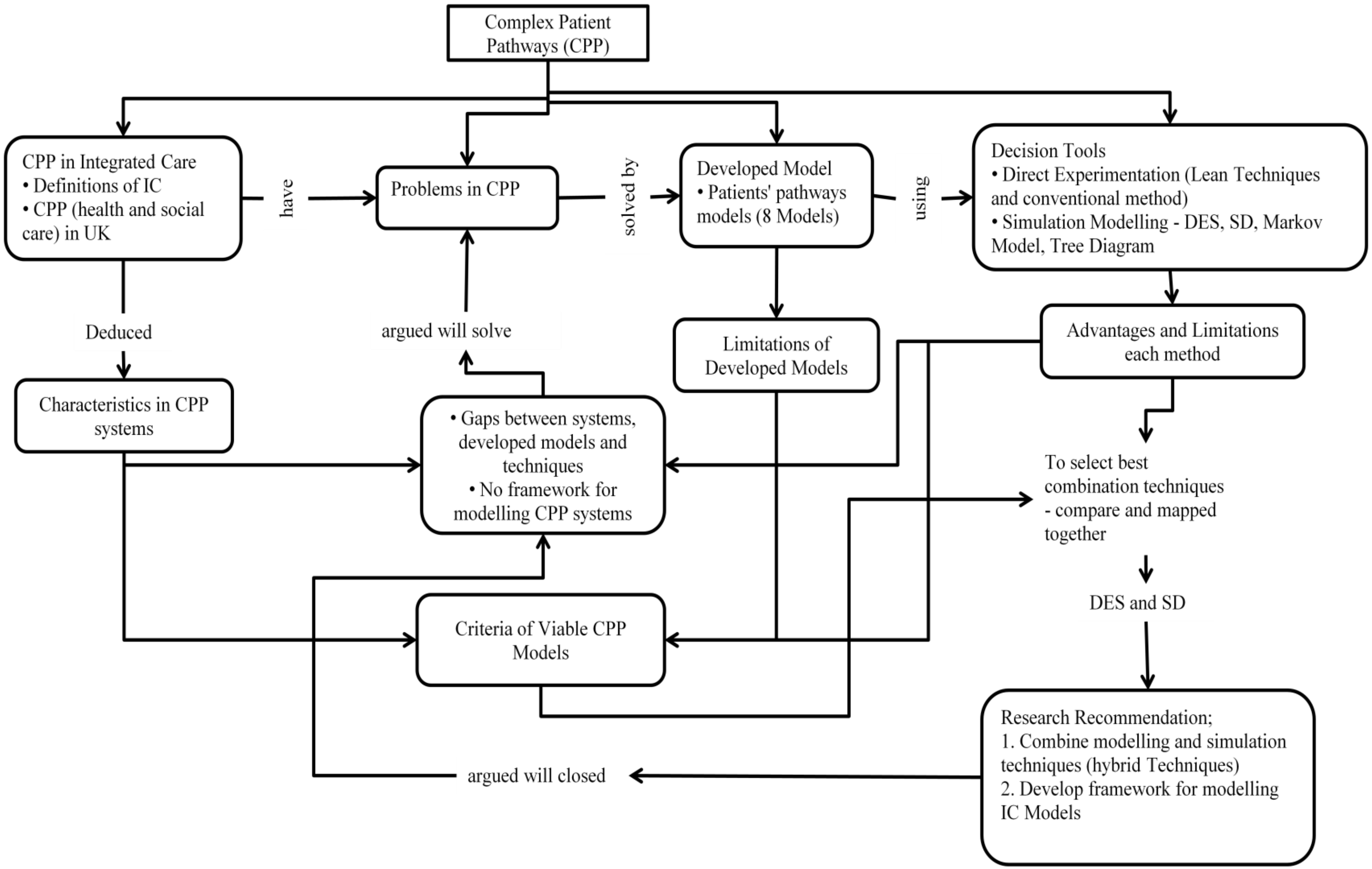


Figure 2.1: Literature Review Structure

These methods can be divided into two categories: (i) Conventional and (ii) Simulation Modelling. Based on the literature, the advantages and limitations of these tools are discussed. By comparing the characteristics of CPP, the limitations in the developed models and the modelling techniques, the gaps between these three components are identified. Therefore, the researcher proposes an alternative modelling technique, i.e. hybrid simulation. The selection of the most suitable combination of modelling techniques is based on the mapping process between the criteria of the CPP model (deduced from the characteristics in the CPP system, developed models and limitations of the techniques) and the various advantages of the techniques. It shows that DES and SD are the best combination of hybrid simulation as they complement each other. There is no existing literature that discusses modelling CPP using hybrid simulation. Therefore, the researcher suggests combining these two techniques and proposes a theoretical framework for modelling CPP; the researcher is of the opinion that this will close the gaps between the CPP and the limitations of the developed CPP models and techniques, and, thus, will improve decision making in CPP systems.

2.2 COMPLEX PATIENT PATHWAYS

This section starts with the concepts and definitions of complex patient pathways (CPP) that involve transferring patient from one care giver or departments to another to enhance understanding of CPP. Based on discussions in these sections and sub-sections, the characteristics of CPP will be identified. These characteristics are then combined to form a set of criteria for a viable CPP model.

2.2.1 Complex Patient Pathways in Integrated Care

The research mainly focuses on the patient pathways across different departments and care givers. As the complexities of a healthcare system increase since they involve many stakeholders within different departments (Eldabi, 1999), and the term ‘integrated’ has been widely used to show two elements or more are being combined to serve as one part (Kodner and Spreeuwenberg, 2002), the researcher has decided to choose to use ‘integrated care’ as a clear and direct example of CPP. Therefore, in some parts of this research, the researcher will use ‘integrated care’ to refer to the CPP system.

Based on previous arguments, CPP systems are referred to as a patient pathway across multiple departments or care givers which provide care services to the patients. In technical writing, instead of using 'integrated care', other authors have used different terminologies such as 'managed care', 'shared care', 'seamless care', 'trans mural care', 'intermediate care', 'care pathways', 'integrated delivery network' as well as 'disease management' (Grone and Barbero, 2001). Terminology such as 'continuous care' or 'comprehensive care' is also used to express the meaning and concept of integrated care (Kodner et al., 2000). Others have used partnership to represent integrated care (Van Raak et al. (2005);joint working (Alaszewki et al., 2003), complimentary care (Pfeffer, 1982), as well as collaboration and cooperation (Galbraith, 1973). Transferable responsibility, in which the patient is transferred from one stage to another stage in care services and the moving activities from a family physician to multiple care service providers shows continuity of care, which can also be defined as integrated care (Herbert et al., 2003; Hollander and Walker, 1998; Sparkel and Anderson, 2000).

Hollander and Walker (1998) categorised integrated care into short- and long-term. The short-term relates to the application from the combined and intensive, as well as the synchronized services plan in a certain given time. Long-term care relates to monitoring and ensures seamless intervention between the involved parties in a continuous given time. Integration can either be at the same level – horizontal integration (Grone and Barbero, 2001), or link to different levels of services – vertical integration (Conrad and Dowling, 1990; Brown and McCool, 1986). The integration can also be between service sectors, professions, care settings, organizations and types of care (Reed et al. 2005). Bank (2004) suggested that integration could also be seen as a scale, which ranges from tolerance, cooperation, joint ventures, and partnerships to mergers. Integration applies to the integration of people, systems and processes. It also applies to knowledge, rules, values and boundaries in each of the inter sectors (Kodner and Spreeuwenberg, 2002).

Earlier in this chapter, the researcher has indicated the use of CPP as integrated care, which comprises health and social care institutions. This research focuses integrated care within health and social care settings in the UK as an example of integrated care. The next sub-section then proceeds with discussions on the CPP in the UK.

2.2.2 Complex Patient Pathways in The United Kingdom

CPP has been defined in a variety of ways as mentioned in the previous sub-sections. In this research, it refers to the transferring of patients from one care giver to another, across several departments in the healthcare system. The whole process is called integrated care. The patient pathways become more complex as they involve many stakeholders in the systems. The integrated care can be in various care settings, such as across several departments within the healthcare system, or outside the healthcare system. The latter is such as in health and social care in the UK, which include intermediate care, that is, a place where patients have a sort of rehabilitation before being transferred to the social care.

In the UK, every person has his/her own general practitioner (GP), a community-based doctor. The GP is responsible to provide care for all aspects of family health. The GP acts as a 'gatekeeper' who is responsible to refer patients to acute hospital services depending on the medical needs, as well as being the intermediate person who refers patients to the social care services (Ham, 1997). In cases such as emergencies, patients can get direct access to the A & E without having to refer to their GPs first. They can also get direct access by contacting the social services team to get specialist services. At the point of delivery, all the services provided by the healthcare are free, and are funded centrally by the national taxpayer. The services are provided by the Primary Care Trusts (PCTs), a group of healthcare professionals that commission and provide the healthcare needs of the local population. In addition, they have to recognise or identify inequality issues as well as purchase services from the NHS bodies.

Referral is divided into three accesses: patient's being referred by GPs or district nurses, self-referral or family carer, and acute hospital (Alaszewski et al., 2003). The initial contact of health and social care is when the patients are discharged from the hospital, which involves intermediate processes. In addition, all the stakeholders such as the physician, patients, family carer, social service professionals, etc. should agree with the package provided to the patients. The process starts when the patient is identified as needing continuing care after being discharged from the hospital. Several procedures and considerations must be made before the patient can be transferred to the social care. The integrated care between the health and social care can be seen as the patient pathway, as shown in Figure 2.2.

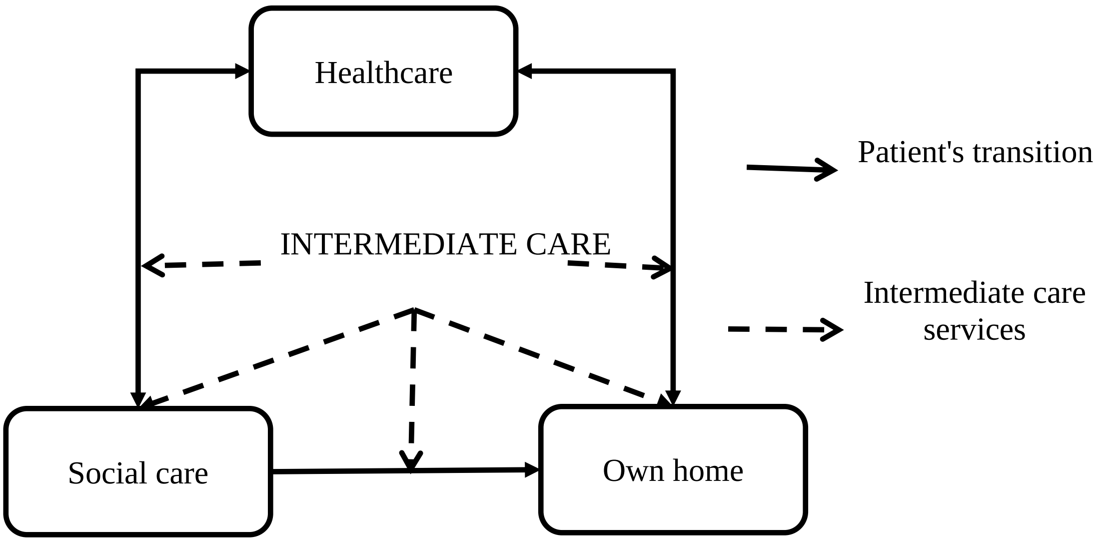


Figure 2.2: Patient's pathways

Healthcare is always put as the frontline of the care services and, as a result, most of the resources allocated specifically to care services will go to healthcare rather than social care. The aim of the establishment of the National Health Services (NHS) was to gather all medical experts – doctors, physicians, optometrists, nurses and other medical practitioners – under one administration so that the citizens can get better services and easy access to good healthcare.

The social care service is responsible for looking after the health and welfare of the citizens. They cover a variety of services, ranging from care homes for those with mental illness, elderly people and homeless children, to the provision of meals for disabled people. The scope of the social services also includes adoption, AIDS and HIV, learning disabilities, child abuse and protection and others. Since social care has a huge range of services, it can operate in many ways. It can be run at residential homes, community councils, centres, as well as in people's own homes. Many companies and organizations that provide social care are linked with the healthcare organization that provides nursing visits to make their service reliable.

Intermediate care is another care package to address the problems arising following discharge. Intermediate care was introduced to support the health and social care systems. The factors identified for establishing the intermediate care are the increased needs of elderly people with multiple illnesses and conditions that require complex needs, pressure on hospital beds, and the development of the primary care as well as NHS plans. The rise of modern technology and more specialisation in work has also influenced the establishment of intermediate care (Steiner, 2001).

The original intention of this programme was to establish integrated services that can facilitate a quicker recovery from illness, and prevent any inappropriate hospital admission. It was also to support people especially the elderly patient in becoming more independent, thus, reducing admission to long-term care.

Due to the complexity of the patient pathways across multiple departments and care givers, it creates several problems in the integrated care. Several researchers have highlighted the relevant problems, especially within health and social care settings. The next sub-section discusses about it.

2.2.3 Problems in Patient Pathways in Integrated Care

There are several studies that have focused on issues of care integration across several departments and care givers that highlighted some of the problems that may arise. For example, a study done by Mur-Veeman et al. (2008) describes such a divide as a "Berlin Wall" since the two entities involve different governing bodies, organizations, providers, funding and professionals. As a result of such problems, the work is not efficient, costs become higher, conflicts arise between the social and healthcare professionals relating to their exact responsibilities, resulting in unsatisfied customers, as well as poor quality in the delivery of services.

Miscommunication also arises between the doctor and the nurses at a certain stage in delivering the medical information (Moret et al., 2008). Indeed, the training module provided by the medical school creates different values and interests in the professionals. Hence, communication and coordination between social and healthcare professionals becomes more difficult when they work together. Rummery and Coleman (2003) highlighted the issue of trust between professionals as a barrier in the effort of integrating social and healthcare. Research by Bryan et al. (2006) identified the problem of the delayed transfer of older people from hospital arising from the policy implementation, which has to deal with many stages before transferring the older people. In addition, the authors found that the delay in transferring the elderly is due to the family opposing the care plan put forward.

Andersson and Karlberg (2000) argued that the problem in integrating these departments or sectors arose from the weaknesses in the steps from one caregiver to another in the "chain-of-care", using an alternative term for integrated care. The authors also stressed that the imbalance in discharging the elderly from the hospital by shortening the length of stay had increased the care load of the nursing homes. Furthermore, the separate authorities providing continuous care for the elderly have a huge impact on the continuity and the collaboration, which do not function as well as expected. Reed et al. (2005) argued that when there are a large number of staffs, services, agencies and sectors providing the care services, the gaps in care, lack of coordination and duplication of services are more likely to occur.

Because of these problems, the effectiveness and efficiency, especially of patients transferred from one care givers or departments to another, are declining and have resulted in higher costs (Reed et al., 2005). Furthermore, the problems created a chain of problems, which, ultimately, resulted in huge cost to cater for the late transfer of the patient and bed blocking problems. Realizing this chain of problems, the decision makers tried to accommodate a new place to cater for the 'late transfer and bed blocking patients', together with the professionals or time, according to their condition, until the patient is ready to be transferred to the social care unit. The new service is called intermediate care service, which was purposely designed to cater for the 'late transfer' patients (Katsaliaki et al., 2005). However, indirectly, offering this type of service is causing other problems as the care sector becomes imbalanced with many patients being transferred to the intermediate care. In addition, to implement another care sector will need huge investment, including venue, resources and funds to implement the intermediate care. Moreover, the intermediate services should be near to the patient's home to ease the patients' access to the intermediate service (Armstrong and Baker, 1994).

Table 2.1 summarizes the problems highlighted by several researchers. The researcher argues that the root of all of the problems identified by several researchers result from the arrangement of the care systems. Regardless of individual human problems, such as human error, if the systems are defined clearly in terms of the respective responsibilities of each of the care providers, how the systems should work between each other, how the system should be set up, etc., all the problems that have been discussed can be reduced to the minimum level.

Table 2.1: Problems in CPP Systems

Researchers	Problems Highlighted	Source of the problems (argued by the researcher, unless stated otherwise)
Mur-Veeman et al. (2008)	Gaps between health and social care, described this problem as a "Berlin Wall", leads to other problems – work is not efficient, high cost, conflicts, unsatisfied customers, poor service quality.	System arrangement.
Moret et al. (2008), Rummery and Coleman (2003)	Miscommunication, issue of trust between professionals in health and social care.	System arrangement that does not define clearly how they should work together.
Bryan et al. (2006)	Delay transferring patients to the social care.	System arrangement (too many procedures and bureaucracy), human factors.
Andersson and Karlberg (2000)	Imbalanced discharge, separate authorities in providing care.	System arrangement (weakness in steps between one care-giver to another).
Reed at al. (2005)	Gaps in care, lack of coordination, duplication of services, division in health and social care, ineffective and inefficient patient transfer process.	System arrangement (large number of staff, services, agencies and sectors providing care services, barrier between health and social care).

(Developed by the researcher)

One of the system arrangement aspects is the patient pathway. Various literatures have identified specific patient pathway problems, such as bed blocking and delayed patient transfer from healthcare to social care (Bryan et al., 2006). In order to reduce the problems in integrated care, researchers, academicians and the policymakers have used several methods to facilitate their decision making. By using this method, several CPP models have been developed with different settings and types throughout the world to minimize the problems.

Subsequently, the next sub-section discusses the characteristics of the CPP system. These characteristics are deduced from the real CPP system and are combined to become the criteria of a viable CPP model.

2.2.4 Characteristics of the Complex Patient Pathways System

Based on the literature so far, it can be concluded that some characteristics or features and the nature of the complex patient pathways (CPP) system are different compared to other areas, such as production and manufacturing, due to the way the system works. Unlike production and manufacturing, which work on a 'robotic' system, CPP is based on a human system in which every 'product' (refers to a patient and staffs) have their own unique cases.

Patient flow in relation to patient pathway is a 'process' from one care giver to another care service giver. This process of patient flow involves a stochastic and sequential nature (Chahal et al., 2009). In other words, the patient's time in the process is not the same as that of other patients. Because of the nature of the healthcare system, most of the decisions made by the decision makers are based on individual patient attributes (Chahal and Eldabi, 2008). Indeed, Baker and Bates (2010) argued that the complexity of healthcare is different as the service needs considerable flexibility as every patient has unique needs. Therefore, it is argued that every patient should be treated independently based on his/her condition as a unique case and not as an average, especially with the patient's time in the system.

Since CPP involves different care givers or departments that are being combined into one to provide care services, which comprise many stakeholders in many environments, any initiative to change the system needs to consider feedback on the whole system as well. The whole system should include the stakeholders and the environments, which should be considered when making decisions. For example, in order to reduce a patient's waiting time and prevent him/her from withdrawing services, the policymakers can increase the opening hours of a clinic. Logically, when these objectives are met, another outcome is likely to happen, which will put pressure on human resources. The work performance is deemed to be associated with the amount of work given to them (Arboleda et al., 2007). Furthermore, the doctors' performance will decrease after they have reached the maximum amount of work (Chahal et al., 2009).

What makes patient pathways system in healthcare more complex than those in other sectors is because it is a human based activity (Baker and Bates, 2010) with every single patient having his/her own individual time to finish certain processes. Time is crucial in care services (Chahal et al., 2009); therefore, it should be dynamic and not static. Time is crucial, especially in healthcare, intermediate care and the assessment process. The time for each process will be the benchmark for the hospital performance. Furthermore, the time to finish the process will ensure that the whole system of integrated care will run smoothly. For example, to reduce the late discharge problem, an intervention must be implemented on the time taken to find and assess a suitable care home or create a new package. This will help prevent bed blocking. The dynamics of the model will also ensure that the model building can be used repeatedly for different intervention experiments (Eldabi, 1999).

As the patient pathways are across several departments and care givers, the pathways system can be very big and, as such, any decision taken consider the short-term or long-term effects. Baker and Bates (2010) argued that it is natural for a system to get worse before it gets better, for what works in the short-term typically makes things worse in the long-term and what works in the long-term will make things worse in the short-term. Therefore, selecting the tools for modelling CPP intervention should consider the effect in the short- and long-term period. Short-term or long-term effects could be averaged out with the correct and suitable tool; however, some effects may turn out to be problems. Table 2.4 presents a summary of the characteristics of the CPP system.

Table 2.2: Characteristics of CPP Systems

Characteristics	**Deduced from:**
All attributes (patient's attributes) are unique and should be treated differently from one to another.	Chahal et al. 2009; Baker and Bates, 2010
The systems have a feedback loop criterion and any intervention done to the systems should consider this criterion.	Arboleda et al. 2007; Chahal et al., 2009
The systems are dynamic and not static.	Chahal et al. 2009; Baker and Bates, 2010
Short-term will affect long-term decision and vice versa.	Baker and Bates, 2010

(Developed by the researcher)

The next section will discuss the modelling methods and the techniques that have been used to develop CPP models. The discussion concerning the developed CPP models especially in health and social care (as it is a clear example of CPP) will also be included in this section.

2.3 DECISION TOOLS FOR COMPLEX PATIENT PATHWAYS

To address problems, many researchers, academicians and policymakers tend to use several decision support system tools and methods. Literatures indicate two types of decision tools or methods that have been used to support decision making process in terms of the CPP system. They are conventional and simulation modelling methods. These methods have been used to develop CPP systems with the hope that they will find the bottleneck in the systems and the solutions to minimize the problems. This section will provide a thorough discussion concerning the methods and several CPP models, which have been developed by using various methods, as mentioned above.

2.3.1 CPP Decision Tools

It is worth explaining and discussing all the decision tools that have been used to develop CPP models. CPP model in this research refers to the any patient pathways models developed for analysing patient pathways in a complex condition (across multiple departments and care givers). The patient pathway analysis involves either the use of conventional method or advanced technology. Analysis using conventional method refers to the CPP models that have been developed in a real time condition, and undergone review for effectiveness after certain period of time. On the other hand, advance technology refers to CPP models developed in computer software,

Some of the decision tools are suitable for certain conditions while others are not. Some of the developed models that have been discussed do not fully utilise the maximum capabilities of each technique. Therefore, this subsection will elaborate on all the decision tools that have been used to model CPP systems. These elaborations will provide ideas concerning the capabilities and limitations of each tool. There are many types of tools to facilitate the decision making activities. These tools have been used to model several CPP systems to support the decision making process and its outcome. Two categories of decision tools for modelling CPP have been identified. These tools are the conventional method and the simulation modelling method.

A conventional tool is a method used to refine the patient's pathways by developing it in a real situation. The decision for intervention is based on previous history and experience. Feedback on the intervention of the system is gathered through questionnaires and interviews. An example of the questionnaire can be found in Kowalyk et al. (2004). The feedback will determine whether the intervention will continue, improve or stop. Generally, most of the policymakers are more likely to use this method (NHS Institute of Improvement and Innovation, 2010). This type of decision tools is one of the lean thinking/techniques. Several terminologies have been used by previous researchers to refer to conventional decision tools. Among others, Wolstenhome et al. (2004) used 'experimentation on the real world', Giachetti et al. (2005) used 'trial and error,' and Katsaliaki and Mustafee (2009) used 'experimentation with the real system'. Based on the existing terminologies, the researcher decides to use 'direct experimentation' in this research, which refers to the conventional method for developing the CPP model.

Academicians, on the other hand, prefer to use more academic oriented methods, such as the simulation modelling method. Shannon (cited in Ingalls, 1975, p.17) defined simulation as:

> "……*the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria for the operation of the system*".

In other words, the simulation modelling tool is a method that transfers a logical model into programming or computer software that will imitate the real system based on the real world situation. The decisions are made based on the output produced by the computer programming or simulation software. The techniques under modelling with simulation that have been used to model CPP systems are the Markov Model, Discrete Event Simulation (DES) and System Dynamic (SD). The Tree diagram will also be included under this method, as suggested by Barton et al. (2004). The following briefly explains these tools.

Direct Experimentation Method: Lean Thinking/Technique

One of the techniques that can be considered as direct experimentation is lean thinking or the lean technique. The lean technique or lean thinking is a new way of making efficient decisions. It can be categorized as business process reengineering. The lean technique is used in 5S housekeeping, process mapping, elimination of waste, smoothed flow, just-in-time, pull versus push, schedule bottlenecks, change reduction and kaizen or continuous improvement (Bates, 2010). One of the lean quality tools is visual management, in which the technique visualizes the processes in the health and social care as a flow chart, with boxes and arrows that will be implemented in the real world (direct implementation). Several tools can be used to support this method, such as Experienced Based Design (EDA), Patient Perspective Module, Value Stream Mapping, Process Mapping Lean Seven Waste and Plan, Do, Study, Act (NHS Institute for Innovation and Improvement, 2010). The lean technique is static, simple to understand and can be modelled by anybody rather than only a specialist in modelling. It can also represent the real system and can cover the whole system of patient pathways in the integrated care as long as the individual understands the processes involved. As the modelling is likely to be drawn on a large sheet of paper, it will be transparent. This technique will allow stakeholders to gain insight into the whole system and to detect any problems related to the pathways or the integrated care system. They can clearly see how the parts of the system connect together. Based on the NHS documentation, the researcher concluded that most of the policymakers were inclined to use conventional and traditional methods, i.e. the direct experimentation method. The Social Health Maintenance Organization (SHMO) and Program of All-Inclusive Care for Elderly (PACE) can be classified using this type of decision tools.

Simulation Modelling Method: Markov Model

The Markov model is suitable for use in showing the trend of certain events so that decision makers can predict the future. People with an expertise in mathematics are needed to develop the Markov Model as it is based on a mathematical model, even when it is simple. It is also difficult to understand and does not provide a clear picture, as claimed by Venkateshwaren et al. (2005). Although the Markov model can assist in decision making by looking at the results, it is short of certain important criteria to be considered a good modelling technique. The Markov model does not allow for experimentation of any intended intervention to be done before the real implementation. It assumes that all patients in a certain state have the same attribute. In addition, the Markov model does not allow for the transfer time from one state to another (Barton et al., 2004). In CPP across several departments and care givers, the transfer time of a patient from one state to another is crucial, as this will imply and reflect the service performance. The technique does not support the interaction among individuals (Barton et al., 2004). Karnon and Brown (1998) suggested that the Markov is suitable for long-term health intervention.

Simulation Modelling Method: Discrete Event Simulation (DES)

DES can be described as a model of a system that contains a set of individual entities that run through a series of queues and activities in a distinct time (Tako and Robinson, 2009). Law and Kelton (1991) argued that DES technique are widely used by the people in OR and management science for analytical purposes. This is because it has a stochastic element, which provides a clearer picture for complex situations compared to other OR techniques, such as mathematical modelling (Venkateshwaren et al., 2005). DES deals with the models that have objectives of what-if scenarios, predictions and optimization (Chahal and Eldabi, 2008). DES is a very effective technique that can provide predictions for the future if certain decisions are made (Miller et al., 2004). Mahapatra et al. (2003) argued that most countries in the world have used simulation techniques to model and analyse the emergency department. This is because of the advantage that the simulation can be used by many policies. Based on certain scenarios, the simulation will facilitate decision makers to determine the most effective policies before the implementation phase (Miller et al., 2003). Furthermore, the DES simulation software is user friendly. The software includes graphical and animation interfaces, which provide more convenience to the users as they can imagine how the system works. Such applications that use DES as decision tools are Caro (2005), Jun et al. (1999), Fone et al. (2003), and Davies and Davies (1994).

Simulation Modelling Method: System Dynamic (SD)

The nature of SD, which shows the whole system interaction, makes the SD a learning laboratory rather than an optimization tool (System Dynamic Society, 2008). People can learn how the system interacts between the parts in the system (Forrester, 1961). If we are looking for an interrelationship study, their causes and their feedback, then the SD method is a suitable method as it will model the whole system based on set boundaries and limitations (Chahal and Eldabi, 2008). With the argument that one system cannot remain independent, the SD technique is the best, as it can represent a big and complex system that interacts with the environment. With this technique, models do not rely much on huge amounts of data, as some healthcare systems do not have useful data (Brailsford, 2008). Based on the above arguments, any model that can picture the whole system or how they can interact with each other can be run in front of the decision maker and certain decisions can be made as soon as possible (Brailsford, 2008). Dangerfield and Robert (1999) suggested that the SD model can be a part of the OR technique that can be used to model the complexity of the healthcare system. Such applications that use SD as a decision tool is Lane et al. (2000), Townshend and Turner (2000), Dangefield and Robert (1999), and Walker and Haslett (2001).

Simulation Modelling Method: Decision Tree

The decision tree technique is useful for patient pathways that have a short time frame and where the different strategies used will not change anything. The outcome of this technique is the probability of each pathway or event. This technique needs to be experimented on a patient that goes through each of the possible pathways in order to obtain its probability results. The results will be multiplied against the total cost of each patient in order to gain the expected value of treatment for each patient's pathway. This technique can be seen in the model of Evans et al. (1997). This technique can be extended more than once. The downside of it is that it has the possibility of having hundreds of possible nodes (Cooper et al., 2007).

As mentioned in the previous section, an example of CPP is integrated care in health and social care settings. In this research also, the models of CPP refer to the models developed specifically to analyse problems and come up with solutions. Therefore, the next sub-section provides several CPP models that were specifically developed to facilitate decision making processes especially in an integrated care setting. The selected developed models are relevant to integrated care, which consists of several departments to provide care services to patients. These CPP models were developed using several modelling methods that have been discussed in the previous section.

2.3.2 Patient Pathway Models

CPP models that involve integrated care across several care givers and departments were mostly developed using various types of decision tools, ranging from conventional and traditional methods such as prototype (pilot) systems, flowchart, to computer applications, such as simulation modelling methods. The patient pathway models were developed because of the prime problems discussed among policymakers and academicians. The main problems associated with the patients' pathways are bed blocking and delays in transferring the patient to social care. On how to solve, or at least minimize the problems, the decision makers, policymakers as well as academicians, are inclined to use several techniques or methods to develop the patient pathway models. Compared to the single healthcare patient pathway model, the developed models that focus on the patient's pathways in the complex systems are limited.

In this research, the selected developed CPP models are discussed based on several types of technique for model building. Table 2.3 summarizes various patient pathway models and a brief explanation of each.

Table 2.3: Examples of Developed Complex Patient Pathways Models

CPP Model	**Authors**	**Techniques**
Adult Service in Hampshire	Desai et al. (2008)	System Dynamics
Best Method for keeping patients	Campbell et al. (2001)	Discrete Event Simulation
Possible Care Pathways for Elderly People	Katsaliaki et al., (2005)	Discrete Event Simulation
Investigating Length of Stay of Elderly Patients	Xie et al. (2005)	Markov Model
Best Place for Keeping Patient	McClen and Millard (2007)	Markov Model
Template of Integrated Care Model	Wolstenhome et al. (2004)	System Dynamics

Social Health Maintenance Organization (SHMO)	Kodner and Kyriacou, (2000)	Direct Experimentation (Lean Technique)
Program of All-Inclusive Care for Elderly (PACE)	Kodner and Kyriacou, (2000)	Direct Experimentation (Lean Technique)

Adult Services in Hampshire

Desai et al. (2008) developed a model for Adult Services in Hampshire using the system dynamics technique to evaluate different interventions to the current system. Their main objective was to predict demand for services for the elderly in the next 5 years. Based on the service demand, several interventions were implemented using the model to cater for predicted demand. Hampshire Adult Services offers several types of care, among them are; day care, domiciliary care, residential care home with personal support for less independent patients and also a nursing home if the patients need specialised medical care. Two types of patients have been considered in need of the continuing care services. These are critical (life of patient is threatened/serious level/have a significant health problem) and substantial (patient has limited choice of environment/cannot carry out most daily activities). The results from the model show that the demand rate for the care packages, especially for 85 year-olds and above, are likely to be more complex and expensive. This is because of the increased population. The authors implemented two interventions to see how the model reacted, changing the eligibility criteria and increasing the number of unqualified social workers.

Possible Care Pathways for Elderly People

Katsaliaki et al. (2005) used Discrete Event Simulation (DES) to investigate possible routes or care pathways for elderly people in Hampshire Social Services. The problem focuses on patient delay by post-acute services due to the limited availability of beds or bed blocking problem. The problems are caused by patients who are unable to transfer until the next social service is available. To reduce the problem, the patient will be transferred to intermediate care. The DES technique is purposely used to explore the suitability and appropriateness of intermediate care to reduce bed blocking in the healthcare institution. The model focuses more on the patient’s transition after discharge and, therefore, it starts from the assessment and does not include the time in the hospital. The modelling only starts from the hospital to social care, or, from the home to social care as referred by other sources (relatives, GP, etc.), including intermediate care. Based on the model, the authors suggested that social care services develop 500 new places for nursing homes that can accommodate and balance the demand for nursing homes for the elderly.

Best Method for Keeping Patients

Campbell et al. (2001) developed a model of CPP using discrete event simulation (DES) to investigate and compare the best method to retain patients. The comparison was between retaining patients in hospital (conventional inpatient care) or hospital-at-home services in terms of their cost. The researchers divided two groups of elderly patients who do not have a major illness; 30 patients received hospital-at-home care for 14 days whilst 21 patients received standard conventional inpatient care. The cost of care (to NHS, community health services provider and social services department) from the initial care up to three months after discharge was collected from each group. One reason for using the DES technique is that this technique can capture the details of each patient, as the time spent for each of the groups was substantial, which will directly affect the cost. From the models, as predicted, the hospital-at-home proved to be cost saving compared to the conventional inpatient care.

Investigating Length of Stay of Elderly Patients

Xie et al. (2005) developed a model using the Markov model to address the problem of late transfer of patients to the nursing or residential home and waiting for the assessment of their needs. In order to investigate the length of stay of elderly patients from healthcare to nursing or residential care homes, the Markov model was used to record the patient moving within and between residential home care and nursing home care. The reason why the authors used the Markov model was based on the research done by Harrison and Millard in 1991 and Taylor et al. in 1998 and 2000 (Xie et al., 2005). Their research proved that the Markov model can capture the behaviour of patients in terms of length of stay (LOSs) for short-stay and long-stay phases in hospital geriatric department seven, though the patients are different. The modelling involved the following patient movement – from residential home care to nursing home care, from nursing home care to discharge (considering that the patient died in care) and from residential home to discharge to own home. The modelling used the Markov process that considered only three classes, residential home care, nursing home care and discharge, due to data restrictions. The model suggested that the length of stay for residential home care was 923 days. The length of stay for nursing home care was 59 days for short-term and 784 days for long-term. In addition, the model also suggested that 64% of all admissions to nursing home care would become long-term residents.

Best Place for Keeping Patients

McClean and Millard (2007) developed a model of health and social care using the Markov reward model to evaluate the cost of patient movement within the healthcare system. This included the social components, such as dependent, rehabilitation, recovery and community care institution. The authors assigned an estimated cost for each of the states. Based on these states, the authors calculated how much the whole system cost. The price also included the cost of new admissions and current patients. The model also showed the comparison cost of keeping patients in acute hospital to ensure fitness for discharge (therapeutic) or in community care (prosthetic). Using an estimate of costing and transition rates, the result was deemed to be a good benchmark for the hospital planner to identify which approach was the most cost effective. Based on the result of the developed Markov model obtained by MATLAB, the result shows that keeping patients in the community centre was more cost effective compared to keeping patients in hospital to improve their fitness. Although the Markov model did not provide the details about the patient's time in hospital and in social care, and needs another speciality distribution to model it, the authors argued that the average length of stay was not an appropriate key to measure the hospital performance. The authors made a comparison with keeping patients longer to improve their fitness, as rapid transfer to nursing or residential care homes will encourage re-admission, and, hence, will increase the cost of care. Therefore, rapid transfer is not a cost effective or efficient solution. The authors deemed that the model developed could be used to test any different option for the delivery of care with supported suitable and accurate data.

Template of Integrated Care Model

Wolstenhome et al. (2004) used the SD technique to develop a template CPP model to be used by other local agencies that suits local circumstances. The model building tried to integrate primary, secondary and tertiary healthcare with social care, to experiment with the pathways in search of improving the efficiency and performance of all the stakeholders in the care sector, including patients. The model addresses the problems of admission prevention and delayed discharge and shows how this can save the resources within the agencies. Since there are many policies that can be implemented to the real system, the model was used to demonstrate and investigate the effect of different policies over time applied to the model of health and social care. As the model can be used for other types of problems, the data, such as resources and some scenarios with elderly people with mental health problems, were included in the template model to suit local circumstances. With the objective of seeking to improve the integrated care and performance relationship between the difference agencies, the authors used iThink SD software to test and find the best policies that relate to the long patient pathways from one agency to another. The modelling process involves many stages, such as specifying model structure and entering data as well as testing the model with different scenarios. The model shows the whole system and can be defined as a series of activities of patient pathways, which shows the usage and average time to finish the treatment.

Social Health Maintenance Organization (SHMO) (Review by Kodner and Kyriacou, 2000)

The Social Health Maintenance Organization (SHMO) project was funded by the US government, which combined health and social care comprising acute and long-term care using the insurance model. With the aims of improving the health of vulnerable older people and minimizing the use of hospitals, this programme is voluntary for all impaired elderly people aged 65 years and over. This model provides a huge range of care services to the elderly including dental care, foot care, eyeglasses, transportation, etc. This model includes the various disciplines that collaborate with each other to provide the service called 'care management'. With this model, the patient is provided with an inclusive assessment, care plan, service authorisation, and the patient condition is observed gradually and is also followed up. Two unique aspects that are included in this model are assessment and care planning and the providers will provide the long-term care for the patient as contracted. The researcher suggests that this type of CPP model could be categorized as using a 'direct experimentation' method, in which its effectiveness could be assessed several years after it was introduced. The work of Harrington et al. in 1990, Kane et al. in 1998, and Newcomer et al. in 1994 (cited in Kodner and Kyriacou, 2000) are among the examples.

Program of All-Inclusive Care for Elderly (PACE) (Review by Kodner and Kyriacou, 2000)

The enrolment for both SHMO and Program of All-Inclusive Care for Elderly (PACE) is on a voluntary basis. The main difference of these two settings is that PACE is limited and exclusively for disabled persons aged 55 and above. It is a fully integrated care system, which provides inclusive acute and long-term care, including social and relief services, outpatient clinics, and on-going clinical oversight. They operate as an adult day healthcare centre and the model is based on OnLok, a San Francisco model for senior citizens. The model uses a geriatric approach or case management, which emphasises primary care, multi-disciplinary teamwork, psychosocial support and prevention. The researcher claimed that this type of CPP model was developed using a *'direct experimentation'* method. Several researchers, such as Chatterji et al., Polivka and Robinson, and Zimmerman et al. have carried out research to determine the effectiveness of this model after it was implemented in the real world (cited in Kodner and Kyriacou, 2000).

In the next section, the researcher will point out some of the limitations of the developed patient pathway models that lead to the ineffectiveness and inefficiency in decision making process. The researcher argues that these limitations are the reasons why problems in the CPP system are persistent as they lack certain important criteria to be a viable CPP model that consequently result in inefficient decision making. The term 'viable' in this research means that the developed complex patient pathways model is a close representation, or workable, in the real world system. The limitations are then combined with the characteristics of the CPP system to form a set of criteria for a viable CPP model.

2.3.3 Limitations of the Developed Patient Pathway Models

The complex patient pathways (CPP) model of Desai et al. (2008) does not include the whole CPP model because they start the model with the assessment based on referral cases. This can cause the decision making to be unreliable as the patient might have stayed for a longer period due to waiting for the assessment which relates to other problems, such as bed blocking. The problem will not be settled as it is interlinked with other healthcare, intermediate care and social care problems. The model also lacks individual time analysis as the SD is not capable of capturing this characteristic and does not include the patient's process finishing time. As every patient has a unique case, this will result in a defect in the decision making. Similar to the model of Desai et al. (2008), Wolstenhome et al.'s (2004) model also lacks individual analysis.

The model of McClean and Millard (2007) does not provide the details concerning the patient's time in hospital or in social care. They need another speciality distribution to model it, as admitted by the authors. Although the authors said that time is not as important as patient fitness, there will be a side impact concerning the healthcare if the patient is kept for a longer time in the hospital. For example, the resources will increase the expenditure. The authors admitted that the model should allow different interventions to be tested, which this model lacks. An expert is needed to build a new model based on a case when the condition of the patient changes, as this model uses mathematical modelling. The model of Xie et al. (2005) only focuses on the social care and not on the whole patient pathways system, as they try to predict how long a patient would be in the social care system for. The model does not provide a clear answer and has to rely on an expert for the interpretation of the results. For example, in this case, the authors suggested that for a short-term decision it is better not to increase the transfer of elderly patients to the residential and nursing home care, as it will have an impact on the financial and organizational consequences.

The model of Campbell et al. (2001) has been tested with six sensitivity analyses. However, this research does not include the direct financial cost of a hospital-at-home setup, such as patient's carer at home, hospital overheads, etc. Furthermore, as admitted by the authors, the evaluation of this case might be biased as some of the hospital-at-home patients might be healthy compared to another group. This is because this group of patients might refuse the inpatient care. Another disadvantage of this model is the inability of DES to provide the feedback effect of the hospital-at-home initiative, including the cost of implementation of such intervention or the impact of such implementation. The model of Katsaliaki et al. (2005) does not include hospital modelling as their focus was only for patients that are medically fit for discharge. Furthermore, due to the size of the system, that is, too big, the authors divided the work into separate areas and ignored the possibility of any interconnection with the wider stakeholders. Due to the unavailability of data, the model does not include long-term social care services.

The SHMO and PACE models were developed based on the observations from the beginning when the system was first introduced. Both systems were developed based on the patients' needs and to improve the healthcare and social care services. Various researchers have reported their suitability by using the survey method after the system had been setup. Therefore, the method is considered using the direct implementation method, in which they model the system on paper, implement it in the real environment and the system suitability is obtained by feedback from the patient who has been using this system. This type of method has huge limitations. Because the system was developed in a real environment, it will need huge investment including cost, time and other resources. After all, the system that was developed is not guaranteed to be the best system and, consequently, could be a waste. Table 2.11 summarizes the limitations of each of the developed models in respect of patient pathways.

Table 2.4: Limitations of Developed CPP Models

Complex Patient Pathways Model	**Limitations**
Adult Service in Hampshire Desai et al. (2008)	- Does not fully cover the whole CPP system - Lack of individual analysis
Best Method for keeping patients Campbell et al. (2001)	- Does not include total cost for implementing hospital-at-home setup - Bias cases - Lack of feedback analyses in implementing interventions - Does not fully cover the whole CPP in integrated care system
Possible Care Pathways for Elderly People Katsaliaki et al., (2005)	- Does not cover the hospital and social care modelling - Tends to ignore the interconnection between sub-system, people, etc.
Investigating Length of Stay of Elderly Patients Xie et al. (2005)	- Does not cover the whole CPP system - Decision depends on the expert - Have to build another model to support each patient - Does not have individuality analyses
Best Place for Keeping Patients McClan and Millard (2007)	- Does not provide detail (time) of hospital and social care - Model does not consider different interventions
Template of Integrated Care Model Wolstenhome et al. (2004)	- Does not provide individuality analyses - Lack of detail of intermediate care services
Social Health Maintenance Organization (SHMO) Kodner and Kyriacou, (2000)	- Implemented in the real world situation - Involves a lot of investment, time, money, etc. - Does not guarantee in the short time that the system will improve
Program of All-Inclusive Care for Elderly (PACE) Kodner and Kyriacou, (2000)	

(Developed by the researcher)

Due to the limitations of these models, the researcher argues that they are not viable enough to represent the real world situation. A real world situation must be represented by a viable model to make it reliable and authentic. The next subsection will discuss the characteristics of CPP models. To date, there is no literature that covers or mentions the characteristics of CPP models. Therefore, the researcher develops these characteristics based on the limitations of the developed CPP models and will be combined with the characteristics of the CPP system to form the criteria for a viable CPP model [Characteristics of CPP System + Characteristics of CPP Model = Criteria of a viable CPP Model]. These criteria will be used for selecting the best technique for decision making tools.

2.3.4 Characteristics of CPP Models

To the best of the researcher's knowledge to date, there is no literature covering the characteristics of CPP model. Therefore, based on the limitations of each of the developed models, the researcher is propelled to find the best criteria for the best model that can represent the CPP system from reading the literature. These characteristics should be considered before developing a CPP model.

The health care environment is very challenging as it deals with a dynamic situation. Policymakers must ensure the output before initiating improvements in the system. The waste of investment must be avoided as the state of the healthcare systems is changing rapidly (Chahal et al., 2009). This criterion is important in order to select the right decision tools for modelling, as argued by Pidd (2004). Direct experimentation in a real world situation could be dangerous and impractical (Wolstenholme et al., 2004). Since many interventions need to be tested, modelling will be best as they can be modelled once and be used for simulation and experimentation many times (Eldabi, 1999).

Care services involve human beings who are sensitive to changes in their environment. Bryan et al. (2006) highlighted various reasons arising from human nature that cause breaches in care services, especially in complex patient pathways in integrated care. These cause other problems in integrated care such as communication, patient pathways, imbalanced supply and demand and many more (Moret et al., 2008; Rummery and Coleman, 2003; Grone and Barbero, 2001; Andersson and Karlberg, 2000). Based on this argument and chain-of-problems situation, it is argued that any tool that is used to model CPP should consider these criteria as any initiative proposed will impact dynamically on the other parts in the system. The nature of the problem must always be considered before selecting decision support tools (Pidd, 2004). Indeed, the interaction between different parts of the system is crucial (Chahal and Eldabi, 2008). McClean and Millard (2007) suggested that any care model should include all departments involves such as the health and social care, for planning. This is to ensure that such improvements will balance the whole system. In accordance with the arguments above, a good CPP model will consider the whole system regardless of their setting. This is to ensure that any implications that affect other parts of the system will be noticed.

The chosen tools to model the CPP system should have the ability to closely represent the real system including their processes inside the systems (Morecroft and Robinson, 2006). This is to ensure that any 'movement' in the process and any changes to the system and model will be noticeable. Furthermore, it is also to ensure that all the stakeholders will understand the whole system that has been modelled. Thus, it will prevent the decision makers making a wrong decision.

A model is used to represent the real complex system to make it simple and easy to understand. This feature will be an advantage to the model (Ward, 1989). Another reason why the simplest model is needed is because it is easier to understand by non-specialists (Cooper et al., 2007) and, thus, easy to validate (Barton et al., 2004). Weinstein et al. (2003) argued that the structure of the model should be as simple as possible while considering the fundamental mechanism of the disease process and interventions. Wolstenholme (2004) argued that the model could be used as a tool for understanding complex systems, such as those that the health and social care planners need to know. Indeed, a model can be used as a medium to understand problems in the system. The selected tool should be easy to learn, understand and use by non-experts.

CPP is a complex system that differs from others (Baker and Bates, 2010), many processes and stakeholders are involved, whose opinion and views must be considered (Kuljis et al., 2007). The main purpose for modelling is to simplify the process. Thus, a good decision tool is needed that can be used to simplify the complexity as this will ensure that all the stakeholders have a holistic view of the CPP system and understand the care process.

Any CPP model that is developed should support the decision making process, especially in clinical practices or healthcare resources (Weinstein et al., 2003). In other words, for every intervention that is implemented using the model it should produce the effect of the implementation. Furthermore, the technique used should have the capability of providing a prediction for the current event (for example, the total number of elderly patients that need care services in the next 5 years), as this will help the higher management to create a plan to comprehend the situation.

It will be a high value model if it has the ability to expose the relation and connection between input and output. This will allow the stakeholders, including the patients, to understand how the care process is conducted. It will also allow the decision makers to see any problem in the system and make correct decisions to solve the problem. Therefore, it should be visible and can be visualize as end users can see how clearly the end results appear (Weinstein et al., 2003). The interactions and interdependencies between the various parts of the system should also be clearly identified as the care sector is a multifaceted system in which the modelling technique can be used to illustrate whether the patient is engaged with another process at the same time (Eldabi, 1999). This will enhance the overall understanding of the system.

Table 2.8 summarizes the characteristics of CPP model that have been deduced from various literatures.

Table 2.5: Characteristics of Viable CPP models

Characteristics	**Deduced from:**
Prior experimentation before real implementation	Chahal et al. (2009); Pidd (2004); Wolstenholme et al. (2004); Eldabi (1999)
Cover the whole system	Pidd, (2004); Chahal and Eldabi, (2008); McClean and Millard (2007)
Represent the real system closely	Morecroft and Robinson, (2006)
Visualization and the model is easy to understand	Ward, (1989); Cooper et al. (2007); Barton et al. (2004); Wolstenholme (2004)
Simplifying complexity	Baker and Bates, (2010); Kuljis, Paul and Stergioulas, (2007)
Assisting decision	Weinstein et al. (2003); Eldabi (1999)

(Developed by the researcher)

A set of criteria for a viable CPP system has been developed based on the characteristics of the CPP system and the limitations of the CPP models. In the next subsection, these criteria will be compared against the capabilities of the techniques.

2.3.5 Viable CPP Model versus Capabilities of the Techniques

A set of criteria should be considered in order to develop viable CPP models and to select a suitable modelling technique. The following points are the criteria that have been identified from the characteristics in the CPP system (Table 2.2), from the limitations of the developed models (Table 2.4) and from the perspective of the technique (section 2.3.1). Table 2.6 presents the criteria that have been identified from these three perspectives and their comparison between the criteria against the capabilities of the techniques.

Table 2.6: Criteria for a Viable CPP model and Modelling Techniques

Criteria from Characteristics of CPP systems	**Criteria from limitation of Developed CPP Models**	**Criteria from Capabilities of the Techniques**	**Modelling Techniques**
i. Unique individual case, ii. Have environment feedback loop, iii. Dynamic system, iv. Short-term decision effecting the long-term decision	i. Prior experimentation, ii. Cover the whole system, iii. Represent the CPP system closely iv. Visualisation and easy to understand the models v. Simplify the complexity of the CPP system vi. Fully support the decision making process	i. Easy, especially for beginners to study, understand and use	i. Direct experimentation ii. Markov Model iii. Discrete Event Simulation (DES) iv. System Dynamic (SD) v. Tree Diagram

Adapted from Table 2.4, Table 2.8, and Section 2.5.1.

Other than the Markov model and SD, the other three techniques have the ability to provide analysis of the ‘individuality’ of the system. However, it will be a mess and become more complex when the system increases in size. SD does not have the capability to capture the individual complexity (Chahal and Eldabi, 2009); neither does the Markov model, as these techniques only capture aggregate attributes (Barton et al., 2004). In contrast, SD has the capability to provide a feedback loop as a result from the interventions. The other four techniques do not have the ability to model the feedback loop.

Sobolev (2005), Walshe and Rundall (2001) and Watt et al. (2005) argued that healthcare should know the impact or consequences for every decision taken before its implementation, as the healthcare sector has zero tolerance when dealing with mistakes and failures. Therefore, the care sector should seek or use tools that can give a holistic view of the consequences caused by any decisions taken by the decision makers. All the above techniques need historical data for experimentation. The difference between these techniques is whether direct implementation without experimentation is done or not. The stakeholders should know the effect and consequences against the system prior to the intervention. Neither direct experimentation nor Decision Trees have the ability to provide what-if scenarios and their consequences. The Markov model can provide consequences of what-if scenarios provided the modellers create additional models for each of the scenarios. This is because the Markov model is only able to show the scenario that has the same attribute, case and entity (McClean and Millard, 2007). To obtain results based on what-if scenarios, most of the modellers will use either the DES or SD, as they provide the whole picture of what could happen to the system if they implement any intervention to the model (Chahal and Eldabi, 2008).

In CPP, the time the patient transferred from one state to another state is crucial as this will indicate and reflect the service performance. DES and SD have the ability to model the dynamic as they include the time in the system model. The Markov model does not allow for the time from being transferred from one state to another (Barton et al., 2004). If the system is based on time, the Markov Model is not suitable. In fact, the mathematical modelling (markov model) can only be used for a certain problem and intervention (Eldabi, 1999). The direct experimentation and decision tree do not have the ability for dynamic modelling as the techniques only allow static modelling.

Since the decision tree is a modelling technique based on the problem and the output is based on the probability, the technique cannot represent the system as a whole. Whole system modelling of CPP using the Markov model can be seen from a study done by McClean and Millard (2007). However, the technique does not have the ability to support the interaction and interdependencies between individuals (Barton et al., 2004). It is not suitable to use the mathematical modelling (markov model), as the interdependencies between the parts in the care system make the care system complicated (Eldabi, 1999). Therefore, direct experimentation, SD and DES can be used to closely represent the system, as these techniques show the interdependencies between the parts of the system. The visual representation on paper makes the lean technique usable to represent the model of the real system.

None of the above techniques can be used to assist decisions in the short-term or long-term period at the same time, especially concerning the implementation of decisions in the current system. However, DES is mostly used to assist decisions concerning operational and tactical problems, which involve short-term decision making, while SD can be used to assist decisions for strategic management (Tako and Robinson, 2009; Mallach, 2000). Even though the direct experimentation can be used to model the system, it does not provide the result for each of the interventions. Therefore, it is hard for the decision makers to create best policies to deal with the problems. The decision tree is suitable for use for short-term decisions and the Markov model is suitable for long-term decision making, as stated by Karnon and Brown (1998).

All of the mentioned techniques can be used to assist the decision making process. The difference between each of the techniques lies in whether the technique can be used as a high or low ‘assistant’ for decision making. The direct experimentation can assist decision making by providing a holistic view of the care system. Based on this view, the decision maker can see the problem in the system and plan the necessary interventions to reduce the problem. The result will be provided after some times as it used direct implementation and questionnaire to gather the results. The decision tree provides the result from the intervention easily. However, since the CPP system is complex with many stakeholders and possible pathways, it will cause confusion if the modeller uses the decision tree, as this will produce hundreds of possible nodes (Cooper et al., 2007). The Markov model can support these decision making processes, as it provides prediction, while the SD and DES provides prediction of the future and what-if scenarios for each of the interventions (Chahal and Eldabi, 2008). Indeed, Tako and Robinson (2009) argued that the DES and SD models are perceived to provide realistic outputs and create confidence in decision making.

These five techniques have the ability to model the whole CPP system. However, some of the techniques will increase the complexities of the model. For example, modelling CPP generate many decisions will produce massive branches. This will create problems in the model (Barton et al., 2004) when using the decision tree. A modeller needs extensive data and needs to develop a different model for different cases in the Markov model (Xie et al., 2005) in order to develop a whole system. The DES is less suitable to model the whole process in a CPP system as the size will increase exponentially and will make the model more complex (Chahal and Eldabi, 2008; Jun et al., 1999; Lowery, 1993). Although, the SD can be used to model the whole CPP system including the environment surrounding the processes, it lacks details of the process of the system (Chahal and Eldabi, 2008). The direct experimentation can be used to model both processes and the environment, as the technique uses conventional method.

The level of visibility and visualization of the system will improves the communication tools between the users and models. As the Markov model is based on mathematical modelling, the technique does not provide the visibility or a clear picture of the care system (Venkateshwaren and Son, 2005; Eldabi, 1999). The decision tree provides a low transparency of the whole system. This is because it only provides a small part of the system based on the problem it addresses. The direct experimentation, SD and DES techniques provide a holistic view of the system. The question is whether we want to cater for techniques that provide the whole system with the surrounding environment (SD) or specifically the whole process of the system (DES). This will give the ability as a communication tool between the users and the models (Tako and Robinson, 2009). As the direct experimentation uses 'manual' tools for decision tool, it will be a huge system to visualize.

The Markov Model is not easy to use. This is because it uses mathematical modelling that requires expertise to develop and explain. Comparatively, other modelling techniques are easy to use and simple to develop. The direct experimentation provides visualization for modelling that uses manual tools such as a flow chart, boxes and arrows. Therefore, it is argued that this technique is easy to use and simple to understand by the user. The decision tree is easy to use by representing the probability for each of the interventions and helps the user to understand how the system works. Although the SD and DES need some aspects to be learnt, they are fairly easy to use as proved by Tako and Robinson (2009). From their empirical study with respondents from among MBA students with no previous experience in modelling, Tako and Robinson (2009) provided a comparison between the SD and DES based on user experience of using the DES and SD. In fact, the models developed using these techniques are easily understood as they provide graphic and model linkage to show exactly how the system works (Tako and Robinson, 2009).

Table 2.7: Modelling Techniques Abilities

Criteria of a viable CPP model	**Discrete Event Simulation (DES)**	**System Dynamics (SD)**	**Direct Experimentation Lean Thinking/ Technique**	**Markov model**	**Decision Tree**
Easy to learn and use/simple to model	Easy to learn and use and simple to model, will be complicated if the system is big	Easy to learn and use, simple to model, especially for a big system	Easy to use, simple to model, need to breakdown the whole system to model	Need a mathematical modeller's expertise to build the model, hard to understand the model as they use mathematics	Easy to use and simple, will be a mess if the system is too big
Assisting decision	High assistance, providing estimation, prediction and what-if-scenarios	High assistance, providing estimation, prediction and what-if-scenarios	Low assistance, providing only a holistic view of the whole system	Medium assistance, providing estimation and prediction	Medium assistance, providing probability that a certain event will happen, cost estimation based on probability of each event happening
Visualization and easy to understand	Explicit inside the system, as the graphical model helps to view the system as a whole, non-expert can understand how the system runs	Not too explicit in the system, explicit outside the system, non-expert can still understand the whole system	Explicit as the graphical model gives more understanding of the system	Implicit and hard to understand for non-experts, hard to see patient flow movement and how the system operates	Explicit if the model is small
Experimentation prior to real implementation	Ability to provide what-if-scenarios, however, needs extensive data for model verification and validation	Ability to provide what-if-scenarios, however, needs a little data for model verification and validation	Not provided, direct experimentation, needs an extensive amount of time and resources for experiment	Ability to provide for what-if-scenarios but have to create additional models for each different case, attribute and entity, experiment only involves prediction and estimation based on historical data	Does not provide for what-if-scenarios and their consequences
Individuality analysis	Provided. One model can be used for different individuals, cases, attributes, entities, etc.	Provided but will be more complicated. The technique uses aggregate attributes to reduce complexity	Not provided as uses direct experimentation	Not provided. Uses aggregate analysis. Needs a new model for other cases, attributes, entities, etc.	Provided, but will be a mess as many branches must be produced to represent each situation and decision

Criteria of a viable CPP model	**Discrete Event Simulation (DES)**	**System Dynamics (SD)**	**Direct Experimentation Lean Thinking/ Technique**	**Markov model**	**Decision Tree**
Feedback loop	Not provided	Provided as a result from any intervention that has been done to the model/system (what-if-scenario)	Not provided as uses direct experimentation. Only known after certain time of experiment	Not provided.	Not provided
Cover the whole system	Can cover the whole system, will be complicated, break down to smaller system then combined, complexity increases exponentially with size	Ability to cover the whole system (process and environment)	Can model both process and environment (manual tools for modelling)	Can model the whole system but needs an extensive historical data, needs to develop other model for other case, attribute, etc.	More complex to the model if many decisions need to be made
Dynamic model	Provided as time included in the model.	Provided as time included in the model.	Static model.	Includes time in the model, but does not allow the time to be transferred from one state to another state.	Static model
Closely represents real system	Representative, flow of information between parts of the system	Representative, but does not present current system visually	Closely represents system but lacks dynamic model	Cannot represent the interaction and interdependencies between parts of the system	Cannot closely represent the system as a whole
Short- and long-term decision making simultaneously	Not provided. Some of the models only support either short-term decision making or long-term decision making				
Simplifying complexity	Simplifying complexity for the process in the system, if system is too big, modellers tend to break down the system	Simplifying complexity for the environment surrounding the system	Simplifying complexity by representing the system as a picture	Simplifying complexity but only modeller understands the model as they use mathematical modelling	Simplifying complexity, if system too big, it will create a more complex model

(Developed by the researcher)

Most of the developed CPP models use a single technique for modelling, as depicted in Table 2.3. This condition leads to problems where many of the criteria of a viable CPP model cannot be covered by the capabilities of the techniques. The next section will discuss the gap between the system needs, capabilities of the techniques and limitations of the models. Due to these gaps, the researcher's recommendation concerning how to cover all of the criteria of a viable CPP model will also be included in the next section. It is hoped that these recommendations will help in the decision making process, especially when the model mimics the real CPP system exactly.

2.4 THE GAPS BETWEEN SYSTEM, MODEL AND TECHNIQUE

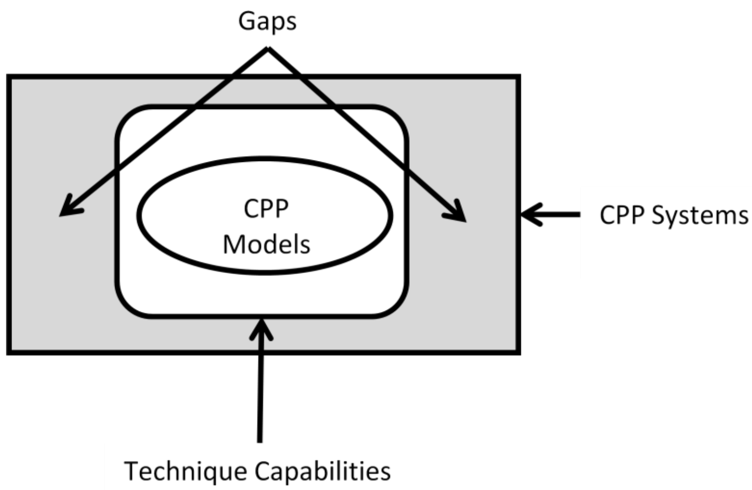


Figure 2.3: Gaps between Systems, Model, and Technique

Figure 2.3 depicts three types of box. The rectangular box represents the characteristics of the CPP systems, the rounded rectangular box represents the capabilities of the techniques whilst the oval represents the CPP model. The CPP system is large as it combines various subsystems and consists of many stakeholders. Thus, the CPP systems have complicated needs, characteristics and problems. The modelling technique has been used to reduce the complexities of the systems and to facilitate problem solving by developing CPP models. However, as a single modelling technique was used, the capabilities of the techniques could not cater for all the needs and characteristics of the CPP system, thereby creating a gap between the system and the capabilities of the techniques. This has been discussed thoroughly and summarized in Table 2.7 of the previous section. Because of this gap, the developed CPP model is not viable enough and results in inefficiency in the decision making process. As the decision is based on the model, the researcher argues that this condition contributes to the inefficient and unreliable decision making in CPP system (Miller et al., 2003). Table 2.9 (mapping criteria with modelling techniques) in the next section will prove that using a single modelling technique might ignore some of the important criteria of a viable CPP model.

Therefore, the researcher suggests a combination of various modelling techniques to cater for all the needs and characteristics of the CPP system. By combining the techniques, the modellers can produce a viable CPP model that exactly mimics the real CPP system. Consequently, the decision making will be more reliable and efficient. Figure 2.4 illustrates how a combination of the modelling techniques will cover all the criteria of a viable CPP model followed by the explanation of the figure in Table 2.8.

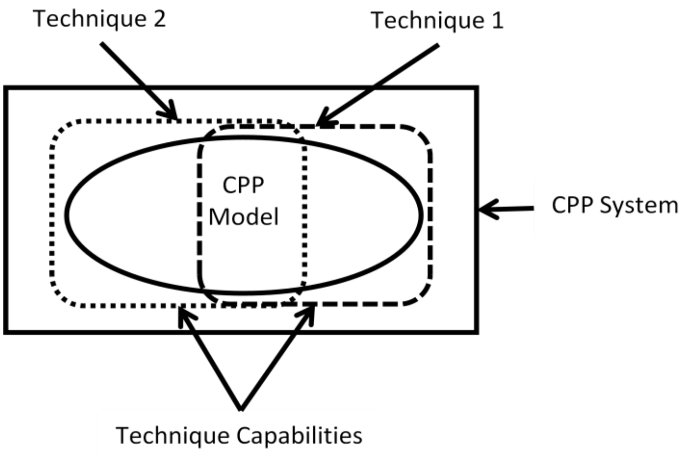


Figure 2.4: Combination of Several Modelling Techniques

Table 2.8: Explanation for Figure 2.4

Figure conditions	Explanation
Gap between techniques and CPP system	Not all characteristics and problems in the CPP system can be solved by using modelling techniques.
Overlap between technique one and two	Both techniques have the same capabilities in order to address some of the CPP problems and characteristics.
Gaps between CPP models and techniques	There are some capabilities offered by the techniques, however, due to some conditions of the model, these capabilities are not being used.

(Developed by the researcher)

The next subsection will present a selection of the best combination techniques used to model the CPP system. The selection of the techniques is based on which techniques can fulfil the criteria of a viable CPP model.

2.4.1 The Best Combination of Techniques for Modelling CPP system

It is a challenge for the modellers to develop CPP models that can cover all the criteria of a viable CPP model that closely represents the real CPP system. Based on the arguments in the previous section, Table 2.9 shows the mapping between the criteria of a viable CPP model with the techniques that have been used or suggested to be used to model the CPP system. If Table 2.9 is used as a benchmark for selecting which are the best techniques to be combined to model the CPP system, DES and SD is preferred, as these two techniques cover most of the criteria of a viable CPP model. For the following subsections, the term '*hybrid simulation'* will be used. This term refers to the meaning of combining SD and DES as an alternative technique for modelling the CPP systems.

Table 2.9: Criteria Mapping for Selecting the Best Combination of Modelling Techniques

Techniques / **Criteria deduced from:**		**Discrete Event Simulation (DES)**	**System Dynamics (SD)**	**Markov Model**	**Decision Tree**	**Direct Experimentation**
Characteristics of CPP systems						
	Unique individual case	√				
	Environment feedback loop		√			
	Dynamic systems	√	√			
	Effect on long- and short-term decision					
Limitations of developed models						
	Prior experimentation before implementation	√	√			
	Cover the whole system	√	√			√
	Closely represent the real system	√	√			√
	Visualization and easy to understand	√	√		√	√
	Simplifying complexity	√	√	√	√	√
	Fully supported decision making	√	√	√	√	√
Capability of Technique						
	Easy to understand and use	√	√		√	√

(Adapted from Table 2.10)

2.4.2 Improving CPP Models using Hybrid Simulation

Using DES alone will ignore the feedback loop and, thus, will impact the system model in the future. DES can cover the whole system to model but it will be too complicated, as the complexity will increase exponentially with its size (Chahal and Eldabi, 2008). However, using the SD alone will ignore individual analysis. Unlike the production sector that produces goods using machines with an almost similar mean time, health and social care are human based systems that result in the complexity of healthcare compared to other sectors. Baker and Bates (2010) argued that the complexity of healthcare is different as it has multi-dimensional patient transformations. It combines physical, mental and spiritual, as well as being extended over time and locations, requiring multiple professional groups, across organizational boundaries and often involving patient's families. Therefore, the process of treatment and time cannot be assumed to be the same for each patient.

There is no framework or guidelines that can be used for modelling CPP to assist decision making in both the short- and long-term. However, DES has the capability of providing and assisting short-term decision making. This is because it is used to model the problem in an operational and tactical environment. However, SD has the capability of providing and assisting long-term decision making because it is used to model the problem at a strategic level (Chahal and Eldabi, 2008). Sweester (1999) argued that SD is the best tool in strategic planning for organization. It involves policy analysis as well as the cause and feedback analysis, whilst Law and Kelton (1991) argued that DES is the best tool for a system since one part of it changes independently as it evolves over time.

There are two types of factors: intangible and tangible. Intangible factors can be defined as factors that cannot be counted explicitly, and are soft and continuous. Such factors are, for example, experience, motivation, satisfaction, performance, knowledge, stress level, recovery level, fatigue, and human emotions. The tangible factors, however, include factors that can be counted explicitly, and are hard and discrete factors. Examples of this type of factor are human resources, beds, time and professionals. Both techniques can measure and model these two types of factors. However, in terms of the complexity and the most appropriate tool to measure and model, DES is more suitable to model and measure tangible factors (as the name is discrete), whilst SD is more suitable for intangible factors (Chahal et al., 2008). As these two types of factors influence and are influenced by the CPP system, these two techniques should be combined and used to model the CPP system to provide a viable model for the system.

To conclude, the DES technique can be used if individual analysis, short-term decision making and modelling hard or tangible factors are needed, whereas these capabilities are inadequate in the SD technique. However, the SD technique can be used if long-term decision making, feedback loop analysis and modelling soft or intangible factors are needed, as these capabilities are lacking in the DES technique. Since all of these criteria are needed in order to develop the CPP model, these two techniques have to be combined. DES and SD compliment the limitations of the other by covering one another (Morecroft and Robinson, 2006). Figure 2.5 depicts how hybrid simulation can help in improving the CPP model.

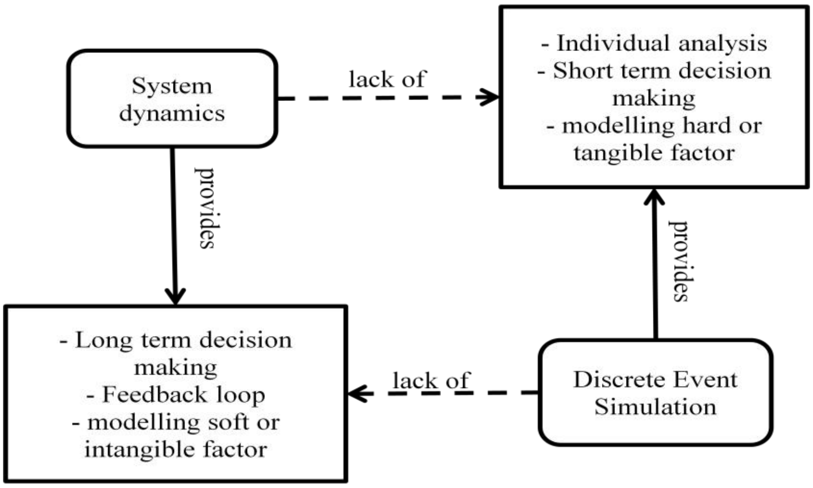


Figure 2.5: How Hybrid Simulation Can Improve the CPP Model

To the best of the researcher's knowledge, there is no developed patient pathways model across several departments and care givers that have used hybrid simulation as a decision tool. A framework is important, as it will provide a guideline of how to develop CPP systems using step-by-step instructions. As such, the modeller does not miss any important step that might, in turn, result in an unreliable model. The next section will discuss the research recommendations that are the aim of this research.

2.5 RESEARCH RECOMMENDATIONS

The previous sections highlight the incapability of certain techniques to cover the whole system needs. It is useful to establish a framework, as it will help the modellers follow the steps in order to produce a viable model of the CPP (Mingers and Brocklesby, 1997). It will also assist all the stakeholders to be involved and engaged in the model building activities. To date, the researcher could not identify a specific framework of how to model the CPP system using the hybrid simulation. Therefore, the researcher proposes to develop a framework of hybrid simulation for modelling the CPP system. With this framework, it is argued that it will close the gap, as mentioned in the previous sections.

In the next chapter, the discussion relates to proposing a framework for hybrid simulation in developing a CPP model. The researcher found several literatures that can be the researcher's references. The researcher believes that Chahal (2009) is the most recent research that concerns a hybrid simulation framework. She has developed a generic framework of the hybrid simulation applied in the healthcare which is based on several previous works by other researchers in various fields, such as Martin and Raffo (2000), Venkateswaran and Son (2005), Lee et al. (2007) and Rabelo et al. (2007). However, there are some limitations in Chahal's (2009) generic framework that are quite impossible to be followed rigidly and will make it problematic to apply to the CPP system. This is because CPP systems are quite different in healthcare, especially in terms of the size of the system, stakeholders, as well as the processes involved. Therefore, besides using the Chahal (2009) framework, this research will also use the framework of Giachetti et al. (2005) and Helal et al (2007) as other references. Helal et al. (2007) focussed on model building using hybrid simulation in the manufacturing supply chain, and focussed more on how to develop a model of a big system. Whilst Giachetti et al. (2005) developed a healthcare system that combined DES and SD simultaneously.

This research is about to extend and improve the frameworks of Chahal (2009), Helal et al. (2007) and Giachetti et al. (2005), so they can be applied to the CPP model. As stated above, due to the limitations in the frameworks, the researcher will amend the framework based on the current features and needs for a viable CPP model to represent and mimic the real world situation of CPP systems.

2.6 CONCLUSIONS

The problems concerning patient pathways are still persistent and are being discussed among policymakers, as well as researchers. It is argued that because of the limitations of the CPP systems, the modelling technique that has been used for modelling cannot fully cover the needs of a viable CPP model. Since there are limitations in the ability of a single modelling technique, combining two techniques of DES and SD, namely, as a hybrid simulation, could improve the CPP models to closely represent the actual CPP system. To date, the researcher could not find any specific literature on the framework for the hybrid simulation modelling that has been applied to the CPP system. This gap has motivated the researcher to propose a theoretical framework for hybrid simulation in modelling CPP system.

Chapter Three will discuss the development of the framework based on several hybrid simulation applications in various sectors and areas, especially Chahal's generic framework and Giachetti et al.'s hybrid simulation in the healthcare area, and Helal et al.'s hybrid simulation, which has been applied in the manufacturing supply chain. These frameworks were chosen to be the main references for the framework development in this research for various reasons. Based on these frameworks and the hybrid models, with several amendments made to suit the needs and criteria of a viable CPP model, a framework of a hybrid simulation for modelling the CPP systems is thus proposed. The framework is divided into three phases and each phase has its own processes or steps.

CHAPTER THREE: PROPOSED THEORETICAL FRAMEWORK FOR HYBRID SIMULATION

3.1 CHAPTER INTRODUCTION

Chapter Two provides in-depth discussions and information about complex patient pathways (CPP) in integrated care, including the concept and the existing problems in the systems. In addition, the decision tools or modelling techniques used for modelling the CPP, their limitations and a selection based on the criteria of viable CPP models, as discussed in Chapter Two, are also put forward. As the lack of capabilities of the modelling techniques, argued by the researcher, it is recommended that the DES and SD modelling techniques, hereby named as the hybrid simulation, be combined for the improvement and enhancement of the CPP model. To date, no literature has focussed on the model or framework development in CPP systems. Therefore, for the purpose of modelling a CPP system, the researcher suggests developing a framework for the hybrid simulation. Arguably, the suggestion will cover the gaps in the literature, as discussed in the previous chapter.

Since the SD and DES are two of the techniques identified in the operational research (OR) discipline, Chapter Three will start with a discussion on the overall hybrid simulation in the OR that have been practised in multiple areas of decision-making. The focus of the argument will then be narrowed down to the hybrid simulation technique, which is a combination of both the SD and DES, with examples of applications in various areas. The following section will then discuss the types of framework/models that will be the main references in developing the proposed framework and, lastly, this chapter concludes with the proposed framework of hybrid simulation for modelling the CPP systems.

3.2 HYBRID TECHNIQUES IN OPERATIONAL RESEARCH (OR)

The hybrid techniques is a form of combining methods and it has been argued that combined methods can also aid stakeholder acceptance (Sachdeva et al., 2006) as the stakeholders have different views of the system, which, in turn, makes the system more complex. The researcher argues that 'hybrid techniques' is about using multiple techniques simultaneously instead of a single technique for a problem solving method, whether it has been combined or not. The hybrid technique is not a new concept in operational research (OR), as this technique has been used before to improve the decision-making process, since a single technique is not able to address the problems that arise (Zulkepli and Eldabi, 2011; Chahal and Eldabi, 2008; Helal et al., 2007; Meeran and Morshed, 2011; Lee et al., 2007). The hybrid technique in OR has been implemented in many areas of business, such as manufacturing (Helal et al., 2005), production, transportation as well as in healthcare systems (Chahal et al., 2009; Giachetti et al., 2005).

The combination of the techniques in OR depends upon the types of problem that exist in any particular area. For example, in overcoming the scheduling and optimization problems, researchers are more likely to use and combine taboo search with genetic algorithms (see Meeran and Morshed, 2011), fuzzy logic with analytic network process (see Ayag and Ozdemir, 2011), neural network with genetic algorithm (see Azadeh et al., 2011) as well as simulation combined with neural network (see Abou Rizk and Wales, 1997), as the optimal decision-making tool. The use of the combination simulation with other OR techniques, however, is much more popular since it allows flexibility in gauging problems against uncertainty and risk by engaging in computer programming several scenarios of real world situations (Kuljis et al., 2007).

An example of an application that uses a combination of simulation with other OR techniques is ant colony optimization (ACO) simulation (Brailsford et al., 2007). Inspired by the nature of an ant colony, in which their collective behaviour enables them to find the shortest path between the nest and their food by releasing the chemical substance between their colony, Dorigo et al. mimicked this ant behaviour using computational capabilities to search and optimize problems (cited by Brailsford et al., 2007). According to Brailsford et. al. (2007), another application that has used combined techniques is simulation with geo-modelling. Harper, Philips and Gallagher, developed and used the DES model, which purposely incorporates GIS, to see the effect of reducing 42 oral and maxillofacial surgery (OMFS) locations to 5 major hubs offering inpatient care. In this model, each patient was assigned to a location based on the decision rules, such as the nearest centre distance to patients. The cost of travelling by different means has also been included to predict the total cost for the patients (cited by Brailsford et al., 2007). AbouRizk and Wales (1997) combined the DES and neural network in the construction sector. The model was developed to determine the impact of weather on the construction process activities. A combined technique of DES, SD and stochastic Analytic Hierarchy Process (AHP) was used in global supply chain activities by Rabelo et al. (2007). Lee et al. (2002) used DES and differential equations to model the discrete and continuous supply chain process, respectively.

3.3 COMBINATION OF DISCRETE EVENT SIMULATION AND SYSTEM DYNAMICS

The combination of techniques can also be within the simulation method. Such techniques in the simulation method are continuous simulation, discrete event simulation (DES), System Dynamic (SD), Monte-Carlo simulation as well as multi agent simulation and artificial intelligence (Kuljis et al., 2007). One type of hybrid technique within the simulation method is by combining DES and SD. Initially, DES and SD are two entirely different fields with their own journals, conferences, groups, interests and views. The situation was altered after experts from both simulation and sat down together and held a meeting in 2000. According to Brailsford (2008), a new interest group, named "SD+", was born as a result of this meeting. Brailsford (2008) suggested that although the result would be beneficial, combining the DES and SD techniques would be challenging, especially in the healthcare sector since the detailed, stochastic and individual patient analysis (provided by DES) and whole system approach (by SD) are two different approaches. Most researchers argued that these two simulation branches have a common basis. However, efforts to combine them together are scarce (Sweester, 1999; Lane, 2000; Brailsford and Hilton, 2001; Moorcroft and Robinson, 2005). The way the hybrid simulation works is in the form of information sharing through which both the DES and SD will evaluate with one another (Chahal and Eldabi, 2008). It is argued that this technique will help the decision maker to consider a more reliable model prior to the implementation of any decision, as they can see from a detailed perspective to the whole picture (Chahal and Eldabi, 2008).

It has been reported in Chahal (2009) that most hybrid simulation has been applied in software development followed by manufacturing, supply chain and construction. Such hybrid applications applied in software development were Christie and Staley (2000), Martin and Raffo (2000) and Setamanit et al. (2007). Most of them used DES for model discrete activities, whilst SD is used to model continuous environment surrounding the activities in the software development process. Rabelo et al. (2003), Rabelo et al. (2005) and Helal et al. (2007) used DES for model operational decisions, whilst the applied SD is used to model strategic decisions in the manufacturing and production planning sector. Reiner (2005) and Venkateswaran et al. (2006) have used SD and DES simultaneously in a supply chain context. Reiner (2005) successfully showed how process improvement (modelled by DES) can increase customer satisfaction (modelled by SD), thus, increasing the demand for the product. Venkateswaran et al. (2006), however, used the hybrid simulation to analyse the decision-making process between different levels of management and within the same level of management. Due to the argument that the environment in construction, especially the weather and management action, cannot be represented by DES accurately, compared with SD, Lee et al. (2007) applied hybrid simulation in the construction industry. Both techniques – SD and DES – were used simultaneously to model the interaction between context and process, respectively. Chahal et al. (2009) and Giachetti et al. (2005) applied hybrid simulation in the healthcare sector.

Chahal (2009) argued that compared to the other sectors, healthcare problems are much wider and are unique compared with other sectors that have been discussed in Chahal (2009). As most applications of hybrid simulation have been documented in Chahal (2009) and the framework of CPP hybrid simulation is not available, the researcher has narrowed down the search scope by setting up the searching criteria. The criteria that have been selected by the researcher are recent applications attached with applied hybrid simulation (using DES and SD techniques simultaneously) for modelling in the healthcare sector and for a large system. Based on these criteria, the suitable frameworks/models that the researcher found available was from Chahal (2009), Helal et al. (2007) and Giachetti et al. (2005). Chahal (2009) developed a generic framework and applied the framework to the healthcare sector; Helal et al. (2007) developed a hybrid model for a large manufacturing supply chain area; while Giachetti et al. (2005) used DES to improve patient cycle time while at the same time using SD to investigate patient behaviours in outpatient clinics. The next subsection will briefly discuss these frameworks as they are the only ones that the researcher found suitable and probable matched with the criteria that have been setup. All these frameworks will be reviewed in the next subsections (Section 3.3.1, 3.3.2 and 3.3.3) and in Section 3.3.4, focusing on the advantages and disadvantages of each one of the frameworks/models.

3.3.1 Chahal's Generic Hybrid Simulation Framework

Since there is no standard framework that could be used as guidance in the healthcare domain, Chahal (2009) developed a generic framework for hybrid simulation techniques in healthcare for similar purposes. The framework was developed as a result of analysis of previous studies concerning existing hybrid simulation applications and frameworks. The analysis found that such applications have been applied in software engineering, manufacturing, construction and supply chain sectors, but not in the healthcare domain (Chahal, 2009). Hence, the situation motivated her to develop a generic framework based on literature concerning hybrid simulation that have been used in different sectors, such as manufacturing, software engineering and in construction. Chahal (2009) suggested that there are three different types of hybrid format: the hierarchical format; the process-environment; and the process environment-performance. The choice of the hybrid format will help the modeller identify the interaction point between the DES and SD techniques. Table 3.1 provides information about the types of hybrid format.

Table 3.1: Different Hybrid Format, Descriptions and Interaction Points

Hybrid Format	**Description**	**Interaction points**
Hierarchical format	SD – strategic level decisions DES – operational level decisions Used for vertical interaction between different levels of the organization	DES to SD – WIP, throughput, utilisation, lead time SD to DES – production plan, allocated resources, targets, policies
Process-environment	DES – process SD – environment Interact cyclic manner through inputs and outputs	SD to DES – change in demand DES and SD – waiting time, lead time
Process performance-environment	DES – process SD – environment factors that affect activities and resources of process Tightly coupled	SD to DES – productivity, resources DES to SD – status of process such as WIP, inventory, throughput

(Source: Chahal, 2009)

Basically, the overall framework has been decomposed into three major phases. The decomposed major phases are problem identification, identification of mapping between DES and SD and identification of mode of interaction. The major phases aligned with her research questions are: why do the problems need a hybrid simulation (phase 1), what information is exchanged between SD and DES (phase 2), and how do the SD and DES models interact with one another over time to exchange information (phase 3). The whole generic framework of Chahal (2009) can be found in Appendix B whilst the applications that have applied Chahal's (2009) framework can be found in Chahal et al. (2009).

3.3.2 Helal et al.'s Integrated Supply Chain Model

Helal et al. (2007) introduced a methodology that could integrate and synchronize the DES and SD applications in an integrated manufacturing enterprise. The reason they used the combined method (SDDES) was due to the inability of the single simulation technique to cover all the needs in the simulation of a complex system (different manufacturing function, different types of behaviour, differences in management level, decision making frequency). Basically, the framework is based on the modular concept. In other words, a big system that has been modelled in SD and DES will be broken down or decomposed into several small systems for modelling purposes. This is to ensure that the modellers do not overlook certain features in the system, facilitating the management of the model and ensure that the communication among modellers is in a better condition. These modules (SD and DES) will be formalised and synchronized using the SDDES controller.

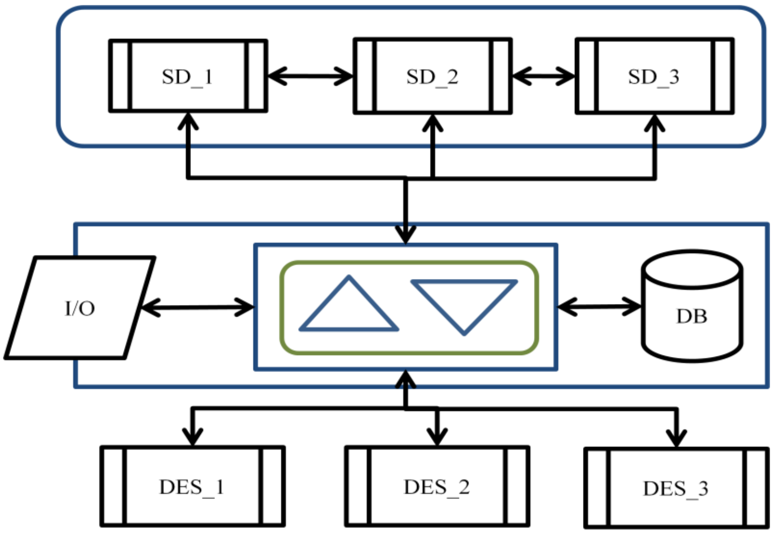


Figure 3.1: SDDES Schematic Diagram *(Source: Helal et al., 2007)*

Figure 3.1 shows the schematic diagram of the SDDES concept and how the two different models that use two different techniques (DES and SD) link to each other using data and information in both models. The SD model is at the top of the figure whilst the DES model is at the bottom of the figure. These two different techniques were connected by the SDDES controller between DES and SD. The SD and DES model were synchronized using the time bucket (TB) synchronizing method. With the modular concept, both DES and SD (hypothetically, but still in one whole model) will be decomposed into several modules to cut the development time and expenses.

3.3.3 Giachetti et al.'s Outpatient Clinic Simulation Model

Another application that used DES and SD simultaneously was developed by Giachetti et al. (2005) for an outpatient clinic simulation model to assess the viability of an open access policy. The authors used DES to analyse the patient cycle time and suggested an improvement, whilst the SD was used to analyse the patient behaviour and factors that lead to the high no-show rate. The SD simulation was also developed to understand the relationship between the scheduling system, patient demand and service capacity. The authors used action research methodology by following general phases, which were diagnosing, action planning, action taking, evaluating and specifying learning based. Although the project was for a year, which started in May 2004, the simulation models were based solely on the data collected during the months of June and July 2004.

Based on the DES simulation, several recommendations were suggested by the authors in terms of discharging patients, patient appointment scheduling, service providers and order in which the patient should be called. These suggestions have been tested using the DES simulation model. To capture the feedback loops that exist in most of all complex systems, they used the SD modelling technique. The loops were developed into two different models (DES and SD) due to the argument that the scheduling system influences patient demand behaviour and most of the existing patient scheduling models did not consider this factor. As the Open Access is a new concept of how to design and operate a scheduling system for the healthcare providers, the simulation techniques (DES and SD) are more useful and worth using than the trial and error previously employed.

3.3.4 Advantages and Limitations of the Chahal, Helal et al. and Giachetti et al.

In Section 3.3, the researcher has setup the criteria for the hybrid frameworks/models choices that will be used as references in developing this framework. These criteria includes the complexity of the developed frameworks/models (easy to follow), suitability with the CPP systems especially in terms of size of the system and the ability to determine what type of system should use a hybrid or single technique. Using these criteria, the researcher has extracted the advantages and limitations of each of the frameworks/models.

The literature has provided considerable information about the hybrid simulation, for example, why they were used, how they were used, as well as how they were combined with each other. While Giachetti et al. (2005) explained why they were using SD and DES techniques for modelling; Chahal (2009) and Helal et al. (2009) have significantly contributed to how the two techniques could be combined together, especially in terms of information exchange. There are advantages and limitations with regards to the hybrid framework/models that have been developed.

Chahal's (2009) generic framework, which has been applied to the healthcare sector, has provided much information about why the hybrid is needed, what is exchanged between SD and DES and how they interact with each other. As this framework for hybrid modelling has been applied to the healthcare sector in Chahal's research, Chahal's framework is, therefore, deemed to fulfil the requirements and the needs of the healthcare system for modelling purposes. However, with regards to the CPP in integrated care, it seems that this framework is lacking in certain needs of the CPP system. First, as mentioned earlier in the second chapter of this research, integrated care involves many different systems that form part of the whole integrated care system. In comparison, Chahal's framework is only suitable as a guideline for a single system and is not suitable as a modelling guideline in an integrated system that is a combination of various multiple systems. Second, Chahal's framework is incomplete since it does not involve guidelines on how to use single simulation techniques for modelling that could either be SD or DES as the integrated systems may use a single technique in the decision-making process. This is due to the fact that some of the problems only require a single modelling technique as various different opinions and solutions could be formed based on the outlook of the problems at hand.

Helal et al. (2007), however, provided information on how to reduce the complexity of a large system, especially when it needs to model using the DES technique. As Chahal's framework is argued to be suitable for single or small scale models, Helal et al. (2007) is deemed to match the requirement of this research where information on how to model and reduce the complexity of a large system model by breaking the whole system into several subsystems (modules) is found. However, the framework of Helal et al. (2007) also has several limitations. As argued by Chahal (2009), the Helal et al. (2007) framework was missing how to select which problem is best to model with DES and which one is best to model using SD, as well as identifying the problems that need the hybrid simulation for modelling. They assumed that all modules have to be developed using hybrid simulation, which takes a longer time to build. Furthermore, as argued by the researcher, the framework of Helal et al. (2007) is too technical and not easy to understand, especially in terms of their hybrid 'operation'.

Giachetti et al. (2005) used DES and SD for developing a healthcare model that focussed more on outpatient clinics to suggest improvements to the scheduling system and investigate patient behaviour in respect of the scheduling system. The case and reason why they used multiple techniques for modelling are similar to the researcher – hybrid simulation applied in healthcare and different techniques should be used for different types of capturing variable data (DES for patient scheduling, SD for patient behaviour). However, neither technique was combined and the researcher argues that the results that are based on the models were neither efficient nor reliable.

Table 3.2 depicts a summary of the advantages and limitations of all the hybrid framework/models. The researcher argues that the framework will have advantages if it is for a large system and applied to healthcare, less technical and shows why hybrid is needed, whilst the limitations are vice versa. This summary will be used as a reference in developing the framework of hybrid simulation for modelling the CPP model.

Table 3.2: Summary of Advantages and Limitations in Hybrid Frameworks/Models

Hybrid Framework/Models	**Advantages**	**Limitations**
Chahal et al. (2009)	- Applied in healthcare - Easy to follow and not too technical - Has ability to determine when it is suitable to use SD or DES	- Stops when it needs single technique, does not fully cover all problems - Probably suitable for the single problem/model
Helal et al. (2007)	- Suitable for large systems - Shows how to reduce complexity by dividing whole system into several modules	- Applied in manufacturing (machine) and not human - Too technical to combine the different techniques - Considers that all the modules have to use hybrid
Giachetti et al. (2005)	- Applied in healthcare - The use of SD and DES are dependent on the type of variable, whether continuous or discrete.	- Does not integrate the DES and SD. Therefore, the outputs produced by the models were not reliable.

(Developed by the researcher)

The aim of this research, as has been mentioned in Chapters One and Two, is to develop and propose a theoretical framework for hybrid simulation in modelling the CPP system as the literature is lacking in suggesting a generic framework that acts as a guideline for developing CPP models using hybrid simulation (Zulkepli and Eldabi, 2011). The next section will elaborate on the proposal of the proposed hybrid simulation framework for modelling the CPP system based on several articles, especially from Chahal et al. (2009), Helal et al. (2007) and Giachetti et al. (2005).

3.4 FRAMEWORK DEVELOPMENT

In the previous sections, the advantages and limitations of each of the frameworks/models that have been selected to be used as references by the researcher to develop the proposed framework for hybrid simulation for modelling the CPP system have been reviewed and discussed. The review and discussion on the framework's/models' advantages and limitations are based on the criteria that has been selected by the researcher in Section 3.3. The researcher will use these advantages and limitations and align them with the needs and requirements of the CPP system in order to build the proposed framework. Some of the advantages will be followed instantly while some advantages and limitations will be modified and improved to ensure that the proposed framework will fit with the needs and requirements of the CPP system.

3.4.1 Main Framework

Chahal (2009) composed all the steps in her framework into three phases, which will provide answers for all the requirements listed. They were – what type of problem requires a hybrid simulation (Phase 1), what is exchanged between SD and DES (Phase 2) and what the mode of interaction (Phase 3) is. Therefore, as per the Chahal (2009) framework composition, this framework will be divided as well into three phases together with different objectives for each phase. The composition of the framework is based on the steps that are involved in developing the proposed framework, from the theoretical (phase one) to the practical (phase two and three) phases. The composition of the steps in the framework will facilitate the smooth modelling and integration process (Pidd, 2001) of a framework development. They are:

a. Conceptual Phase – transferring from actual CPP system into more descriptive logical process (building blocks)
b. Modelling Phase – transferring CPP conceptual systems into simulation software (developing models)
c. Integration Phase – integrates different models (SD and DES)

Each phase will be decomposed into several steps. The conceptual phase involves planning and analysing the problems that occur in the system, developing a conceptual model (in building blocks), selecting the suitable modelling techniques and the final part is a modelling plan. Based on the modelling plan, the modelling phase involves converting the description of a conceptual model (building blocks) into simulation software. The last phase is the integration phase. This phase will link all the modules with different modelling techniques into one integrated model. Figure 3.2 shows the main phases of the theoretical framework and the subsequent sections will discuss the proposed framework based on these three phases.

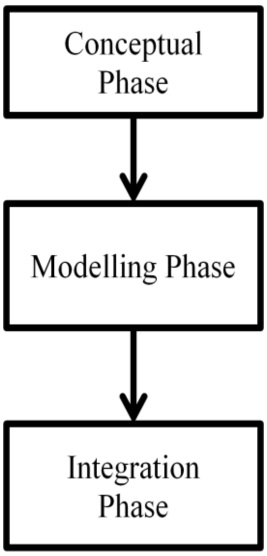


Figure 3.2: Phases in Modelling CPP system

3.4.2 Conceptual Phase

In this phase, the focus is more on defining the logical processes that exist in the actual system of the CPP system. It includes dividing the whole process into several modules and selecting the best technique for modelling. To reach the final step in phase one, a modeller should follow several preliminary steps, as this will help the modeller to avoid missing any feature of the system based on the current problems. The steps of the first phase and their descriptions are explained as follows.

STEP ONE: Problem Source Definition and Objective Identification

The purpose of developing the model is not only to provide information about how the system works but also to provide guidance for analysing the problems that exist in the system (Robinson, 2004). Defining the cause of the problem in the system is challenging, especially when it deals with different parties, as they have different opinions and suggestions (Chahal and Eldabi, 2008; Eldabi, 1999). For example, in the case of CPP in integrated care, when a patient is transferred into social care at a later stage, the healthcare sector will put the blame on the social care as information about the availability in the social care was received with inadequate notice. The people in the assessment process, however, will blame the healthcare personnel accusing them of releasing a patient too early. Consequently, the professionals in the social care claim that they are too short staffed to cater for the patient's needs and blame the whole system. As a result, the patient will be in a dilemma and the patient's waiting time in the system would be too long. Problem definition will also aid the professionals in suggesting the intervention that should be done in the system. Errors in identifying the source of the problems will result in wrong intervention identification and, thus, lead towards bad decisions.

STEP TWO: Conceptual Model and Modularization

After defining the cause of the problem and the objectives of the modelling, the second task is to make the actual system more visible. To do so, a conceptual model (building blocks) can be helpful for this purpose. The conceptual model will enhance the understanding of how the whole system works, and help the modellers to understand the domain and support communication between the modellers and users (Wand and Weber, 2002). The third principle of model building introduced by Pidd (2001), which is 'divide and conquer', will also be helpful.

Chahal (2009) decomposed the main objective into several sub-objectives and based on several criteria, the researcher matches the objectives and criteria to determine which technique is suitable to be used. The researcher argues that the objective for developing the model is too abstract and, therefore, dividing the objective will be too difficult and can be more confusing. Furthermore, this framework is for large scale systems and if the proposed framework follows Chahal (2009), it will add more to the confusion and can create many main objectives as the CPP system consists of many stakeholders that have different perspectives about the problems arising (Eldabi, 1999).

Instead of this step, the researcher is more confident in dividing the whole system/pathways/processes into several parts/sub-systems/sub-processes as Helal et al.'s (2007) framework, which is called the 'modularization process'. This process is adapted from the software engineering and system development concept (Pressman, 1997; Turban et al. 2007), where several processes, or steps, are divided into several groups, named as 'module', to facilitate the system model building (Wand and Weber, 2002). The process of dividing a whole system into several modules, or 'modularization' process, depends on the size of the systems, pathways or processes. For example, if the processes are too long or complicated in the healthcare alone, it might be helpful to divide the healthcare system into two or three separate modules. Figure 3.3 depicts the example of a 'modularization' process for a patient that needs an X-ray examination in the outpatient department of a Malaysian hospital based on the researcher's experience. Due to long patient pathways, a series of several processes in the pathways have been grouped and put into several modules (in dashed boxes) as shown in Figure 3.3.

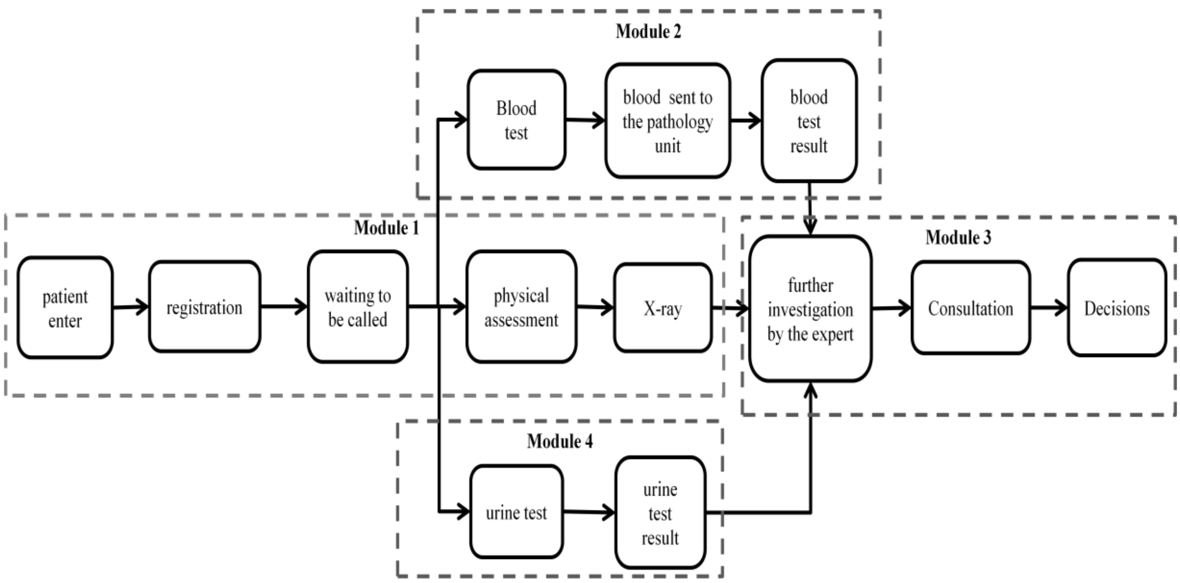


Figure 3.3: Modularization process by grouping several processes into modules

The 'modularization' process can also be done by categorising and grouping several processes according to their settings/place (healthcare, social care). Figure 3.4 depicts the example of the modularization processes according to their care setting in the care continuation process in the UK (Bryan et al., 2005). The processes that happen in the healthcare will be grouped as one module, whilst all the processes in social care will also be grouped as one module depending on where the care process is provided.

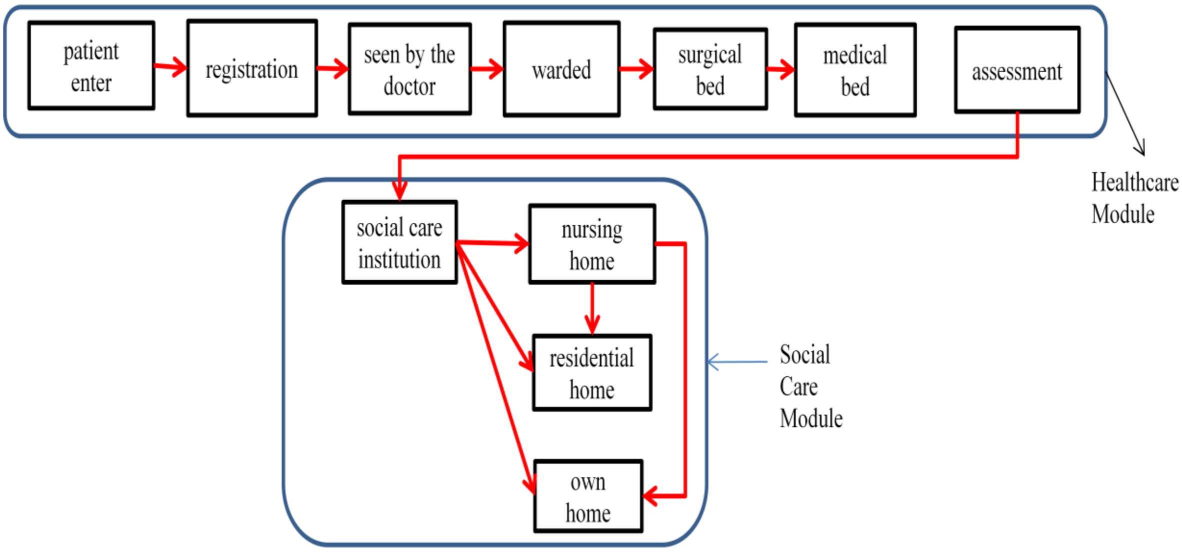


Figure 3.4: Modularization process according to their care setting

The process of modularization will help the model run smoothly (as it is not too complicated), especially when it needs to be modelled with DES. The modularization will also facilitate model building in the simulation software and provide easy understanding of the whole system. For module management, it is advisable to name each of the modules after the modularization process.

STEP THREE: Identify modules that will be affected by the overall objective

In the Helal et al. (2007) framework, one of their steps is defining the module(s) that have been affected by the overall problem and objectives. The same step will be followed in this framework, as it will help the modellers define the boundaries of the model. This step will ensure that changes in module/s that will not affect the whole system as a result of the intervention are not included. It will also help the decision makers to focus more on the affected area of the system and suggest relevant intervention and, thus, it will be timesaving for the purpose of modelling. It will be helpful if they have a lot of historical data as this will help identify whether or not a certain module is affected by the problems or objectives. Opinions from the professionals and other relevant documents could be an added advantage and, lastly, this step should be followed by justifying the affected modules in terms of why and how it affects the model in the long- or short-term period.

STEP FOUR: Define the criteria of each module

In the previous chapter, how the CPP systems should be modelled using the hybrid simulation to fulfil the needs, characteristics of the CPP system was identified and clarified. By fulfilling these, it will help in achieving better decision making (Rabelo et al., 2005; Venkateswaran et al., 2005). In Helal et al. (2007), all the modules were considered to be developed using the hybrid simulation. However, the researcher argues that the hybrid simulation might not be suitable for modelling the whole system, as, in the previous chapter, the researcher identified the gap concerning the importance of individual analysis and feedback loop, which needs to be considered before using the hybrid simulation. For example, for modelling the social care, the researcher argues that it is not necessary to use the DES technique, as the social care is a place for same group of people regardless of their type of illness and their needs as long as they are eligible to stay there. This is the missing point in Helal et al.'s (2007) framework, but which is covered in Chahal's (2009) framework.

In Chahal's (2009) framework, prior to selecting the appropriate technique for modelling (DES or SD or Hybrid), the main objective was divided into several separate objectives. The objectives were being mapped with selected criteria as depicted in Table 3.3. The mapped criteria and the sub-objective will facilitate what type of technique is suitable and should be used for modelling each of the particular sub-objectives. The hybrid simulation emerges when the overall objective is combined with some of the objectives that are to be modelled by DES and others being modelled by SD.

Table 3.3: Criteria for determining suitable techniques

Problem's Perspective		
Purpose	Decision: Optimisation, prediction and comparison	Policy making, overall understanding
Importance of randomness	High	Low
Importance of interaction between individual entities	High	Low
Required level of Resolution	Detailed individual level	Aggregate, high level

System's Perspective		
System View	Detailed Microscopic view	Holistic Telescopic view
Complexity of importance	Detail Complexity	Dynamic Complexity
Evolution over time	Discontinuous event based	Continuous
Control parameter	Holding (queues)	Rates (flows)
Suitable Modelling Technique	**DES**	**SD**

(Source: Chahal, 2009)

As this framework deals with many modules (Step Two), it will create more complexities should we strictly adhere to Chahal's (2009) criteria. Since the whole CPP system has been divided into several modules (Step Two) instead of dividing them according to their objective (Chahal, 2009), the modules will be matched with criteria that will facilitate the suitable modelling technique to be used for each of the modules. Table 3.3 provides the properties and criteria for suitable techniques to be used from Chahal's (2009) framework. However, the researcher argues that some of the criteria listed by Chahal (2009) are redundant and can be grouped into two main criteria – in terms of effect (time) and type of modelling analysis. There are two different variables that belong to each of the main criteria – long- or short- term effect and either aggregate or individual modelling analysis.

Long-term effects are related to policy and strategic decisions which are continuous processes. The upper management are more interested with this since it is more holistic in nature (Brailsford and Hilton, 2001; Mallach, 2000; Chahal and Eldabi, 2008; Taylor and Lane, 1998). Due to the nature of the process, it deals with low randomness, low level of individual interaction and concerns with rate (Mallach, 2000) and these features have been composed into an aggregate type of analysis. The impact from the optimisation process is a result from the operational short-term decision making process (Brailsford and Hilton, 2001; Mallach, 2000; Chahal and Eldabi, 2008), concern with microscopic view (Mallach, 2000; Taylor and Lane, 1998) and is a discontinuous process which the middle and tactical management are concern with. As the process is discontinuous and more detailed in manner (Mallach, 2000), the level of randomness and interaction between the individuals are most likely to be high. As the system becomes more detailed in manner, it depicts the queues rather than rates, which triggers the individual analysis. Figure 3.5 depicts Chahal's (2009) criteria composition.

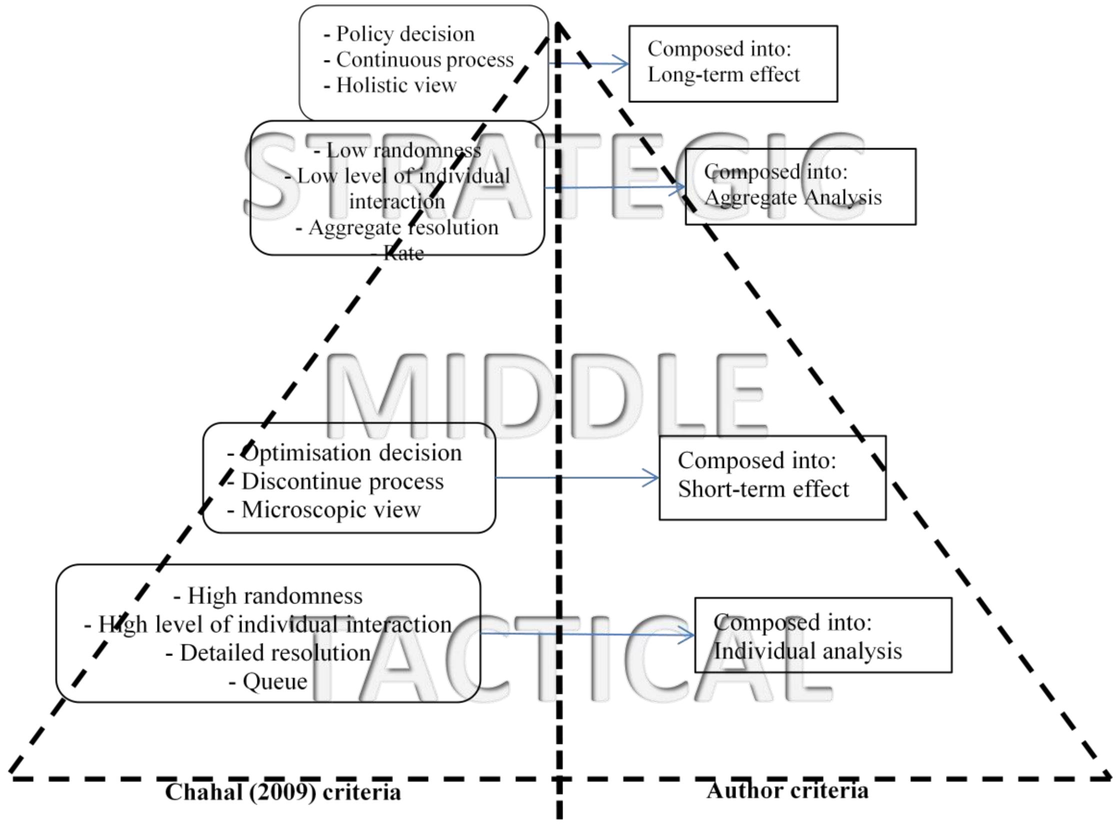


Figure 3.5: Composed criteria
(*Adapted from Brailsford and Hilton, 2001; Mallach, 2000; Venkateshwaran et al., 2007; Chahal and Eldabi, 2008; Mallach, 2000; Taylor and Lane, 1998*)

However, two criteria to determine the suitable technique for modelling the module might not be convincing enough. To enhance the justification why a particular modelling technique is suitable, the researcher will add one more criterion. The criterion is to see whether changes inflicted on a certain module will create feedback to the previous modules or not. This scenario is also called a feedback loop (Giachetti et al., 2005), or referred to as a dynamic model in the criteria from Chahal (2009).

For example, consider one model that has been divided into two modules as in Figure 3.6 and intervention has been conducted on the second module. The feedback loop in this context would refer to any effect that would be triggered by the first module due to the intervention that takes place in module one.

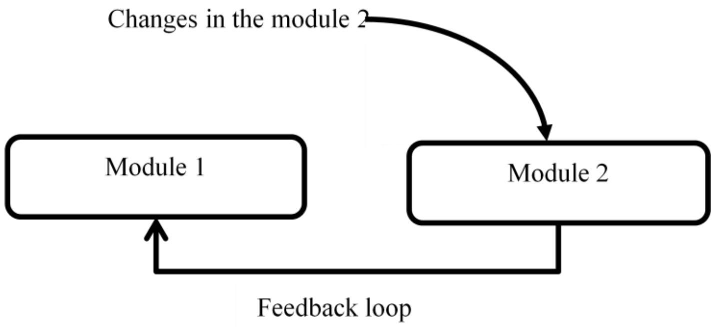


Figure 3.6: Meaning of Feedback Loop

Based on the above arguments, the following are the criteria that will be matched with the affected modules (Step Three).

i. Type of modelling analysis – individual or aggregate
ii. Have an effect in short-term (operational) or/and long-term (strategic)
iii. Have a feedback loop to the previous module (Giachetti et al., 2005; Chahal, 2009)

To determine the criteria, expert opinion can be sought. Each of the modules might have more than one variable in one main criterion. For example, in terms of the effect, whether short- or long-term, the module might have both long-term as well as short-term effects. The criteria determination of each module will help in defining the appropriate technique for modelling in the next step.

STEP FIVE: Selecting the suitable technique for modelling

The method selection will be based on the criteria of each module. The DES technique will be used if the effect is short-term, analysis is based on individuality (Chahal and Eldabi, 2008; Brailsford and Hilton, 2001) and it does not have a feedback loop to the previous module (Chahal and Eldabi, 2008; Giachetti et al., 2005). The SD technique, however, will be used if the effects are long-term, analysis is based on aggregate (Chahal and Eldabi, 2008; Brailsford and Hilton, 2001) and it has a feedback loop to the previous module (Chahal and Eldabi, 2008; Giachetti et al., 2005; Reiner, 2005). Table 3.4 shows the selected technique based on the selected criteria mentioned above.

Table 3.4: Selected technique based on selected criteria

Criteria	Variable	Selected technique
Effect	Short-term	DES
	Long-term	SD
Type of analysis	Individual	DES
	Aggregate	SD
Feedback loop	Yes	SD
	No	DES

The final decision will be based on the selected technique for modelling each module. The hybrid simulation will be used if the module has to use DES and SD simultaneously based on the main group criteria and variables. For example, if the module has a short-term effect (DES), and requires individual analysis (DES) and a feedback loop (SD), the module has to be developed by hybrid simulation.

STEP SIX: Modelling Plan

There are many possible solutions in order to model the CPP system as it has several modules and each module has its own suitable technique to model. In Helal et al.'s (2007) framework, each module has to use a hybrid simulation where each module has its own DES and SD model. The DES module will be combined with other DES modules and the SD model as well. However, it has been clarified previously that some of the modules may have different techniques of modelling. This is a substantial limitation of the Helal et al.'s (2007) model, as argued by the present researcher argues that some of the modules might not need to be modelled using hybrid simulation. Chahal's (2009) framework, on the other hand, will be stopped if the model has to be developed using a single technique or if the different models (SD and DES) cannot be integrated. The researcher argues that her framework is not complete as it ignores some of the modelling possibilities.

To facilitate the modelling phase, it is good to have the planning completed before steps are taken for modelling in simulation software as every module has its own suitable technique. The planning period for modelling is based on the selected technique for each module. Basically, there are several categories of planning based on several different cases. These cases can be divided into three main types – all modules use single techniques (SD or DES), single technique with hybrid (SD + Hybrid or DES + Hybrid or SD + DES + Hybrid), and all hybrid. Based on the categories of modelling planning, several possible types of modelling planning can be identified. There are:

i. All modules use Discrete Event Simulation (DES)
ii. All modules use System Dynamics (SD)
iii. Some modules use DES and some use hybrid
iv. Some modules use SD and some use hybrid
v. Some modules use SD, some use DES and some use hybrid
vi. All modules use hybrid.

Basically, if a module needs to use DES, then each module will be modelled separately and will be combined using the output (e.g. time finish from module 1) from the first module to the second module. If a module needs to use SD, then two methods can be done. It is either to model the module by module and then links it with factors/variables from one module to another, or to model the system as a whole. The full explanation for each type of the modelling plan on how it is going to be modelled is given in the modelling phase, which is in Section 3.3.3. Figure 3.7 depicts the modelling plans that have been combined, whilst Table 3.5 summarises the conceptual phase.

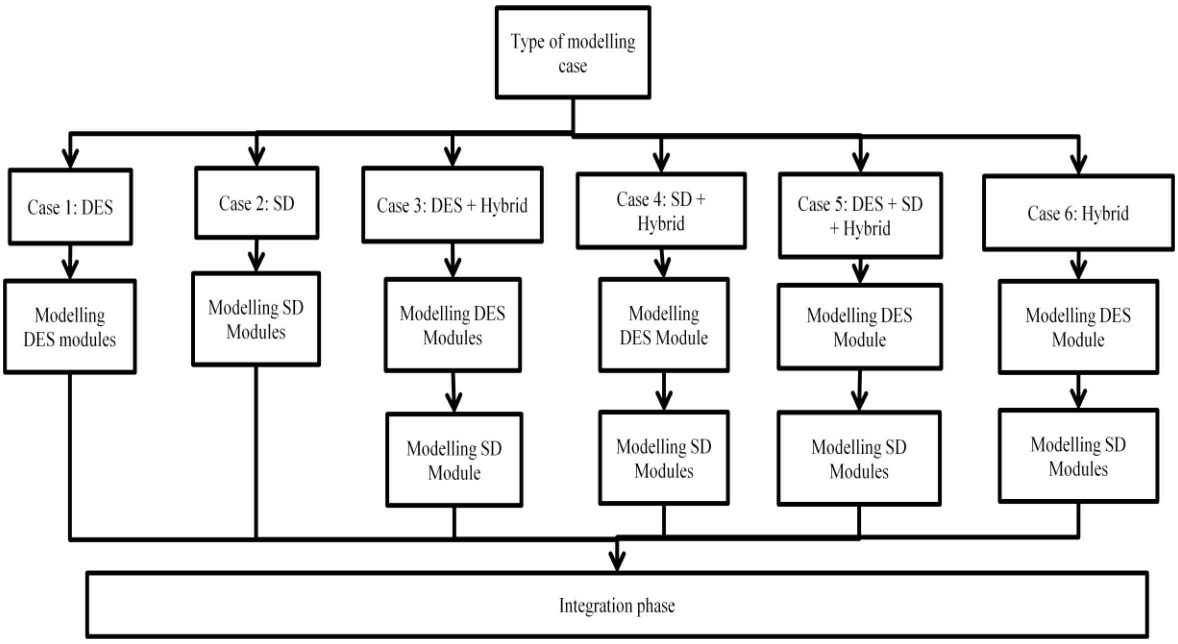


Figure 3.7: Combines Modelling Plan

Table 3.5: Summary of Steps in Conceptual Phase

Phase/Steps		Objectives	Method (How)
1.	Problem Source Definition and Objective Identification	To set the boundaries of model building and identify which subsystems are involved	By asking the opinion of professional experts
2.	Conceptual Model and Modularization	To reduce the complexities of model development	Conceptual Model – scratch from system description to logical system (building blocks) Modularization – divide several processes into a group or divide into several subsystems or care settings
3.	Identify modules that will be affected by the overall objective	To reduce time in model building and to set the boundaries	By asking the opinion of professionals or by looking at the subsystems that have a direct impact on the defined objectives
4.	Define the criteria of each module	For selection of a suitable technique for modelling each module	By defining the variables of each of the criteria
5.	Selecting the suitable technique for modelling	Due to the fact that not every module has to use hybrid modelling, it decreases the time for modelling	Refer to Table 3.3 in Chapter Three
6.	Modelling Plan	To facilitate the modelling activities as it shows how logically to model each of the modules	Straightforward process which is based on the Figures 3.3 – 3.8.

(Developed by the researcher)

3.4.3 Modelling Phase

It is the second phase in this framework where the activities involved developing the models or transferring the conceptual model into simulation software. The models are developed based on the last output from the conceptual phase, which is the modelling plan. From the modelling plan, it will facilitate the module that has to be developed using DES or SD or hybrid simulation and it will also facilitate which module needs more or less detail.

The development of the DES and SD model will use any of the SD and DES simulation software packages. There are many packages that can be used for modelling. Such DES software packages are PowerDEVS, Tortuga, Galatea and Mason, Arena, Any logic, ExtendSim and NetSIM, as well as Simul8. On the other hand, such SD software packages are AnyLogic (Java), PowerSim (C++) and DYNAMO (Pascal), Stella @ iThink and Vensim.

As in the previous section, the researcher has clarified the six types of modelling possibilities. In this subsection, the second phase of the proposed framework will describe how these modelling possibilities will be modelled.

Case One: Suitable technique for all modules is DES

The process will start with modelling module by module. The methodology of developing the model will be the same as developing any model using DES. When the modelling process has been completed, these modules will be combined together at the second stage. The unit basis used to combine these modules is the time that each patient remains in the system. The starting time for the second module depends on a patient's finishing time in the first module. For example, assume that there only two modules involved, i.e. healthcare and assessment. Patient 1 finishes the whole process in the healthcare system in 5days. Therefore, the start time for patient 1 in the assessment system will start at day five. For complete guidance on how to develop the DES model, please refer to Law and Kelton (2000), as well as Robinson (2004).

Case Two: Suitable technique for all modules is SD

Although the model has been divided into several modules, it could still be modelled as one whole system. The modelling methodology for the modules will follow exactly as in the SD method. Basically, there are five steps involved in modelling using the SD technique. They are; Problem Identification & Definition, System Conceptualization, Model Formulation, Model Formulation and Policy Analysis & Improvements. Please see Sterman (2000) as a reference for guidance in the development of the SD model.

Case Three: Suitable techniques are DES and Hybrid

There is a possibility that the suitable technique for modelling some of the modules is DES whilst for other modules it might be the hybrid simulation. Should this be the case, all the DES models will be developed first, and then these models are combined together as in case one. For modules that are suitable using the hybrid simulation (SD + DES), the SD component will be modelled in more detail compared to other components for which the suitable method is the DES only. For example, the problem has been divided into two modules – healthcare (hybrid) and assessment (DES). The DES component for the healthcare and assessment will be combined together whilst the SD component for the healthcare will be modelled in more detail (it has several parts to the system) compared to the assessment part, since the assessment process is simple (single process only). Then, these two different methods will be combined in the third phase of the proposed framework.

Case Four: Suitable techniques are SD and Hybrid

In some cases, there is a possibility that the suitable technique for some modules will be the SD and others will be the hybrid. This type of case is a more straightforward modelling. The DES model will be developed first followed by the SD model. However, the DES model will be modelled alone, whilst the SD model will be modelled for the whole system. For example, assume two modules exist, namely, healthcare and social care. The healthcare module has to use the hybrid simulation whilst the social care module has to use the SD. Therefore, the DES model for the healthcare module will be developed first followed by the SD model for the whole system, which is the healthcare and the social care modules combined together in the third phase of the proposed framework.

Case Five: Suitable techniques are DES, SD and Hybrid

In this case, some of the modules may have to be modelled using DES, some with SD and some with the hybrid. Therefore, in this type of case, the modelling will start with developing all the DES models (including the hybrid) and then all the modules are combined together. The next step is to develop all the SD models, including the modules that need a hybrid simulation. The last step is to consider whether the modules need to be integrated based on their inputs and outputs.

Case Six: Suitable technique for all modules is hybrid

The last type of possible modelling is the scenario in which all the modules have to use the hybrid simulation. In this case, the same method will be used as in case one and case two. For example, assume there are two modules – healthcare and social care. Both modules have to use the hybrid simulation for modelling. The DES model for each of the modules will be developed and then linked together (case 1). The SD model for all the modules will be developed as a whole system. At the end of the modelling process, the SD and DES models for all the modules will be integrated together. The linking process will be conducted in the third phase of the framework.

3.4.4 Integration Phase

The third phase of this proposed framework for modelling the CPP system is the integration phase. As the CPP system comprises many sub-systems that have been combined together to provide care services to the patient, it needs a mechanism to link these different modules, different systems, as well as the different techniques of modelling. The term ‘integration’ can also be referred to as interaction or communication between different parts (Chahal, 2009; Venkateswaran et al., 2007). There are two types of integration in this phase – horizontal integration and vertical integration (Venkateswaran et al., 2006; Mallach, 2000). Venkateswaran et al. (2006) defined vertical integration as the interaction between different levels and horizontal integration as interaction within the same level. Based on that definition, the researcher defines horizontal integration as the integration between modules within the same modelling technique, whilst vertical integration involves integrating different models that use different techniques (Helal et al., 2007). Figure 3.8 depicts these two types of integration.

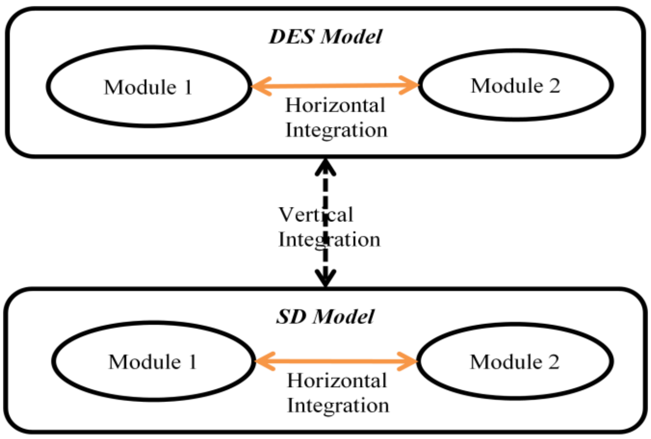


Figure 3.8: Types of Integration

In the DES model, the process of horizontal integration will use the output from module one as the input for module two and so on. In the SD model, horizontal integration is by connecting each of the module’s variables/factors (Helal et al., 2007).

Giachetti et al. (2005) does not include an explanation of how the different developed models are connected or combined. Therefore, the researcher assumed that Giachetti et al. (2005) developed the DES and SD model separately and does not combine the two models. Thus, the results produced have an unreliable output as the models are not connected to each other. Helal et al. (2007) used the time bucket synchronization to combine and synchronize between the two different models. The researcher argues that the model combination method of Helal et al. (2007) is too technical and complicated, similar to the arguments proposed by Chahal (2009). For that reason, the researcher argues that Chahal (2009) has developed a less technical and less complicated model combination method in her framework.

As the vertical integration represents the combination of different techniques, the steps in vertical integration will follow exactly the same steps that have been provided in Chahal's (2009) framework in phases two and three. The following explanations are the steps involved in this phase and Table 3.7 represents the summary of this phase.

STEP ONE: Identify Variables that are Accurately Captured by Other Models

Some of the variables are accurately captured by a certain technique (Lee et al., 2007; Giachetti et al., 2005; Martin and Raffo, 2000). For example, where there are numbers that can be counted or tangible and discrete (time, people, resources), it is more appropriate to use DES (Giachetti et al., 2005; Martin and Raffo, 2000). SD is more suitable to measure the variables that are intangible or uncounted and continuous (Lee et al., 2007), such as, the rate of fatigue due to long working hours (Giachetti et al., 2005), productivity (Chahal et al., 2009) and knowledge (Elf and Putilova, 2005), as well as the environment surrounding the process (Lee et al., 2007). Several literatures, such as Chahal et al. (2008) and Brailsford and Hilton (2001), have provided a list of criteria for selecting which technique (SD or DES) is most suitable for capturing the appropriate variable for modelling.

STEP TWO: Identify Variables that are Influenced by Other Models

Each of the models will have various variables and these variables could be influencing other variables within the same model or in different models (Venkateswaran et al., 2006).

One of the methods of linking between different platforms proposed by the Chahal (2009) framework is to identify the influencing variables. For example, Martin and Raffo (2000) gave an example of productivity (suitable for modelling by SD as it cannot be counted 'physically') that could be influenced by the working time (time can be counted 'physically') that will eventually produce higher productivity. This step will guide the modellers on how different models are linked using several variables in each model. For the purpose of visibility, the modellers can put in a table which variables are *'influencing'* and which variable are 'influenced by'. The researcher suggests that in order to define these variables, the modeller should select the variables that have been listed in the previous steps one by one, and test whether each variable has an impact on the other in the same model, or if it affects other variables in the other models. The impact and the effect that the modeller should look at would be the considerable changes that would happen to the target variable in focus should one variable be set in motion. The modeller then can seek advice and opinions from the professionals and experts in the field. Table 3.6 depicts an example of variable identification and suitable technique can be used to capture them.

Table 3.6: Example of Types of Variables and their Suitable Technique

Variable Influence *(Suitable Captured by DES):*	**Variable 'Influenced' *(Suitable Captured by SD):***
Total patients (workload)	Professional: performance, motivation, pressure
Incentives	Performance and motivation
Total professionals working	Professional: performance, motivation, pressure
Time frame (e.g. 4 hours for treating patient)	Pressure, performance

STEP THREE: Identify Interaction Points

The previous step (identify variables that are 'influencing' or 'influenced by') will be used as guidance for this step. The objective of this step is to show which variables in different models are communicating with each other. The interaction points are actually the variables that exchange their information actively between the different techniques that have been used for modelling (Chahal, 2009), as in Figure 3.9. The variable will continuously exchange information until both models are in a stable state. For example, total patient admission depicted in the DES model is the influencing variable and creates an impact to the performance variable, which is depicted in the SD model. As more patients enter into healthcare, the performance of the professional will decrease after it has reached peak level (Chahal et al., 2009). The professional's performance will re-influence other variables in the DES model, such as patient readmission will influence total waiting time. This information (total patient admission, performance, patient readmission, waiting time) will continuously be exchanged between both models until they reach equilibrium (both models are in stable state).

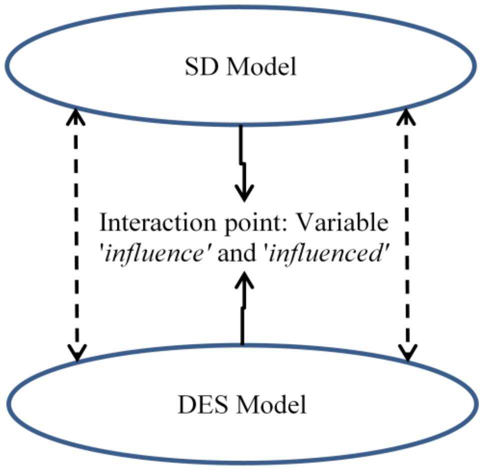


Figure 3.9: Interaction points between DES and SD Models

STEP FOUR: Formulate Interaction Points

As the variables are modelled by different methods, the next step is to formulate the interaction points as this will ensure that the knowledge exchange happens. Based on the Chahal (2009) framework, there are three ways to formulate the interaction points: direct replacement of value, aggregation/disaggregation and causal. As the term direct replacement implies, the method is just simply changing the variables between the different modules. While in aggregation/disaggregation, the value transferred to the other models/modules will be summed/divided first before their knowledge is exchanged. This is due to the concept in the technique itself, which is that the SD engages with aggregation while the DES engages with the disaggregation (Chahal et al., 2008). Whilst the third type are variables that influence each other and cannot be represented by the other two types as above, as it changes the knowledge frequently (causal). An example of this type of variable is productivity, which is influenced by or influencing the hours of work. Figure 3.10 depicts these types of interaction points.

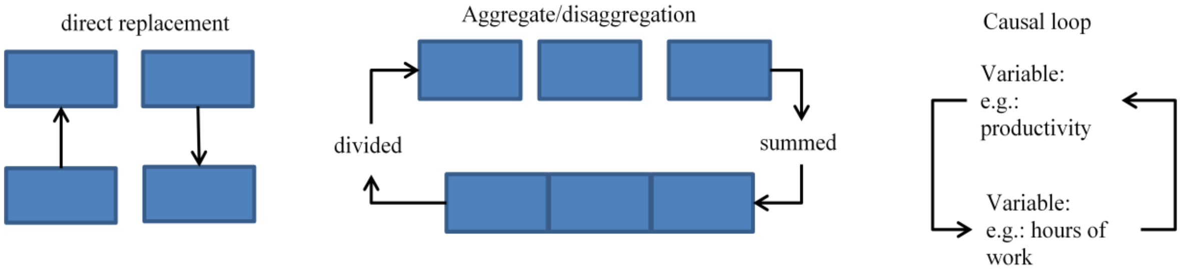


Figure 3.10: Types of interaction points

STEP FIVE: Map Interaction Points

As the previous step has been completed, the next step is to make things more explicit. It will be a straightforward case for mapping the interaction points that deal with the direct replacement and aggregation/disaggregation. An example for direct replacement, if the variable in the first model is *'one patient'*, then *'one patient'* will be transferred to another model. Unlike direct replacement, aggregation/disaggregation deals with summed/divide of the variable depending on where the variable is located. If the variable is in the DES model and has to be fed to the SD, it should be summed and aggregated. On the other hand, if the variable is in the SD and has to be fed to the DES model, it should be divided. For the third type, some representation should be put in place in order to harmonize the continuous exchange of data.

STEP SIX: Identification Mode of Interaction

Once the mapping had been done, the next step is to identify the type of exchange in data interaction. Based on Chahal's framework, two types of interaction modes have been defined – parallel and cyclic. The interaction between the models in parallel mode happens while the models are still running. Whilst in the cyclic interaction, the models are run separately and interact after the running process has finished. To determine the mode of interaction, if the variables are closely linked in space and in time, and the interactions between them are important, a parallel interaction is required. Otherwise, a cyclic interaction is required. Figure 3.11 depicts the difference in how the interaction happens (dotted arrows) between the models in both the parallel interaction (a) and cyclic interaction (b).

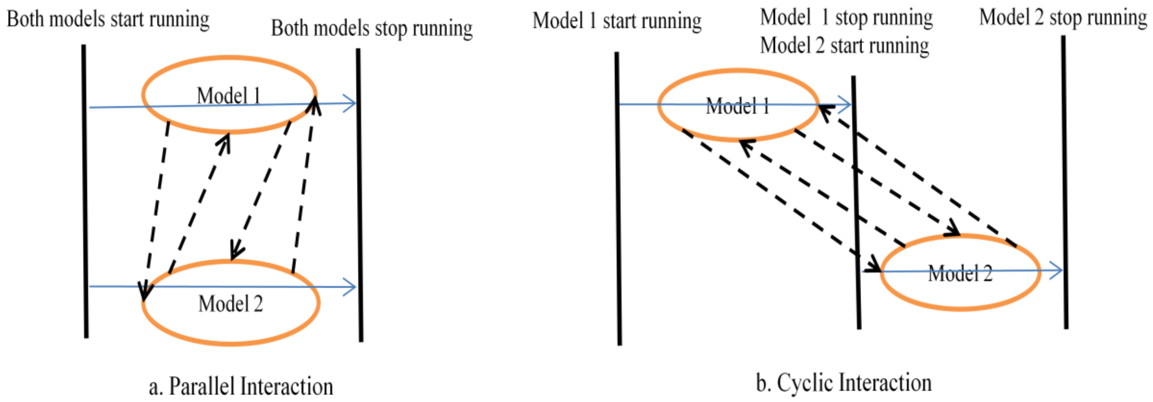


Figure 3.11: Types of Variable Interactions

Based on the brief explanation about the integration phase, Table 3.7 depicts the summary of the steps in the Integration Phase.

Table 3.7: Summary of Integration Phase

Phase/Steps		Objectives	Method (How)
1.	Identify variables that are accurately captured by other models	To ensure that the model is valid	Can use table of properties for selecting SD or DES in Chahal and Eldabi, (2008).
2.	Identify variables that are influenced by other models	To find how SD and DES models can be integrated	
3.	Identify interaction points	To see interaction between variables in both models	By looking at the previous step (variable influencing and influenced by)
4.	Formulate interaction points	To synchronize the models as both models are different in capturing variables (aggregate and individual analysis)	Sum or divided depends on the variables that have been captured by different techniques
5.	Map interaction points	To define the previous step explicitly	Based on the previous step
6.	Identification mode of interaction	To see how models should be run	Whether both models are run separately or in parallel

(Developed by the researcher)

The development of the framework is based on the previous literatures as the framework for modelling the CPP model that uses the hybrid simulation is not available currently. Therefore, the researcher has proposed this framework by referring to several hybrid frameworks/models as discussed in Section 3.3. The proposed framework will be validated by applying it against a CPP system. A CPP model will be developed practically based on this framework and will be revised and modified in order to ensure that the framework is fit with the CPP system model. For all of these purposes, it will be discussed in the next chapter, i.e. Chapter Four.

3.5 CONCLUSIONS

This chapter presents the proposed framework of modelling the CPP based on three main references, Chahal, Helal et al. and Giachetti et al. These main references basically provide the framework involved in modelling in healthcare and large systems using hybrid simulation. The proposed framework comprises three main phases: conceptual phase, modelling phase and integration phase. The conceptual phase is further decomposed into several steps, the modelling phase involves several cases of modelling possibilities, whilst the integration phase is totally based on Chahal's framework.

The next chapter will cover the whole process of framework assessment, as well as its modifications. To assess the suitability of the framework with regards to the CPP model development using hybrid simulation, the researcher will develop a CPP model based on the framework that has been proposed in this chapter. The objective of the assessment is to enhance the framework so it could fit into the CPP system case. Based on the observation of the assessment, the proposed framework will be modified accordingly.

CHAPTER FOUR: FRAMEWORK ASSESSMENT FROM A PRACTICAL APPROACH

4.1 INTRODUCTION

In Chapter Two, the researcher pointed out the inability of a single modelling technique to meet the needs and the criteria of a viable complex patient pathways (CPP) model, which leads to inefficient and wrong decision making. Therefore, it has been proposed to combine two simulation techniques for modelling, namely, Discrete Event Simulation (DES) and System Dynamic (SD), which is named a hybrid simulation. It is proposed to combine these two techniques as they complement each other and have the capability to cover the needs and features in CPP systems. This is after studying many techniques that have been used to model the CPP systems. In Chapter Three, the development of the proposed framework for the hybrid simulation for modelling the CPP systems is discussed. Since the CPP system is slightly different among government agencies in relation to their procedures and regulations, it is proposed to have a standard framework for the hybrid simulation modelling technique. This framework could be used as guidance in CPP modelling and prevent modellers from missing any important steps. The researcher could only find limited literature that discusses the hybrid simulation specifically in respect of combining the DES and SD techniques applied in healthcare and large systems. These frameworks have been used in order to develop the researcher's hybrid framework for modelling CPP systems. Table 4.1 depicts a summary of the phases/steps, objectives and methods for each of the steps.

The purpose of this chapter is to provide thorough discussions on the assessment and testing of the proposed framework by developing a CPP system practically, as one type of the assessment and testing of the proposed framework. This has been mentioned in Section 1.5 Methodology, in Chapter One. The next section will discuss applying the framework to the case studies of CPP systems involving health and social care. The case is selected as some of the criteria of a viable CPP system that have been developed in Chapter Two were based on health and social care integration – large, integrates between health and social care, complicated systems, etc., leading to the proposed framework in Chapter Three. Thus, the case will ensure that the framework will fit with the CPP system. Based on the assessment results, the last section in this chapter will discuss the modified framework.

Table 4.1: Summary of the Proposed Framework

Phase/Steps		Objectives	Method (How)
Phase One: Conceptual Phase			
1.	Problem Source Definition and Objective Identification	To set the boundaries of model building and identify which subsystems are involved	By asking the expert opinion of professionals
2.	Conceptual Model and Modularization	To reduce the complexities of model development	Conceptual Model – from system description to logical system (building blocks) Modularization – divide several processes into a group or divide into several subsystems or care settings
3.	Identify modules that will be affected by the overall objective	To reduce time in model building and to set the boundaries	By asking the opinion of professionals or by looking at the subsystems that have a direct impact on the defined objectives
4.	Define the criteria for each module	Selection of suitable technique for modelling each module	By defining the variables for each of the criteria
5.	Selecting a suitable technique for modelling	Decrease time for modelling, as not every module has to use hybrid modelling	Refer to Table 3.3 in Chapter Three
6.	Modelling IC Plan	To facilitate the modelling activities as it shows how to logically model each of the modules	Straightforward process.
Phase Two: Modelling Phase			
1.	Modelling DES Model	To capture individual analysis of the model	Using any DES software packages (Refer to Section 3.3.3 for the list of software packages)
2.	Modelling SD Model	To capture the feedback loop of the model	Using any SD software packages (Refer to Section 3.3.3 for the list of software packages)
Phase Three: Integration Phase			
1.	Identify variables that are accurately captured by other models	To ensure that the model is valid	Can use table properties for selecting SD or DES in Chahal and Eldabi, (2008) and other literature
2.	Identify variables that are influenced by other models	To find how SD and DES models can be integrated	
3.	Identify interaction points	To see interaction between variables in both models	By looking at the previous step (variable influencing and influenced by)
4.	Formulate interaction points	To synchronize the models as both models are different in capturing variables (aggregate and individual analysis)	Sum or divided depends on the variables that have been captured by different techniques
5.	Map interaction points	To explicitly define the previous step	Based on the previous step
6.	Identification mode of interaction	To see how models should be run	Whether both models are run separately or parallel

(*Adapted from Table 3.5 and Table 3.7*)

4.2 CASE OF HEALTH AND SOCIAL CARE

The framework that has been proposed will be applied to a case study of CPP in health and social care setting or refers as integrated care (IC), mentioned in the literatures, which consists of healthcare, intermediate care, assessment, as well as social care. This case has been selected as most of the criteria of a viable CPP system that has been developed in Chapter Two (e.g. large and complicated system) were based on the health and social care integration case, leading to the development of the proposed framework in Chapter Three, as there is no framework/model that used hybrid simulation for modelling the CPP system. As a result, this case will be used as an experiment material for assessing and testing the proposed framework, by developing the CPP model practically. The development of the CPP model for this case is based on previous case studies that have used a single technique to model the systems, as in Table 2.3 in Chapter Two, with support by other references, literatures and professional expert opinions. As mentioned in the previous chapter, the proposed framework is to provide a guideline primarily for modelling CPP. It has also been clarified that the purpose of this chapter is to assess the applicability and suitability of the framework. Therefore, the full assessment for the validity of the models is not the researcher's prime concern and will not be included in the discussion in this chapter.

4.2.1 Background of the Case

Bryan et al. (2005) listed several reasons that contributed to the problems with CPP system within health and social care setting. Such problems are; awaiting decisions about social service funding, people seeking care home placements by social services, or privately, family delays, domiciliary care unavailable, no sub-acute NHS bed, lack of professionals in the community, as well as confusion of responsibilities between health and social services. These problems have led to the bed blocking dilemma.

To address the problems, the decision makers have introduced intermediate care, a place for the elderly to stay whilst waiting for other sorts of care management procedures. By introducing intermediate care the patients can be moved to another place, which will create a place for other patients. The social care has enough time to provide a place for the elderly. The care manager has a longer time to assess the patient, thus, providing a suitable place for the patient. The healthcare team can be sure that the patient goes to social care after their condition improves and avoids patient readmission. The intermediate care team will help the patient take care of their lives and provide rehabilitation, and, thus, will reduce the dependency of the social care (Wolstenhome et al., 2004; Katsaliaki et al., 2005).

To assess the suitability of intermediate care in health and social care, using a conventional method will be costly as it needs to develop new facilities and it does not ensure that it will reduce the problems. As this is considered an extension of the classical work flow of the business process, or business process reengineering, in which there are huge changes to the system, simulation will be a suitable technique for doing the analysis of the business process, as it can reduce the risk and increase the success of the business process re-engineering (Hlupic and Robinson, 1998). Using techniques in the simulation method, a hybrid model of the CPP system will be developed to assess the suitability and effectiveness as well as their impacts of introducing the intermediate care. The developed model will support the decision of whether the introduction of intermediate care can achieve the objectives or not.

To examine and assess the proposed framework, the developed model that contains intermediate care in the integrated care will only take the original definition. This service establishes an integrated service that can facilitate quicker recovery from illness, prevent any inappropriate hospital admission and support elderly people to be more independent, which, consequently, will reduce the admission of long-term care. The definition from Steiner (2001) refers to intermediate care as services or activities concerning the transition of patients between hospital and home. Medical/social dependence to functional independence will also be taken into consideration. Several rules for intermediate care have also been based on Wolstenhome et al. (2004), which includes; alternatives to admission, time limitation and preventing bed blocking. The intermediate care setting will take place in a different location from health and social care (considering rehab place) for two weeks. After that time, the patient will be transferred either to the patient’s own home and be followed-up or transferred to another home care, either short- or long-term care, depending on the patient’s condition.

4.2.2 Applying the Framework: Conceptual Phase

Chapter Three has discussed the development of the framework, which has been divided into three phases and each phase has several steps that should be followed. The first phase in the framework is the Conceptual Phase, which is then broken down into several steps. Starting with the problem definition and objective identification, the final outcome of this phase is the modelling planning. This outcome will provide guidance in the modelling phase. The following steps are as follows:

STEP ONE: Problem Definition and Objective Identification

The researcher argues that intermediate care was first set up in 1994, based on the first literature that defines the meaning of intermediate care in Armstrong and Baker (1994), whilst the first model of integrated care that includes intermediate care as an intervention was found in 2001, by Campbell et al. (2001), using the DES technique as their modelling method. Based on this argument, the researcher is of the opinion that intermediate care is being setup in the real world situation or ‘try and error’ (Giachetti et al., 2005) in order to test the effect. This requires considerable investment including financial, time, and human resources. Therefore, it is essential to evaluate the effect of intermediate care by using modelling and the simulation method. Although Campbell et al. (2001) and Wolstenhome et al. (2004) developed the CPP models that include intermediate care in both models; they both have some limitations, such as no feedback loop in Campbell et al. (2001) and lack of individual analysis in Wolstenhome et al. (2004). Due to these limitations, the researcher argues that the DES and SD techniques should be combined to address the limitations.

Based on the main case described above, the overall objective is ‘to assess the effect of implementation of the intermediate care’, which acts as a temporary place for the patients for a maximum period of two weeks. Patients will be given some therapy that will make them more independent. It also aims to provide a place for the patient whilst waiting for the assessment result. To assess their suitability, the effect, as well as the effectiveness of intermediate care in reducing bed blocking and late transfer, the hybrid modelling technique (DES and SD) is required, as this will help in the decision making process.

STEP TWO: Conceptual Model and Modularization

The next step can be done simultaneously, or it can follow the Pidd (2001) model building principle. It can be done first by module then expanded to a more detailed process or the other way around (details first followed by the grouping (module) process). The conceptual model is based on Katsaliaki et al. (2005), Wolstenhome et al. (2004) and Bryan et al., (2006) with some modification based on expert opinion.

Based on the definition of intermediate care, it is known as the services or activities concerning the transition of patients between hospital and home, as an alternative to admission, time limitation and preventing bed blocking (Steiner, 2001; Wolstenhome et al., 2004). Based on the definition and function of intermediate care, it can be assumed that intermediate care plays a role in the rehabilitation unit while waiting for the assessment results. Therefore, the intermediate care unit will be regarded by assessment as a parallel process. The patient will be sent to intermediate care and the patient's records will go through the assessment process. The conceptual model (considering the patients' needs for social care services) for the whole process, involving this patient pathway, is shown in Figure 4.1.

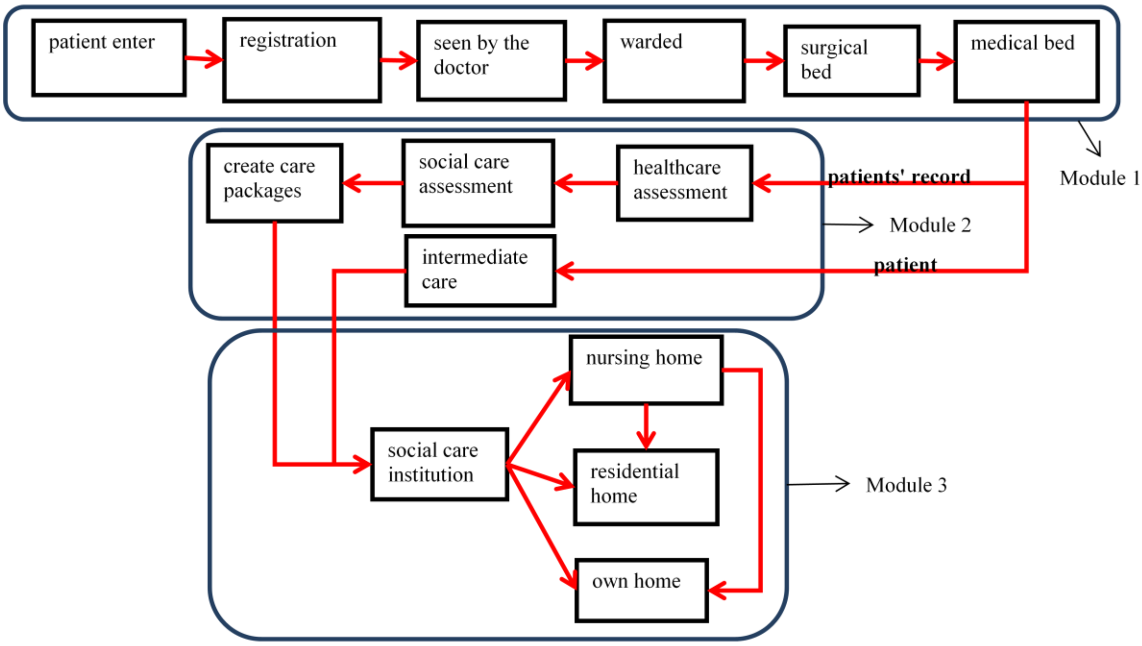


Figure 4.1: Conceptual Model and Modularization of Health and Social Care Model
(Adapted from Katsaliaki et al., 2005; Wolstenhome et al., 2004; Bryan et al., 2006)

After developing the conceptual model, all the processes involved will be grouped into several modules. This process is called the 'modularization' process. This process will reduce the complexity of the model and facilitate model building in the simulation software packages. As mentioned and explained in Chapter Three Section 3.3.2, the processes can be grouped by care settings (healthcare/social care, etc.) or by process (large system divided into several groups/parts). In this case, the process of modularization will be done by dividing the whole process into the care setting (healthcare, intermediate care/assessment and social care). The modularization process is shown in Figure 4.1 in big boxes that accumulate several processes. To facilitate the model building and management, the modules are then named as 'healthcare' (module 1), 'assessment/intermediate care' (module 2) and 'social care' (module 3).

STEP THREE: Identify modules that will be affected by the main objectives

The next step is to determine which one of the modules is affected by the introduction of intermediate care. This will identify the boundaries of the models, and, thus, save time in model development due to the condition that some of the modules may not be affected directly by the main objective or by the intervention (Helal et al., 2007). Justifications should also be followed to ensure that all the modules are affected by the objective/interventions.

Based on expert opinion, the affected modules will be *'healthcare'*, *'assessment'* and *'social care'*. The introduction of intermediate care will reduce the bed blocking problems in healthcare and increase pressure on the assessment staff as they have a limited time (2 weeks) to come up with a proposal for a suitable place for the social care and needs of the patient. The social care institution will also be affected, as more patients from intermediate care will be moved to social care as the period finishes. The total number of patients in social care will eventually reduce when the patient is fit to be discharged from the social care. This is the result from the rehabilitation process of the intermediate care. These are some justifications why *'healthcare'*, *'assessment'* and *'social care'* modules are affected by the introduction of the intermediate care. Considering that the 'home' has their own carer and does not use any resources from the social care institution (thus, not affecting the other social care institutions), the patient's 'own home' will be excluded from the model.

STEP FOUR: Define the criteria of each module.

Adapted from Chahal and Eldabi's (2008) criteria for selecting the best technique, which has been composed into three main criteria, as in Section 3.3.2, the next step is to define the criteria for each of the modules. The criteria that should be assessed and assigned to each of the modules are in terms of their effect on the module (short- or long-term), modelling analysis (individual or aggregate) and whether or not there is a feedback loop. Expert opinion can also be used for this purpose. The defining criteria will help the modeller select the best technique for modelling.

Based on expert opinion in terms of the effect of the criteria, the 'healthcare' module has a simultaneous short- and long-term effect, as the 'assessment' module only has a short-term effect whilst the social care only has a long-term effect. For the short-term effect of the 'healthcare' module, fewer patients will be in healthcare when more patients are transferred to intermediate care, whilst its long-term effect is that more patients will be admitted to the healthcare as extra beds become available. This includes patient readmission. Due to the limited time given to the assessment team (2 weeks), they will be pressured to find suitable social care for the patients. As the rehabilitation in intermediate care has a time limit and the intermediate care is crowded (resulting from patients being transferred to the intermediate care to clear some space in healthcare), some of the patients might be readmitted to the healthcare. This is due to the condition where the quality of health is influenced by total patients in the same place (Elf and Putilova, 2005). This will reduce the number of patients in social care in the long-term. Figure 4.2 depicts these situations.

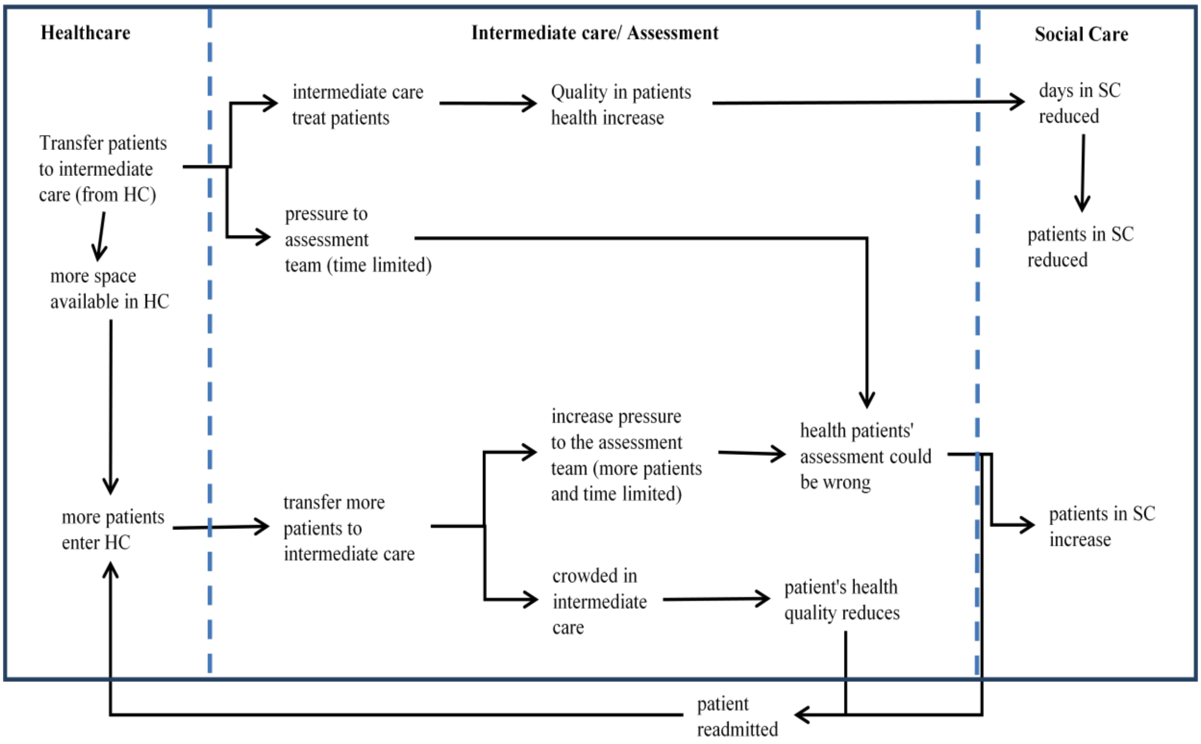


Figure 4.2: Effects to the Modules

The modelling analysis criteria will determine whether the analysis should be done individually or aggregated. If the gap between patients' attributes (e.g., time finish, type of illness) is large, then it should be analysed individually. Otherwise, the attributes can be analysed by aggregate. Expert opinion can also be used for determining the criteria for each module. For modelling analysis, the 'healthcare' and 'assessment' module should be completed more by individual analysis, whilst social care should be modelled by aggregate. This is due to the condition in which each patient has a different illness. Therefore, the time for treatment for each of the patients should be different from each other. Whilst for 'social care' module, all the patients were placed in the same category regardless of type of illness, age, or gender as long as the social care institution was suitable for the needs of the patients.

The feedback loop criteria will determine whether or not the intervention that has been introduced (in this case, the intermediate care) to the system will be affected by the previous module. Based on Figure 4.2, more patients can be treated in healthcare as more space is available. In social care, some of the patients from intermediate care that have been discharged to social care might be returned back to the healthcare. This is due to the following conditions:

a. Intermediate care is crowded with patients (as patients are being transferred from healthcare to intermediate care to admit other patients). This condition will affect the patient's health quality, thus, more patients will be readmitted.
b. As more patients are transferred to intermediate care, it will increase the pressure on the assessment teams, as they have to work harder to find suitable social care for the patients. This might affect the assessment of the patient's health and needs, which leads to unsuitable social care. Consequently, the patients from the social care might have to be readmitted to the healthcare or their condition reassessed.

Therefore, 'healthcare' and 'social care' modules have a feedback loop whilst the 'assessment' module does not. Table 4.2 exhibits the criteria, the variable, as well as the justification for each of the modules that have been determined and affected due to the introduction of intermediate care.

Table 4.2: Criteria for Each of the Modules

Criteria / **Module**	**Effect (time)**	**Modelling analysis**	**Feedback loop**
Healthcare	Short-term – fewer patients in healthcare Long-term – more patients will enter healthcare (patient readmission)	Individual – unique case for each patient	Yes – affected the healthcare processes
Assessment	Short-term – pressure on the assessment team to find suitable place	Individual – unique patient cases	No
Social care	Long-term – number of patients in social care reduced as they are transferred to intermediate care	Aggregate – patients transferred to social care as an aggregate, not a unique case	Yes – affected the assessment (if no availability of the place) affected the healthcare as well as social care processes

STEP FIVE: Selecting a suitable technique for modelling

Based on the criteria that have been defined in each of the modules a suitable technique for modelling each of the modules can be determined. Each of the criteria has its own variables and each of the variables has its own suitable modelling technique. The suitable techniques for modelling depend on the criteria that have been mapped. The hybrid simulation will be used for modelling the modules if the suitable modelling technique is both DES and SD. As depicted in Table 3.4 in Section 3.3.2, Chapter Three, and based on the determined variables (in each criteria) of the module in Table 4.2, Step Four, the 'healthcare' module is suitable to be modelled by a hybrid, the 'assessment' module by DES and the 'social care' module by SD. Table 4.3 determines the suitable technique for modelling each of the modules.

Table 4.3: Technique Selection

Criteria / Module	Effect	Modelling analysis	Feedback loop	Final Technique
Healthcare	Short-term – DES Long-term – SD	Individual – DES	Yes – SD	Hybrid simulation
Assessment	Short-term – DES	Individual – DES	No – DES	DES
Social care	Long-term – SD	Aggregate – SD	Yes – SD	SD

STEP SIX: Modelling Plan

As in Chapter Three, in Section 3.3.1, there are six possible modelling types. Based on Table 4.3 in Step Five, each module has a different suitable technique for modelling. It is considered that the suitable technique for modelling 'healthcare' is the hybrid; 'assessment' is more suitable with DES, whilst 'social care' is more suitable with SD. The module with the hybrid and DES modules will be modelled first, followed by the SD and hybrid modules. As depicted in Figure 4.3, the DES and hybrid modules (based on DES model) will be combined together. The modules with SD and the hybrid (based on SD model) will be modelled later. Since the assessment is neither hybrid nor SD, the module will be merely included in SD but not in a detailed process (just one single step). The planning for modelling is shown in Figure 4.3 below.

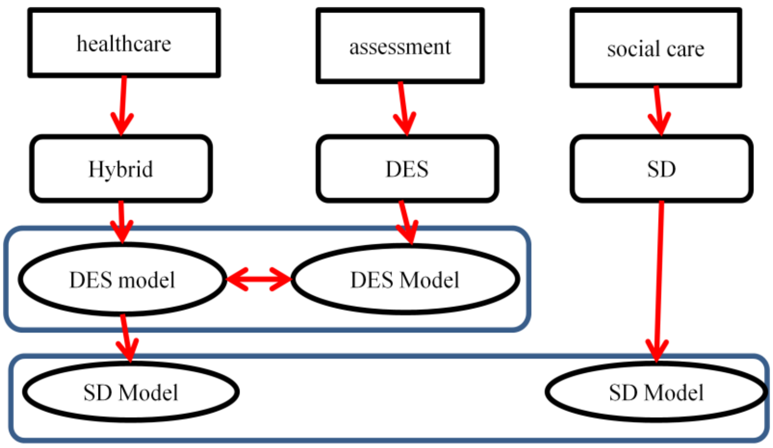


Figure 4.3: Modelling Plan

4.2.3 Applying the Framework: Modelling Phase

The framework for the Second Phase is the modelling phase, in which the conceptual model is transferred into simulation software. This phase is based on the last output from the conceptual phase, which involves the modelling plan. The modelling plan will show which module should be modelled in detail (especially with SD) and which should not. Various simulation software can be used, as mentioned by the researcher in Chapter Three. For the purpose of developing health and social care models using hybrid simulation in this research, the researcher will use Simul8 simulation software for developing the DES model and Vensim simulation software for developing the SD model.

The modelling phase will start with the modelling of the DES model for each of the modules. Based on the conceptual model, as depicted in Figure 4.1, the starting point for the patient is when the doctors decide that the patient has to be admitted. The last destination of the DES models is when the patient is waiting to be transferred to the social care. For the system dynamics model, it will start from the healthcare (as the module needs a hybrid simulation) to social care. This model will be developed using Vensim Software.

There are some clarifications in order to develop these models. Due to several limitations (data, time, and technical support) the researcher could not establish a model that mimics the real system exactly. However, as mentioned in the previous chapter, the objective of this part is to assess the framework that can be used for guiding modellers on how to model the CPP systems using hybrid simulation (how these two different models are developed and can be linked to each other). Therefore, the validity of the models and the results are not the prime concern. Furthermore, the researcher argues that the complexity of the model does not affect the framework as long as the modellers know what to link between the DES and SD (what variables that influence and have been influenced), what types of information can be obtained and used as an input for the SD model and what type of output can be used as an input for the DES model.

a. Discrete Event Simulation Model

In the DES model there are many patient attributes which make each patient unique, for example, type of illness, time finished in the system, age, gender and other variables.

However, for the DES model development in this research, the researcher will only consider the finishing time for each of the patients as being the criterion that makes each patient unique. As depicted in Section 4.2.2, Conceptual Phase, Step Two, the whole CPP system has been divided into three modules – ‘Healthcare’, ‘Intermediate Care/Assessment’ and ‘Social Care’. Based on the Modelling Plan in Step Six, Conceptual Phase, only healthcare and assessment will be modelled by DES. Since intermediate care is a parallel process with assessment and it has only one process (considering the patient is having rehabilitation in two weeks), it will not be included in the ‘assessment’ or ‘healthcare’ modules. The following explains the model development for both modules. These models use Simul8 Simulation software.

DES Model Development: Healthcare Module

The DES model development is based on the conceptual model, as depicted in Figure 4.1, Section 4.4.2, in Step Two under the Conceptual Phase. The ‘healthcare’ model starts with patients being admitted to the ward. The patient is first assessed by the medical doctor upon admission. The patient will undergo various tests and an assessment. Some of the patients will be discharged after the doctor’s assessment and some might need further review. Assuming that the patient must undergo a surgical procedure, he/she will be admitted to the hospital while waiting for surgery. After the patient has undergone his/her operation, he/she will be placed in a recovery room until he/she regains consciousness and is stable. The patient will then be transferred to the normal ward until they are medically fit enough to be discharged. There are two probability pathways for the post-operative patient. The patient will either be discharged or require continuing care services. Those who require continuity of care, especially for the older people, will be continued under the assessment module. The researcher assumes that patients who enter the healthcare for assessment by the social care are the patients who have illnesses that need continuing care, regardless of their type of illness and other variables that makes each patient unique. Figure 4.4 depicts the DES model of the healthcare module using Simul8 Software.

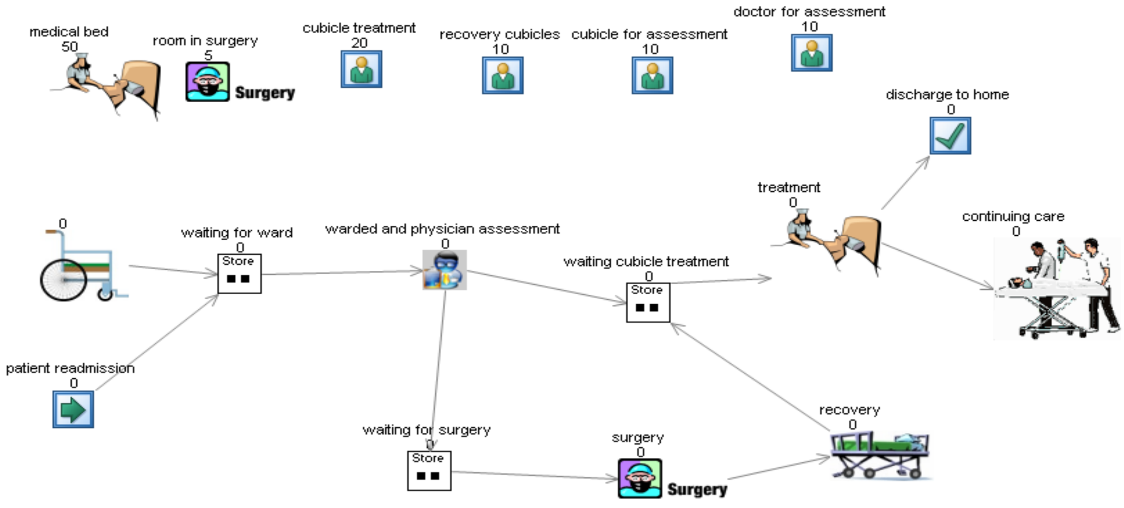


Figure 4.4: DES Model for the Healthcare Module

DES Model Development: Assessment Module

As with the 'healthcare' module, the DES model development is also based on the conceptual model that has been depicted in Figure 4.1 in Section 4.4.2. The assessment process starts when a patient that is medically fit is ready for discharge. The patient's record will be assessed (to find suitable care and create care planning) by the assessment team while the patient is being transferred to intermediate care. The assessment begins with a review of the patient's physical and psychological needs by healthcare professionals, such as an occupational therapist or psychiatric nurses. This assessment is to ensure that the placement of care is equipped with all the patient's needs in terms of the medical perspective. After the patient's needs are assessed, the care manager will continue the assessment to see whether the patient needs personal care and whether the patient can carry out household tasks. This includes the assessment of the availability of the formal or informal care, as well as their financial support (own or public support). Once finished, the care package will be created and the appropriate placement must be found. The placement should meet all the individual needs with available resources (Bryan et al., 2006). All these assessments will be done while the patient is in intermediate care. The assessment and intermediate care process will be considered as one parallel process, thus, only one model is considered. The maximum process for the assessment is two weeks (as in intermediate care). Figure 4.5 illustrates the patient's assessment process.

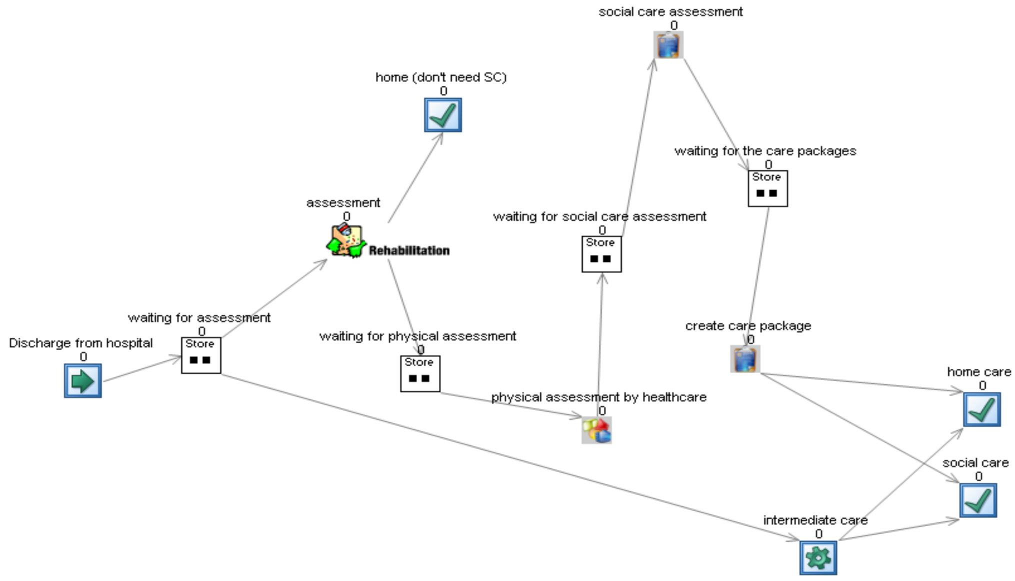


Figure 4.5: DES Model for the Assessment/Intermediate Module

b. System Dynamics Model

In the SD model, there are several factors that can influence other factors, regardless of the type – tangible or intangible. For example, the total number of patients that are admitted to the hospital will influence the motivation of the professionals, waiting times for the patient, and the pressure on professionals. Total working hours will influence the performance of the professionals, and the incentive will also influence the performance of the professionals, and more factors can be included in the development of the CPP model using the SD technique. However, only two factors have been considered by the researcher for developing the model using SD techniques in this research due to various limitations – time, technical support and data availability. They are stress level among the staffs and professionals and total spaces in the intermediate care. The SD model development in this research will use Vensim SD software.

The assessment and intermediate care modules will be combined as one unit as they provide the care services at the same time, as shown in Figure 4.1 – the conceptual model of the CPP systems. However, in the SD model, the researcher only models the intermediate care process rather than assessment process. Based on Figure 4.3 Modelling Plan for this case, the 'assessment/intermediate care' module has to use only DES. However, for the purpose of modelling in the SD model, this module has to be included to complete the whole system. Unlike assessment process, intermediate care process is only one single step (rehabilitation in two weeks). Therefore, in the SD model, the intermediate care will be included rather than assessment processes.

To facilitate the modelling activity using the SD technique, the researcher will use the Divide and Conquer Principle by Pidd (2004), which is done by modelling module by module and connecting the module with the variables. Figure 4.6 depicts the SD model for the whole system and is followed by an explanation of each of the modules. The equations of the SD Model are as in Appendix B.

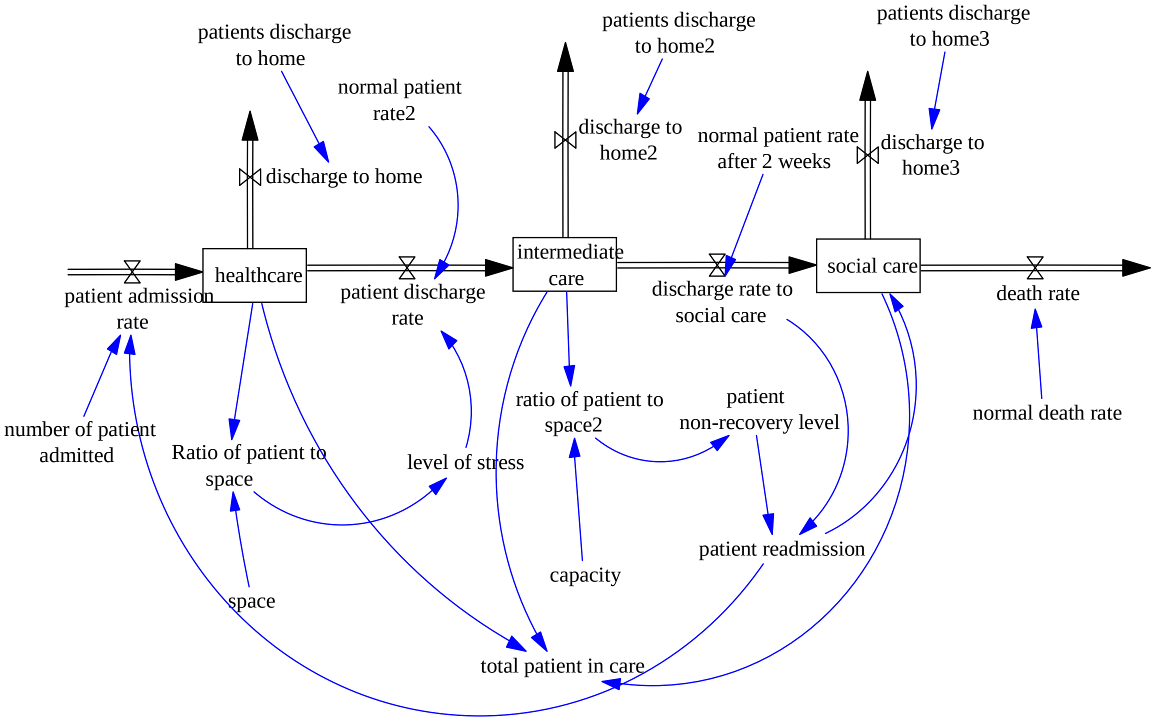


Figure 4.6: System Dynamic Model for the CPP system

SD Model Development: Healthcare Module

The 'ratio of patients to space' (considering available beds) depends on the total patients entering healthcare. Based on expert opinion, the ratio of patients to space (considering available resources), thereby influencing the level of stress of staff, leads to the patients' discharge rate. The higher the rate of the 'ratio of patients to space', the higher the level of stress experienced by the staff, and therefore, the higher the rate of patients discharged will be. Therefore, the relationship between the 'ratio of patients to space' and the level of stress is a positive relationship.

Assuming that if the stress level is zero to 0.5, there is a normal discharge of patients (patients are fit enough to be discharged). However, if the level of stress is more than 0.5, a number of patients will be forced to discharge to give some space for incoming patients. This assumption is made and adapted based on the hybrid model developed by Lee et al. (2007), where new resources should be added when the resource utilisation reaches 0.9. To see how many patients are forced to be discharged, the level of stress (as it reached more than 0.5) will be multiplied by the normal discharge rate. The graph in Figure 4.7 depicts the level of stress (x) versus the ratio of the patients' discharge rate (y). There is one function in the SD software (Vensim) that will provide the reading for the level of stress based on the ratio when the model is running. The function name is 'lookup table'. This data, as in Figure 4.7, will be inserted into the function.

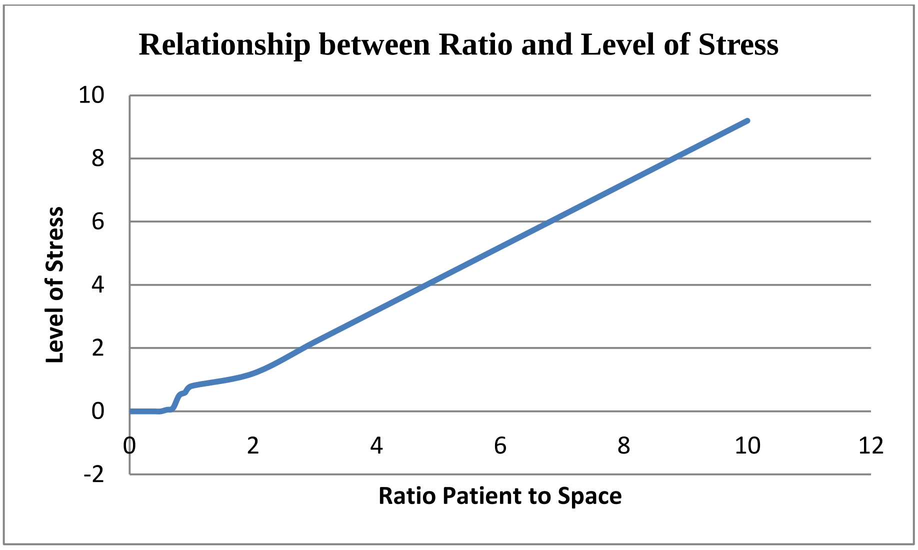


Figure 4.7: Relationship between Patient Ratio and Level of Stress
(Adapted from Lee et al., 2007)

SD Model Development: Intermediate Care Module

It is assumed that patients who need continuing care (discharged from healthcare to intermediate care) will be moved to another place (not in hospital) while waiting for the care manager to set up their care planner, and that all patients that have been discharged to intermediate care will stay in the intermediate care facility for a maximum of two weeks. The total number of patients and the area in intermediate care will create the ratio of patients to capacity (in the model named as 'ratio of patient to space2'). This ratio will influence the patient non-recovery level (Elf and Putilova, 2005), which leads to patient readmission. Adapted from Lee et al. (2007), where resources should be added when they reach 0.9 utilisation, the same concept will be used in developing this model for the intermediate care module. Assuming a certain ratio of patients to capacity (a value more than 0.6, as it will create crowding in the intermediate care, thus, influencing patient recovery), it will generate a certain rate of patient non-recovery level. This non-recovery level will be multiplied by the normal patient discharge to social care (gathered from the DES model) to get readmission when the model is run. This patient will be admitted back to the healthcare and will decrease the number of patients in social care. The graph in Figure 4.8 depicts this scenario and based on this graph, it will be inserted into the function 'lookup table' in the SD CPP model.

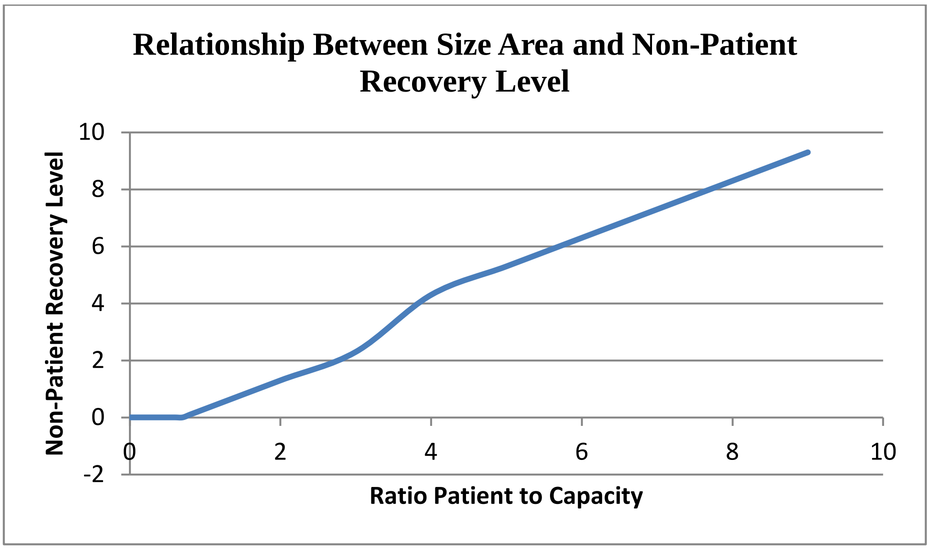


Figure 4.8: Relationship between Size Area and Non-Patient Recovery Level
(Adapted from Lee et al., 2007)

SD Model Development: Social Care Module

Two types of social care are residential care and nursing home. To avoid the complexities in the model, the researcher only used a single stock for the patients in social care. The patient in residential care can be moved to their own home whilst the patients in a nursing home will remain there until they die. Through that statement, the researcher assumes that patients that have been discharged home are the patients from residential care, whilst patients that died whilst they are in social care, are patients that stay in a nursing home.

4.2.4 Applying the Framework: Integration Phase

Upon developing the models and trying to integrate both models, the researcher realizes and argues that some of Chahal's (2009) framework cannot be rigidly followed as it has redundant steps and is somewhat complicated. For example, there are redundant steps in step two (*Identify Variables that are Influenced by Other Models*) and step three (*Identify Interaction Points*). As step two has defined the variables – 'influencing' and 'influenced by' – by developing a table, the researcher argues that the table itself can be used as the map for the interaction points. As the third phase of this research follows the framework of Chahal (2009) exactly, this section will not be explained as this phase needs a major modification and the new steps in this phase are explained in Section 4.3. However, as this phase integrates two different models, this section will explain the hybrid operation and how the models are integrated by variables.

Running the Models

There are two types of hybrid interaction based on Chahal (2009). If the variables are linked in space and time, they must be run in parallel, otherwise, there would be cyclic interaction, which should be run model by model. As the influencing variable is the total patients' admitted, which will influence the total number of patients discharged and non-patient recovery level, the interaction of these models is parallel. It should be run at the same time. However, there is limited technical support to run both models simultaneously. The researcher believes that there should be a function that will act as an 'agent' that will connect and enable the interaction of both models.

In Helal et al. (2007), they used the time bucket function as the SDDES controller, which acts as an agent between both models. This agent will synchronize the interaction so both models run in balance (model run not monopolized by a certain model/technique). Unlike Helal et al. (2007), who used the SDDES controller as an agent to synchronize both models in terms of time, the agent used in this hybrid simulation in this research is to act as an intermediate agent between both models that will synchronize the interaction of both models' (involving the variables 'influencing' and 'influenced by'). The same combining of methods between models was developed by Venkateswaran and Son (2004) in the production and manufacturing area using HLA/RTI, and Lee et al. (2007) using Anylogic in the construction area. However, the researcher argues that these agents need custom programming to make the variable interaction in parallel happen.

This proposed framework is developed purposely for the benefits of the stakeholders of the complex healthcare system, which integrates across several departments and care givers, so they can be actively involved in the CPP model development. One of the objectives of framework development is to introduce an alternative modelling technique that is less complicated and simple yet can model all the needs of the CPP system. Although using simulation software with a programming language, such as AnyLogic (using Java language), is powerful to link both and runs the models simultaneously, it also adds more complexity rather than simplicity to the model development. Based on this argument, the researcher will use a manual method, which includes collecting and transferring data from one model to another. Therefore, parallel interaction, as suggested by Chahal (2009), could not be done as the researcher argues it will need custom programming and will increase the complexity of the model development. Instead, the researcher will use cyclic interaction, which is run model by model separately. Once the data that has been collected from the DES model has been run, the data will be utilised for the next model. This process will continue until both models produce 'stable' outputs. The researcher defines a 'stable' output in this research as when the gap in the output values between each run do not differ much. Figure 4.9 and Figure 4.10 below, in the next section, depicts this process. Further explanation of the interaction between both models will be in the next section (hybrid operation).

Total patients admitted from the healthcare to home, intermediate care, social care and patients that have been discharged to home from healthcare and intermediate care (based on DES), is taken and saved in an Excel file (as in Appendix E). The researcher uses the 'pause' button from the Simul8 Software to gather the total patients' admission and discharge, and the time equal to one week. This is to synchronize the time with the SD model, as the time is based on a weekly basis. The researcher assumes that all the processes in the model are running between the hours of 0800 to 2200 every day. Since the SD model is being run for 30 weeks, the DES model will be run for 2940 minutes (30wks * 7days * 14hours).

Hybrid Operation

Figure 4.9 depicts the variables exchanged between both models theoretically, whilst Figure 4.10 depicts the variable exchanged between both models practically. Based on both figures, patients will enter the healthcare to have treatment for their illness. After a certain period the patients will be discharged to a home or intermediate care/assessment. Those patients who need continuing care will be discharged to intermediate care. The healthcare and intermediate care module is linked using the healthcare output, i.e., discharge time for each patient. After collecting data from the healthcare module, the intermediate care module will start running and data, such as the number of patients entering and being discharged to intermediate care and social care, will be gathered. This data (in an Excel file as in Appendix C) will then be passed to the SD model and will be run to generate outputs – the number of patients discharged and readmission onto ward. The total number of patient readmissions will then be given back to the DES model (healthcare and intermediate care module) to generate a new output. This should be done as the first run of DES model does not consider patient readmissions.

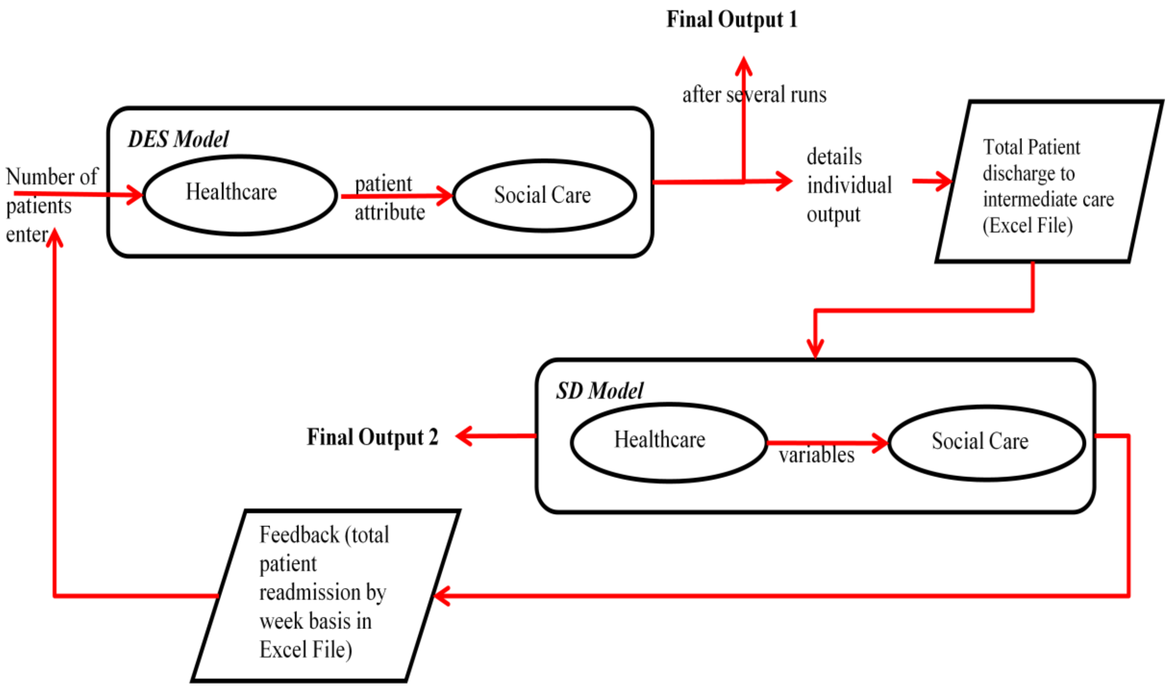


Figure 4.9: Variables exchanged between Models (Theoretical)

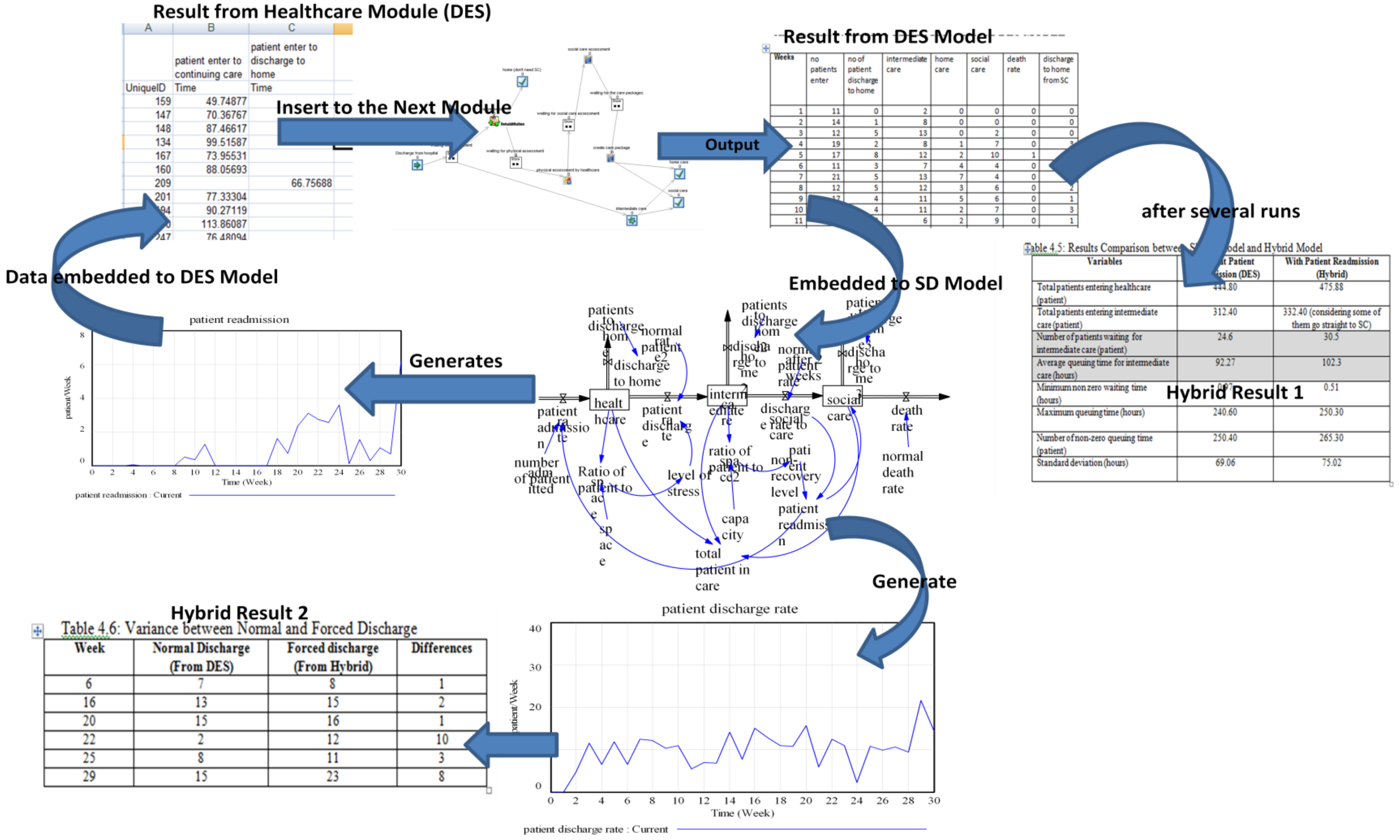


Figure 4.10: Practical Variable Exchanged

The communication between both models (iteration process between DES and SD) will be stopped if the 'influenced by' variable is not influencing another variable. For example, in this case, the total number of patients will influence the staff stress level, and, consequently, more patients will be discharged. Patients that have been discharged have no effect on the other variables in either the SD or DES models. The exchange of variables and running model activities stops here.

Another condition that will stop the running and variable changing processes between both models is when the difference from each value of the output from each run is small (the researcher considers the output as stable). Figure 4.11 depicts these conditions. The figure to the left depicts how the interaction between both models is stopped as the variable stopped influencing other variables, whilst the figure to the right depicts how the interaction between both models is stopped due to almost the same outputs being produced after several runs.

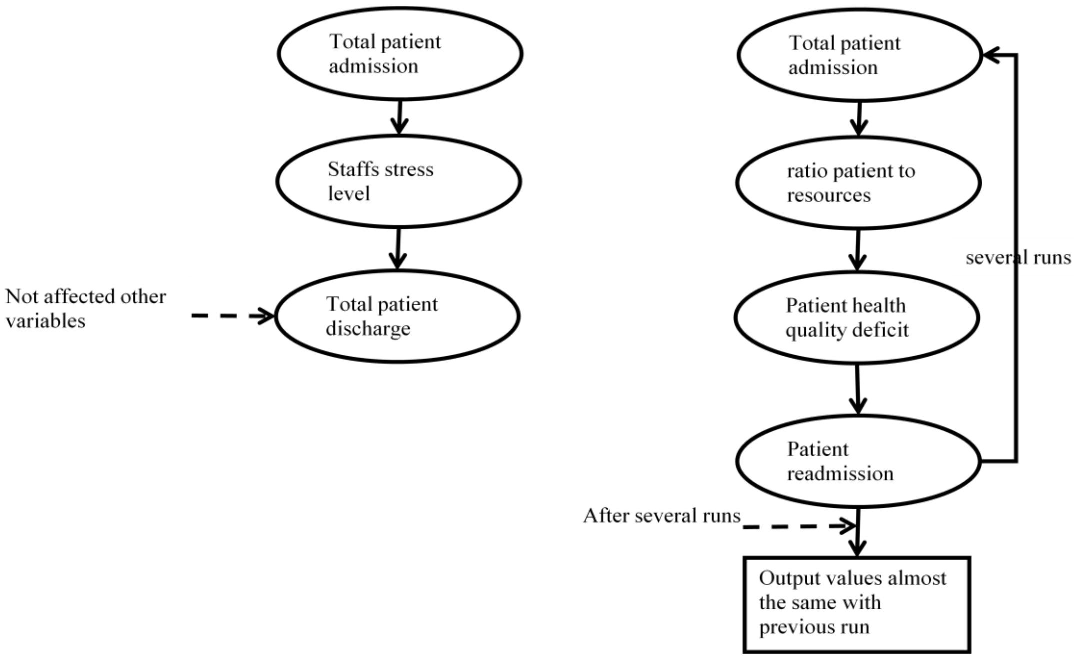
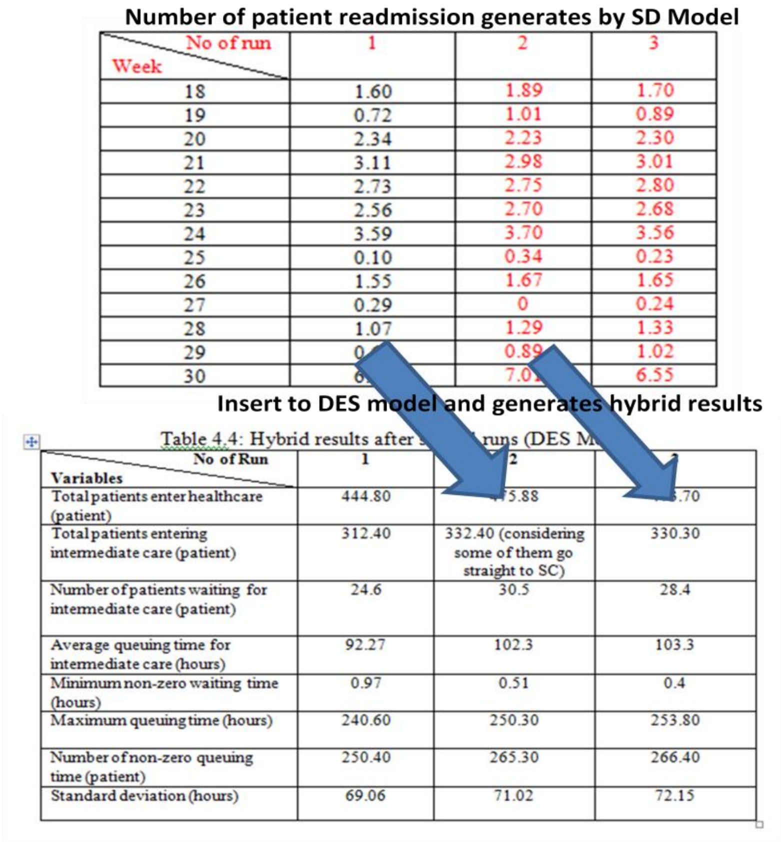


Figure 4.11: Two Conditions of How Communication between Both Models Stopped

The researcher has transferred the data from DES to SD, since the total patient discharge influences the total number of patient readmission (due to stress level of the professional and patient non-recovery level). The numbers of patient readmission were re-fed to DES model and generated new output (after considering patient readmission). This iteration process continues until the outputs were in stable manner. Based on Figure 4.12, at the third run of SD model that generated total patient readmission for certain weeks, it seems that the gap between each run was not too different. Therefore, the iteration process (transferring data from DES to SD and vice versa) has been stopped as the researcher assumed that the data were stable.



Week \ No of run	1	2	3
18	1.60	1.89	1.70
19	0.72	1.01	0.89
20	2.34	2.23	2.30
21	3.11	2.98	3.01
22	2.73	2.75	2.80
23	2.56	2.70	2.68
24	3.59	3.70	3.56
25	0.10	0.34	0.23
26	1.55	1.67	1.65
27	0.29	0	0.24
28	1.07	1.29	1.33
29	[illegible]	0.89	1.02
30	[illegible]	[illegible]	6.55

Table 4.4: Hybrid results after [illegible] runs (DES M[illegible]

Variables \ No of Run	1	2	[illegible]
Total patients enter healthcare (patient)	444.80	[illegible]5.88	[illegible].70
Total patients entering intermediate care (patient)	312.40	332.40 (considering some of them go straight to SC)	330.30
Number of patients waiting for intermediate care (patient)	24.6	30.5	28.4
Average queuing time for intermediate care (hours)	92.27	102.3	103.3
Minimum non-zero waiting time (hours)	0.97	0.51	0.4
Maximum queuing time (hours)	240.60	250.30	253.80
Number of non-zero queuing time (patient)	250.40	265.30	266.40
Standard deviation (hours)	69.06	71.02	72.15

Figure 4.12: Transferring data between DES and SD (Iteration process)

4.2.5 Discussion and Analysis of the Results

As mentioned in Chapter Two, the reason why the researcher suggested developing the CPP system using hybrid simulation was partly because of the unsuitable technique to capture some of the variables. Using DES alone will ignore the feedback loop possibility, especially for the previous processes (Giachetti et al., 2005; Zulkepli and Eldabi, 2011), whilst using SD alone will ignore the individual analysis, as most of the decisions are made based on the individual analysis (Chahal and Eldabi, 2008), for example, the total waiting time and time in the system for each patient. The limitations of each of the techniques will cause ineffective decision making. As this chapter is about the development of the CPP system, which is based on the developed framework as proposed in Chapter Three, this section will discuss the results that have been gathered from the hybrid models. Three types of results will be presented in this subsection – results from the DES model, the SD model and the hybrid model. The results from the hybrid model will be compared against the single models, which shows how the hybrid model can facilitate the decision making process efficiently compared to the results produced by a single technique.

Result from the DES Model

The DES model shows outputs from the perspective of the individual cases. Such outputs that concern the decision maker are; total patients in waiting, waiting time and time in the system, and the average time to finish each process, as well as patient admissions to healthcare, social care and intermediate care.

Table 4.4: Result of DES Model

Variables	**Current (intermediate care = 20)**
Total patients enter healthcare (patient)	444.80
Total patients entering intermediate care (patient)	312.40
Number of patients waiting for intermediate care (patient)	24.6
Average queuing time for intermediate care (hours)	92.27
Minimum non-zero waiting time (hours)	0.97
Maximum queuing time (hours)	240.60
Number of non-zero queuing time (patient)	250.40
Standard deviation (hours)	69.06

Table 4.5 presents the results from the DES model. Based on the table, with the current space available in intermediate care being 20 spaces, with a maximum stay in intermediate care being 196 (14hours * 14days), the total patients waiting for the intermediate care is almost 25 patients and the average waiting time for the intermediate care is 92.27 hours, which is slightly high in terms of the numbers waiting and the waiting time. These patients have to wait for an available place for intermediate care or healthcare. If the patient is placed in healthcare, it will create bed blocking problems (Bryan et al., 2005) as the healthcare will be crowded. Thus, a new patient has to wait for the next available place. If these patients are transferred to intermediate care (considering that the ideal total number

of patients is 20 patients), it will create a situation where the place is too crowded and will reduce the quality of the patients' health (Elf and Putilova, 2005). As a result, the patients discharged from intermediate care will be readmitted to the healthcare.

However, patients readmitted to the healthcare as a result of the reduced quality of health, cannot be captured accurately by the DES model. This is because the quality of the patients' health is a continuous variable and is influenced by the total number of patients that enter intermediate care. Therefore, the researcher used data that has been collected from the DES model. The total number of patients discharged to intermediate care is being linked together with the SD model. The SD model will produce the total number of patient readmissions when the patient's health quality is decreasing as a result of the crowded space (in the SD model, it has been named as 'ratio of patients to space2').

Results from the SD Model

The graph in Figure 4.13 presents the 'ratio of patients to space2' and the 'patient non-recovery level', whilst the graph in Figure 4.14 presents the 'total patient readmissions' due to 'non-recovery level'. The higher ratio means that intermediate care is crowded and will make the place not conducive to patient rehabilitation. This will cause an increase in the patient non-recovery level. As a result, from that condition, more patients will be readmitted to healthcare. Based on the graph in Figure 4.8, the researcher assumes that if the 'ratio to space2' is more than 0.6 the patient will be readmitted to healthcare.

Based on Figure 4.14, readmission into healthcare starts to increase in week 8 and decreases again after week 12 and starts to increase back in week 17 to week 24, where almost four patients were readmitted to healthcare. As patient readmissions will influence the waiting time of each patient (as they contribute to the total number of patient admissions), this data will be re-fed into the DES model to generate a new waiting time, time in the system, total patients waiting and other attributes that might be of concern to the professionals.

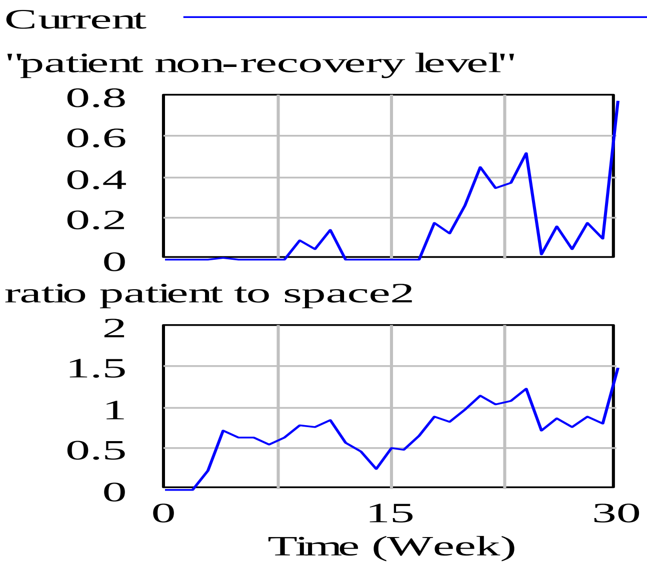


Figure 4.13: Effect on Patient Recovery Level Due to Patients Increases

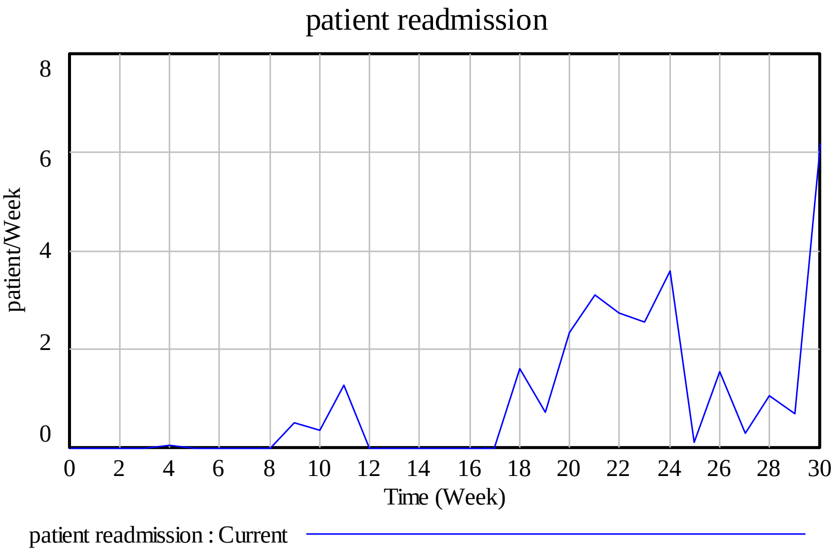


Figure 4.14: Total Patients Readmission Per-Week

Results from Hybrid Models

The researcher presents and discusses two different results produced by the hybrid simulation in which the decision makers might be interested. They are; waiting time, total patients waiting in intermediate care and total patients discharged from healthcare due to the stress of staff as more patients enter healthcare. These hybrid results are compared with the single results to determine their difference, such as waiting time after considering patient readmission and the total number of patients that are being 'forced' to discharge due to the crowded space in healthcare.

a. Patient Waiting Time

The results from the SD model (total patients readmission) will be passed back to the DES model to generate new outputs after considering the patient readmission. Attributes, such as waiting time and total patients waiting for intermediate care, after considering patient readmission (third column) are the hybrid result/output, as in Table 4.6. Table 4.6 provides a comparison of results between the single technique from DES Model (without considering patient readmission) and the hybrid simulation (after considering patient readmission).

Table 4.5: Results Comparison between Single Model and Hybrid Model

Variables	Without Patient Readmission (DES)	With Patient Readmission (Hybrid)
Total patients entering healthcare (patient)	444.80	475.88
Total patients entering intermediate care (patient)	312.40	332.40 (considering some of them go straight to SC)
Number of patients waiting for intermediate care (patient)	24.6	30.5
Average queuing time for intermediate care (hours)	92.27	102.3
Minimum non zero waiting time (hours)	0.97	0.51
Maximum queuing time (hours)	240.60	250.30
Number of non-zero queuing time (patient)	250.40	265.30
Standard deviation (hours)	69.06	71.02

Based on expert opinion, depending on the patient's health status, some of the readmitted patients will not go through the same process as new patients. However, some of these patients still need to be monitored and they will be transferred to intermediate care for another two weeks. Therefore, it will contribute to the waiting time for intermediate care, which will increase to 102.3 minutes instead of 92.27 minutes before readmission occurs and the total number of patients waiting for intermediate care will also increase to 30.5 patients.

The researcher argues that the results from hybrid simulation ('with patient readmission' column) will help decision makers to implement the necessary and appropriate action to reduce the waiting time and total number of patients waiting for intermediate care compared to the single technique ('without patient readmission' column). If only the DES model is used to model the health and social care system, the value of the results from the single technique might be bigger as the simulation does not consider the probability of patients transferring straight to the social care after several treatments in healthcare. For example, the total number of patients waiting for intermediate care generated from the single simulation model was 150 patients. The decision maker will add more resources based on that figure. In reality, the need to add more resources to intermediate care is not practical. Consequently, it will result in underutilisation. Furthermore, the DES model is not suitable to capture the number of patients who will be readmitted due to the reduction in the health quality of the patients. Although the SD model alone can be used to capture all these variables (total patients readmitted due to health deficit), the decision maker will lose information about how many patients are waiting for intermediate care. Furthermore, they will not know how much time each of the patients has to wait in respect of the longest time or shortest time.

b. Total Patients Discharged

Another hybrid result that is found in the models is the total number of patients discharged due to the level of stress of the staff. The stress level is 'counted' based on the total patients entering the healthcare versus total resources (assuming total beds available), this is termed as 'ratio of patients to space' in the SD model. The 'ratio of patients to space' is directly proportional to the 'staff stress level'. As the ratio increases, the stress level will also increase proportionately.

The graph in Figure 4.15 depicts the 'level of stress'. The higher the rate of the ratio the greater the stress level of the staff. The graph in Figure 4.14 depicts the total number of patients that have been discharged due to the stress level of the staff. As the 'ratio of patients to space' increases, the 'level of stress' will also increase, thereby resulting in more patients being discharged from healthcare. Based on the graph in Figure 4.7 I previous sub-section, if the 'level of stress' is more than 0.5, more patients (not the normal rate of patients discharged) will be discharged to intermediate care, giving space to other patients.

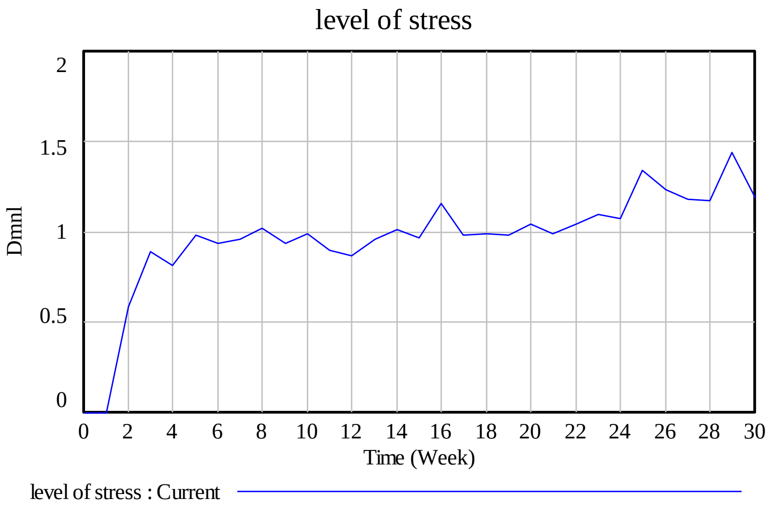


Figure 4.15: Level of Stress Based on Patient Admission

Based on expert opinion, an increase in stress levels will result in a higher probability of incorrect assessments of patients. For example, almost 20 patients were discharged to intermediate care due to the increased level of stress. This is because of new patients entering healthcare who require a bed. This result (shown in the graph in Figure 4.16) will not be fed back to the DES model as this is the final output from the hybrid model. The researcher argues that this patient rate of discharge does not influence any other variable (as it has not been modelled).

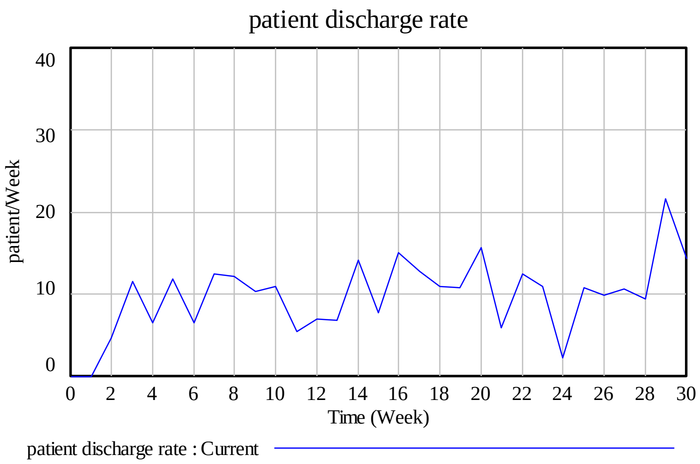


Figure 4.16: Patients Discharge Rate due to Stress Level

Table 4.6 depicts the difference in the figures between a normal discharge generated by DES (assuming that the patient is fit enough to be discharged) and the actual and forced discharge by intermediate care generated by the SD model after considering the staff stress levels in relation to the total patient admissions, for certain weeks. With the support of expert opinion, the researcher argues that the number of patients that have been forced to discharge should still be in healthcare as they were not fit enough to be transferred.

Table 4.6: Variance between Normal and Forced Discharge

Week	Normal Discharge (From DES)	Forced discharge (From Hybrid)	Differences
6	7	8	1
16	13	15	2
20	15	16	1
22	2	12	10
25	8	11	3
29	15	23	8

The figures from the 'differences' column show how many patients were being forced to discharge by the professionals to provide space for new patients. This can be used as a reference if the decision maker intends to improve healthcare, for example, by adding new resources. If the intervention is based on the results from a single technique (model), the decision concerning how many beds should be added to healthcare might be incorrect, as patients who have been 'forced' to be discharged are not considered.

Although the SD technique can be used independently to model the patients discharged to intermediate care together with cause and effect (feedback loop), it can only take an average number of patients for each week. In reality, the patients discharged to intermediate care changes every week. There are weeks in which the resources are fully utilised and other weeks where this is not the case. In considering the above argument, if the total number of patients discharged is based on the average, the total number of patients discharged might not be accurate (different week, different total patient discharge). This will lead to unreliable results, and, consequently, lead to inaccurate decision making.

4.3 REFLECTIONS FROM DEVELOPMENT OF THE PRACTICAL MODEL

From the first assessment by practically developing a hybrid model, the researcher found that many modifications should be made to the proposed framework in order to make sure that the framework can be used by other non technical modellers and will not be too complicated. The modifications include:

4.3.1 Main Phases in the framework

In Chapter Three, the framework was divided into three phases. In the integration phase, the researcher clarified that there will be two types of integration – horizontal and vertical integration. Horizontal refers to the integration between modules in the same technique, whilst vertical refers to the integration between different models. During the development of the models, the researcher realized that these two integrations were not being completed in the same phase, i.e., linking the module within the same technique completed in the modelling phase whilst integration between models is done in phase three. Therefore, the researcher will include horizontal integration (module linking) into the modelling phase whilst the integration phase only involves vertical integration – different models integration. Figure 4.17 depicts the changes in the main phases of this framework.

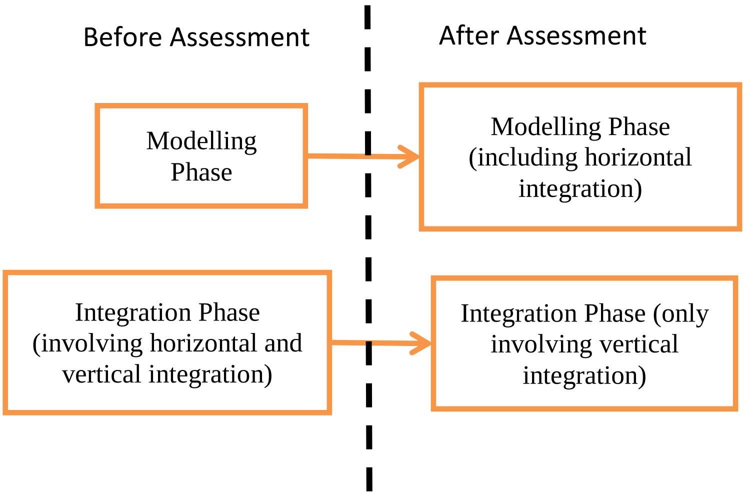


Figure 4.17: Modification in the Main Framework

As the integration phase only deals with vertical (different models) integration, it should have some requirements as not all the different models – SD and DES – can be integrated. Therefore, the framework will continue to the integration phase based on the following conditions:

i. Two different techniques (SD and DES) are used simultaneously
ii. Both models can be integrated.

If only a single technique is used, the model is a single model. If two different techniques are used simultaneously for modelling and both models cannot be integrated, then the models will be separate models. Both models can be integrated if at least one variable from the DES model influences another variable in the SD model. For example, total patient admissions to intermediate care will influence the quality of health of the patient (Elf and Putilova, 2005). As total patient admissions is suitable for capturing by DES, patient health quality is suitable for capturing by SD, and both variables influence each other, both models can be integrated. Based on this argument, the new main framework for the hybrid simulation for modelling complex patient pathways systems are as shown in Figure 4.18.

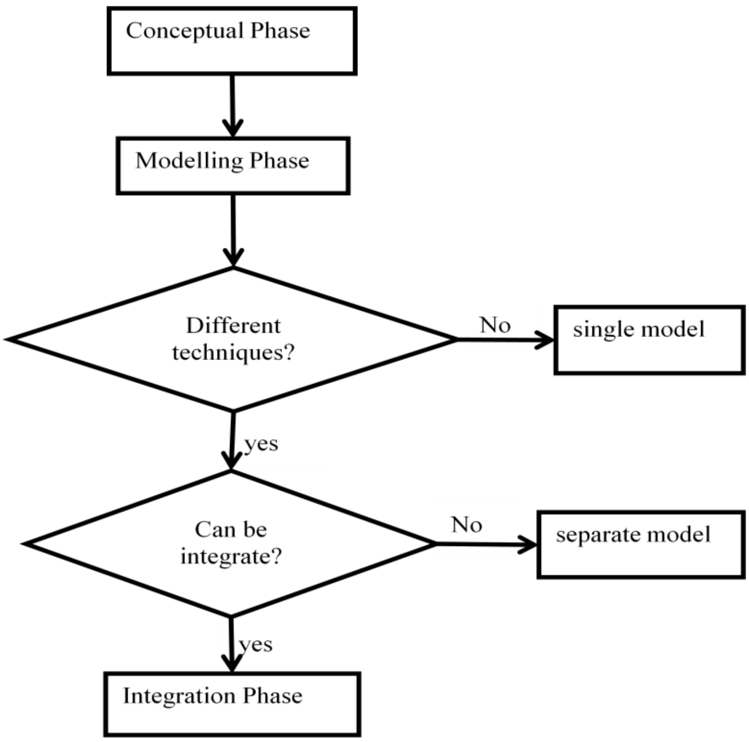


Figure 4.18: Modified Framework – Main Phase

4.3.2 Modification in the Conceptual Phase

In Step Four, the Conceptual Phase, the criteria for all modules has to be defined to facilitate the modelling activities. These are: effect time (short- or long-term effect), type of modelling analysis (aggregate or individual) and having a feedback loop or not. When selecting the match against the module, the researcher feels that there might be some confusion in terms of selecting which variable of the criteria is suitable for each of the modules. Therefore, the researcher argues that there should be some questions that can facilitate the criteria selection. To facilitate variable selection in each of the criteria to be matched with each of the modules, several questions should be asked. Table 4.7 shows the questions that should be asked in order to select the variable of the criteria for each of the modules.

Table 4.7: Questions to Determine Criteria

Criteria	**Questions**
Effect	Will the intervention affect the other subsystems in short- or/as well as long-term (consider short-term within 6 month period and long-term being longer than that)?
Modelling analysis	Is the value (e.g., time/patient's type of disease) between individuals very different?
Feedback loop	Does the feedback loop cause an imbalance in part of the system?

There are no major changes in the rest of the conceptual phase. The final outcome of this phase is the modelling plan which shows how to model the modules. This step is a more graphical notation, which is important as it will guide the modeller in how to integrate horizontally (same technique for different modules) and how to integrate vertically (different model with different techniques), and how the details for each module should be modelled.

4.3.3 Modification in Modelling Phase

In the proposed framework in Chapter Three, the researcher defined this phase as modelling and the activity is transferred in a conceptual model into simulation software (e.g., Simul8 and Vensim) without involving horizontal integration (linking module by module) in the SD and DES model. The horizontal integration has been put under the integration phase. However, upon developing the model, the researcher realized that the horizontal integration is being executed when running the models. For example, in the DES model, once the running of the healthcare module finishes, the researcher has to run the assessment module and only then can the researcher collect the data before transferring the data file (Excel File) to the SD model (vertical integration). Therefore, the phase activity was changed. Instead of modelling module by module followed by modelling the models and then linked all the modules and integrates the models together, it should be develop model by model, assuming that all the modules in the same model (SD or DES models) have been linked (horizontal integration), followed by integration phase. As the modification took place in the main framework (Section 4.3.1), this phase will be modified as well. Figure 4.19 depicts the amended process in the modelling phase.

As proposed in Chapter Three, there are six possibilities for modelling the model, which are divided into three categories; a suitable technique for all modules is the single technique, the suitable technique for some modules is single while some modules require hybrid and the suitable technique for all modules is hybrid. The suitable technique for modelling is the single technique which has two possibilities of modelling – DES (Case One) and SD (Case Two). For Case One the suitable technique is DES and the process for model development is by modelling module by module and then linking all the modules using the output from the first module to the second module and so on (for example, patient attribute – time in the system, patient unique no). For the second case the suitable technique is SD and the process of model development is module by module as well, but they are linked using variables or factors (Helal et al., 2007), or can be model as a whole system. For example, the total number of patients discharged in the healthcare module is being linked with the stress level of the assessment team. The rest of the cases have to use both techniques, SD and DES simultaneously. If there is a need to model the CPP system using the DES and SD techniques simultaneously, the modelling will start with the DES models for each module, linking all the modules together, followed by the SD model for all modules. Both models can actually be modelled at the same time, if the resources (e.g. expertise, software, computers) are enough. The level of the details, especially with the SD model, will depend on the modelling plan.

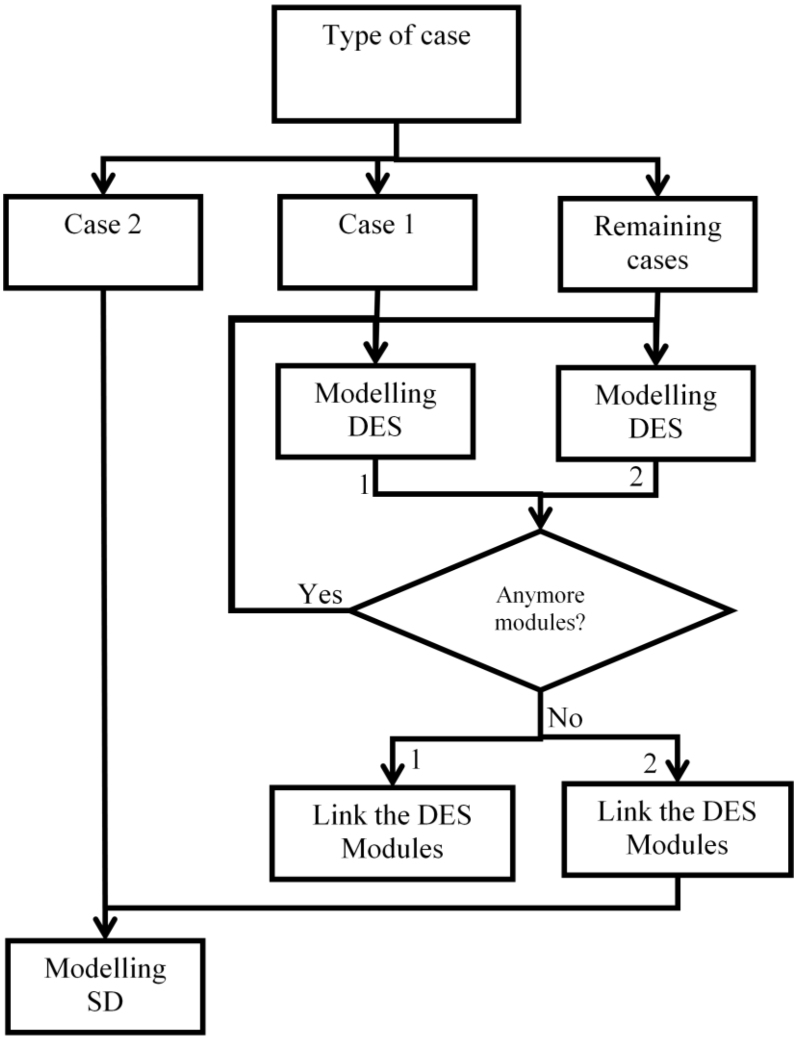


Figure 4.19: Modified Framework – Modelling Phase

4.3.4 Modification in the Integration Phase

Upon practical evaluation of the framework by developing the CPP models, the researcher found that the approach that Chahal (2009) took in integrating both models is different. Some of the steps of Chahal (2009) are repetitive, as mentioned in Section 4.2.4. Upon performing the hybrid operation, the researcher realized that the hybrid operation of Chahal (2009) is somewhat complicated. Therefore, as phase three is totally taken from Chahal's (2009) framework, it will be modified as a whole. The following are the new steps for this phase.

The first step in this phase will be ***identifying variables in both models that can be linked together***. This step is actually a repetitive step in order to ensure that both models can be integrated. Prior to this phase, the modellers should define at least one variable from DES that can be integrated with the SD. This step assumes that more than one variable can be integrated between DES and SD (variables in DES influencing the variables in SD model). This action, therefore, will clearly define which variables from both models can be integrated together.

As the researcher has made the first step defining all the 'influencing' and 'influenced by' variables and mapping them using a table (For example, Table 3.6 in Chapter Three), the next step is to ***define the last output from the variable linkage*** from the relationship between integration of the variables. For example, as mentioned in the health and social care models that have been developed, the variable linkage between patient admission from the DES technique and the level of stress captured by the SD technique, will influence the discharge patient rate. The total number of patients in intermediate care (captured by DES) will also influence the patients' health quality (captured by SD), which will re-affect the waiting time in each as a result of patient readmission. The patient discharge rate and waiting time, after considering patient readmission, are the last outputs.

The next step is to ***run both models and exchange all variables involved between the DES and SD Models.*** The running process will be started by gathering all the influencing variables with the DES model and putting them in one file, such as an Excel File. This file will then be transferred to the SD model, where the 'influenced by' variables in SD are connected with the 'influencing' variables in DES. For example, total patient admissions from the DES influences patient health quality, modelled in SD. As a result of the connection and communication between both variables ('influencing' and 'influenced by'), influencing other variables (patient readmission), will be a iterative process of the data transferring output produced by the SD model, as a result of the variables communication between the SD and DES, influencing other variables in the DES. For example, in the models that have been developed, the total patients admission/discharged influences the total space in intermediate care (becomes more crowded). As a result, it will influence patient health quality, and, consequently, will affect patient readmission into healthcare. As patient readmission is a tangible factor, which is suitable to be modelled in DES and influences the total waiting time for each patient, those patients who are readmitted will be fed back into the DES model. The process of transferring data from DES to SD and SD back to DES again will take place until the output is 'stable'. The word 'stable' here means that outputs generated from the current running process and previous running process does not differ much.

However, if the output produced by the SD model, as a result of the communication between the variables in the DES and SD, does not influence other variables in the DES model, the running process will stop here as the final output has been produced. Figure 4.20 depicts the process for this step.

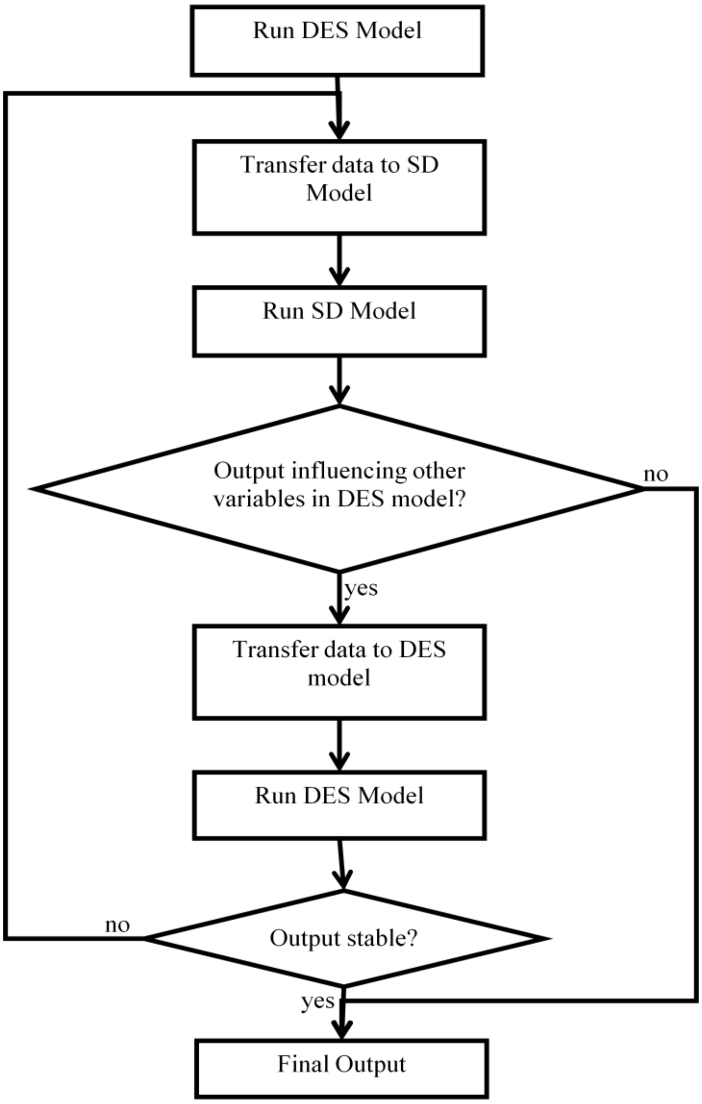


Figure 4.20: Decomposed Process of Step Three

The second from last and last step in this phase is ***evaluation of the outputs that have been produced and suggestions for system improvements***. The last output will be either in the DES or SD model, depending on which variables were previously 'influenced by', or 'influencing' other variables in the other model. If the variables that have been 'influenced by' in SD have influenced other variables in DES, the last output will be in the DES model. Otherwise, the model will be in the SD model, as the variable that was 'influenced by' in the SD model is not influencing the DES model. The flowchart in Figure 4.21 depicts the process of determination of which model will provide the last output (variable).

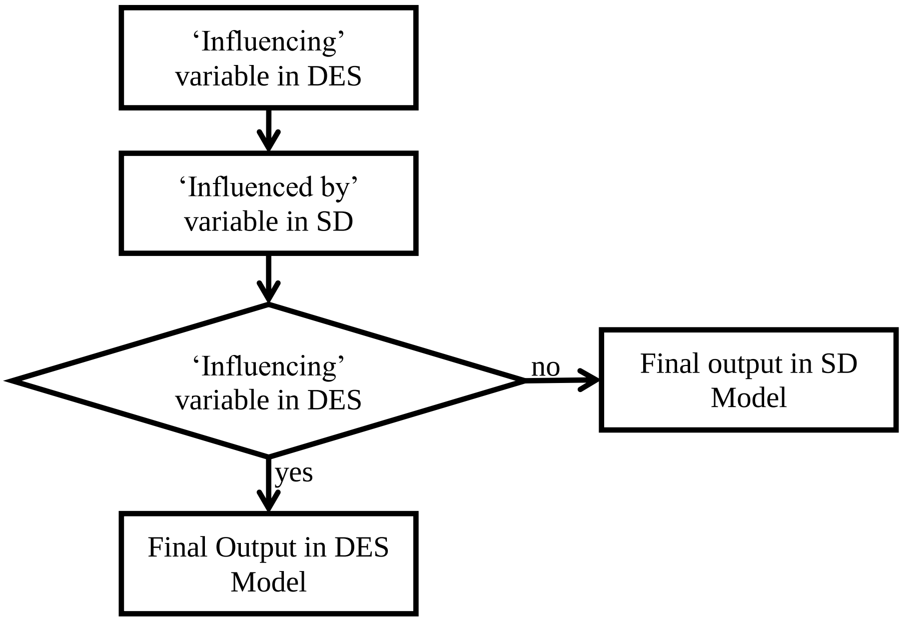


Figure 4.21: Determining Outputs in Which Model

If the decision maker makes improvements to the system, the decision maker basically should change the inputs in both models to maintain the variables' models integration and the outputs viability and reliability. The changing of inputs for any intervention should be done in both models to show a relationship when both are connected to each other. For example, to reduce the patient waiting time, the policy makers will increase the resources, such as beds, to accommodate more patients. This will reduce the stress levels experienced by the professionals. As a result, the patient assessment's error will be minimized, thus, reducing the total number of patients' readmitted. Since the resources are a tangible factor that influences the stress levels (intangible factor) captured by the SD model, the inputs (number of beds) in both models should be changed to maintain the reliability of the models communication and outputs from both models. However, there are certain circumstances that only a particular model needs to change its variable (intervention).

There are guidelines to determine whether or not the changing variables should be in both models. If an intervention was done to 'X' model and it influences other variables in 'Y' model, the variables in both models should be changed. Otherwise, only variables in 'X' model should be changed. Figure 4.22 depicts this situation, where X model refers to either the DES or SD model.

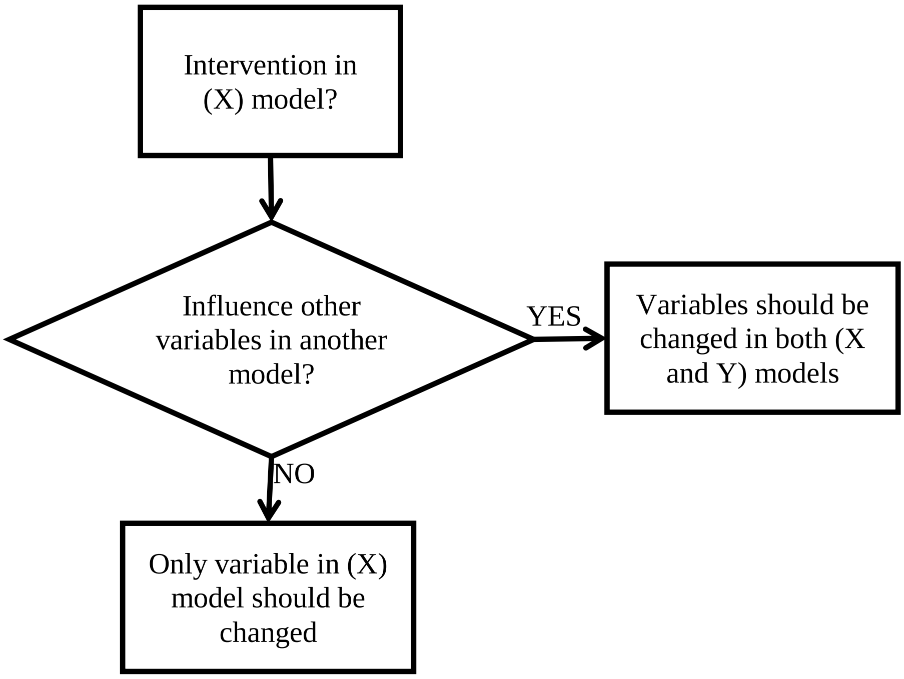


Figure 4.22: Conditions for Changing the Inputs for Intervention

4.4 CONCLUSIONS

This chapter has provided thorough discussions on the applicability and suitability of the developed framework to the CPP systems. The framework was applied to the health and social care. To assess the initiative of introducing intermediate care between health and social care, a hybrid model was developed based on the framework that was proposed in Chapter Three. The development of the hybrid model was based on various literature and expert opinion. The researcher discussed some of the outputs produced by DES, SD and the hybrid simulation. The hybrid result was compared with the single result to show the importance of the hybrid simulation to the decision makers. Upon developing and linking the processes of both models, the researcher realized that some steps of the proposed framework were not quite suitable and did not fit the CPP model very well. Therefore, several steps were modified based on the researcher's evaluation. The evaluation and modification is to ensure that the framework is less technical, fits with the CPP model development and is easy to follow.

The next chapter will provide another testing of the framework. The modified framework will be applied to other case studies that have been taken from the NHS Institute for Innovation and Improvement. Most of the case studies used conventional and traditional methods in problem solving. In addition to testing the framework for improvement, it also aims to show how modelling can be a powerful tool for the decision making process.

CHAPTER FIVE: FRAMEWORK ASSESSMENT FROM THEORETICAL PERSPECTIVES

5.1 INTRODUCTION

The previous chapter has provided the assessment of the proposed framework by applying it to a case especially to a health and social care setting that uses a single technique for modelling the complex patient pathways (CPP). Since the focus of the assessment was to see the framework's applicability and suitability to the CPP, the validity of the developed model is not the prime concern. Based on the observation and application of framework to the health and social care case, several steps in the framework proposed earlier in Chapter Three have been modified. This is to ensure that it is the best way to model the CPP systems. The changes mainly involved the overall framework, which included reorganizing the main phases, the names of the phases and the modification on modelling and integration phase.

A limitation of a case study strategy is that the framework can only be used within the case study area (Chahal, 2009). Therefore, to see the applicability and suitability of the framework to other types of CPP, the framework needs to be assessed again using several study cases from several care settings. These case studies are taken from documentation in NHS Institute of Improvement and Innovation (2010). Four case studies were used to assess and test the framework. The researcher managed to find several 'influencing' and 'influenced by' variables that can be included in both models (SD and DES) theoretically. Most variables that have been defined in each case are almost the same. As defined by Tashakkori and Teddlie (2003), data collection activity should be stopped when it reaches saturation. Data saturation, as defined by Tashakkori and Teddlie (2003), refers to the condition where the researcher cannot find any new item after several data collection activities. In this research, since the variables 'influence/influenced', as defined by the researcher, are similar for each case study and the researcher could not find any new variables, only four case studies were used.

The aim of this chapter is to improve the framework using a theoretical approach by applying it against a few case studies argued to have a CPP system that involves transferring patients across several departments or care givers. To capture all the variables involved, it is better to first develop the model and observe it. From the developed models, the variables involved can be observed. Views of policy makers, professionals, as well as other stakeholders can be used to identify all the variables involved. Furthermore, the modelling exercise will enhance the understanding of the systems and its boundaries will become clearer. However, due to several limitations, such as time, technical support, and data availability, this chapter does not explain the practical modelling, linking or integration (modelling using the software) but theoretical. Each step of the framework is summarized in Table 5.1. These phases and steps will be applied to several case studies to improve the framework. As this chapter does not include modelling activities, phase two, which is the modelling phase, is briefly defined as whether both models can be classified as hybrid or not. This step will guide whether or not to continue to the next phase.

Table 5.1: Phase and Steps in the Framework

Phases/Steps		**Objective**	**Method (How)**
Phase One: Conceptual Phase			
1.	Problem Source Definition and Objective Identification	To set boundaries of model building and identify which subsystems are involved	By asking professional expert opinion
2.	Conceptual Model and Modularization	To reduce the complexities of model development	Conceptual Model – from scratch from system description to logical system (building blocks) Modularization – divide several processes into a group or divide into several subsystems or care settings
3.	Identify modules that will be affected by the overall objective	To reduce time in model building and to set boundaries	By asking professionals opinion or by looking at the subsystems that have a direct impact on the defined objectives
4.	Define the criteria of each module	For selection of suitable technique for modelling each module	Answering the questions that have been provided. It will provide a guide to the selection of the criteria properties
5.	Selecting the suitable technique for modelling	Due to the fact that not every module has to use hybrid modelling; decreases time for modelling	Refer to Table 3.3 in Chapter Three.
6.	Modelling IC Plan	To facilitate the modelling activities as it shows how logically to model each of the modules	Straightforward process based on the previous step.
Phase Two: Modelling Phase			
1.	Single Model or Hybrid Model	To identify whether both models can be integrated or not. If not, integration phase will not be conducted.	By identifying whether or not variable(s) in DES model influence variable(s) in SD model.
Phase Three: Integration Phase			
1.	Identifying the variables in both models that can be linked together	To identify remaining variables that are influencing/influenced by.	By searching which variable in DES model influences variable in SD model

Phases/Steps		Objective	Method (How)
2.	Define the last output from the variable linkage	To show how the variables are related and produce final output	Output produced by step 1.

5.2 CASE ONE: CPP WITHIN HEALTHCARE SYSTEM

The NHS 2000 plan introduced a performance indicator for the A&E departments in British hospitals – that every patient who enters A&E should finish his/her journey within 4 hours (Chahal et al., 2009). The indicator was made in order to receive a significant increase in government funding (Chahal et al., 2009). To improve the performance, many hospitals have used multiple approaches to achieve the national target to avoid a cut in their finances as well as other penalties. One of the initiatives was to promote and implement an Information Technology and Communication (ICT) infrastructure, for example, the introduction of an electronic whiteboard for patient tracking in the A&E, although implementing this system involved huge investment, the short- and long-term results are uncertain (Chahal et al., 2009).

The researcher argues that the implementation of the whiteboard for patient tracking will affected other departments as well, such as the inpatient department (as the pressure from the electronic whiteboard) and the surgery department, as more patients will be transferred to wards for treatment as the A&E would not be able to fully support the needs of the patients. Furthermore, as more patients enter A&E, pressure will mount on the A&E departments. This is because they need to treat the patients within 4 hours. The reason why the researcher expands the case until discharge is because there is a probability that a patient from the A&E will be transferred into the ward, thereby creating a problem such as bed blocking. The researcher assumes that due to faster processes in the A&E, the patient will have to queue-up to enter the next phase of the treatment. Based on the expert opinion from the professionals, two conditions will happen as a result of the pressure. Either the professionals will treat the patient urgently and ward the patient (making the in-patient ward busier), or the professional will send the patient home. Consequently, the patient will re-enter A&E when the illness returns.

The researcher applied the framework to this case based on experts and expanded the case from A&E to other departments (surgery and wards).

5.2.1 Conceptual Phase – Case One

There are six steps in Phase One. This phase involves transferring the logical business process of each department and transferring it into a building block and finally, to a modelling plan. The modelling plan is the last output produced by Phase One and is a guide for Phase Two, which is the modelling phase. The following explanations are the steps involved in the Conceptual Phase.

STEP ONE: Problem Source Definition and Objective Identification

Problem definition: As each patient has to be treated within 4 hours, the researcher argues that it will indirectly affect other departments, such as the inpatient unit (ward) and the surgery unit. These departments are connected to the A&E departments. The A&E department will decide on where the patients will go after being treated, whether they return home or stay on the ward. The impact of the introduction of the initiative is only known to A&E, and not by other departments that are connected with the A&E. With the above arguments, the researcher states that modelling the impact of the initiative, as in Chahal et al. (2009), should be expanded to include other departments that are integrated with the A&E department. Based on the arguments, the problem definition of this case is: The impacts on the other departments, such as surgery, rehabilitation unit, etc., are not known due to the introduction of staff performance indicators (the patient should be treated within 4 hours) since these departments are connected to the A&E department.

Objective Identification: As the impact of the introduction of the initiative is not known to the other units in the healthcare (inpatient, surgery, rehabilitation), the objective of the modelling is to identify the impact of the electronic white board to the healthcare system as a whole.

STEP TWO: Conceptual Model and Modularization

First, the patient will enter the healthcare gate for registration. The patient will be assessed initially by a nurse to see whether the patient needs to have a blood test or not. Then, the doctor will continue with the treatment after assessment has been done. If the patient is not considered medically fit enough for discharge and needs to have surgery (for example, an accident involving a fracture), the patient will be admitted to a ward. The operating theatre should be booked before the surgery. After the surgery, the patient will be placed on a ward and have rehabilitation and physiotherapy activities until the patient is medically fit enough to be discharged. Figure 5.1 depicts the pathways that the patient experiences starting from arriving at A&E until discharge.

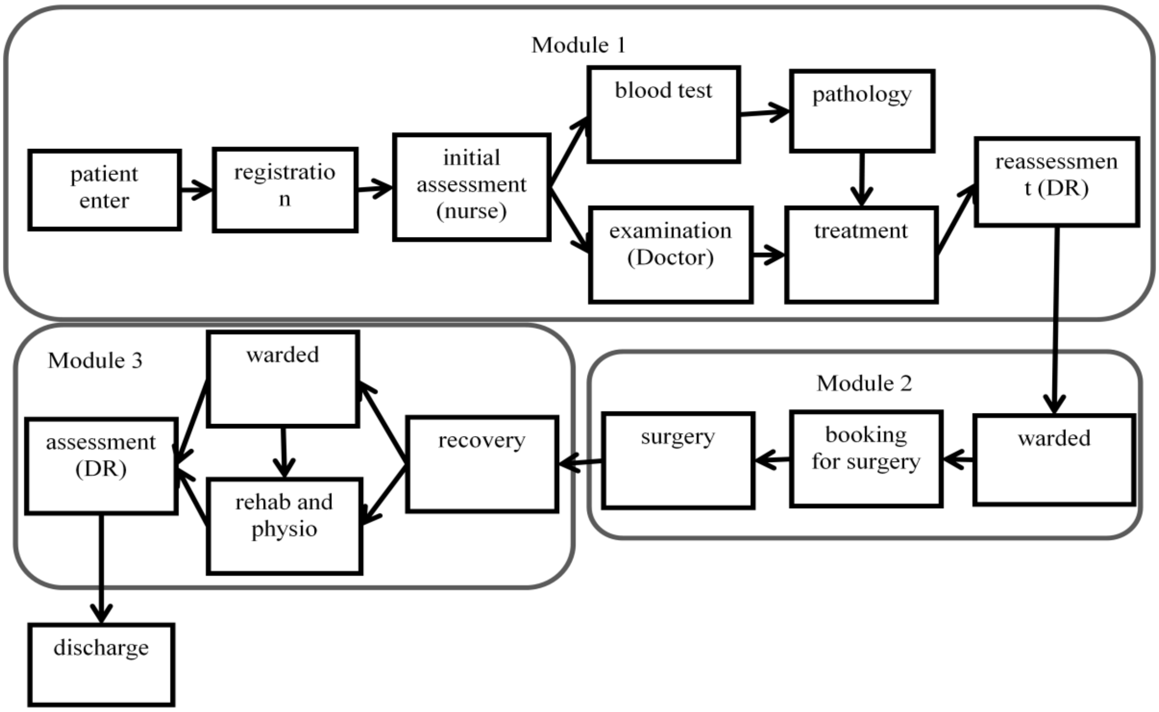


Figure 5.1: Conceptual Model and Modules – Case One

As the process in Case One is long and complicated to model, especially when using the DES technique, it should be grouped into several modules. This process is called 'modularization'. As explained in Chapter Three, there are two options in modularization, either by dividing the whole process into several modules, or by dividing it based on departments or care settings. As the process in Case One involves multiple departments, the modularization is based on the process, in which a large process will then be divided into several modules. The researcher grouped the patient pathways into several modules, which are; Module 1 (*'A&E'*), Module 2 ('*Surgery*') and Module 3 ('*Rehabilitation*').

STEP THREE: Identify modules that will be affected by the overall objective

Based on expert opinions, several consequences are expected to happen due to the introduction of the electronic patient tracking system initiative. Due to the introduction of the initiative, it will increase the pressure on the professionals as they have limited time to assess the patient. Due to the limited time as well, it will push the patient to other departments, especially when they are not medically fit enough to be discharged on the spot. On the other hand, due to limited time, it will affect the assessment time. This will increase the possibility of wrong assessment and the patient is discharged home. In the end, the patient will enter back to A&E, especially if their illness is recurring. There were also possibilities of problems in the long term, as patients seeing that the A&E is not fully occupied will come for treatment when they do not have an emergency case (Chahal et al., 2009). Considering that there are many patients involved in accidents at one time that need to have surgery immediately, it will increase tension among the surgery staff and many patients will have to wait due to the limited resources. After surgery, the patient will then be transferred to a ward for rehabilitation and physiotherapy. As patients are being transferred to the wards for rehabilitation and physiotherapy, it will reduce the available resources and cause bed blocking.

Therefore, based on the arguments, the researcher states that the affected modules, due to the implementation of the electronic tracking of patients to the A&E unit, will be the ‘A&E’ module, ‘surgery’ module and ‘rehabilitation’ module. The rehabilitation and physiotherapy processes are grouped into one module as the process occurs at the same time. Table 5.2 depicts a summary of justifications for the selection of the affected modules.

Table 5.2: Justification for the Affected Modules – Case One

Module	**Justification**
A&E	- Increase pressure on the professionals - Decrease patients in the A&E area - More patients will enter the A&E (patient readmission) and, consequently, there will be mistakes in patient assessment due to more patients, and to fulfil the performance indicator
Surgery	- increase in patients for surgery - increase in tension of surgery staff - long wait due to limited resources
Rehabilitation	- long wait due to the limited resources - bed blocking to the ward (due to rehab and physiotherapy)

STEP FOUR: Define the criteria for each module

The next step is to define the criteria for each of the modules. This setting up of criteria will determine which technique (DES or SD) is suitable for modelling the modules. The initial framework has been modified by adding questions before setting up the criteria for each module. This is to ensure that the criteria that have been set up for each of the modules are suitable for the module’s condition. Although one question should be answered for each module, the answer could be both. For example, the answer to the question in respect of time could be either short- or long-term effect.

As mentioned in the previous chapter, the questions are in respect of affected time, type of analysis and feedback loop. The question will facilitate the selection of the answer, whilst the professional's opinion can be used as guidance to answer the questions. The questions that should be asked to facilitate the selection of the criteria are as follows:

a. Effect – Will the intervention affect the other modules/subsystems in short or/as well as long-term? (Answer – short or long-term effect)
b. Modelling analysis – Is the value (e.g., time/patient's type of disease) between individuals very different? (Answer – YES, therefore, modelling analysis should be individual analysis, NO – therefore, should be aggregate analysis)
c. Feedback loop – can the feedback loop cause an imbalance to the system? (Answer – YES or NO).

Based on expert opinion, in terms of the effect, 'A&E' modules will have short- and long-term effects. In the short term it will clear the A&E, whilst the long term effect would be more patients will be entering A&E as they see idle resources in the A&E department. With many patients having to undergo a surgery process, physiotherapy, rehabilitation, as well as being placed on a ward, the waiting time for each patient will be increased in the short-term period. Regarding the type of modelling analysis, due to the condition that 'A&E' and 'surgery' modules have a large variance between individual values (e.g. time finish), the modelling analysis should be an individual analysis for both modules. For the 'rehabilitation' module, it should use aggregate analysis as the values between individuals are not very different. As the A&E department is clear and idle, more patients will enter the A&E department. However, by clearing the rehabilitation unit, many patients will be discharged early, which will result in patient readmission. Therefore, both modules (i.e., 'A&E' and 'rehabilitation') will cause feedback loop to the system, whilst the 'surgery' module will not affect other parts of the system, i.e., does not have a feedback loop. Table 5.3 exhibits the questions for each of the modules and the answers for each of the criteria, as well as the selection of the suitable technique for modelling each of the modules.

Table 5.3: Criteria and Variables for Each of the Modules – Case One

Criteria	Questions		
Effect	Will the intervention affect the other subsystems in the short- or/as well as in the long-term?		
	A&E	Surgery	Rehabilitation
	Short-term: clear A&E Long-term: more patients will enter A&E	Short-term: long wait due to excessive number of patients	Short-term: long waiting for bed, rehab and physiotherapy
Modelling analysis	Is the value (e.g., time/patient's type of disease) between individuals very different?		
	A&E	Surgery	Rehabilitation
	YES - Individual analysis	YES – Individual analysis	NO – Aggregate analysis
Feedback loop	Can the feedback loop cause an imbalance in part of the system?		
	A&E	Surgery	Rehabilitation
	Yes – A&E clear, more patients enter, especially from patient readmission	No feedback loop	Yes – release of patients early to clear bed blocking, consequences patient re-enter

STEP FIVE: Selecting a Suitable Technique for Modelling

There are different suitable techniques for modelling each of the modules, as each module has three criteria that should be assigned to it. Each criterion has a different answer with a different suitable modelling technique. The final technique is based on the set up criteria, whereas, if the modules have to be modelled using different techniques (i.e., SD and DES), the hybrid simulation is the most suitable. The A&E module has a short and long term effect, which suggests different suitable techniques (SD for the long-term effect and DES for the short-term effect), should be analysed individually (suitable technique – DES) and have a feedback loop, (suitable technique – SD). If the module has to use SD and DES based on the set up criteria, the hybrid simulation will be used for modelling this module.

The surgery module has a short-term effect, should be analysed individually and does not have a feedback loop. Therefore, the suitable modelling technique for this module is DES. The suitable modelling technique for the rehabilitation module is the hybrid simulation, as it has a short-term effect, which can be modelled using DES, should be analysed by aggregate analysis and has a feedback loop on which both criteria are suitable to be modelled by SD. Table 5.4 depicts the suitable modelling techniques for Case One.

Table 5.4: Suitable Technique for Modelling – Case One

Criteria / Module	**Effect**	**Modelling analysis**	**Feedback loop**	**Final Technique**
A&E	Short-term – DES Long-term – SD	Individual – DES	Yes – SD	Hybrid simulation
Surgery	Short-term – DES	Individual – DES	No – DES	DES
Rehabilitation	Short-term – DES	Aggregate – SD	Yes – SD	Hybrid simulation

STEP SIX: Modelling Plan

Based on Tables 5.3 and 5.4, Figure 5.3 depicts the modelling plan for Case Study One. The explanation of how these modules and models will be developed is in Section 5.2.2.

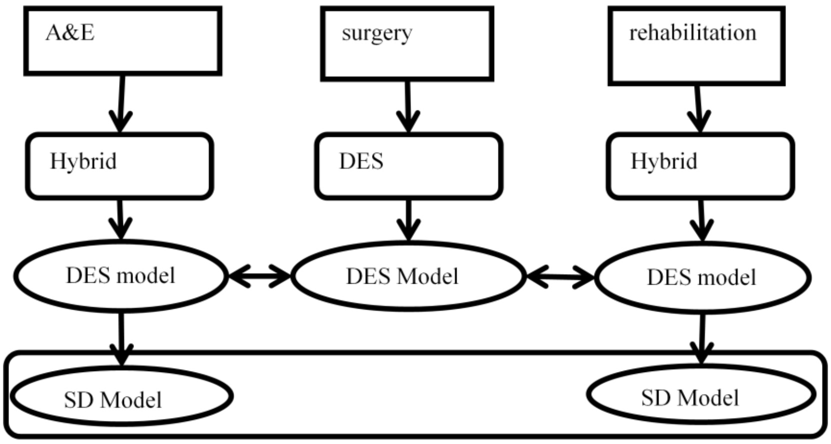


Figure 5.2: Modelling Plan – Case One

5.2.2 Modelling Phase – Case One

Based on the modelling plan in Figure 5.2, the 'A&E' and 'rehabilitation' modules have to use DES and SD techniques simultaneously, whilst the 'surgery' module only has to use the DES technique for modelling. The modelling phase will start with the development of the DES model based on module by module and will be linked to each other using the time variable. To link the DES models' modules, the output from the first module will be used as an input for the second module, whilst the output from the second will be used as an input for the third module. After that, the SD development is started. The SD model is more detailed for the 'A&E' module, as well as the 'rehabilitation' module. The 'surgery' module will be put in the SD model but will not be too detailed, or just one step will be applied for the surgery module. SD development will also be modelled module-by-module and will be linked using variables/factors. For example, variables from the 'A&E' module (total patients' discharged) will be connected with variables from the 'surgery' module (level of staff pressure).

Single Model or Hybrid Model

The whole system needs to be developed using different techniques. The first step is to decide whether different models can be integrated or not. The decision will depend on the variables in SD that have been influenced by the variables in DES. Looking at the conceptual model and phases, the researcher assumes that the total admission of patients to the healthcare will affect the level of pressure among the staff and professionals. The suitable technique for modelling the patient pathways is DES, whilst the pressure indicator is suitable to be modelled by the SD technique. The pressure experienced by the professionals due to the performance indicator will influence the errors in patient assessment. As a result, it will increase the patient re-admission (in that more patients are not assessed correctly and are sent home). As there are variables in DES (total patients admitted) that will be influencing the variables in SD (pressure level), these two models can be integrated.

5.2.3 Integration Phase – Case One

After determining that these two models can be integrated, the next step is to integrate both models using variables that have been detected. The determination as to whether these two models can be integrated or not is based on the previous step, where there is at least one variable in the DES model that influences one of the SD's variables. This phase will determine more variables from DES that can be connected with variables in SD. The explanations of the first two steps in this phase and how these variables exchange information theoretically are as follows:

STEP ONE: Identifying the variables in both models that can be linked together

Although the previous step has shown that the total number of patients admitted (from the DES model) can influence the level of pressure among the staff (modelled by SD), there are some other variables that can be integrated as well. Therefore, this step is to determine the other variables from both models that can be integrated together. The following lists are the variables from DES that influence variables from SD based on professional experts.

Variables from the DES Model: Total patient admission to A&E, surgery, rehabilitation, warded, time for assessing patient in A&E (within 4 hours)
Variables from the SD Model: pressure among professionals, patient fatigue (due to waiting time)

STEP TWO: Define the last output from the variable linkage

A new variable will emerge after the integration of these variables, which the researcher recognises as the 'final output'. This final output will re-influence other variables in the model. For example, in the previous chapter, the total patient admission will influence the pressure on staff as they contribute to the bed-blocking problem. Consequently, some patients may have to be discharged early when they should have been kept in the ward, which will increase patient readmission. This will affect the time duration for assessing patients and will increase the waiting time. Based on this description, the total patient admission ('influencing' variable) from DES will be integrated with the pressure of staff ('influenced by' variable) from SD that produces the final output, which is patient readmission. Depending on the model that has been developed, sometimes the final output of the variable integration will re-influence other variables, while other times it will not (example can be referred to in Chapter Four, Section 4.2.5, Discussion and Analysis of the Results).

This step is to make clear what variables from DES will be integrated with other variables in the SD model, and what kind of variables will be produced by the integration (final output). Based on expert opinion, the following are the variables integration and their final output.

i. Total patient admission to any unit in healthcare (A&E, wards, rehabilitation, etc.) will influence the pressure among the professionals. Consequently, it will contribute to wrong patient assessment (some of patients) and some patients that have been discharged will not be fully recovered or fit enough, contributing to patient readmission. The total patient admission and professional pressure is the integration between the DES and SD model. These two variables will produce other variables – wrong patient assessment and patient readmission (patient is not assessed carefully).

ii. As the resources are fixed and the patients are variables that can change anytime, the ratio between total patient admissions in A&E and resources, such as doctors, will increase if more patients enter A&E and the resources are limited. This condition will influence the time to assess each patient. As this happens, it will influence the patient's mood (become bored and fatigued) leading to the patient leaving the hospital without having their treatment. This will also lead to the patient's breach of the system. Therefore, the time for assessing the patient from the DES model will influence the patient's mood modelled in SD, consequently, creating a condition in which the patient leaves before having the treatment.

Variable Exchange – Theoretically

From the DES Model

The DES model will be run first to generate total patient admission and discharge. This data will be gathered and put in an Excel file. This file will be embedded in the SD model to generate output in terms of human emotions (patient fatigue, pressure) that cannot be read by the DES model.

To the SD Model

In this model, there will be extra variables that are level with professional pressure and the level of patient fatigue. These variables will be connected with the data of patient admission/discharge via the Excel file. When the SD model is run, it will compare with the table lookup function in the SD. There will be two table lookups in this model. The first table lookup is the ratio of patients to staff (patient/available staff) and professional pressure. At a certain point, when the level of pressure reaches its peak, due to time limitation and more patient admission, the professional involved will make an inadequate assessment of the patient. This situation will lead to the patient's readmission. The patient readmission data will be passed back to the DES model to generate a new output (e.g.: waiting time). The second lookup table is the total waiting time versus total patient breach. This lookup table will generate total patient breach, as the assessment time is too long.

5.3 CASE TWO: BREACH ANALYSIS AND PATHWAY REDESIGN

The nature of the journey of hepatitis patients' was unclear. This is because some patients have no fixed abode and have substance abuse problems, while some have multiple pathologies (NHS Institute for Improvement and Innovation, 2010). There were no clear patient pathways. The patients often breached, but it was difficult to determine why given the variability of the pathways and the nature of the complex lives of the patients. Patients often did not attend their appointments and were not contactable. Consequently, the staff and professionals joined together to identify the cause of the problem by reviewing and randomly selecting six of the hepatology case notes. Based on the notes, each pathway was detailed on a bespoke breach analysis form. These were then summarized on a breach analysis summary form to evaluate trends and patterns. A similar method has been used to identify breach analysis for lung cancer.

5.3.1 Conceptual Phase – Case Two

There are six steps that should be followed in the first phase of this framework. This phase will focus on developing from the conceptual model towards the modelling plan. This plan depicts how the models will be developed as they might have to use multiple techniques, i.e., DES and SD techniques simultaneously. The following explanations are the steps involved in the Conceptual Phase for this case.

STEP ONE: Problem Source Definition and Objective Identification

Problem Definition: The researcher argues that there are two reasons that contribute to the cause of the problem. The hospital has too many different patient pathways, which depend on the patient's condition. Also, they do not have a standard 'flow chart' that can identify which pathway the patients with hepatitis should follow based on their case (disease and treatments). Consequently, it will affect the patient's mood (causing fatigue due to finding the right pathways, which takes more time) leading to the patient breach. Therefore, many patients do not come to their appointments, thereby causing a waste of resources. The researcher assumes that the patient pathway redesign, which is based on the patients' trend and pattern analysis, is done using the conventional method (paper analysis). This will contribute to other problems, such as, no idea how long patients are in the system, as well as the waiting time.

Objective Identification: Based on the problem definition, the modelling objective for this case is to redesign patient pathways. Upon finishing the modelling of the patients' pathways, the researcher argues that it will minimize other problems, such as patients not attending their appointment (as the pathways are clear). Having said that, the patient's behaviour will not be included in the model to reduce the modelling development time.

STEP TWO: Conceptual Model and Modularization

Figure 5.3 depicts the conceptual model of the patient pathways, which is based on the document in NHS Improvement and Innovation (2010). Patients go to A&E or an outpatient clinic to see a doctor when they have a problem with their health. When the patient is suspected of having hepatitis, they will be sent to a consultant at a specialist clinic or ward and will undergo several tests, including a blood test. Upon confirming that the patient is suffering from the hepatitis disease, the patient will once again be seen by a specialist consultant. At this time the patient will be registered by a clinical nurse specialist who arranges the specialist drug treatment after consultation with the patient, and explains how the aggressive treatment could affect their life. Once agreed, the patient will undergo a course of treatment until the patient is fit to be discharged. The treatment will also be given during the appointment. In other words, although the patient has been discharged from the ward, the patient still has to undergo treatment until a full recovery is made.

Upon finishing the conceptual model, the next step is the ‘modularization’ process. The modularization for this case is based on grouping several processes into several modules instead of separating them based on their care setting. The process for ‘patient enter healthcare’ is where the patient starts the process, which may be from A&E or an outpatient clinic. The A&E unit and outpatient clinics have their own process. Therefore, the researcher considers this as one module, respectively. Based on the document, some of the patients will have multiple pathologies. Therefore, the researcher has grouped the process of being suspected and seen by the consultant, multiple blood tests and waiting for the results as one module. It seems that these processes have only three steps. However, as the patient might have multiple blood tests to confirm the disease, it will make the process more complicated, as the patient has to undergo several tests with different results. To make the process less complicated the three steps, as in the conceptual module, will be included in one module. The patients will also undergo several treatments. Considering that there are many processes or pathways (the researcher could not define these due to lack of knowledge and references) in each of the treatments, only four processes (from the conceptual model) will be put under one module, as in Figure 5.3. Based on the document, although the patient is discharged, they have to undergo a series of appointments until full recovery. Considering that there will be a series of processes (booking and cancelling appointments), it will be put under one module.

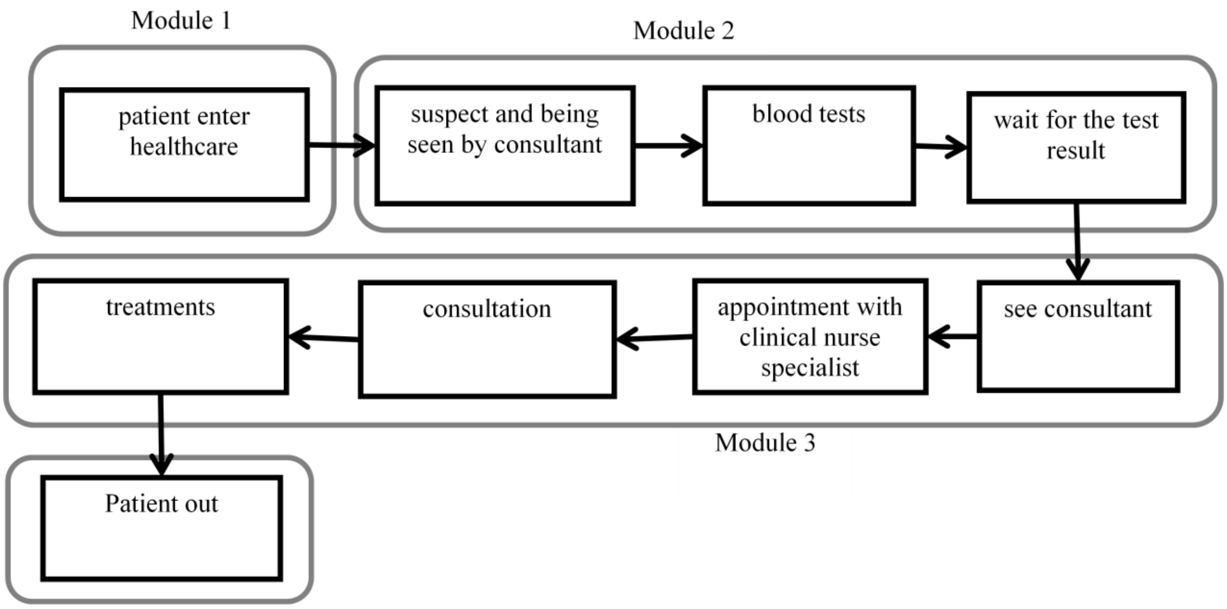


Figure 5.3: Conceptual Model and Modules – Case Two

STEP THREE: Identify modules that will be affected by the main objectives

The whole pathway has been grouped into several modules to facilitate the model development, as has been described by the researcher in the previous step. For the management module, Module 1 is known as 'A&E', where the patients are examined and referred to a consultant, and Module 2 is known as 'Test', where the patient has multiple tests depending on their conditions. Module 3 is named as 'Consultation', where the patient attends a consultation prior to the treatment, and Module 4 is named the 'Appointment' module in which the patient receives an appointment when they are discharged. Based on the objectives that have been identified and the opinion from the expert, the researcher argues that for any intervention done to the system, the effect will be in the 'test' and 'consultation' modules. If the intervention done to the test module (by adding more physicians and consultants) results in more patients getting their treatment during the 'test' module and reduces patient waiting time, then more patients will be transferred to the 'consultation' module per stipulated time. The consequences are that the time for each patient's consultation will be reduced (as more patients have to be entertained) to enable all the patients to receive the service. The researcher does not include A&E and the appointment module for various reasons, as follows:

a. Assuming that there are few patients that are suspected of having hepatitis, the impact on the other modules is small.
b. The researcher also assumes that the appointment module is the process where the patient will have a consultation with the physician, with minor treatment, compared with the first

treatment when the patient is admitted. Therefore, the researcher argues that this module has no effect on the other module.

Therefore, only the 'tests' and 'consultation' modules are affected and will be included in the modelling activity.

STEP FOUR: Define the criteria for each module

All the modules must be assigned with specific variables from the three different criteria that have been developed. This is to facilitate the suitable technique/s that has/have to be used in order to develop the modules. A question will be asked to help the modeller determine the suitable answer for each of the criteria. The criteria must be determined as each of the modules affects the modelling analysis as well as the feedback loop. Based on the questions in Section 5.2.1 (Step 4), both modules have a short-term effect depending on the intervention, e.g., adding more physicians and other resources to treat the patients. As a result, more patients are treated faster leading to more patients entering the consultation module. The value gaps between one individual and another, such as time in the system, type of disease and treatment, are wide for both modules, thus, both modules should be analysed individually to avoid errors in the decision making process. As the feedback loop is more sequential in both modules, there is no feedback loop in either module. Table 5.5 exhibits the questions for each of the modules and summarizes the answers for each of the criteria for Case Two.

Table 5.5: Criteria and Variables for Each Module – Case Two

<table>
<tr><th>Criteria</th><th colspan="2">Questions</th></tr>
<tr><td rowspan="3">Effect</td><td colspan="2">Will the intervention affect the other subsystems in short- or/as well as in long-term?</td></tr>
<tr><td>Test</td><td>Consultation</td></tr>
<tr><td>Short term – patients are treated faster</td><td>Short term – more patients enter the consultation</td></tr>
<tr><td rowspan="3">Modelling analysis</td><td colspan="2">Is the value (e.g., time/patient's type of disease) between individuals very different?</td></tr>
<tr><td>Test</td><td>Consultation</td></tr>
<tr><td>YES – Individual analysis</td><td>YES – Individual analysis</td></tr>
<tr><td rowspan="3">Feedback loop</td><td colspan="2">Can the feedback loop cause an imbalance in part of the system?</td></tr>
<tr><td>Test</td><td>Consultation</td></tr>
<tr><td>No.</td><td>No</td></tr>
</table>

STEP FIVE: Selecting a suitable technique for modelling

The next step is to define a suitable technique for modelling based on the criteria that was determined in the previous step. For the short-term effect, the suitable technique for modelling this kind of variable is the DES technique. The DES technique is suitable for individual analysis but is not capable of modelling the feedback loop. Therefore, both modules have to undergo individual analysis and are not involved in modelling the feedback loop. Consequently, the suitable technique for modelling these variables is the DES technique. Since all criteria in both modules have to use DES as the modelling technique, the final suitable technique for modelling both modules is DES. Figure 5.6 summarizes the suitable technique for modelling for Case Two.

Table 5.6: Suitable Technique for Modelling – Case Two

Criteria / Module	Effect	Modelling analysis	Feedback loop	Final Technique
Test	Short term: DES	Individual: DES	No: DES	DES
Consultation	Short term: DES	Individual: DES	No: DES	DES

STEP SIX: Modelling Plan

Based on Tables 5.5 and 5.6, Figure 5.4 depicts the modelling plan for Case Two. The explanation of how these modules and models will be developed is in Section 5.3.2.

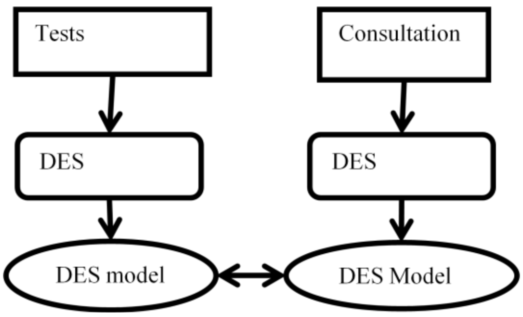


Figure 5.4: Modelling Plan – Case Two

5.3.2 Modelling Phase – Case Two

The modelling activity starts with the development of the 'test' module using the DES technique. Since there are many types of cases and patient pathways depending on the complexity of their illnesses and needs, all the possible pathways will be modelled in this module. The different types of consultation, based on the types of illness, will be modelled in the next module, i.e., the 'consultation' module. Both modules will then be combined using the individual variables from the 'test' module to the 'consultation' module. Individual variables, such as time and type of illness (where treatment in the 'consultation' module is based on the 'test' module) from the 'test' module will be the input for the 'consultation' module. This is how both modules are linked.

As both modules have to use the DES technique for modelling, the remaining steps in this framework are not applicable to this case.

5.4 CASE THREE: COMMISSIONING FOR THE BEST PATIENT PATHWAYS

Currently, there are many patient pathways for the same illness, i.e., cataract sufferers. Therefore, policy makers must decide which patient pathways are suitable to represent at the national level. Many example cases have been chosen for selection for the best patient pathway. The other objectives are; looking into the effect of patients' health through the pathways and the rate of intervention (types of medication) needed to improve the patient's health.

5.4.1 Conceptual Phase – Case Three

This phase consists of six sequential steps. The steps start with defining the root of the problem by detailing all the required information and, subsequently, are followed by identifying the objectives of the exercise. At completion, the last step involves defining the modelling plan. The description detailing each step in the conceptual phase will be explained below using Case Three.

STEP ONE: Problem Source Definition and Objective Identification

Problem Definition: There are too many patient pathways for the same illness (cataract sufferers). Each of the patient's pathways has their own variables in terms of health after receiving the care and costs involved. Due to that complexity, the professionals do not have clear guidelines on how to define each individual pathway that could represent each patient case at the national level. The researcher argues that, on paper, the professionals are trying their best to find the most suitable pathway in the conventional method. Since one of the objectives in the NHS

Institute for Improvement and Innovation (2010) document is to assess the best pathways in terms of medical intervention, as well as the costs involved, using the conventional method will not help the professionals find the best pathway. The problem definition for this case is that there are too many patient pathways making it difficult for the professional to identify and define which one is the best that could represent the cataract patients at the national level.

Objective Identification: One of the advantages of using simulation modelling, as compared to the conventional method, is that it can mimic the real world situation based on the information that has been included in the computer model (Chahal and Eldabi, 2008). Using the simulation method will also help the decision maker to make the decision-making more efficient. Based on the problem identified in the case introduction and problem definition, the objective of modelling is to identify the best pathway and interventions that will improve the health assessment for cataract patients. The pathway will also include how the medical intervention will help improve patient health.

STEP TWO: Conceptual model and Modularization

Figure 5.5 depicts the conceptual model for Case Three. The journey of the patient starts with the patient entering the outpatient unit after being referred by the optometrist. The patient will have assessments and diagnostic intervention once the doctor suspects that the patient is suffering from cataracts. Before going for surgery, the patient will have to undergo a pre-operative assessment to ensure that the patient is not allergic to any medication that would be used in the surgery. The surgery will take place after all the documentation and examinations have been completed. The patient will stay in recovery (on a ward) to enable the medical personnel to assess the patient’s health condition after surgery. A follow-up session will be conducted a few days after the surgery when the patient would be discharged.

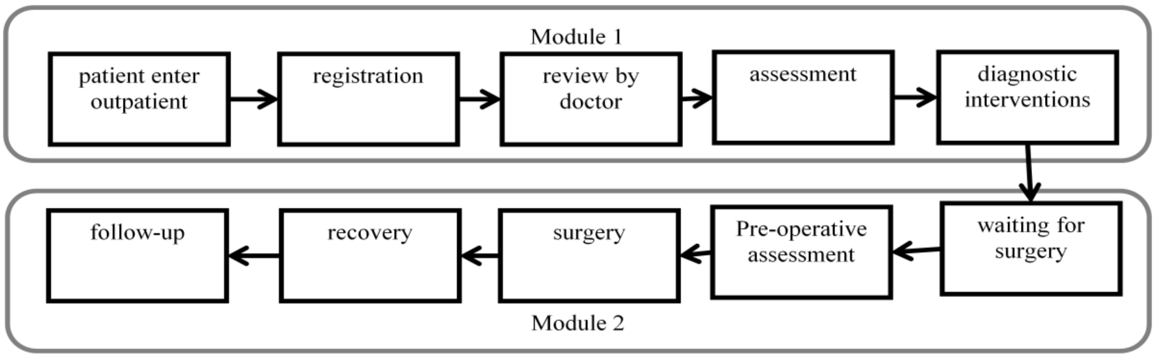


Figure 5.5: Conceptual Model and Modules – Case Three

Based on Figure 5.5, the process appears to be long and complicated if DES is used as a modelling tool. Furthermore, based on expert opinion, there are various pathways that are involved in the assessment, diagnostic intervention, as well as the pre-operative assessment, which are all based on the various different conditions of each patient. Therefore, to facilitate the modelling activity, a 'modularization' process is needed in order to make the model less complex. The researcher argued that it is best to do the modularization process based on the care process rather than the care setting. This is because the patient pathways in the care setting (e.g., healthcare) is much too long compared to other care settings (e.g., a ward where the patient is placed after surgery for the recovery process). Therefore, a series of processes is grouped into several modules and, as shown in Figure 5.5, the researcher has divided the whole process into two modules (in a big rounded rectangle).

STEP THREE: Identify modules that will be affected by the main objectives

To facilitate the process of defining the following steps of the framework, each of the modules will be assigned with a unique name. The researcher has assigned the name 'Assessment' to module 1 and 'Surgery' to module 2. Based on expert opinion, the researcher argues that both modules will be affected due to the intervention done to any of these modules. For example, if the review, assessment and diagnosis have been assigned to the optometrist instead of the doctor, it will decrease the waiting time of the patient in the 'assessment' module. As a result, more patients will be sent for surgery and, consequently, the surgery module will be crowded. These conditions will affect the waiting time for the patient waiting for surgery as there are limited resources in the surgery process to cater for all patients. The ward will also be crowded as more patients have to be moved to a normal ward for recovery which will then increase bed-blocking problems for the ward. As the bed-blocking problems occur, the researcher argues that it will also affect the professional motivation and performance.

STEP FOUR: Define the criteria for each module

There are three criteria that should be assigned to each of the affected modules. Each of the criteria has questions that should be asked in each module in order to facilitate the assigning of suitable criteria to each of the modules. In short-term, any intervention that is performed on the 'assessment' module, such as professionals' knowledge and experience, the patient will be treated faster. As a result, the number of patients in the 'surgery' module will increase in the short-term period and, subsequently, the waiting time in this module will also increase. The modelling analysis used an aggregate analysis since the number of symptoms that each patient experiences is the same for each similar kind of disease (cataract patient), and they are being treated in the same manner. Unlike the 'assessment' module, the 'surgery' module will be analysed individually since the variables that each patient encounters (e.g., time patient finishes the surgery and fully recovers is dependent on many factors) varies and are unique to each individual patient.

Only the 'surgery' module will cause an imbalance to part of the system by creating the feedback loop to the other processes in the 'surgery' module. For example, assume that the number of patients increased in the 'surgery' module due to the increase in the professional's knowledge and efficiency in conducting the assessment of the patient (the patients are treated faster). The increase in numbers will also affect the judgment (errors in assessment) of the staff involved, as the staff might be stressed and tired due to the high number of patients treated. Due to an error of judgement, some of the patients will be discharged early from the recovery ward although the patient may not have fully recovered and, in due time, the patient might be readmitted to the ward. As the ward for recovery after the surgery process is in the 'surgery' module, this module will have the feedback loop. Figure 5.6 depicts the feedback loop entity to the 'surgery' module whilst Table 5.7 exhibits the summary of questions for each of the criteria and the answers for each of the modules.

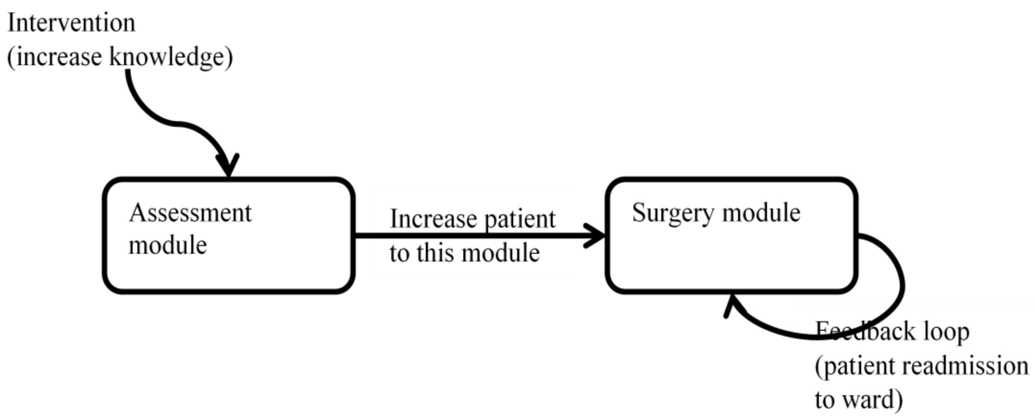


Figure 5.6: Feedback loop for surgery module

Table 5.7: Criteria and Variables – Case Three

<table>
<tr><th>Criteria</th><th>Questions</th></tr>
<tr><td>Effect</td><td>Will the intervention affect the other subsystems in the short- or/as well as in long-term?
<table><tr><td>Assessment</td><td>Surgery</td></tr><tr><td>Short term – patients are treated faster</td><td>Short term – more patients enter for surgery</td></tr></table></td></tr>
<tr><td>Modelling analysis</td><td>Is the value (e.g., time/patient’s type of disease) between individuals very different?
<table><tr><td>Assessment</td><td>Surgery</td></tr><tr><td>NO – Aggregate</td><td>YES – Individual</td></tr></table></td></tr>
<tr><td>Feedback loop</td><td>Can the feedback loop cause an imbalance in part of the system?
<table><tr><td>Assessment</td><td>Surgery</td></tr><tr><td>NO</td><td>YES</td></tr></table></td></tr>
</table>

STEP FIVE: Selecting a suitable technique for modelling

Both modules have to use DES and SD simultaneously, i.e., the hybrid simulation. This is due to the difference in the suitable techniques for modelling each of the criteria. For example, the ‘assessment’ module effect is only in the short-term period and does not have a feedback loop. The suitable modelling technique to capture this type of criteria is DES. However, to capture the aggregate analysis in the ‘assessment’ module, the suitable technique is SD. Thus, for the ‘assessment’ module, both techniques should be adopted and combined into the hybrid simulation. For the ‘surgery’ module, however, the effect is in the short-term period and uses individual analysis. The suitable technique, therefore, is DES. However, since this module has a feedback loop, which only allows SD to capture the data, both techniques are to be used to model the ‘surgery’ module. To sum up, the suitable technique for modelling is the combination of both SD and DES; the hybrid simulation. Table 5.8 depicts a summary of the suitable modelling techniques for Case Three.

Table 5.8: Suitable Technique for Modelling – Case Three

Criteria / Module	Effect	Modelling analysis	Feedback loop	Final Technique
Assessment	Short-term: DES	Aggregate: SD	NO: DES	Hybrid
Surgery	Short-term: DES	Individual: DES	YES: SD	Hybrid

STEP SIX: Modelling Plan

The objective of this step, called the modelling plan, is to facilitate the model development activity. This modelling plan will show how to model the module, especially when the module has to use both techniques, i.e., DES and SD. Based on Table 5.7 and Table 5.8, Figure 5.7 depicts the modelling plan for Case Three. The explanation on how these modules and models will be developed is given in Section 5.4.2.

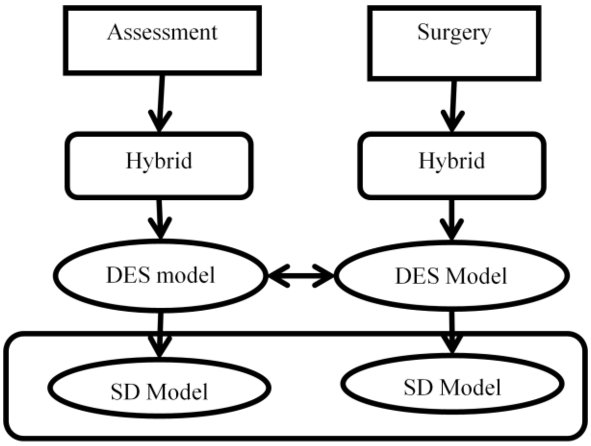


Figure 5.7: Modelling Plan for Case 3

5.4.2 Modelling Phase – Case Three

The modelling activity starts with the development of the 'assessment' module, where the patient enters the healthcare to see the optometrist (after being referred from a private optometrist or other sources) until the patient has the diagnostic interventions. The development continues with the 'surgery' module. In this module, the patient has been transferred to the professional optometrist who can perform the surgery. This module will end when the patient has finished their follow-up session. The patient pathways in both modules, which are based on the conceptual model, as shown in Figure 5.5, will be modelled using the DES technique initially. The two DES modules are then linked together using the patient's variables information. The output (finishing time in the module) from the 'assessment' module will be the input for the 'surgery' module.

The modelling activity continues with the development of the SD model, which will be modelled module by module. Unlike the DES modules' linking, the SD module links will be connected through variables that have connectivity in terms of cause and effect. This will also include modelling intangible factors that are defined in the objective, such as health improvement based on the assessment time and knowledge of the professionals. The DES model, however, is used to examine which types of intervention or pathway will lead to decreasing the number of patient's breaching and failing to attend their appointment.

Single Model or Hybrid

The next step in the framework for modelling the CPP model is to determine whether these models (DES and SD models) that have been developed could be integrated or not. To ascertain this condition any variable from the DES, or any tangible factor that will influence other variables in the SD model, will have to be identified. Both models can be linked if the tangible factors from the DES model influences the intangible factor modelled by the SD technique. As the objective of this modelling is to assess the intervention that could best represent the patient pathway at the national level, the researcher argued that one possible type of intervention is by increasing the knowledge and experience of the professionals. Therefore, the professionals' knowledge and experience will be the main input for the assessment time. A higher level of knowledge leads to a better assessment of the patients and a decrease in the time for assessment. The decreasing assessment time will result in more patients being assessed at the same stipulated time. Better patient assessment will also reduce the patient readmission.

The assessment time can be used as an input for the DES model to predict how much time is needed for the patient assessment. This will be seen from the graph generated by the SD model. Since the level of knowledge, modelled by the SD technique, will influence the total patient assessment time that is modelled by DES, these two models can be integrated by placing the SD output as the input of the DES model.

5.4.3 Integration Phase – Case Three

As explained, both models can be integrated since both models have 'influencing' and 'influenced by' variables. The framework will continue with the last step, which is the integration phase. The first two steps in this phase are explained below and how they are integrated (theoretically) is described as follows:

Step ONE: Identifying the variables in both models that can be linked together

The objective of modelling is to experiment and test which patient pathways could best represent the others at the national level for cataract patients. With the support of the experts, the researcher suggests and argues that one possible intervention is by increasing the professional's knowledge and experience. As the knowledge and experience of the professional increases, it will reduce the patient's assessment time and reduce errors in assessment. Therefore, the level of knowledge and experience is suitable to be captured by the SD technique, which, in turn, will influence the patient assessment time. The patient assessment time is suitable to be captured by the DES technique. As the level of knowledge and experience of the professional will also influence errors in assessment, the reduction in patient readmission could be a possibility. Patient readmission is a process in the 'surgery' module that is suitable to be captured using the DES technique.

The researcher also argues that this case has another variable that can be linked between both models which is not based on the objective of the modelling. For example, the total space available in a care setting is depicted in the DES model and will influence the patient recovery level, depicted in the SD model (Elf and Putilova, 2005). Therefore, the following is a summary of the variables that can be integrated together.

From the SD model: level of knowledge and experience, performance and motivation, patient recovery level

From the DES model: time for the patient assessment, patient readmission, resources (space)

Step TWO: Define the last output from the variable linkage

In step two, which is in phase three in this framework, the aim is to define the output based on the linked variables that have been defined in the first step. This step maps the relationship between the variables that have been integrated. Based on the first step, the researcher has defined two variables from each of the models that could be integrated together.

i. In the first variable, knowledge of the professionals and the assessment time is integrated. As argued in the previous step, the more knowledge and experience gained by the professionals, the shorter the assessment time. As the assessment time decreases, the total number of patients discharged will also increase in both modules. The suitable technique to capture knowledge and experience is SD, as both data are continuous types of variables. The assessment time, however, is a discrete type of variable and, thus, the suitable technique for modelling this type of variable is DES.

ii. Another variable that the researcher has identified that could be integrated together is the total space involved in the care operation. The suitable technique to capture this form of variable is DES. The total space used in the care exercise will influence the patients' health recovery level (Elf and Putilova, 2005). As more patients are admitted in a certain unit/department, the more crowded the unit/department will be. As a result, the quality of the patient's health will be reduced as it creates a non-conducive place for patient recovery. Since the quality of the patients' recovery level is a continuous variable, it can be captured by the SD technique. The combination of these variables ('influencing' and 'influenced by' variables) will influence total patient readmission, as the patient that has been discharged may not be fully recovered.

Variables Exchange (Theoretically)

Based on the explanation in the previous phases and steps, this case requires extensive work. This is due to the condition where the initial influencing variables are in different models, which may cause the modeller to be confused as to which model should run first. Should this happen, the modeller should run the first model that contains the initial influencing variable (for example, in this case, the SD model) to gather all information and exchange the variables involved (from SD to DES). These steps will be repeated for the second initial influencing variable in the second model (for example, in this case, the DES model), similarly gathering all the information and exchanging the variable involved (DES to SD). The flowchart in Figure 5.8 depicts this condition and solution.

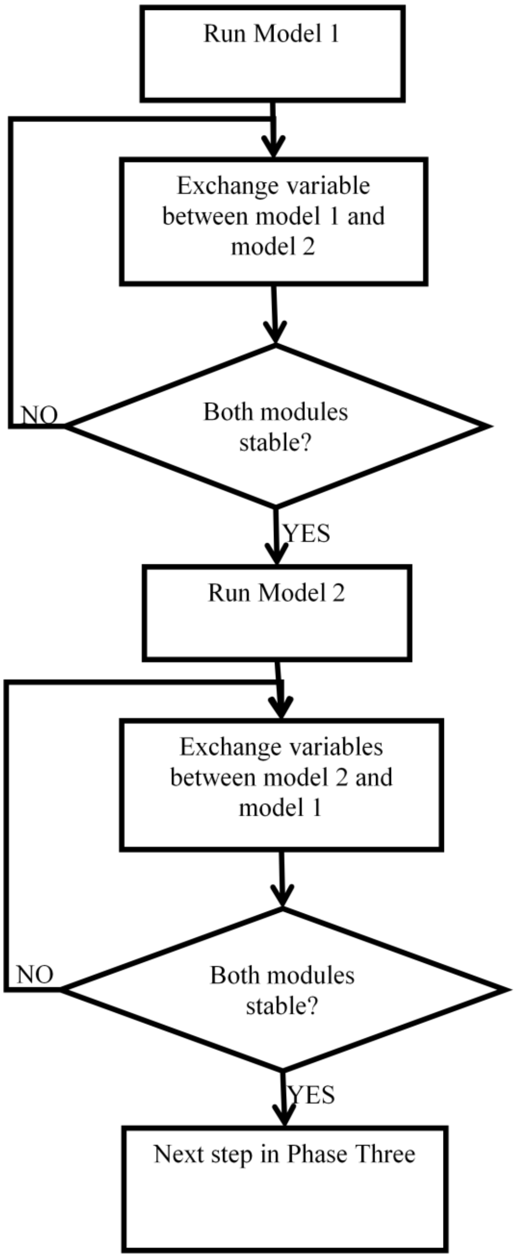


Figure 5. 8: Flowchart of Variable Exchange for Case Three

Hybrid Operation 1:

From the SD Model

The SD model that contains the initial variable, which influences another variable in the DES model, will have to be run first. The level of experiences and knowledge data from the SD model, which influences the assessment time (considering total assessment time will be reduced by several minutes depending on the professional level of experience and knowledge), will be gathered. Based on this data, information will be fed to the DES model, for instance, the time taken to complete the whole process in the SD model. Each patient's time in the system will be different and will vary in nature. For example, some professionals might need an hour to complete the patient assessment, while others might need one and a half hours, and some might just need half an hour. All of this will depend on the level of professional knowledge and experience.

To DES Model

The patients' various finishing times will be fed to the DES model. This model will be run to generate the patients' data in the system. Each patient has been passed through the patient's pathway, gathering the waiting time that each of the patients has taken and other variables in which the professional might be interested. Depending on the model that has been developed (if these variables influence any variables in the SD model), these variables, such as waiting time, and the total number of patients across the pathways, will be fed back to the SD model. The exchanging variables between both models will continue until both models are stable (the variances of the outputs from several runs is not too large).

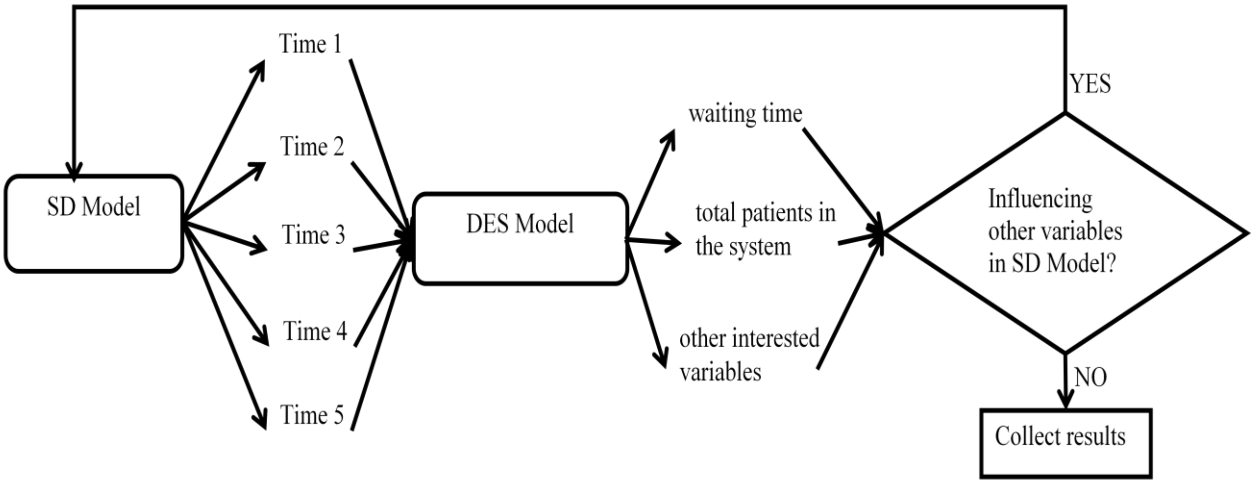


Figure 5.9: Hybrid Operation (1) – Case Three

Hybrid Operation 2:

From DES Model

Another variable that will influence other variables in the other models is the total patient admission and the resources (i.e. available bed) available. Outputs from the DES model will be gathered and put in an Excel file. This file will be embedded into the SD model to generate new outputs after considering factors that cannot be captured by the DES model, i.e., the patient recovery level.

To the SD Model

The data that has been gathered from the DES model and put in an Excel File will be embedded into the SD model. This variable will be linked with the patient recovery level which will then be linked to the total patient readmission. The output of the model is the total patients' readmission data, which will be fed back to the DES model depending on the decision makers concerns. For example, if the decision makers are concerned with patient waiting time, total patient readmission should be passed back to the DES model. The DES model is then re-run to generate a new output after considering the patient readmission data. The process of exchanging variables will continue until both models are stable in terms of their output. However, if the decision maker is only concerned with the patient readmission information, the output that has been generated by the SD model will not be passed back to the DES model.

5.5 CASE FOUR: TEACHING HOSPITAL (NHS) FOUNDATION TRUST

The government has set that patients should receive their treatment (RTT – Referral to treatment) in not more than 18 weeks. Although the workers are aware of the 18 weeks, they do not fully understand their role in achieving it (NHS Institute for Improvement and Innovation, 2010). To understand how the involvement of the staff will impact the whole organization in order to achieve the mission, the simulation modelling method can be used as tools. Creating patient pathways from referral until the patient is discharged will need an extensive effort in order to list down a different pathway for a different type of patient. Therefore, the whole process will be started by using the orthopaedic department as a pilot.

5.5.1 Conceptual Phase – Case Four

Six steps are involved in Phase One of this framework. Starting with defining the source of the problem until model planning, phase one is about exposing the system into a more visible item to the stakeholders. The exposure is in the form of defining the objective of the modelling, transferring the logical system into a conceptual model, followed by grouping the conceptual model into several modules, identifying which module will be affected and their criteria, defining the suitable technique to model each of the modules and finally ending with a modelling plan. This phase will facilitate model building in the simulation software. The following explanations are the steps involved in the Conceptual Phase.

STEP ONE: Problem Source Definition and Objective Identification

Problem Definition: Many staff and professionals do not understand their roles in achieving the target of 18 weeks RTT (Referral to Treatment). There are many patient pathways that are not 'visible' to them. Even if patients have the same type of disease, not all patients will have the same pathways. For example, some patients in the orthopaedic ward must have a series of surgeries, some will have minor surgery and some are not involved in any surgery. Some patients also have to undergo many series of therapy and some do not. These multiple patient pathways for one type of patient are not visible to the staff, especially those that are related to their contribution and how they affect the operations of the hospital when the benchmark of 18w RTT is introduced. The researcher argues that upper management use the conventional method (paper based) for modelling the system and, thus, it makes the system 'invisible'. The developed model will also show how staff contribution will affect the whole system when the 18w RTT benchmark is introduced. Therefore, the researcher argues that the problem is the method used is not viable enough to show how staff contribution will affect the system as a static, and not a dynamic model, has been developed.

Objective Identification: The model should be a dynamic model instead of a static one. This is to ensure that the developed model will 'show' all the effects, including how the 18w RTT benchmark affects the staff and system, the costs involved for each of the patients, how long the patient will be in the system and whether the 18w RTT benchmark can be achieved with the limited available resources. Therefore, the objective of the modelling is to *identify the impact of introducing the18w RTT benchmark.*

STEP TWO: Conceptual Model and Modularization

Patients can come from various pathways. They can come from the A&E unit as well as from the outpatient department. As this model is concerned with the orthopaedic patients, the researcher considered that the patients that enter through the outpatient department have minor injuries, whilst patients that enter through the A&E unit are patients that have major injuries or have had an accident. Upon checking with the A&E or outpatient departments and based on the patients' condition, they might be put on a ward. The patient will be registered to the surgery ward if surgery is needed (moderate to major injury). Once the surgery has been conducted, the patient will have to undergo a series of treatments, including a physiotherapy session. Once the patient is fit enough, they will go for a follow-up session until they can be fully discharged from the hospital. There are also cases where the patient does not need a surgery procedure, but needs a physiotherapy session (moderate injury and patient readmission). There are also cases where the patient is only placed on a ward until the patient is fit enough for final discharge (minor injury). Figure 5.10 depicts the conceptual model of Case Four. Details concerning the processes in the A&E unit and the outpatient clinic are not described by the researcher as they have multiple patient pathways and it will complicate the conceptual model. However, in the modelling activity, it will be modelled in detail.

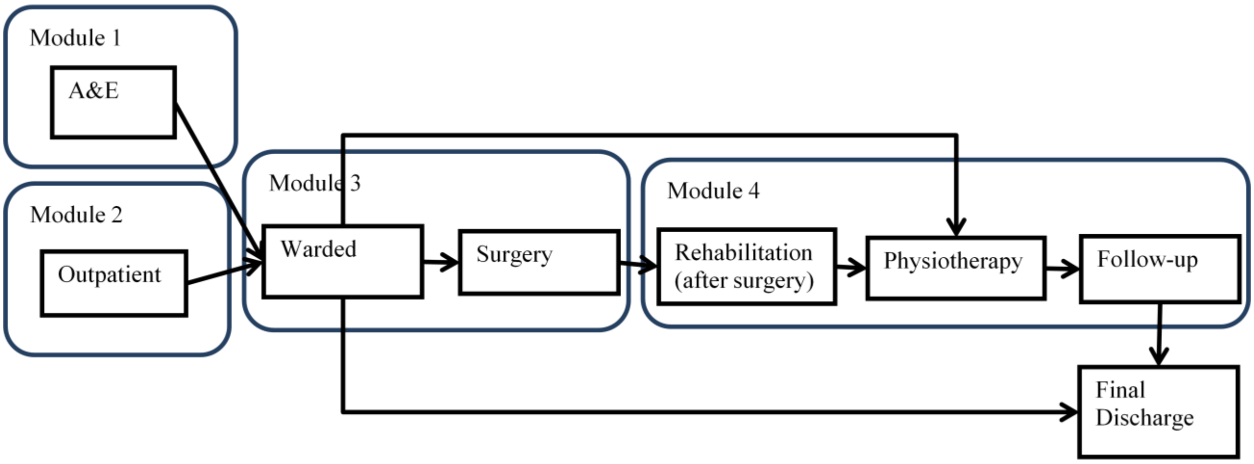


Figure 5.10: Conceptual Model and Modules for Case Four

Once the conceptual model has been developed, the next step is to group the processes into several bigger groups or modules. This process is called the 'modularization' process. As the A&E and outpatient departments have several processes before the patient is referred to the ward, the A&E and outpatient units will have their own respective modules. The process in the ward where the patient is referred to from the A&E or outpatient departments, and the surgery process will be grouped together as one module, whilst the physiotherapy and follow-up sessions will be grouped as another module. This modularization process is based on dividing several processes into several modules and is not based on the care setting. Figure 5.10 depicts the modularization processes (in rounded rectangle) that have been divided into four modules. For easy tracking of the modules, Module 1 is named 'A&E', Module 2 as 'Outpatient', Module 3 as 'Treatment' and Module 4 as 'Rehabilitation'.

STEP THREE: Identify modules that will be affected by the main objectives

The main objective of modelling is to assess the effect of the 18w RTT benchmark. RTT starts from the patient being sent to the physician, and being placed on a ward. These patients are referred from the A&E or Outpatient modules. The patient will then be transferred to a ward, which is in the 'treatment' module and includes all sorts of other treatments, such as surgery, rehabilitation, physiotherapy and follow-up sessions, until the patient is fully discharged. Therefore, the researcher argues that the 18w RTT starts from the 'treatment' module, up until the 'rehabilitation' module. Considering that due to the impact of the 18weeks RTT, the physician accelerates the process of treatment to speed-up the patient discharge process. The researcher argues that due to the pressure of the 18w RTT, the patient might be discharged early without being fully recovered. In the long-term, the patient will re-enter the outpatient or A&E departments, creating a scene called re-admission. The patient will be sent to a ward again and the process will go on as in the conceptual model. This scenario will lead to a bed-blocking problem and other problems to other departments and staff. Due to these conditions, the researcher argues that all of the modules are affected although the 18w RTT begins from the 'treatment' module to the 'rehabilitation' module.

STEP FOUR: Define the criteria of each module

After selecting the modules that will be included in the modelling activity, the next step is to define the criteria for each of the modules. This is to facilitate the suitable technique for modelling each module. For each of the modules there are three criteria that need to be defined by the modeller. To facilitate this, each of the criteria is followed by a question and the answer is obtained from the experts. With regard to the effect of time (short- or long-term effect) due to any intervention introduced to the system, the A&E and outpatient modules deal with the long-term effect as the researcher argues that these patients are from readmission, whilst the effect of the 'treatment' and 'rehabilitation' modules is in the short-term. When the 18w RTT benchmark is introduced, the time allowed for treatment in the 'treatment' module will be shorter, causing the level of pressure for the staff to increase. As a result, it leads to more patient admissions to the 'rehabilitation' module and, in turn, will create bed-blocking problems. As the models are developed for the orthopaedic patients, and the referral starts from the 'treatment' module, the researcher argues that the modelling analysis does not need an individual analysis for the A&E and outpatient modules. This is due to the fact that it will take almost the same time frame to treat patients and refer them to the 'treatment' module.

However, as the recovery for each patient depends on several factors including emotional, physical and spiritual, there would be a large gap in the differences of each patient's variable data. Consequently, the 'treatment' and 'rehabilitation' modules will use individual analysis for the modelling exercise. As the pressure caused by the 18w RTT benchmark increases, some patients might be discharged early before having fully recovered. As a consequence, they might be readmitted to the ward in the long-term and they will be the previous patients of either the A&E or outpatient modules. The treatment process will continue as depicted in the conceptual model. Based on this argument and assumption, all modules will have a feedback loop due to the introduction of the 18w RTT benchmark. Table 5.9 exhibits the questions for each of the modules and the answers for each of the criteria, as well as the selection of suitable techniques for modelling each of the modules for Case Four.

Table 5.9: Criteria and Variables Each of the Modules – Case Four

Module / **Criteria**	**A&E**	**Outpatient**	**Treatment**	**Rehabilitation**
Effect	Will the intervention affect the other subsystems in the short- or/as well as the long-term?			
	Long term – patient readmission	Long term – patient readmission	Short term – time of treatment shorter, staff stress	Short term – more patients, bed-blocking
Modelling analysis	Is the value (e.g. time/patient's type of disease) between individuals very different?			
	Aggregate – patient assessment time almost the same for the type of disease	Aggregate – patient assessment time almost the same for the type of disease	Individual – treatment between patients depends on several factors	Individual – treatment between patients depends on several factors
Feedback loop	Can the feedback loop cause an imbalance in part of the system?			
	Yes	Yes	Yes	Yes

STEP FIVE: Selecting a suitable technique for modelling

In Chapters Two and Three, the researcher defined which technique is suitable to capture the different types of variables based on each technique's capabilities. Each module that has been defined has its own criteria to facilitate the selection of the suitable technique for modelling. The final modelling technique chosen is based on these criteria. Based on the criteria that has been defined in Table 5.9 above, the 'A&E' and 'outpatient' modules are suitable to be modelled using the SD technique. This is due to the condition where all the variables (long-term effect, aggregate analysis and has a feedback loop) in the criteria are suitably captured by the SD technique. Although the suitable technique to capture the short-term effect and individual analysis, as defined in the 'treatment' and 'rehabilitation' modules, is DES, both modules, need both techniques, i.e., a hybrid simulation as both modules have a feedback loop, which the suitable method to capture this type of variable is the SD technique. Table 5.10 summarizes the suitable modelling techniques for each module based on the defined criteria in the previous step in this framework.

Table 5.10: Suitable Technique for Modelling – Case Four

Criteria / Module	**Effect**	**Modelling analysis**	**Feedback loop**	**Final Technique**
A&E	Long-term: SD	Aggregate: SD	Yes: SD	SD
Outpatient	Long-term: SD	Aggregate: SD	Yes: SD	SD
Treatment	Short-term: DES	Individual: DES	Yes: SD	Hybrid
Rehab	Short-term: DES	Individual: DES	Yes: SD	Hybrid

STEP SIX: Modelling Plan

Based on Tables 5.9 and 5.10, Figure 5.11 depicts the modelling plan for Case Four. The explanation of how these modules and models will be developed is in Section 5.5.2.

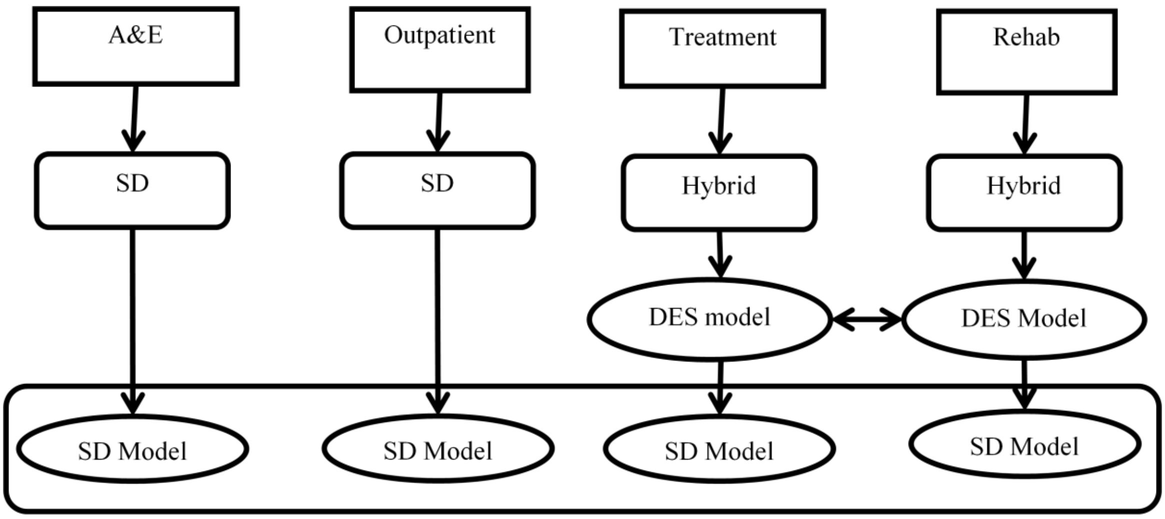


Figure 5.11: Modelling Plan – Case Four

5.5.2 Modelling and Linking Phase – Case Four

There are four modules that are involved in the modelling process. The 'treatment' and 'rehabilitation' modules need to be modelled by the DES and SD techniques, whilst the 'A&E' and 'outpatient' modules need to be modelled only using the SD technique. Based on Figure 5.11, the DES model will start with the 'treatment' module, followed by the 'rehabilitation' module. These modules will be linked together using variables from the first module to the second module, i.e., the output from the 'treatment' module will be the input for the 'rehabilitation' module. Such variables that could be used to link the modules are time and type of patient. The modelling activity will then continue with modelling the SD model for the whole system, i.e., the 'A&E', 'outpatient', 'treatment' and 'rehabilitation' modules. Since the 'A&E' and 'outpatient' modules are not involved in the DES modelling exercise, only a single step or process (less detail) will be modelled in the SD. However, the treatment and rehabilitation modules should be modelled in more detail as both modules need the DES simultaneously as the modelling technique. The modules in the SD model will be linked together also using variables. The difference between the DES and SD linking process is the SD linking exercise, which is done by linking the variables that affect other variables (cause and effect). For example, the variable of total patients admitted will affect the performance and motivation of the staff.

Single model or hybrid

Assumingly, due to the policy, the professionals have limited time to assess the patient's condition as the number of patients is increasing. Due to limitations in the assessment time, it will create pressure among the physicians. This will result in errors in the assessment, leading to discharge of the patient earlier than is sensible. If the patient assessment is not done correctly, it will create a situation where the patient will be readmitted for the treatment. Since the total number of patients is a discrete variable, which is suitable to be captured by the DES method, influencing the stress level of the physicians is a variable that is suitable to be captured by the SD technique. Therefore, these two models can be integrated as there is interplay (variables 'influencing' and 'influenced by') between both models.

5.2.3 Integration Phase – Case Four

The last phase in this framework is to integrate both models as they are using both techniques simultaneously and can be integrated together. As this chapter does not include the modelling activities, only the first two steps in this phase will be described. However, in respect of the hybrid operation (how these variables exchange information between both models), this will be explained theoretically. The first two steps in this framework and how the hybrid operation runs are explained as follows.

Step ONE: Identify the variables in both models that can be linked together

The first step in this phase is to define all the variables in both models that could be linked together. Although the previous step has defined the variables, this step is to ensure that all the variables that can be linked together are clearly defined, as there might be other influencing variables in each of the models. First, the modellers should find the initial variable in one model that will influence another variable in the other model. This will show the modeller the linkage associated with influencing variables. From the researcher's observation, one variable that will influence another variable in the other model is total patient admission in the DES model. Total patient admission here refers to the total number of patients' admitted to the A&E, outpatient, and rehabilitation, as well as the time allocated for patient treatment (18 weeks). The increase in total patient admission will have an impact on the professionals, as the level of pressure among the professionals will increase as the number of patients they have to treat increases within a limited time. The suitable technique to capture this form of variable is the SD.

Based on the study by Elf and Putilova (2005), the total space allocated for patient's care will significantly influence the quality of the patients' recovery level. A crowded environment (as more patients are admitted) will decrease the quality of patients' recovery level. As the total space available is a discrete type of variable, whilst the patient recovery level is a continuous type of variable, the suitable technique for capturing these variables is DES and SD, respectively. These two variables are the 'influencing' and 'influenced by' variables from two different models. However, these two variables can be linked together irrespective of where the two variables are located. The following shows the summary of variables that could be linked together.

From the DES model: Total patient admission to A&E, outpatient, treatment, rehabilitation, time for assessing patient in treatment (within 18 weeks), total space

From the SD model: pressure among professionals, patient recovery level

Step TWO: Define the last output from the variable linkage

The second step in the integration phase is to define the output that has been produced by the linked variables in both models. The experts agreed that as more patients enter the modules, the pressure on professionals will also increase. Consequently, it might lead to the wrong patient assessment and, in turn, will increase patient readmission to any part of the module. The ratio of space to patients also has an impact on the patient recovery level. This is based on the study by Elf and Putilova (2005) who found that this situation causes some patients to be discharged without fully recovering and, in turn, leading to patients being readmitted.

Exchange Variables (Theoretically)

From the DES Model

Since the initial variable that influences another variable is in the DES model, the DES model will have to be run first to generate the intended outputs. The outputs (total patient admission and total space available for patients) that are gathered will be put in an Excel file. This file will then be embedded into the SD model.

To SD Model

The total patients' admission data will be embedded and linked with the level of professional pressure information to create an output of total patients that might be given an erroneous health assessment. However, the total space for patient care data will be linked to the patient recovery level to generate an output of patients that have been discharged, but not fit enough due to space constraints (too many patients and crowded). The number of patient readmissions increases due to these conditions (wrong patient assessment and patient discharge without being fit enough). The patient readmission information will then be fed back into the DES model to generate new outputs. The hybrid operation for this case is almost the same as in Chapter Four i.e., the hybrid model of health and social care system.

5.6 REFLECTION FROM THE THEORETICAL FRAMEWORK ASSESSMENT

The framework has been applied with different points of view in several case studies. The case studies are taken from the literature and the NHS Institute for Innovation and Improvement documents. Some cases have been selected by the researcher to show how modelling can help in the decision making process, and also to assess how the developed framework can be applied across the wide area of primary care to secondary and tertiary care, as well as from a single department to multiple departments. Upon assessment of the framework using several case studies, the researcher found that some modification of the framework is needed to fit into several cases.

5.6.1 Modification in the Main Framework

The terminology used in phase three in this framework is the integration phase. The researcher realizes that this terminology does not represent the purpose and activities or steps. The word 'integration' is more towards combining two different models into one model. The actual activity in this phase is defining the variables in each of the models that can be linked together (based on 'influencing' and 'influenced by' variables) and then interchanging them between models to produce outputs. The main activity in the third phase of this framework involves the model's communication, as both models continuously exchange their variables until both models produce stable outputs. The models communication is performed via the variable's interaction between both models ('influencing' and 'influenced by' variables). Therefore, based on the researcher's observation, the words 'models communication' is a more suitable term to represent all the activities in this phase. Therefore, starting from this point onward, phase three will be named as the 'models communication' phase.

5.6.2 Modification in the Conceptual Phase

Upon applying the framework to several cases, the researcher realized that some modifications need to be done in order to ensure that the decision makers and other stakeholders understand how to use this framework. It is also to ensure that this framework is suitable as a guide for modelling any of the CPP systems within several care settings using the hybrid simulation. The modifications that are involved in this phase are as follows;

a. Step Three of the Conceptual Phase

   The wording in step three (*identify modules that will be affected by the main objectives*) does not show exactly what should be done. The word 'identify' is too complicated, as some of the policy makers cannot see and identify which modules could be affected by the overall objectives. There are some circumstances in which the 'affected modules' are not based on the overall modelling objectives, but based on intervention, or the existing problems, or because the modules are partly in the patient pathways. Consequently, the researcher changed the step into '*identify affected modules'*. The affected module can be referred to as *'due to the intervention, or due to the existing problems, or due to the chains in the patients care'.*

b. Step Four of the Conceptual Phase

There are steps in the conceptual phase for which the name of the step is not sufficient enough to show exactly what should be done. Upon assessment, the researcher found that step four is one of them. Step Four in the conceptual phase is '*define the criteria of each module*'. There are three criteria that should be defined in each module in order to select the best technique for modelling, since each criterion has its own variables. However, the step's name does not reflect the real activity, which is identifying the variable in each of the criteria for each of the modules. Therefore, instead of *'define the criteria of each module'*, the researcher will change the name of this step to '*identify the variables of the criteria for each module*'.

c. Question to determine whether a module has a feedback loop

In Chapter Four, the researcher has introduced a set of three questions that should be answered by the modellers in order to define what criteria each module should have. These questions will facilitate the selection of the criteria that should be defined according to each module. One criterion that should be defined is the feedback loop item. The question that has been setup for this criterion is, '*Can the feedback loop cause an imbalance to any part of the system?'*

The feedback loop in this research refers to the condition where an intervention or action is introduced to a certain module and the impact goes backwards instead of forwards. For example, suppose there are two modules – healthcare and social care. Due to the insufficient resources, social care has to discharge some of the patients, however, patients that are discharged early are actually unfit and have not fully recovered. As a result, some of the patients that have been discharged could have been readmitted to the healthcare. This situation (effects on module one when action/intervention is done to module two) calls for a feedback loop as the condition, as explained, would require one to be in existence. The researcher suggests that this criterion is one of the limitations in the DES technique that cannot be captured backward as feedback. As the questions that have been setup do not represent the 'meaning' of the feedback loop in this context, the researcher argues that it should be changed to;

'Will any interventions/actions cause a backward feedback (previous module/steps)?'

If the answer is YES, the module will have a feedback loop and vice versa.

5.6.3 Modification on Phase Three (Models Communication Phase)

The framework will be continued if the hybrid simulation were used and the models can be integrated, and communication between both models takes place (changing variables 'influencing' and 'influenced'). There are several steps in this phase that should be changed in order to fulfil the framework of the CPP modelling requirements.

There are a number of variables that are the 'influencing' and 'influenced' type in both models. However, depending on the objective of the modelling activity, there should be an **INITIAL** variable in one model that starts the influencing cycle of another variable in the other model. Upon determining the initial influencing variable, it will help facilitate the modeller to decide which model should be run first, as this framework only deal with the cyclic interaction (Chahal, 2009). To capture this initial influencing variable, an additional step will be included in this phase. The name of this step is '*identify initial influencing variable*' and it will take place after step two (*define the last output from variable linkage*) of this phase. This additional step will determine which model should be run first prior to exchanging variables activity, as there is also a possibility that a variable from the SD would be the initial influencing variable (as in Case Three, Section 5.4).

Since there is a possibility of the initiating variable being in the SD model, all processes that have been decomposed into step three (*Run both models and exchange all variables involved between DES and SD Models*) in this phase will be amended as well. Instead of using an initial influencing variable in a specific model (previously, the researcher assumed the DES model will influence the SD model), the researcher will use a general terminology to represent whichever model could have the initial 'influencing' and 'influenced' variables. The term 'source model' will be used to show that the model contains an initial 'influencing' variable, whilst the 'destination model' will be used to show that the model has an initial 'influenced' variable. Due to the change that has been introduced, the composed step three in this phase will be amended as well. Figure 5.12 depicts the amended decomposed step three.

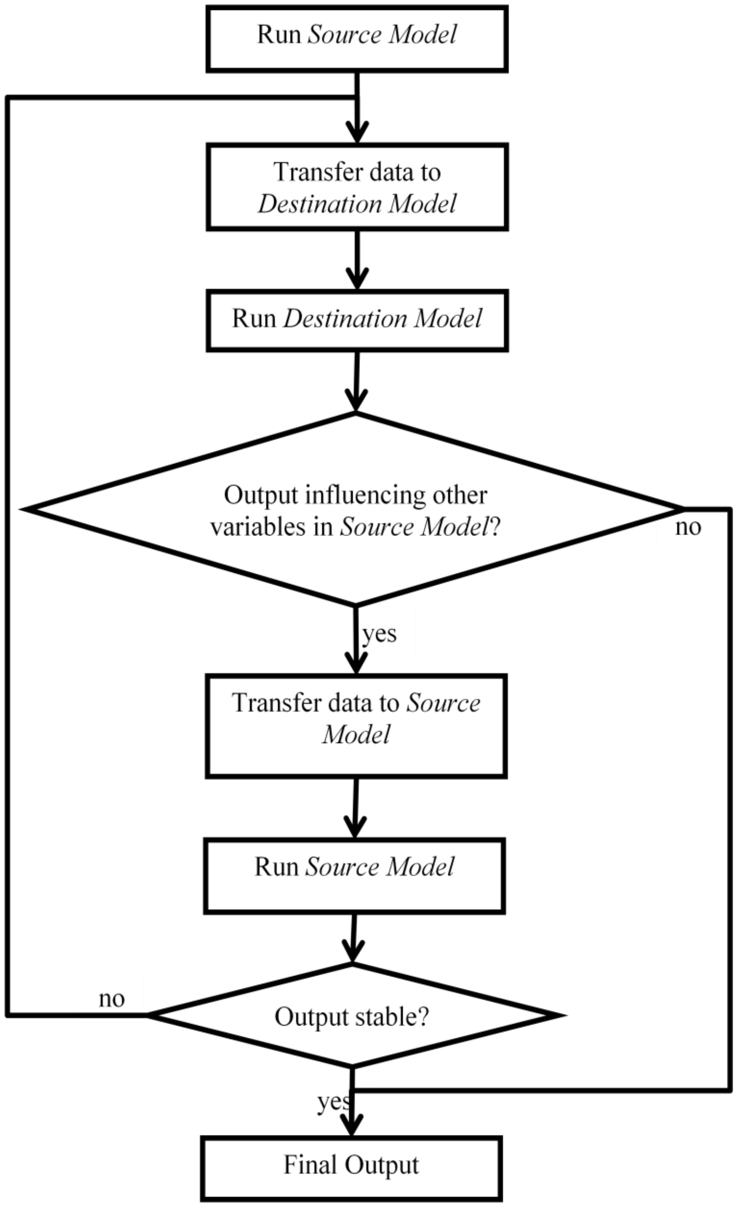


Figure 5.12: Step Three (Phase Three) Decomposition

The source model can be detected directly from the previous step (identify initial 'influencing' variables). The model that contains the initial 'influencing' variable will automatically be the source model, whilst the model that contains the initial 'influenced' variable will be the destination model. The changing variable (step three) will be continued until the output is stable between the models, or the 'influencing' variable has stopped influencing other variables as depicted in Figure 5.12.

There is also a possibility that the number of initial 'influencing' variables is more than the one in the different models. For example, as in Case Four in Section 5.4, the initial 'influencing' variables are total patient admission and resources depicted in the DES model and level of knowledge/experience of professionals, as depicted in the SD model. Should this situation happen, the modeller should perform the decomposing of step three in this phase (as in Figure 5.12) of the first initial 'influencing' variable followed by the same process to the second initial 'influencing' variable in the other model. Due to this possibility, all the steps in Phase Three will be amended as well.

Prior to the last step of this phase, which is the '*evaluation of the outputs that have been produced and suggestions for system improvements'*, there will be an additional 'if-else' step. If there is another initial 'influencing' variable, step four (*run both models and exchange all variables involved*) will be performed again. Otherwise, the process should continue to the last step. As per the arguments above, Figure 5.13 depicts the new steps in this Communication Model Phase.

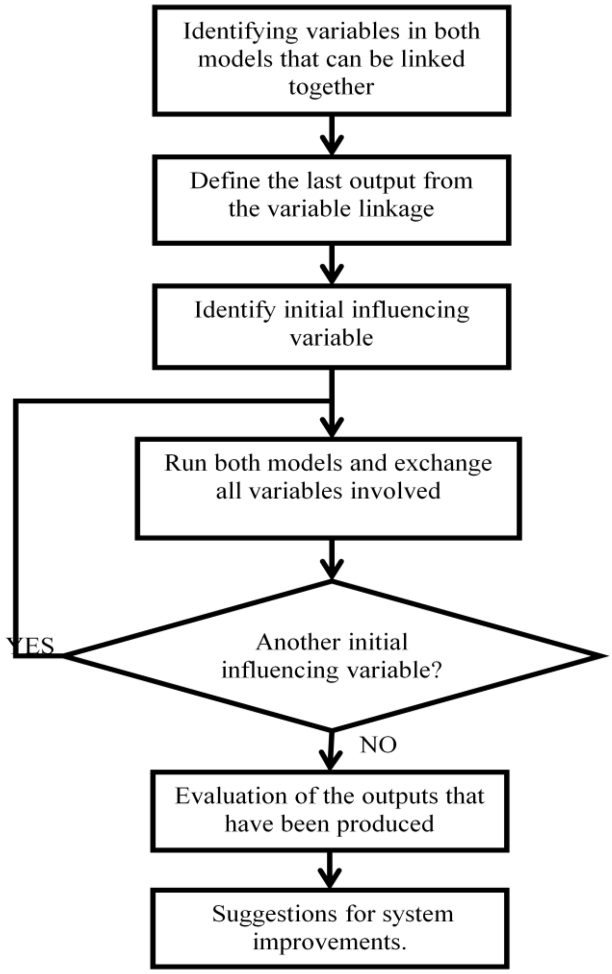


Figure 5.13: Steps in the Model Communication Phase

5.7 CONCLUSIONS

This chapter has presented the framework assessment for the second time. This is due to the limitations in the case study strategy where the framework is only suitable for the case that has been applied to the framework. Therefore, to extend the framework into multiple cases and settings of complex patient pathways, the researcher has applied the framework into several case studies. The objective of this chapter is to examine the framework and refine it until it fits into several cases within several settings and objectives of modelling. These cases were taken from the literature and documentation found at the NHS Institute of Innovation and Improvement. Based on these assessments, the framework was modified.

In the next chapter the framework is finalised and a discussion is presented, which includes a reflection on the gaps that have been identified in Chapter Two, as well as the advantages and limitations of the established framework.

CHAPTER SIX: FINALIZE FRAMEWORK

6.1 INTRODUCTION

The previous chapters have discussed the needs and requirements for using the hybrid simulation technique for developing the complex patient pathways (CPP) model. Unlike the single modelling techniques, the hybrid simulation will ensure that all important needs and requirements, such as the individuality analysis and the feedback loop, are fulfilled. Due to the lack of framework for the hybrid simulation for modelling the CPP system, the researcher has proposed a framework for this purpose. This framework has been tested and assessed practically by developing a hybrid model of the health and social care system (Chapter Four), and theoretically by applying the framework using several case studies within several care setting (Chapter Five). Based on the test and assessments, the researcher has made several amendments to ensure that the proposed framework is suitable for the real CPP system.

This chapter discusses the overall framework that has been finalized. The discussion of the finalized framework is in the following section. In the next section, the discussion will focus on researcher's self-evaluation of the finalized framework, in which the evaluation is based on the criteria of the viable CPP model that was developed in Chapter Two. In the last section, the researcher will discuss several matters concerning the framework, followed by the chapter conclusion.

6.2 THEORETICAL FRAMEWORK FOR HYBRID SIMULATION FOR MODELLING COMPLEX PATIENT PATHWAYS

In Chapter Two, the researcher has presented several ideas that lead to the development of the framework for the hybrid simulation. The existing developed CPP models are still not able to cope with the problems in the CPP system leading to inefficient and ineffective decision making. Several techniques for analysing the patient pathways have been used to reduce the problems such as; the Markov model, Direct Experimentation (Lean Technique), Discrete Event Simulation (DES), System Dynamics (SD) as well as the Tree Diagram, but to no avail. These techniques could be categorized into two methods: direct experimentation and simulation modelling.

Due to the limitations of a single modelling technique (incapable of analysing feedback loop and individual analysis), as well as the static model, the researcher has suggested that combining DES and SD, named as the hybrid simulation, for modelling, that will provide considerable advantages, especially when pathway modelling is involved. The advantages of the respective techniques will cover the limitations of each other, thereby complementing each other. The researcher believes that by combining the DES and SD, the decision making process will be enhanced as the techniques' limitations and weaknesses will be covered by each other. The researcher also believes that the hybrid simulation will improve the viability of the model.

As suggested in the previous paragraph, to the best of the researcher's knowledge, no existing framework for hybrid simulation (combining DES and SD) has been developed, particularly for the CPP system. The researcher argues that the framework is much more important compared to the standard hybrid CPP model itself as there is no specific model that will represent standard CPP model due to the different stakeholders, systems, and regulations, as well as the objective of model development (MacAdam, 2008). A framework is also important as it will ensure that the developed model will run smoothly, the same as a real system (Mingers and Brocklesby, 1997). The framework will provide guidelines for modelling multiple departments/modules to ease the modelling process and help with the complexity of the model. It will also help the stakeholders to understand and be actively involved in the development of the model itself. The following is the finalized framework after several amendments were implemented in Chapter Four and Chapter Five.

6.2.1 Main Framework

This framework has been divided into three phases, with each phase having their own objective. They are:

a. Conceptual Phase – transferring from the actual system into a more descriptive logical process (building blocks)
b. Modelling Phase – transferring conceptual systems into simulation software (developing models)
c. Models Communication Phase – integrates different models (SD and DES)

Figure 6.1 depicts the main framework. The framework will continue with the model communication phase depending on two conditions. The techniques used for modelling are the

SD and DES simultaneously and, if not, then a single model, either the DES or the SD model, is produced. The second condition is that both models can be integrated and, if not, separate models are produced. The models communication phase happens when one or more of the inputs/outputs from one model are influenced by another input of the other model and vice versa.

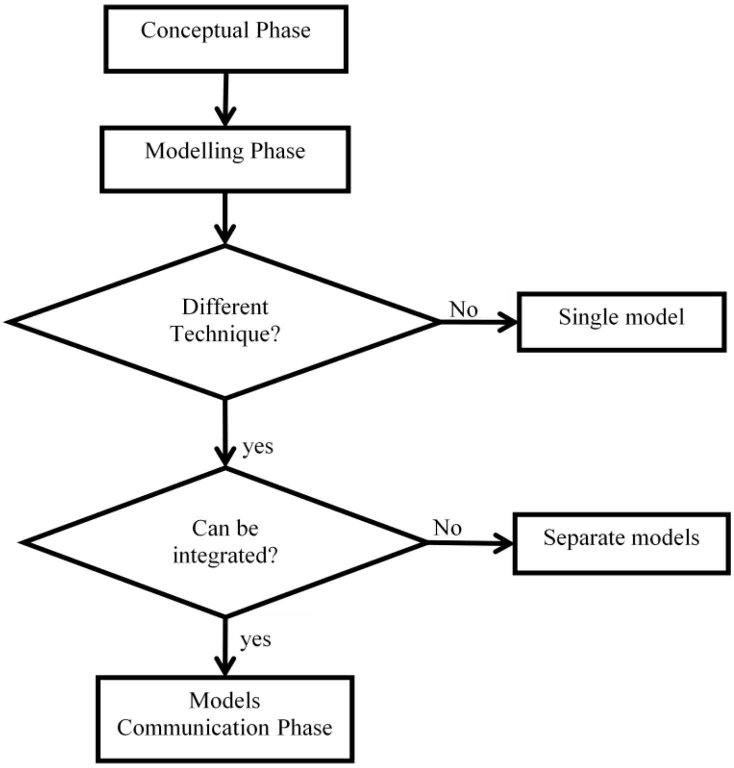


Figure 6.1: Main Framework

6.2.2 Phase 1: Conceptual Phase

The objective of the first phase in this framework is to transfer the actual system into a more logical descriptive process that will be presented into building blocks. Generally, the conceptual phase involved in the conceptualization aspect of the model is to make it visible as this will help the modellers and the stakeholders view the system as a whole. There are six steps and each step in this phase has its own objectives. Figure 6.2 depicts the steps involved in the conceptual phase of this framework, followed by their explanation, whilst Table 6.1 summarizes the steps, their objectives and method (how to perform this task).

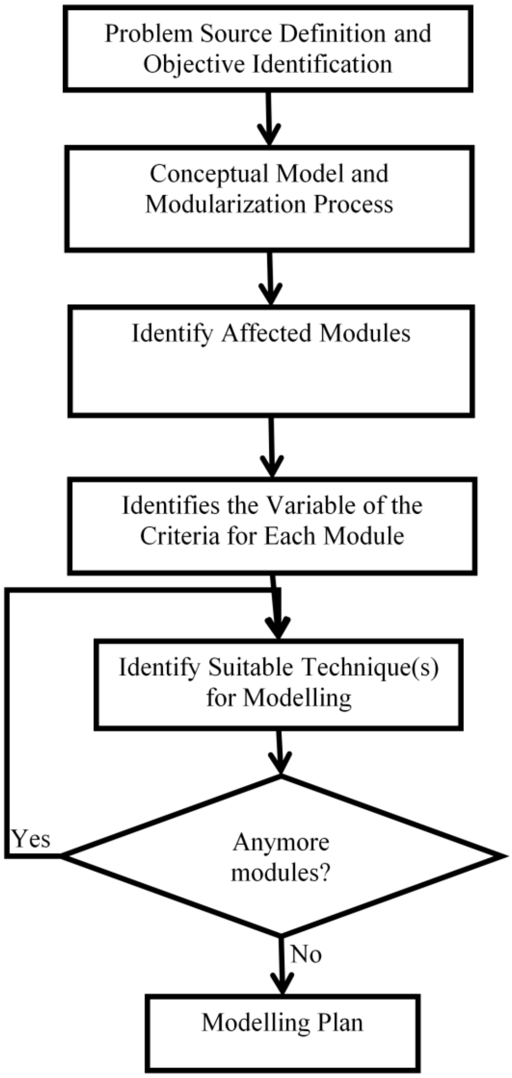


Figure 6.2: Conceptual Phase in the Framework

Step one is '*Problem Source Definition and an Objective Identification*'. This step is important as it will help the modellers in defining the boundaries of the model and focus more on the problems that lead to the modelling activity. This activity can be done by collecting all the information from the stakeholders involved in the CPP system. This step is crucial due to the condition that each stakeholder has their own problems and perception, which makes the step more complicated (Eldabi, 1999). The process of collecting all the information from the stakeholders will ensure that the modellers focus more on the root of the problem rather than small problems and also ensure that the modelling activities are not too complicated. This process will also facilitate identification of the objective, which will identify the boundaries of the model (Pressman, 1997) and, consequently, reduce the time and other resources for model development.

The second step is the '*conceptual model and modularization process.*' The conceptual model will allow the modellers to make the system more visible by transferring the actual system into more descriptive building blocks. This step will ease the process of translating the model into the simulation software. This step is followed by the modularization process, which deals with the composition of several processes or the grouping of several processes of a system into modules (Pressman, 1997). The composition into several modules will facilitate the modelling activities, especially when it deals with the DES technique, as it will reduce the complexity of the model. This step can be done by dividing several processes based on the care setting (where the care is provided e.g., healthcare, social care, A&E, surgery, outpatient, etc.) and by dividing long patient pathways or processes into modules.

The third step in this phase is to '*identify affected modules.*' The effected module(s) are detected due to the objectives, or due to the problem definition, or due to the intervention. This will inform the modeller about the limitations and boundaries of the model and, consequently, will reduce the model development time. The selection process will depend on the professionals and stakeholders that are involved in the decision making activities.

Following step three is step four, which *'identifies the variable of the criteria for each module'*. Identifying the variable in each of the criteria will help the modellers decide which technique(s) is suitable for modelling a specified module. The criteria that should be defined by the modellers are; effect (short- or long-term), type of analysis (individual or aggregate), and feedback requirement. To facilitate this activity, a set of questions was devised by the researcher, as follows.

a. To determine whether the module is affected long- or short-term – Will the intervention affect the other subsystems in the short- or/as well as the long-term? There can be two answers for this criterion as the intervention can affect other modules short- and long-term.
b. To determine what type of analysis should be done to each module – Is the value (e.g., time/patient's type of disease) between individuals very different? If the answer is YES then an individual analysis is required, and if the answer is NO then an aggregate analysis is required for the particular module.
c. To determine whether the module has a feedback loop or not – Will any interventions/actions cause backward feedback (previous module/steps)?

The modellers can seek professional advice to determine the answer for each of the criteria. This step will continue until all modules have been identified by their variables of the criteria.

The second to last step for this phase is to *'identify the suitable technique for modelling'* each of the module and the rest of the models. The activity for this step depends on the previous step, whereas each of the variables in the criteria will have its own suitable technique to be captured. As each module has its own criteria and each criterion has its own variable, different techniques are required to capture the variables. Therefore, each module will have a different technique that is suitable for modelling. One suitable technique to capture the short-term effect, and individual analysis, but does not have a feedback loop, is DES, while SD is more suitable to capture the long-term effect, aggregate analysis and it has a feedback loop. A hybrid simulation is required if the variables of the criteria for that particular module has a different, more suitable technique to capture.

The last step is the '*modelling plan*', which depicts what technique should be used for modelling each module and how detailed each module should be, especially when the SD technique is required. This step will facilitate the modelling activity in the next phase of this framework. There are six possible modelling plans, which have been categorized into three main categories. These are:

a. All modules use a single technique – either SD or DES technique
b. Some module(s) use a single technique, whilst some use the hybrid – SD + hybrid or DES + hybrid
c. All modules have to use the hybrid simulation

Table 6.1: Summary of the Conceptual Phase

Phases/Steps		**Objective**	**Method (How)**
Phase One: Conceptual Phase – transferring from the actual CPP system into a more descriptive logical process (building blocks)			
1.	Problem Source Definition and Objective Identification	To set a boundary of model building and identify which subsystems are involved.	By asking expert opinion.
2.	Conceptual Model and Modularization Process	To reduce the complexities of model development.	Conceptual Model – scratch from system description to logical system (building blocks). Modularization – divide several processes into a group or divide into several subsystems or care settings.

Phases/Steps		Objective	Method (How)
3.	Identify Affected Module(s)	To reduce time in model building and to set a boundary.	By asking professionals opinion or by looking at the subsystems that have a direct impact on the defined objectives.
4.	Identify the variable(s) of the criteria for each module	For the selection of a suitable technique for modelling of each module.	Answering the questions that have been provided. It will guide the selection of the criteria properties.
5.	Identify the suitable technique for modelling	Due to the fact that not every module has to use hybrid modelling; it will decrease the time for modelling.	Refer to the Table 3.3 in Chapter Three.
6.	Modelling Plan	To facilitate the modelling activities as it shows how to model each module.	By developing a conceptual model of how each module will be developed (as in Figures 3.7 – 3.12 Section 3.4.2 in Chapter Three)

6.2.3 Phase 2: Modelling Phase

The second phase in the framework is the modelling phase, which is depicted in Figure 6.3. The practical aspect of the modelling will be based on the modelling plan defined in the previous phase. Depending on the modelling plan, there are six possible types of modelling for each module. They are; a single technique that will either use DES or SD (case 1 and 2 respectively, as in Figure 6.3), or hybrid simulation, that is, a combination of DES and SD or hybrid (remaining case, as in Figure 6.3).

The translation of the modelling activities into the software will start by modelling the DES model, module by module using any DES simulation software, such as Simul8 or other DES software as described in Chapter Three. These modules will be linked together using the output from the first module, which will serve as the input for the second module. The variables involved in this process are; the patients' information, such as the time taken to complete the tasks in certain modules, and the background of the patients (age, type of illness, sex, etc.), as they are unique cases.

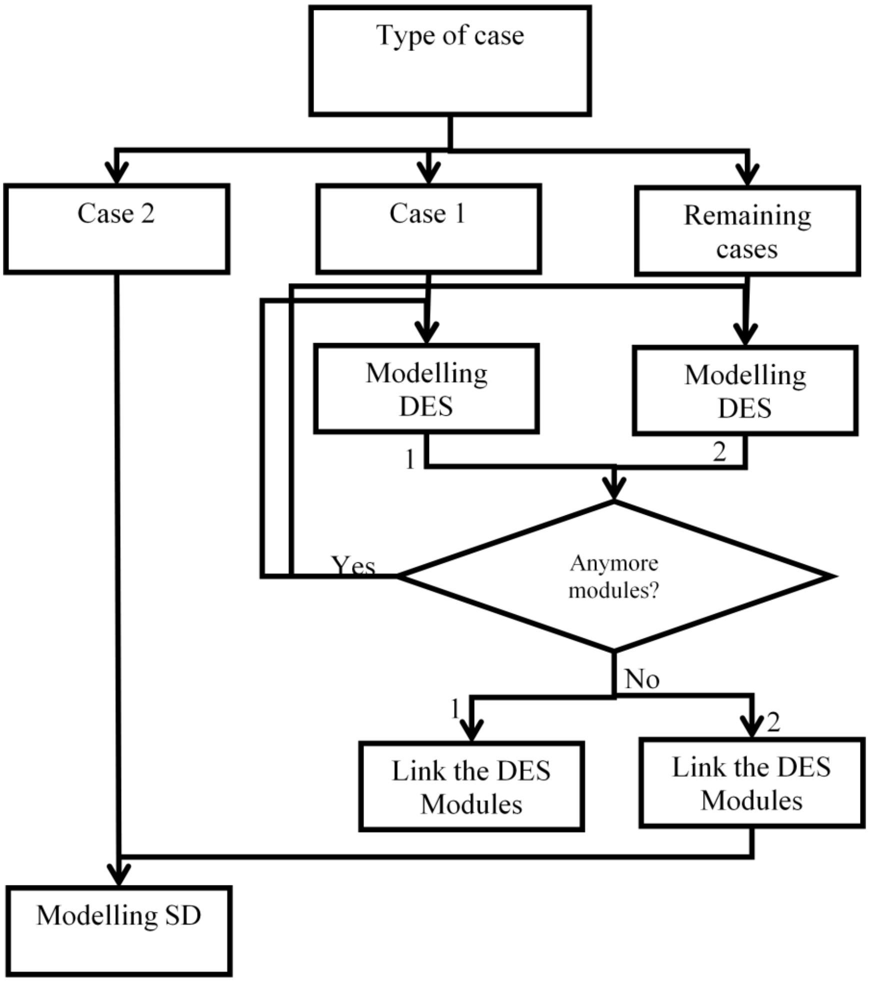


Figure 6.3: Modelling Phase in the Framework

The modelling process will continue with the SD model for cases that need multiple techniques for modelling. The SD model will be applied on a module-by-module basis and will link the module by connecting the stock and flow, or connecting their auxiliary, or connecting with their associates' factors, using any of SD software, such as Vensim or other SD software as described in Chapter Three. However, the modelling process can also be modelled as a whole system. The detailed and more rigorous part of the modules in the SD modelling will be conducted depending on the modelling plan that has been identified in the conceptual model. The SD and DES modelling activities can be done simultaneously if the expertise is sufficient. Table 6.2 summarize the modelling phase.

Table 6.2: Summary of the Modelling and Linking Phase

Phases/Steps		**Objective**	**Method (How)**
Phase Two: Modelling Phase - translation of the building block into the simulation software			
1.	Modelling DES Model	Translating conceptual models (building blocks) into simulation software. The simulation process will save time, money and other resources.	Using any DES Software.
2.	Linking DES Modules		Using outputs from the first module to be the input for the second module, and so forth.
3.	Modelling SD Model		Using any SD Software.
4.	Linking SD Modules		Using variables connecting to other variables.

6.2.4 Phase 3: Models Communication Phase

Depending on the two conditions, which are; multiple techniques used simultaneously for modelling (SD + DES), and the models that can be integrated, the framework continues to the models communication phase. Prior to this phase, the modeller should determine whether both models can be integrated or not, and identify the variables from one model that will influence another variable in the second model (Chahal, 2009). Identifying the variables will inform the modellers whether to continue to this phase or not. This phase will determine how the communication between both models takes place. The following provides the explanation of the six steps involved in this phase. Some of the steps will be decomposed into several other activities to ensure that the phase and the framework are not complicated.

The first step in this phase is *'identifying variables in both models that can be linked together.'* in both models. The identification of variables that can be linked together is done by detecting all the variables that 'influence' or that is 'influenced' in both models. Expert opinion can be gathered to ensure which variables 'influence' and which are 'influenced'.

The second step is to *'define the last output from the variable linkage'*. Based on the previous variables linkage, the new output will be produced, which may or may not influence another variable depending on the model (whether it has been modelled or not). For example, the total number of patients will influence the performance of the professional. Consequently, the patient assessment could be wrong due to the reduced performance of the professional. In this case, the variables linkage is total patients and performance, whilst the last output is patient assessment.

As there could be many variables that can be linked between the models, the modeller should define the initial influencing variable. Therefore, the next step is to *'identify the initial influencing variable'*. This step can be done by seeking the opinion of an expert as to which variable will be the initial influencing variable. This step will also facilitate the modeller in deciding which model should be run first, as this framework will only deal with the cyclic interaction. Although Chahal (2009) introduced two types of interaction, or model communication, the researcher is more confident in using the 'cyclic' interaction which runs the models one by one. This is also due to the researcher manually transferring data and arguing that using 'parallel' interaction is impractical when performing a manual data transfer. The researcher also argues that parallel interaction needs custom programming to be used as an agent that will facilitate the models interactions.

Following the previous step is; *'run both models and exchange all the variables involved'.* The 'variables involved' is the variable that was identified in Step One that has an 'influence' and 'influenced' relationship. This step will be performed two times at most as it might involve a loop process, especially when the modeller identifies that both models have initial influencing variables. As the SD and DES models both have the possibility of having an initial influencing variable, the researcher will use general terms in this framework. The 'source model' refers to the model that has the initial 'influencing' variable(s), whilst the 'destination model' contains the initial 'influenced' variable(s). The process of running and transferring data between both models will be done until either of the following situations takes place – the 'influenced' variable in the 'destination model' is not influenced by another variable in the 'source model', or, the output of both models are stable whereas the output between the running process and another running process is not much different. Example of what is stable output after several running process is depicted in Table 6.3. The value of total number patient readmission between each run is not in large different (small gap). Figure 6.4 depicts the decomposed Step Four of the Model Communication Phase.

Table 6.3: Number of patient readmission (certain week) for each run (SD Model)

Week \ No of run	1	2	3
18	1.60	1.89	1.70
20	2.34	2.23	2.30
21	3.11	2.98	3.01
22	2.73	2.75	2.80
23	2.56	2.70	2.68
24	3.59	3.70	3.56
28	1.07	1.29	1.33
29	0.67	0.89	1.02
30	6.19	7.01	6.55

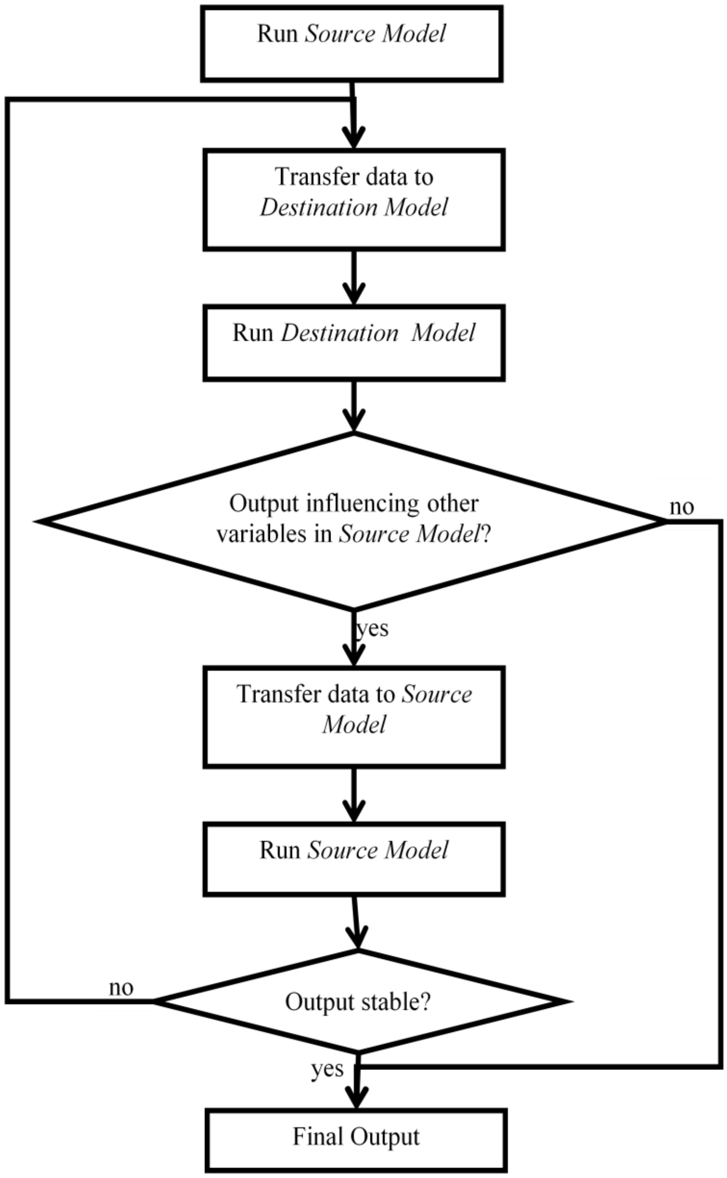


Figure 6.4: Step Four (Phase Three) Decomposition

The second to last step in this phase is the *'evaluation of the outputs that have been produced'*. The last output can be in either the 'source' or the 'destination' model, depending on these two conditions. If the variables that have been 'influenced by' in the 'destination' model have influenced other variables in the 'source' model, the last output will be in the 'source' model. Otherwise, the model will be in the 'destination' model, as the variable that was 'influenced' in the 'destination' model is not influencing the 'source' model. The flowchart in Figure 6.5 depicts the process of determination of which model will provide the last output (variable).

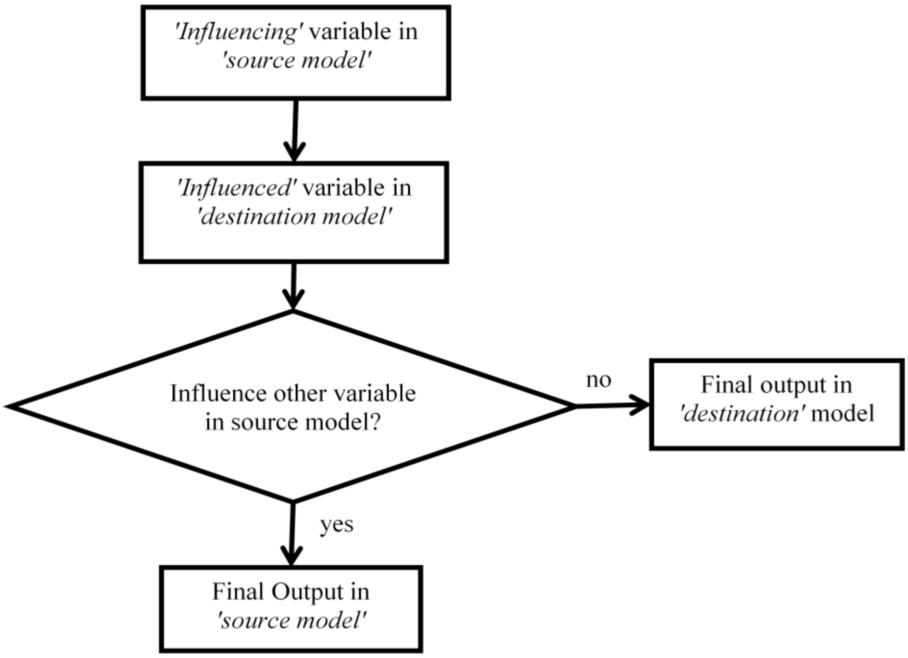


Figure 6.5: Outputs Determination (Step Five)

The last step in this phase and, consequently, the last step in this framework are '*suggestions for system improvements*'. One of the advantages of the simulation method that can be used for experimentation is that several interventions can be performed by the modeller to select the best intervention (changing inputs) for system improvements. Basically, to maintain the relationship between both models, the changing input should be done in both models. However, there are certain situations where only the input/variable of a particular model should be changed.

If the intervention is done in the 'source model' and influences other variables in the 'destination model', the variables in both models should be changed. If the variable in the 'source model' that performed the intervention does not influence another variable in the 'destination model', only the variable in the 'source model' is involved in variable changing. If the intervention is done in the 'destination model', and the variable in the 'destination model' influences another variable in the 'source model', both models should be changed. However, if the variables in the 'destination model' where the intervention is being done do not influence other variables in the 'source model', only the variable in the 'destination model' should be changed. Put simply, if the intervention is being done in a particular model and the variable influences other variables in another model, the variable should be changed in both models, otherwise, only the particular model is involved in variable changing. Figure 6.6 depicts the different situation as to whether to change the variable or not.

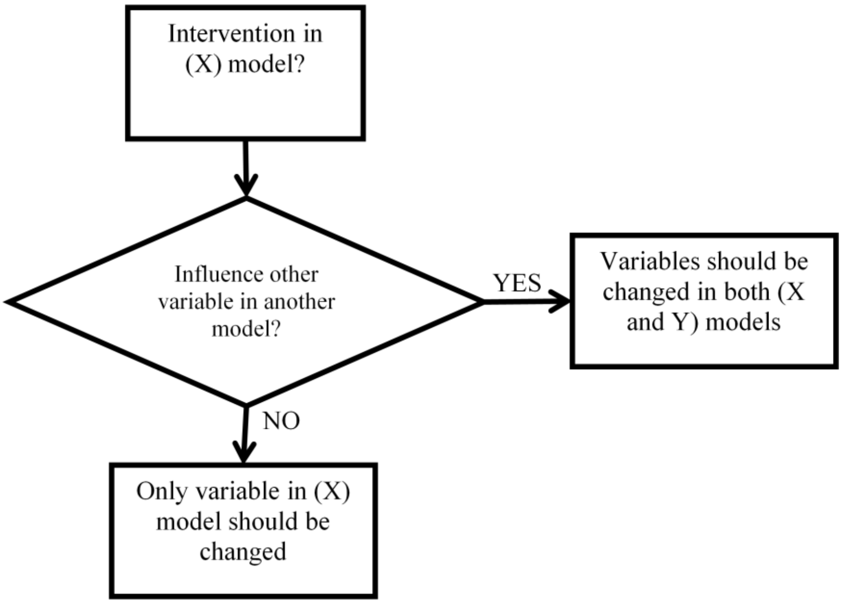


Figure 6.6: Changing Variables (Step Six)

Table 6.4 summarizes the steps involved in the model communication phase, which is followed by the model communication phase depicted in the flowchart in Figure 6.7, whereas the (X) and (Y) models are refers to either *'source model'* or *'destination model'*.

Table 6.4: Summary of the Models Communication Phase

Phase Three: Models Communication Phase			
	Steps	Objectives	Method
1.	Identifying the variables in both models that can be linked together.	To identify remaining variables that influences or is influenced by.	By identifying which variable in the DES model will influence the variable in the SD model.
2.	Define the last output from the variable linkage.	To determine what is the final outputs from the variable linkage.	Variables in the model that 'influence' is the source model, whilst the variable that is 'influenced by' is the destination model.
3.	Identify initial influencing variables	To determine which model should be run first before performing variables exchange	By seeking advice from an expert.
4.	Run both models and exchange all variables involved	To link between both models and produce reliable outputs	As depicted in Figure 6.4.
5.	Evaluation of the outputs that have been produced	To evaluate all the outputs and make suggestions for the system improvements	Seeking advice from an expert
6.	Suggestion for the system improvements	To experiment with several interventions to the system and select the best solution	Seeking advice from an expert

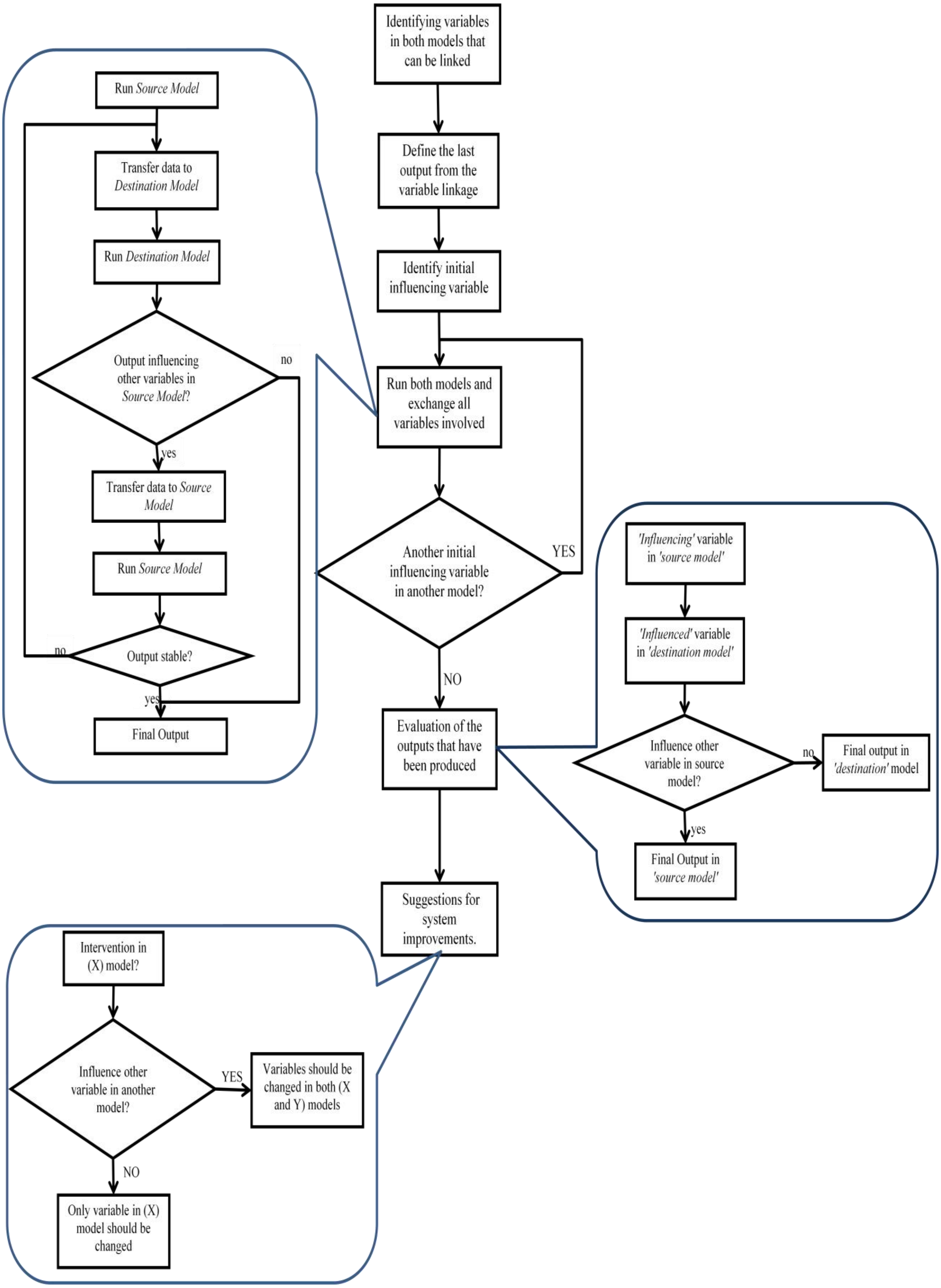


Figure 6.7: Model Communication Phase

The next section will discuss the framework reflections, in which the discussion regarding the researcher's self-evaluation of the framework has been developed. This includes the discussion about the health and social care model that was developed in Chapter Four, to see whether all the criteria of a viable complex patient pathway model have been fulfilled or not.

6.3 OVERALL FRAMEWORK REFLECTIONS

This section aims to discuss the evaluation of the developed hybrid simulation model that has been developed in the previous chapter using the established framework. The framework will also be evaluated. These evaluations are compared with some of the criteria for a viable CPP model that was developed in Chapter Two. Using the finalised framework, one can see whether the needs and requirements of the viable CPP model identified earlier could be covered by both the framework and the models. Table 6.5 presents the framework evaluation plan which has been divided into two types of evaluation – evaluation of the developed model and evaluation of the framework. The evaluation criteria were taken from the criteria of a viable CPP model that was identified in Chapter Two.

The finalised framework will also be compared against the frameworks of Chahal (2009), Helal et al. (2007) and Giachetti et al. (2005) to identify the differences and enhancements between this framework and their framework/models.

Table 6.5: Framework Evaluation Plan

6.3.1 Evaluation of the Developed Model	**6.3.2 Evaluation of The Framework**
a) Prior experimentation b) Cover the whole system c) Represent the system closely d) Easy to understand the models e) Simplify the complexity of the CPP system f) Fully support the decision making process g) Dynamic Models	a) Provides guidelines for selecting the best technique(s) for modelling b) Provides guidelines of how to simplify a complex system c) Ease of use and understandable d) Provide justification for selecting individual analysis (DES) and feedback loop (SD)

6.3.1 Evaluation of the Developed Model

In Chapter Two, the researcher listed several limitations of models that have been developed for the CPP system. The main objective of this research is to provide the framework for modelling the CPP system which will provide all the guidelines that allow a viable CPP model to be created. As the model of the CPP system will be developed based on the framework, the researcher will assess the developed model using the criteria that has been established from the limitations of the developed CPP models. The criteria that will be assessed with the developed model are as follows;

a. Prior Experimentation Implementation

The researcher believes that the implementation of intermediate care into the health and social care system was done prior to experimentation by simulation being conducted. The researcher also believes that this experimentation was carried out by introducing intermediate care in a real life situation and the results were taken from observation of the experiment within a certain period of time. In other words, they were using direct experimentation, or try and error (Giachetti et al., 2005). This argument is based on Armstrong and Baker (1994) who provided the meaning of intermediate care. This indicates that intermediate care was already formed, however, no literature was found relating to the simulation modelling of intermediate care prior to the year 1994, when it is believed to have first been implemented. As argued in the previous chapter, implementing real life experimentation will involve high cost and resources. Using simulation software will help the decision makers see the consequences of every intervention proposed for CPP systems. Since the model uses DES and SD simultaneously, all the limitations of using a single simulation technique, as discussed before, are considered to have been covered.

b. Cover the Whole System

The CPP are interdependent upon each part. Any intervention done to any one of the subsystems will have a huge impact on the other parts. Therefore, any impact from any intervention intended for one sub-system should consider its impact on the other sub-systems as well. However, it is not worth the effort and is illogical if all the sub-systems, and the environment surrounding the system, should be taken into consideration for modelling purposes. This will depend entirely upon the policymakers and modellers to set the models' boundaries. Thus, the researcher suggests that the only sub-systems that have a direct impact on the whole system should be included in the models, which will depend on the overall objectives of the model building. For example, if the purpose of the developed model is to solve the patient pathway problem in public hospitals, the modellers should only include the subsystem or environment that the patient will go through rather than including a supplier of the service provider, which is from a private company that is outside the consideration of the subsystem. To conclude, the selection of the sub-system or environment surrounding the system will depend on the knowledge and experience of the policymakers and the modellers.

c. Closely Represent the Whole System

The researcher has tried his best to model the CPP system closely to the real systems. However, to establish a model that is the exact replicate of the actual system, which includes all the factors, elements and the systems' environment, is an impossible task. This is because every model should have its own specific boundaries and limitations. This is also to prevent the model from becoming too complicated and hard to understand. The developed model does not closely represent the whole system, as the researcher experienced inadequate time for gathering the actual data for testing purposes. As has been emphasized before, the objective of this research is to develop a framework. The testing with the case studies is done purposely to assess and ensure that the framework is working accordingly and is easy to follow. As such, the model has included individual analysis, as well as the feedback section, as the consequences of putting intermediate care between the health and social care sectors.

d. Easy to Understand (System Model)

The use of the Simul8 software for modelling the DES model has 'exemplified' the CPP system. It shows graphically how the CPP system operates and shows the different patient pathways. As the saying goes, a picture speaks a thousand words, the graphical annotation and pictures will help people within the system to understand it easily and to enable them to identify the bottleneck in the system, detect problems and analyse the decision wisely. Using Vensim for SD modelling needs a little bit of understanding of how the dynamic system works (stock and flow, causal diagram). The modellers also have to understand the graphs depicted in the results of the model, as the output of the SD is in graphical form. However, the graphs shown are not too complicated to 'read' and are easy to understand. With a brief explanation of how the model works, the researcher believes that models using the SD and DES techniques are easy to understand compared to mathematical or statistical modelling, especially for beginners or persons who are not involved in the modelling area has been proved by Tako and Robinson (2009).

e. Simplifying Complexity

To model the whole CPP system (from one department or care givers to another) with one stroke will involve a longer time frame and the model may become more complicated. Furthermore, it will take more time to run the model, especially if the model uses the DES technique. The SD technique can be used for modelling the whole system (Chahal et al., 2008), however, important features such as individual analysis will be disregarded. Therefore, clustering the whole model into several areas/divisions will ensure that the complexity of the system is reduced while making it easier to develop, remain flexible and ensure it is easy to interpret the results (Robinson, 2006). It also helps the modellers not to forget important elements that need to be included in the model. Based on the model that has been developed in Chapter Four, it shows that the model has been clustered into several modules. The clusters will make the model easy to understand and develop, and run much faster and the developed model will be less complex, even though it was initially a complex system.

f. Support Decision Making

The term of 'fully support decision making', as clarified in Chapter Two, means that all the intended interventions done to the system will show the results immediately and not after the real implementation has taken place. By looking at the above, the developed DES model showed areas that experienced a bottleneck that caused the CPP system's problems and also showed how the interventions (adding intermediate care) can help to reduce the CPP problems. The SD model enables the decision maker to explore possible policies that need to be implemented into a stable system for a longer period of time. The results of all interventions and policies that have been done to the system will show an immediate result and help make the decision making process more reliable and efficient. However, the output from the model will very much depend on the input reliability and useful data.

g. Dynamic Model

Most of the developed CPP models are static and need real time experimentation to assess the suitability of use in the system (NHS Institute for Improvement and Innovation, 2010), require time and high financial resources and they are non-convincing as a problem solver. Using the mathematical model has to be based on the objectives and cannot be re-used for another intervention for the same system (Venkateshwaren and Son, 2005). The dynamic model that has been developed using simulation will mimic the real system environment as the model will respond to any interventions and policies introduced over time.

6.3.2 Evaluation of the Established Framework

As the developed framework is based on the criteria of a viable CPP model, the framework will be assessed thoroughly against the criteria of a viable model that has been established based on the characteristics of the CPP system. The criteria that have been established are as follows:

a. Provide Guidelines for Selecting the Best Modelling Technique(s)

Depending on certain criteria, different techniques should be used for modelling some of the modules as every modelling technique has its own strength and limitations. Therefore, the framework has included several tips in order to determine what technique should be used for a particular module. This is the step that Helal et al. (2007) missed. The guideline of selecting the best technique that has been developed by Chahal et al. (2008) was decomposed into several criteria. The researcher did not include all of the criteria as it will make the technique selection more complicated.

b. Provide Guidelines on How to Simplify a Complex System

A system can be more complex depending on three criteria: the number of components involved, the pattern of connections and the nature of the connection (Brooks and Tobias, 1996). Based on this definition, patient pathways in integrated care can be defined as a complex system as it has multiple components. The pathways are varied and the connections are connected throughout the system. One of the objectives of modelling is to reduce the complexity of a system (Eldabi, 1999) and make the system more ‘visible’ in detecting the problems within it. Since the CPP system is a large-scale system and comprises of several other systems, the easiest way to ensure the CPP models are less complicated is to cluster several processes and model them based on module-by-module and then link them together. This is to ensure that the system model is modelled thoroughly without missing any important features that will result in poor decision making. The framework will guide the modellers on how to simplify the complexity of the system once the objective of the modelling is defined.

c. Ease of Use and Understandable

The framework will provide the guidelines in terms of step-by-step instructions in order to model the whole CPP system. By doing this, the researcher agrees that the framework should be easy to follow and understand. The first, second and third phases are quite easy and involve straightforward processes. However, those who are new to the area of modelling will take some time to enhance their knowledge of modelling using software. Depending on the level of the modellers' experience, the later phase, which involves defining the integration points and integrating them between different techniques, might be a challenging task. This has been admitted by Chahal (2009) who developed the method of how to integrate between different modelling techniques (DES and SD).

d. Provide Justification for Selecting Individual Analysis (DES) and Feedback Loop (SD)

Some cases might need individual analysis, especially when the time, or cases, between one patient to another patient has a large interval. Some other cases might have to be analysed by cohort or aggregate, for example, for the problems and the models in the social care. Social care has been divided into several modules and the unique individual case is not important as all the patients have been divided into several groups (based on medication, treatment, etc.). Both types of analysis have their own advantages and disadvantages, especially for decision making purposes (Griffin et al., 2005). The proposed framework has provided several criteria in order to justify the needs based on individual analysis. The individual case will depend on the modellers' and experts' opinions, and the framework provides the justification should they need individual analysis. The identification of a unique individual case should be included and will provide clues for selecting the DES technique for modelling. The modellers should understand the technique and be aware of when to use individual analysis. Further analysis for selecting the appropriate model structure can be found in Brennan et al. (2006).

6.3.3 Comparison of Hybrid Frameworks

This framework is developed based on Giachetti et al. (2005), Helal et al. (2007) and Chahal (2009). Consequently, this subsection will provide a comparison of the differences between their frameworks/models and this framework. It will also provide an argument for the enhancement made by the researcher. The comparisons of the differences and enhancements are based on several perspectives, such as; in terms of the framework development process and suitability, guidance for intervention, guidance for selecting suitable techniques for modelling, the hybrid operation, synchronization and the process of running both models. The following are the explanations and justification of the comparisons, differences and enhancements between these frameworks, followed by a summary in Table 6.6.

a. Framework Development Process

Giachetti et al. (2005): This started with the needs of using DES for analysing patient pathways and used SD for analysing patient's emotion. They developed two different models with two different objectives applied in the healthcare sector.

Helal et al. (2007): This started with the needs of individual analysis and a feedback loop in the supply chain area. They developed a hybrid model for a manufacturing supply chain without developing the framework.

Chahal (2009): This started with the theory about what type of problem can be solved using decision tools, especially concerning the aspect of modelling with simulation (DES, SD, Hybrid), and followed this by applying the framework to the case study in healthcare. This is the reason why the framework was initially tested against the theoretical approach before being applied practically.

Author (2011): This started with the case of complex patient pathways, finding the best decision tool (hybrid modelling simulation techniques) to facilitate the decision making process and develop the framework based on the actual case study. That is why the researcher evaluates the framework using the practical approach (suitable for a specific case), followed by the theoretical approach (suitable for other cases that have been identified as CPP in the integrated care).

b. Framework's suitability

Giachetti et al. (2005): Suitable for the healthcare sector. The models are developed based on the techniques' advantages – DES for capturing individual analysis and SD for capturing patient's behaviour and emotion.

Helal et al. (2007): Suitable for large units and multiple departments in the manufacturing supply chain area.

Chahal (2007): Suitable for single departments. Furthermore, the framework is limited to the hybrid simulation that could be combined using different models.

Author (2011): Suitable for multiple departments with multiple and complex patient pathways. The framework is not limited to only one case as the researcher has identified several cases or types of model communication, including a single technique. To avoid the complexity of dealing with multiple pathways, especially those with regard to modelling with DES, the model structure has been broken into several modules and will be linked using the output from the first module.

c. Guidance for Intervention

Giachetti et al. (2005): The researcher argues that they do not combine the models; therefore, the intervention is the same as in a single model.

Helal et al. (2007): Not provided.

Chahal (2009): Does not really show how to deal with the intervention for both hybrid and single models.

Author (2011): Shows exactly how to deal with the intervention and whether the change is in the form of inputs from a single model only or from both models.

d. Selecting Suitable Techniques for Modelling (leading to hybrid simulation)

Giachetti et al. (2005): They used DES for modelling patient pathways and SD for modelling patient behaviour. As they do not mention whether the models were combined, the researcher argues that neither model was combined (the term hybrid is used due to the fact that they used DES and SD simultaneously for modelling).

Helal et al., (2007): Assumes that all modules have to be developed using hybrid simulation. The researcher argues that this will take a longer time to develop. Some of the modules do not have to be developed using the hybrid simulation.

Chahal (2009): Breaks down the whole objective into several parts. Based on the sub-objective, suitable techniques will be identified. The researcher argues that breaking the main objective into several objectives will be confusing and difficult to define, especially when dealing with many modules.

Author (2011): The researcher breaks down the whole model into several modules. As the whole model was broken down into several modules, the identification of suitable techniques to be used is based on the modules themselves. Several guidelines, in the form of questions, have been developed in order to help a decision maker select which tools should be used. Professional expertise could also be engaged to determine which module should use single or hybrid simulation.

e. Hybrid Operation

Giachetti et al. (2005): Not provided.

Helal et al. (2007): All variables in both models were involved in exchanging activity. It is argued that this hybrid operation is too complicated and technical.

Chahal (2009): Based on the researcher's understanding, in terms of a hybrid operation, most of the variables in each of the models will be interchangeable between the models. There are three types of operation for the variables that are interchangeable: direct replacement, aggregated/disaggregated and causal loop (for variables that influence and are influenced by). The models will be run either separately (cyclic) or in parallel. She does not clearly mention in her framework when the interchangeable variables measures should be stopped.

Author (2011): Interchangeable variables involve variables that influence and are influenced. To maintain the synchronization of both models, the data flow is from the 'source model' to the 'destination model'. The researcher has also clearly mentioned the hybrid operation stopping point measures. The interchangeable variables activity will stop if either these conditions happen – outputs are stable or the variable is not influencing other variable.

f. Synchronization between Different Models

Giachetti et al. (2005): Not provided.

Helal et al. (2007): Synchronized by a time bucket called the SDDES controller. This type of synchronization might be too technical and complicated to follow.

Chahal (2009): Did not clearly mention how both models could be synchronized.

Author (2011): When it is identified that the models need to use hybrid simulation, both models (SD and DES) are developed separately. In terms of the synchronization, the researcher clearly described to the modellers that it is pertinent to ensure that both models are synchronized, especially in terms of inputs and outputs. Any form of inflow and outflow (patient pathways) from the model should be identified and observed to ensure that both models are synchronized.

g. Process of Running the Models

Giachetti et al. (2005): Assumed that both models are running parallel and both results produced different perspectives – DES with individual analysis and SD with patient behaviour.

Helal et al. (2007): Not provided.

Chahal (2009): The models were run either simultaneously (parallel) or one by one (cyclic). Chahal (2009) acknowledged that one of her limitations is that the interactions between both models were done manually. Practically, the fact that the SD model will produce the outputs within seconds after the model has been run raises a question – if both the models are run in parallel, how does the interaction (changing the variable between both models) happen as the author was doing this manually? This is one of the limitations in this framework as she has not clearly defined how the models interact with each other.

Author (2011): Provides systematic guidelines as to which model should be run first and also facilitates and shows how the interchangeable variables happen. The 'source model' should be run first, followed by the 'destination model'. Depending on the developed model, the output from the destination model will be passed back to the source model to generate results of hybrid model.

Table 6.6: Summary of Differences and Enhancements

Frameworks/Models In terms of:	Giachetti et al. (2005) Model	Helal et al. (2007) Model	Chahal (2009) framework	Author (2011) framework
Framework Development Process (Difference)	Started with the needs of using DES for analysing patient pathways and SD used for analysing patient's emotion. Developed two different models with two different objectives applied in the healthcare sector.	Started with the needs of an individual analysis and a feedback loop in the supply chain area. Developed a hybrid model instead of developing the framework.	Started with theory about what type of problem can be solved using decision tools (DES, SD, Hybrid), followed by applying the framework to the case study.	Started with the case of IC, finding the best decision tool (hybrid modelling simulation techniques) to facilitate the decision making process and develop the framework based on the actual case study.
Framework's Suitability (Difference)	Suitable for the healthcare sector. Neither model was combined.	Multiple departments, more complex systems.	Single department.	Multiple departments, more complex systems.
Guidance for Intervention (Enhancement)	The researcher argues that they do not combine the models; therefore, the intervention is the same as in a single model.	Not Provided.	Not provided.	Shows exactly how to deal with the intervention, whether the change is in the form of inputs from a single model only or from both models.
Selecting suitable Technique(s) for Modelling (Enhancement)	They used DES for modelling patient pathways and SD for modelling patient behaviour. Neither model was combined.	Assumes all modules have to model with hybrid simulation.	Breaks down the whole objective into several parts. Based on the sub-objective, suitable techniques will be identified. Could be confusing.	The researcher breaks down model into several modules. The identification of suitable techniques to be used is based on the modules themselves. Provides some guidelines in order to help a decision maker select which technique should be used.
Hybrid Operation (Enhancement)	Not provided.	All variables seem involved in the hybrid operations. Too technical and complicated.	Most of the variables in both models will be interchangeable. Does not show how to stop the hybrid operation.	Only a few (influencing and influenced by) variables will be interchangeable between both models. Determines exactly when to stop the hybrid operation.

Frameworks/Models In terms of:	Giachetti et al. (2005) Model	Helal et al. (2007) Model	Chahal (2009) framework	Author (2011) framework
Synchronization between different models (Enhancement)	Not provided	Using SDDES time bucket controller. Looks too complicated and technical.	Not provided.	Any form of inflow and outflow (patient pathways) from the model should be identified and noticed to ensure that both models are synchronized.
Process of Running the Models	Assumed that both models are running parallel and both results produced different perspectives – DES with individual analysis and SD with patient behaviour.	Not provided.	Parallel or cyclic. Does not clearly define how parallel interaction was done practically as the SD model runs within seconds or how the variables exchange.	Provides systematic guidelines to which model should be run first and how the variables between both models interchange.

(Develop by the researcher)

6.4 DISCUSSION CONCERNING THE DEVELOPED FRAMEWORK

Upon searching the case study for the proposed framework assessment, the researcher concludes that most of the professionals are using the conventional methods rather than modelling or using other OR techniques in helping them reduce the problems in the hospitals (NHS Institute for Innovation and Improvement, 2010). The researcher argues that this is due to the limited time and lack of modellers for developing the model as they need a longer time to sit and discuss the problem together. Furthermore, developing the model could take considerable time, especially when it comes to data collection. By developing a framework, the researcher expects that the policymakers and professionals in the care sector will be actively involved in complex patient pathways (CPP) model development activities.

The researcher has tried to apply the proposed framework practically (Chapter Four) and theoretically (Chapter Five) to several case studies, within several settings, to see the framework's applicability. Upon doing that, the researcher found that there are certain models that need a single technique for modelling, and certain models need hybrid simulation for modelling. However, as mentioned in Chapter Two, it actually depends on the professionals whether they need a single technique or a hybrid simulation. It also depends on the type of patient and their need for individual analysis (Chahal, 2009). For example, if the characteristics of every patient are almost the same, such as the type of patient in social care, a single technique that uses aggregate analysis is suitable (Xie et al., 2005). However, where the decision makers are only interested in seeing the implications in the short-term period, the DES technique is suitable for use as the modelling technique (Katsaliaki et al., 2005). In the conceptual phase, the researcher has developed several questions that lead to the usage of the single or hybrid simulation. These questions can be used for guidance on which technique is viable depending on the objective of the user.

In Chapter Four, the researcher tried his best to model the health and social care system using hybrid simulation. Although the models are simple and do not fully cover all the variables involved in both models, the researcher argues that it does not affect this framework as long as the modellers know what kind of variables are suitable for capturing by DES or SD, and which variables can be linked. Table 6.7 depicts several variables that are involved in modelling the complex patient pathways system. The linkages for these variables were taken from several literatures and based on the expert opinions. These variables are divided into two types ('influence' and 'influenced') and divided, which is a suitable technique to capture these variables.

Table 6.7: Example of Variable 'Influence' and 'Influenced'

Variable Influencing		**Variable 'Influenced by'**		**References**
Suitable Captured by:		Suitable Captured by:		
DES	SD	DES	SD	
Total patients (workload)		Time: waiting and finished in the system Patients: total waiting	Professional: performance, motivation, pressure Patient: fatigue, bored	Pauliakas and Theodossiou (2009); Pfeffer and Langton (1993),
	Professionals' Knowledge and experiences	Time: waiting and finish time in the system, Total patients finish within time frame	Performance and motivation, assessment of the patients health	Expert opinion
Incentives, compensation			Performance and motivation	McCausland et al. (2005); Pauliakas and Theodossiou (2009); James (2005)
Total professionals working		Waiting time, total patient finished in the system	Professional: performance, motivation, pressure	Pauliakas and Theodossiou (2009); Pfeffer and Langton (1993)
Time frame (e.g. 4 hours for treating patient)			Pressure, performance	Chahal and Eldabi (2009)
Space in the institutions		Total patient	Quality of the patient's health	Elf and Putilova (2005)
	Motivation, performance	Waiting time	Quality in patient assessment	Chahal and Eldabi (2009)
Resources (other than professionals)		Waiting time	Performance, quality in patient assessment	Elf and Putilova (2005)
Waiting time			Patient emotion (fatigue and bored)	Expert opinion
	Pressure/stress of the professionals		Quality of the patient assessment	Aiken et al. (2002)
Total patient readmission			Distance from hospital as they hard to get the treatment	Dellasega et al. (1999)
Treatment time		Quality of assessment	Patient's satisfaction	McCausland et al. (2005)
	Quality of assessment		Patient's satisfaction	Aiken et al. (1998)
	Performance	Incentives		McCausland et al. (2005)
Facilities		Demand		Bird et al. (2007); Ulrich, (1991)
	Performance		Job satisfaction	Heywood and Wei (2006)

Developed by the researcher

In the real world situation, no system could exist on its own. Every system is dependent on other systems to help it survive. The dynamics of the systems will help the universe to maintain the surviving balance in each of the systems. Considering this argument, the researcher claims that to ensure the dependency of a system is balanced in order to maintain its dynamicity, any intervention introduced to the system should be considered as part of the other systems as well. To see the impact of the intervention on the other parts of the systems, it is argued that all systems that are actively related to the main system have to be modelled together. This action will ensure that the impact on one part of a system will be taken care of and, in turn, will improve the decision making process.

It is also argued that the proposed framework can be applied to any of the supply chain problems in manufacturing, production, as well as in other large organizations that need modelling to help the decision making process.

6.5 CONCLUSIONS

Chapter Six presented the proposed framework for modelling the CPP system. The framework has been established after several amendments have been done based on the output of the assessment process. The reflection in Chapter Two has confirmed that the proposed framework will close the gaps that have been initially identified. By applying this framework, it will help the policymakers to make efficient decisions as the model that is developed based on the proposed framework is viable enough to mimic the real system, especially in CPP. With some modification, this framework is deemed to be applicable in other types of supply chain areas, as it provides the general guidance on how to develop models that use hybrid simulation.

The next chapter will provide the recommendations and conclusions of this research. It will include discussions on the arguments and justifications regarding the research contributions and suggested future works. The conclusion part of this research will touch generally on the research and specifically on the proposed framework. The researcher will conclude based on the overall discussions from the beginning to the end of this research.

CHAPTER SEVEN: CONTRIBUTIONS, FUTURE WORKS AND FINAL CONCLUSION

7.1 INTRODUCTION

Chapter Six has discussed establishing the framework of hybrid simulation used for modelling the complex patient pathways (CPP) system. This framework was established after several processes of 'cleaning and polishing' by applying the framework in several case studies. This chapter will discuss the findings, including recommendations, contributions of the framework, and suggestions for future research.

The first section will discuss the contributions of this research, followed by suggestions for future research. This chapter will end with the conclusion of the whole research.

7.2 RESEARCH CONTRIBUTIONS

Chapter One has listed the aims and objectives leading to the proposed research. Based on the problem statements, the aim of the research was derived. In order to achieve the aim, several objectives were developed. Based on the listed objectives, several contributions were identified. This section will discuss the contributions as follows.

Contribution One: Developing Criteria for a Viable CPP Model

Developing a model that closely mimics the real system is hard, especially concerning the exact definition that should be added into the model. There is no specific literature that covers the topic on a viable model, especially for a CPP system (Zulkepli and Eldabi, 2011), which refers to the care integration of several departments and care givers. In the real environment, CPP system is very complex as it deals with various people, resources, policies, systems and the environment (Eldabi, 1999). It also involves various pathways, which depend on the condition of the patients (NHS Institute for Improvement and Innovation, 2010). Since there is no literature concerning the criteria of a viable CPP model, therefore, based on certain literature concerning CPP in various care settings, the researcher has developed the criteria for a viable CPP model. This set of criteria serves as guidance or a 'checklist' for modellers to ensure that the model mimics the real system of

CPP. The researcher has discovered important criteria, or features, that need to be included in the developed model. The criteria will be used as a benchmark for selecting a suitable technique for modelling. This contribution was obtained after completing objective one, i.e. *to capture information about the CPP (patient pathways across several departments and care givers) systems, their problems, previously developed CPP models, decision tools that have been used, advantages and limitations.*

Contribution Two: Developing Hybrid Simulation Model of Health and Social Care

There are some techniques that are suitable for different types of problems, as maintained by Brennan et al. (2006) and Barton et al. (2004). Most problems discussed by policymakers and academicians are related to the patient pathways. Consequently, the researcher argued that using conventional, single, mathematical and statistical modelling techniques is not enough to facilitate the decision making process. Hence, the researcher developed a hybrid simulation model within health and social care settings to see its applicability of the proposed framework. The hybrid model is argued to be able to produce better results than the single simulation modelling technique. This contribution was achieved upon completing objective two, i.e. *to verify and modify the proposed framework by practical assessment.*

Contribution Three: Provide an Alternative and Simple Hybrid Simulation to Non-Technical People

Agent based modelling and simulation (ABMS) is one of the current and advanced modelling techniques. The technique is used to model dynamic complex systems which comprise the system, system behaviour, agent and the environment surrounding the system (Macal and North, 2010). This method has been applied to several areas and disciplines, such as, marketing, supply chains, medical, social behaviour and many others. From the definition and explanation provided by Macal and North (2010), it seems that ABMS is similar to a hybrid simulation which uses the DES for modelling the operation of the systems and SD for modelling the environment surrounding the systems. The implementation can be done using various software or toolkits, from spread sheets to specially developed software for modelling. Using the spread sheet is easy, but only limited functions of the agent behaviour can be done. For advanced large-scale system modelling, it is better to use a programming language such as Java, C and C++ as it is developed based on the demand. However, it will be very expensive to develop if the model were to be developed from scratch. Therefore, although this method seems suitable for hybrid simulation (DES + SD), in terms of an easier and less complicated modelling technique, the framework of the hybrid simulation, as proposed by the researcher, is much more simple than the ABMS method. The DES and SD techniques are easy to understand and use for those who are new to modelling. The researcher also argued that the hybrid simulation using software can be used as an alternative to the complex modelling method. This contribution was attained after two of the overall objectives had been met, i.e. *to verify and modify the proposed framework by practical assessment; and to propose a framework of hybrid simulation for modelling a CPP system*

Contribution Four: Develop a Theoretical Framework (step by step process) for Modelling the CPP

A patient pathways system across several care givers and departments is a complicated system since it deals with many pathways depending on the type of patients, professional services and departmental policies. To analyse the bottleneck of the system, or to assess the intervention intended to implement the whole CPP system, a huge investment in terms of time, money and resources is needed. The framework of the hybrid simulation in modelling the CPP system is the main contribution in this research. It also contributes to the knowledge gap in that no frameworks exist for modelling using a suitable modelling technique. The theoretical framework development for hybrid simulation for modelling the CPP system is based on Chahal (2009), Helal et al. (2007) and Giachetti et al. (2005). Case studies were used to validate the credibility and suitability of the framework. Several amendments have been made to the initial proposed framework based on the practical and theoretical assessments.

Complex patient pathways (CPP) could be developed in a few designs depending on where it is and how it is designed as many things must be taken into account (Jain, 2006). Various councils or private sectors have their own system, regulations, procedures, experts and their own set of laws depending on what stage they are at; as a result, one standard model cannot be used to cater all CPP models. In addition, whilst the developing process is taking place, some important features that make the system viable are commonly missed. This framework will therefore provide a guide as to what steps need to be taken to make the CPP model viable without missing any important features (Mingers and Brocklesby, 1997). Due to these reasons, the researcher was inclined to propose a theoretical framework rather than the model itself. In addition, the decision makers (top management) can be actively involved in the model development stage. With this uncomplicated and easy-to-follow framework, the researcher hopes that it will help the policymakers and the other stakeholders in the development of the model. This last contribution was achieved after completing the final objective, i.e. *to propose a framework of hybrid simulation for modelling a CPP system.*

7.3 FUTURE WORKS

The established framework can be used as guide to develop a model for complex patient pathways using hybrid simulation. The following are proposed future works to improve the framework.

Future Work 1: Expanding the framework to other OR techniques by considering the suitability of the problems at hand and the capabilities of the techniques.

In Chapter Two, the researcher has narrowed down a few selected techniques to use for modelling the CPP system i.e. DES or SD or hybrid. There are many modelling methods, or techniques, in the operational research (OR) area. Most of the literature only focuses on the differentiation between DES and SD and what types of problems they are suitable (Chahal et al., 2008; Brailsford and Hilton, 2001). The researcher believes that other methods (other than DES and SD) also have their own advantages as a tool for decision making. Therefore, based on the problems at hand (due to the limited time), a list of several OR techniques, their advantages, as well as the types of problem that suit the capabilities of the techniques used for decision making tools should be suggested. Not all SD and DES techniques are suitable to solve all types of problems. For example, DES is not suitable to be used as an optimization tool (Centeno and Carrillo, 2001), therefore, the technique was combined with the Markov dynamic programming to estimate the blood demand and supply, as well as its optimization (Haijema et al. 2007). It is also possible to study the possibility of several modelling methods for different types of problems, objectives and issues (Brennan et al. 2006).

Future Work 2: Empirical Studies of the Established Framework to Non-Modellers.

The framework needs to be assessed is to determine whether it is easy to follow and understand. The review of the framework is mainly the researcher's. To ensure that the framework is easy to understand and follow, empirical studies should be conducted, as done by Tako and Robinson (2009), when they compared two techniques to determine which one works better when applying the user's expectations and experience. The empirical studies should explain how to use SD and DES software for the same group of people and try to model any integrated system by using the framework given. It may take a longer time to understand but when understood, it will provide a more reliable result.

Future Work 3: Custom programming for variable exchange

Due to the limited technical abilities, the change variable between both models has to be done manually using Excel. Every process of the 'source model' has to be identified and transferred into an excel file step-by-step. Consequently, a longer time is needed to transfer all the inputs to the 'destination model' until the outputs from both models are stable. Therefore, it would be beneficial if the outputs from the source model could be automatically transferred. This could be done by developing custom programming to exchange these variables automatically.

Future Work 4: Developing a more complex patient pathways model based on the framework.

To validate the developed framework, the researcher has practically developed a model of health and social care based on several case studies that used a single modelling technique. However, due to several limitations including time, technical support and data availability, only one CPP model was developed, which might mean that several variables were not included in the model. However, it is not a prime concern here as the aim of this research is to assess the framework that can suit the CPP system modelling. The researcher has theoretically assessed the framework again with several other case studies during which some missing components in the framework might not be able to be identified. It is argued that to notice any gap in the framework, a model should be developed based on the framework. Therefore, to enhance the framework, a more complex CPP system should be developed in the future.

7.4 FINAL CONCLUSION

This research is about developing a theoretical framework for hybrid simulation modelling, i.e. Discrete Event Simulation (DES) and System Dynamics (SD), for modelling complex patient pathways (CPP), which refers to the transferring of patients from one department or care giver to another in an integrated care manner. The researcher suggests a combination of DES and SD techniques, as they complement each other, to cover the whole needs and requirements of the CPP model. By doing so, viable patient pathways models that will enhance decision making and consequently reduce the problems in the system could be developed.

The complexity of the patient pathways across multiple departments and care givers creates problems. Problems such as miscommunication, bed blocking, late patient transfer to another care provider, lack of patients' information, too many assessments, and unsatisfied patients and staff, make the system more 'fragile'. Based on the literature, the researcher concluded that these problems could occur due to the systems' setting, policy, and nature, such as patient pathways, which lead to other problems. To reduce and minimize these problems, policymakers, stakeholders and academicians have used several methods. Two methods have been used regarding the patient pathways. These are direct experimentation in the lean thinking/technique and simulation modelling. The researcher assumed that most stakeholders in the care sector would likely use the first method, whilst academicians would prefer to use the second method. Although many CPP models have been developed using several techniques based on these two methods, problems still persist.

Therefore, with the help of various literatures, the researcher managed to identify the reasons for the continuing problems. The researcher produced a list of the characteristics of the CPP systems and the limitations of the existing CPP models. The researcher than designated them as the criteria for a viable CPP model. The researcher also listed several advantages and limitations of various techniques, such as, Direct Experimentation, the Tree Diagram, the Markov Model, Discrete Event Simulation (DES), and System Dynamics

(SD). These two lists that contained the criteria of a viable model and the technique's advantages were mapped together. No technique was found to be able to cover all the needs of the CPP systems. To do so, the researcher suggested to combine the techniques. Based on the mapping process, the researcher suggested for the integration of DES and SD, named as a hybrid simulation, as both techniques could complement each other. But upon reviewing the literature, the researcher could not find any hybrid simulation that has been applied to the specific area of CPP systems. Hence, the researcher proposed a framework of a hybrid simulation as an alternative decision tool for modelling the CPP systems. The framework identifies the steps modellers need to follow to ensure that no important features of a viable CPP model are missing. The framework will also help stakeholders, especially top management, to participate in the CPP model building activities. To develop the framework, the researcher has used Chahal's framework, Helal et al.'s model and Giachetti et al.'s models as references. These frameworks were selected from various hybrid frameworks because each framework has its own advantages to overcome the limitations of the other respective techniques.

Modelling a whole system with multiple departments is important for various reasons. Due to interdependencies of each part in the system, any intervention to a certain part will affect the other, directly or indirectly, with visible or hidden effects. Both individual analysis and a feedback loop are also important. Modelling the whole system is important, and using DES alone will make the model much more complicated. Even if SD is suitable for the task, it will lose the patient's unique individual analysis. Considering these important features, this framework provides guidelines on:

(a) How to make whole system modelling less complicated yet simple,
(b) How to select the best technique for modelling and
(c) How to integrate SD and DES models.

The framework is basically divided into three main phases: conceptual, modelling and models communication. The conceptual phase involves a division of the whole system into smaller modules to ease the model development and minimize the complexity, by choosing the best technique for modelling and the plan for modelling (how the whole system will be modelled). The modelling phase involves modelling the system based on the modelling planning (final stage in the conceptual phase), by using any simulation software such as

Simul8 for the DES model or Vensim for the SD model. This phase includes linking the modules within the same modelling technique. The framework will continue with the models communication phase depending on two conditions. First, the technique used for modelling is SD and DES, in which both models can be integrated. Second, the models can be integrated when one or more variable(s) from one model is influenced by a variable(s) of the other model. The proposed framework was then applied to several study cases to assess the applicability and suitability of the CPP systems. Two different approaches to assess the framework were employed: practical and theoretical. Based on the assessments, the framework was modified to suit the CPP systems model needs.

Upon finding the case study for modelling, the researcher concluded that modelling and simulation could be used for several purposed. Besides learning the effect of certain interventions, the method can also be used for teaching and learning for professional purposes, finding the bottleneck in the system and much more. However, as with the limitations of the simulation, this method is not suitable for certain purposes.

The selection of the techniques for problem solving can be extended into several OR techniques, and is not limited to the SD and DES alone. It is suggested that this framework should be tested among modellers to see whether the framework is user friendly or not. The theoretical framework for hybrid simulation for modelling the CPP systems can be used as a benchmark and a guideline for modelling complex systems and can be applied to other areas, especially in supply chains in various areas.

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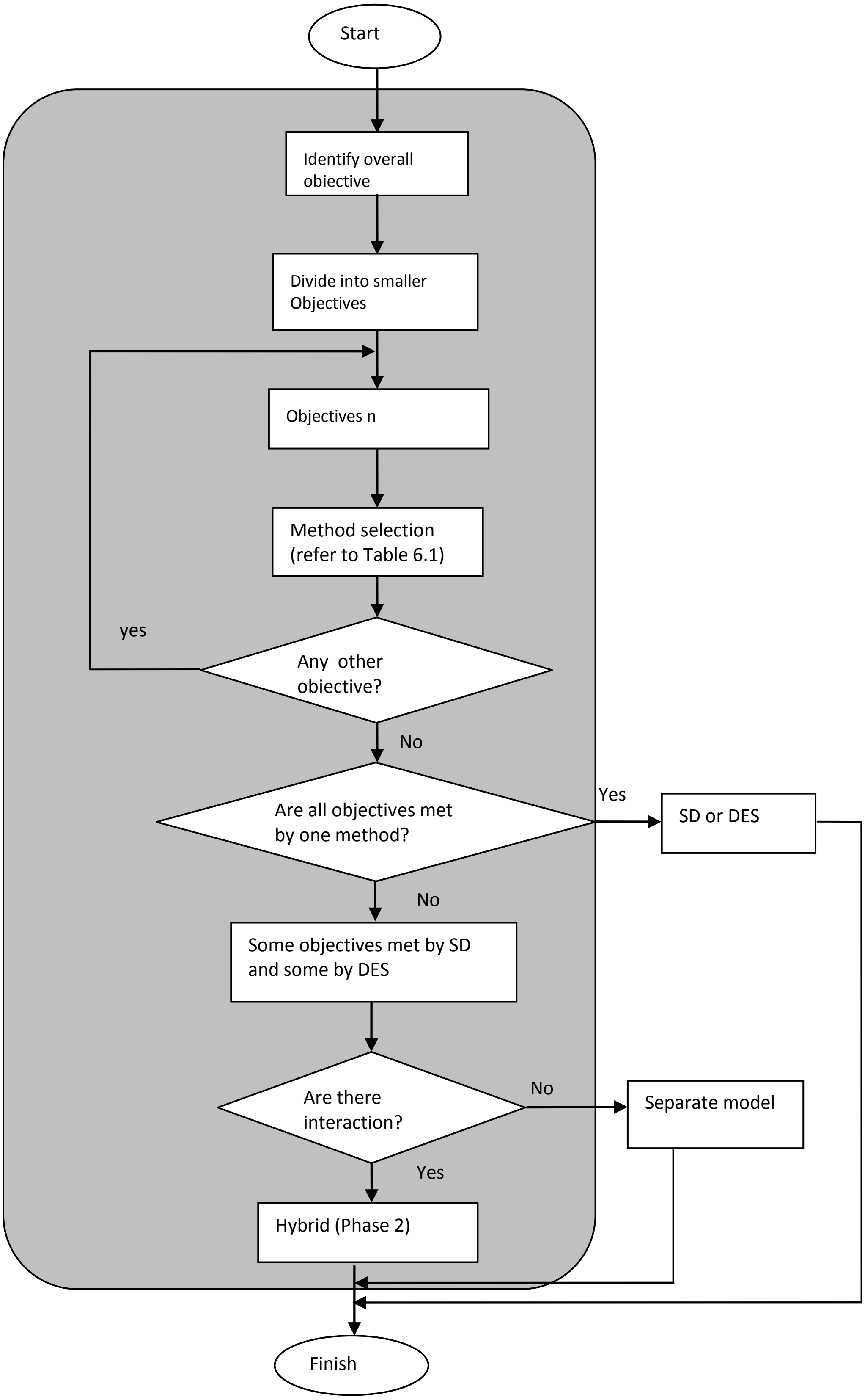
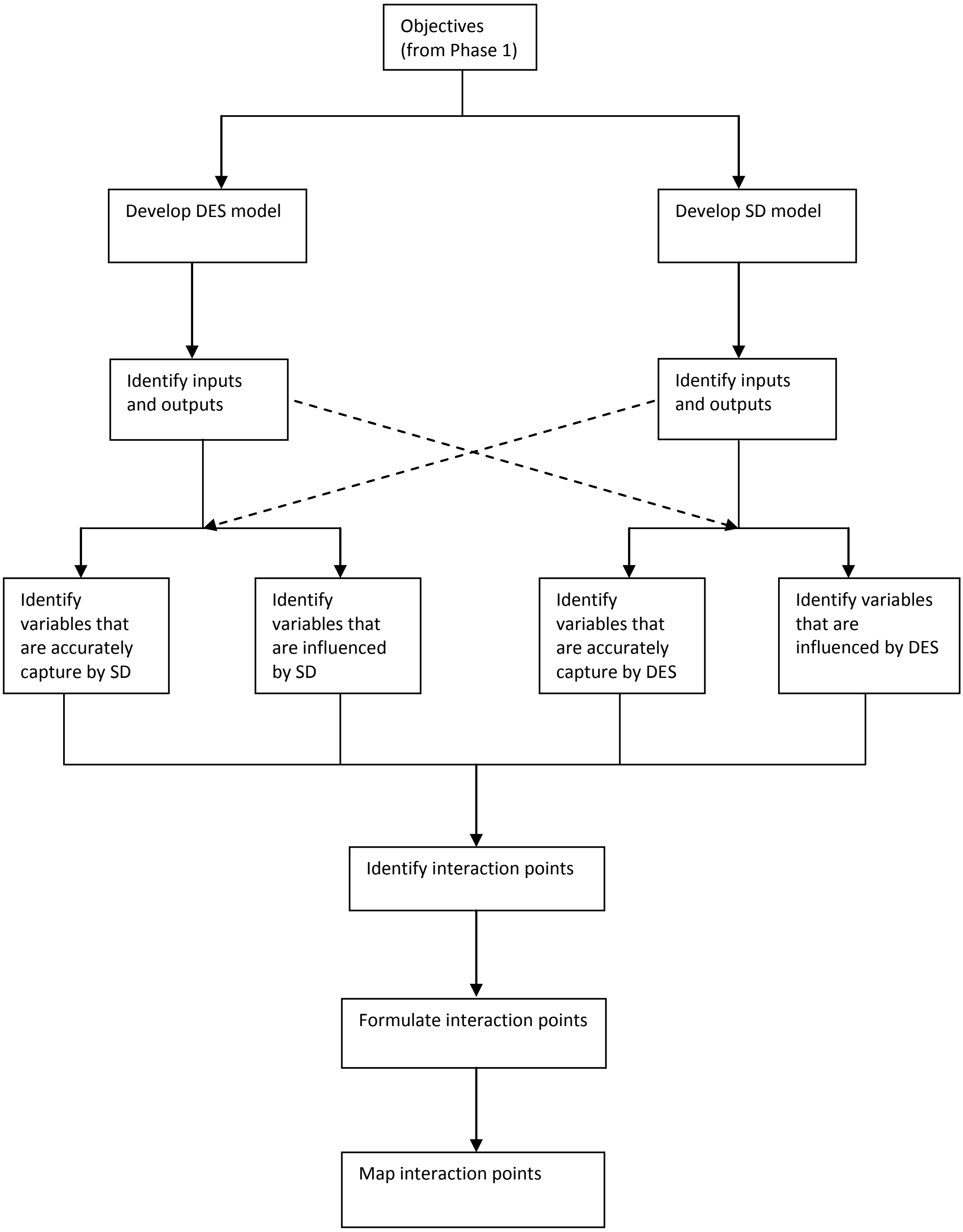
APPENDICES

APPENDIX A: CHAHAL (2009) GENERIC FRAMEWORK OF HYBRID SIMULATION TECHNIQUES

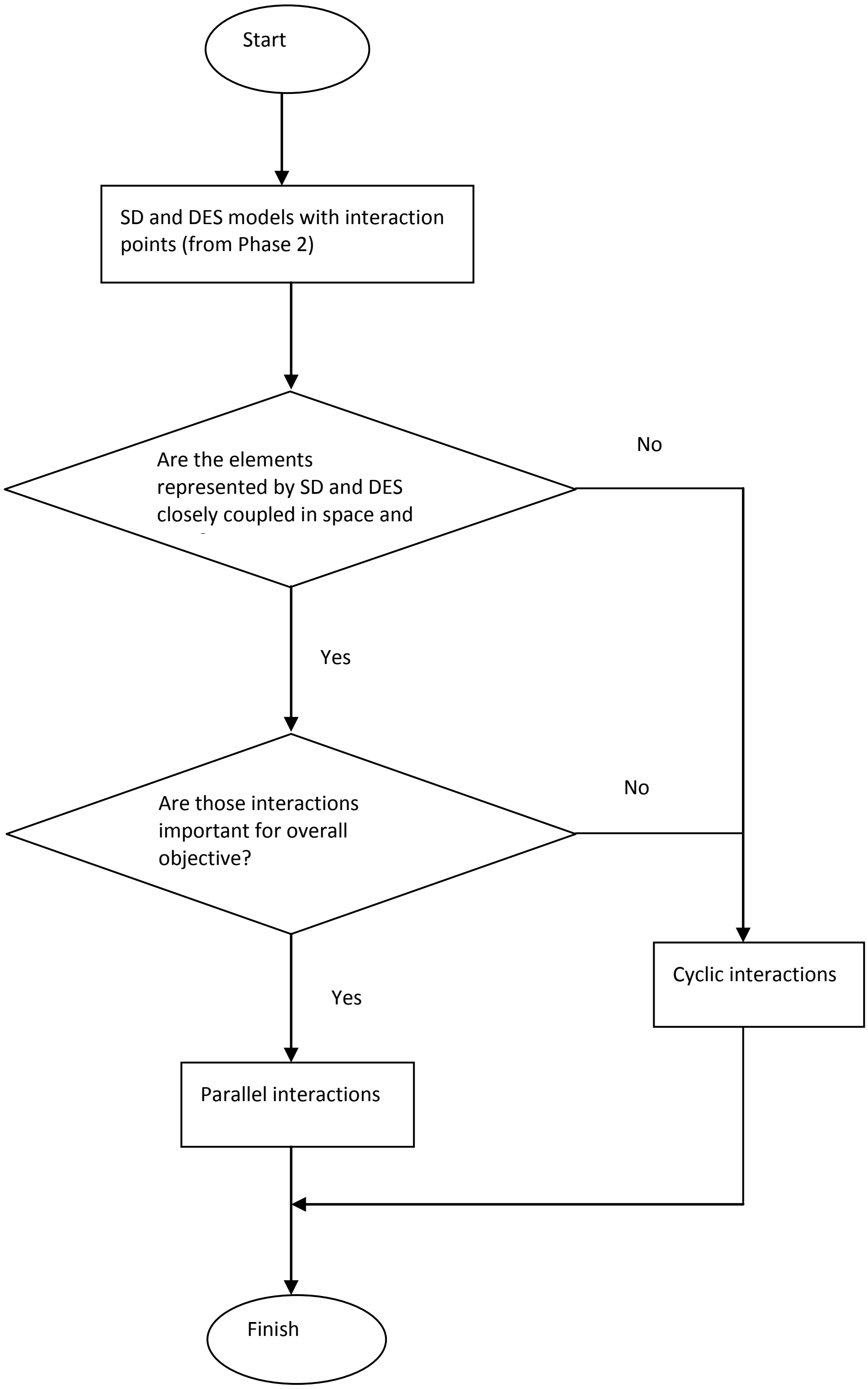
Phase One: Problem Identification



Phase Two: Identification of Mapping between SD and DES Models



Phase Three: Identification of Mode of Interaction



(Source: Chahal, 2009)

APPENDIX B: SYSTEM DYNAMICS EQUATIONS

(01) capacity=

20

Units: patient

(02) death rate=

normal death rate

Units: patient/Week

(03) discharge rate to social care=

normal patient rate after 2 weeks

Units: patient/Week

(04) discharge to home=

patients discharge to home

Units: patient/Week

(05) discharge to home2=

patients discharge to home2

Units: patient/Week

(06) discharge to home3=

patients discharge to home3

Units: patient/Week

(07) FINAL TIME = 30

Units: Week

The final time for the simulation.

(08) healthcare= INTEG (

patient admission rate-discharge to home-patient discharge rate,

0)

Units: patient

(09) INITIAL TIME = 0

Units: Week

The initial time for the simulation.

(10) intermediate care= INTEG (

patient discharge rate-discharge rate to social care-discharge to home2,

0)

Units: patient

(11) level of stress = WITH LOOKUP (

ratio patient to space,

([(0,0)-(10,10)],(0,0),(0.1,0),(0.2,0),(0.3,0),(0.4,0),(0.5,0),(0.6,0.05
),(0.7,0.1),(0.8,0.5),(0.9,0.6),(1,0.8),(2,1.2),(3,2.2),(4,3.2),(5,4.2),(6
,5.2),(7,6.2),(8,7.2),(9,8.2),(10,9.2)))

Units: Dmnl

(12) normal death rate:=

GET XLS DATA('patients enter.xls', 'Sheet1' , 'A' , 'L3')

Units: patient/Week

(13) normal patient rate after 2 weeks:=

GET XLS DATA('patients enter.xls', 'Sheet1' , 'A' , 'K3')

Units: patient/Week

(14) normal patient rate2:=

GET XLS DATA('patients enter.xls', 'Sheet1' , 'A' , 'G3')

Units: patient/Week

(15) number of patient admitted:=

GET XLS DATA('patients enter.xls', 'Sheet1' , 'A' , 'C3')

Units: patient/Week

(16) patient admission rate=

number of patient admitted+patient readmission

Units: patient/Week

(17) patient discharge rate=

level of stress*normal patient rate2

Units: patient/Week

(18) "patient non-recovery level" = WITH LOOKUP (

ratio patient to space2,

([(0,0)-(9,10)],(0.1,0),(0.2,0),(0.3,0),(0.4,0),(0.5,0),(0.6,0),(0.7,0),
(0.8,0.1),(0.9,0.2),(1,0.3),(2,1.3),(3,2.3),(4,3.3),(5,4.3),(6,5.3),(7,6.3
),(8,7.3),(9,8.3)))

Units: Dmnl

(19) patient readmission=

discharge rate to social care*"patient non-recovery level"

Units: patient/Week

(20) patients discharge to home:=

GET XLS DATA('patients enter.xls', 'sheet1' , 'A' , 'E3')

Units: patient/Week

(21) patients discharge to home2:=

GET XLS DATA('patients enter.xls', 'Sheet1' , 'A' , 'I3')

Units: patient/Week

(22) patients discharge to home3:=

GET XLS DATA('patients enter.xls', 'Sheet1' , 'A' , 'M3')

Units: patient/Week

(23) ratio patient to space=

healthcare/space

Units: Dmnl

(24) ratio patient to space2=

intermediate care/capacity

Units: Dmnl

(25) SAVEPER =

TIME STEP

Units: Week [0,?]

The frequency with which output is stored.

(26) social care= INTEG (

discharge rate to social care-death rate-discharge to home3-patient readmission

,

0)

Units: patient

(27) space=

25

Units: patient

(28) TIME STEP = 1

Units: Week [0,?]

The time step for the simulation.

(29) total patient in care=

healthcare+intermediate care+social care

Units: patient

APPENDIX C: DATA COLLECTION FROM DES MODEL

Weeks	no patients enter	no of patient discharge to home	intermediate care	home care	social care	death rate	discharge to home from SC
1	11	0	2	0	0	0	0
2	14	1	8	0	0	0	0
3	12	5	13	0	2	0	0
4	19	2	8	1	7	0	3
5	17	8	12	2	10	1	3
6	11	3	7	4	4	0	1
7	21	5	13	7	4	0	2
8	12	5	12	3	6	0	2
9	17	4	11	5	6	0	1
10	9	4	11	2	7	0	3
11	5	3	6	2	9	0	1
12	15	2	8	1	8	0	2
13	13	3	7	2	9	1	2
14	12	1	14	2	7	0	5
15	24	4	8	3	5	0	1
16	13	9	13	6	6	0	0
17	16	3	13	4	4	0	1
18	13	4	11	3	9	2	0
19	16	2	11	2	6	0	0
20	13	3	15	3	9	3	2
21	8	2	6	1	7	0	0
22	16	3	12	4	8	0	3
23	10	3	10	1	7	1	4
24	13	3	2	5	7	0	1
25	15	7	8	3	5	0	1
26	11	5	8	2	10	2	0
27	15	5	9	2	6	0	2
28	21	5	8	5	6	0	0
29	20	6	15	1	7	0	2
30	24	7	12	1	8	2	4