A Generic Framework for Hybrid Simulation in Healthcare

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ABSTRACT

Healthcare problems are complex; they exhibit both detail and dynamic complexity. It has been argued that discrete event simulation (DES), with its ability to capture detail is ideal for problems exhibiting detail complexity. However from the strategic perspective, System Dynamics (SD) with its focus on a holistic perspective and its ability to comprehend dynamic complexity has advantages over DES. Both paradigms provide valuable insights but none of them is capable to capture both detail and dynamic complexity to the same extent. It has been argued in literature that an integrated hybrid approach will provide more realistic picture of complex system with fewer assumptions and less complexity.

Hybrid simulation is a form of mixing methodologies and due to fundamental differences, mixing methodologies is quite challenging. In order to overcome these challenges this paper has attempted to provide a conceptual framework for hybrid simulation. On the basis of knowledge induced from literature, three requirements for framework have been established. In order to address these requirements, a three phase conceptual framework for hybrid simulation has been proposed. In future work the proposed framework will be evaluated with examples from healthcare.

Keywords

Simulation, System Dynamics, Discrete event simulation, Hybrid simulation, interaction points, framework

1 Introduction

Due to overwhelming complexity and high intolerance to failures, healthcare providers require tools to foresee the consequences of their decisions. The need to evaluate decisions prior to implementation is well recognised (Sobolev, 2005; Walshe and Rundall, 2001; Watt et al 2005). One way to explore the different consequences of alternative decision scenarios effectively is simulation and modelling. The use of simulation approaches for healthcare problems has received a great deal of attention recently. Eldabi et al (2007) have described a dramatic increase in use of simulation in healthcare studies since 2000. Discrete Event Simulation (DES) and System Dynamics (SD) are two approaches to simulation modelling which are being widely used in healthcare. Both DES and SD model the behaviour of the system over the time. DES as a methodology is based on the philosophy that behaviour of the system over time is cause of its endogenous and exogenous variation (Morecroft and Robinson, 2006). SD on the other hand is based on the philosophy that the structure of the system is responsible for its behaviour over the time (Morecroft and Robinson 2006).
Healthcare problems exhibit both detailed and dynamic complexity. It has been argued that Discrete Event Simulation (DES), with its ability to capture detail, is ideal for problems exhibiting this type of complexity. On the other hand, System Dynamics (SD) with its focus on feedback and nonlinear relationships lends itself naturally to comprehend dynamic complexity. Although these modelling paradigms provide valuable insights, neither of them are proficient in capturing both detail and dynamic complexity to the same extent. It has been argued in literature that a hybrid approach, wherein SD and DES are integrated symbiotically, will provide more realistic picture of complex systems with fewer assumptions and less complexity (Chahal and Eldabi, 2008; Brailsford et al 2003).

In spite of wide recognition of healthcare as a complex multi- dimensional system, there has not been much reported literature on use of hybrid simulation. As mention by Mingers (1997), this could be attributed to the fact that due to fundamental differences, the mixing of methodologies is quite challenging. In order to overcome these challenges a generic theoretical framework for hybrid simulation is required. However, there is presently no such generic framework which provides guidance about integration of SD and DES to form hybrid models. This paper has attempted to provide such a framework for hybrid simulation which can be utilised in healthcare domain.
The structure of the paper is as follows: the next section provides discussion on need for generic theoretical framework. Section three highlights requirements of the framework induced from the literature, followed by section four which provides elaborate discussion on the proposed framework. Finally the last section provides conclusions.

2 Need For Hybrid simulation Framework

The appetite for mixing methods in the healthcare domain has been documented (Sachdeva et al, 2006; Eldabi et al, 2007; Brailsford et al, 2003). Healthcare is complex and there is a plethora of problems which cannot be analysed using a single method.

There are problems which exhibit elements which require both SD and DES, and there are interactions between them. In those scenarios accurate analysis demands to capture those interactions. It has been argued in literature that a hybrid approach, where SD and DES are integrated symbiotically, will provide more insight and accurate analysis of such problems with fewer assumptions. As proposed by Chahal and Eldabi (2008c) there are various contexts in healthcare where hybrid simulation will be more applicable. Despite the appetite for mixing SD and DES in healthcare, there is an absence of reported study which has applied these methods in an integrated way. It could be due to the challenges associated with mixing methods and the absence of a generic framework which provide guidance with regards to implementation of hybrid simulation.

It has been argued that mixing methodology has the potential to provide a more complete way of dealing with the complexity of the real world, however mixing methods in practice presents challenges due to their different philosophical stance (Mingers, 2003). Theoretical frameworks are required to provide practical guidance for mixing methodologies. Mingers and Brocklesby (1997) stated that task of investigating the logical possibilities for combining methods, putting them to work and then reflecting upon the results needs to be preceded after establishment of frameworks. However from the reported literature it has been observed that it has followed a reverse order. No reported theoretical framework has been identified which provides guidance about mixing SD and DES to form hybrid models. On the other hand a handful of frameworks, which have attempted to address the technical interoperability between SD and DES have been identified (Martin and Raffo, 2000; Venkateswaran et al, 2005; Helal et al, 2007). As discussed in the previous sections, frameworks developed in the past have emphasised more on technical automation of exchange of information between SD and DES rather than providing generic guidance for implementation of hybrid simulation. Another limitation of previous frameworks is their problem-centric approach. They explain which information is exchanged between SD and DES within their problem context however they have not provided generic guidance on how they made those selections. This limits their generalisation to wider problem contexts. Due to this tight problem specific approach it is difficult to apply those frameworks to the healthcare context. This paper attempts to fill that gap by providing a generic theoretical framework for hybrid simulation.

3 Requirements of the Framework

As suggested by Robinson (2008a), it is useful to establish requirements for generic conceptual frameworks. The descriptive nature of the model at this stage poses a challenge to set measurable criteria for evaluation. These requirements provide the basis for evaluation of conceptual frameworks. On the basis of knowledge induced from literature, three requirements for the generic framework have been established. It is argued that the framework for hybrid simulation should be able to provide answers to Why (why hybrid simulation is required), What (what information is exchanged between SD and DES models) and How (how SD and DES models are going to interact with each other over the time to exchange information) within the context of implementation of hybrid simulation to different problem scenarios

It has been argued in the literature that prior to integrated deployment of SD and DES, there should be justification for the need of hybrid simulation (Frahland, 1970; Lee 2002). It implies that problems requiring hybrid simulation should be identified prior to any further analysis. Once the problem is identified as one which requires hybrid simulation, the next challenge is to establish linkage between SD and DES models. Due to different philosophical stance, establishment of linkage between SD and DES has been quite challenging (Lee et al 2009). In order to link SD and DES models in hybrid simulation, the following information is required:

- What is exchanged between SD and DES?
- How SD and DES models interact with each other to exchange this information?

Variables whose values are changed or influenced by variables of the other model and variables which replace or influence the values of variables of other models during hybrid simulation are named as ***"interaction points".*** They are named interaction points because all the interactions between SD and DES model occur through these variables. *Similarly depending upon the problem situation, different modes of interaction (the way SD and DES interact with each other over the time for exchanging information) have been identified.* From the above discussion it can be deduced that the generic conceptual framework should be able to provide answers to following questions:

1. Why the problem in hand requires hybrid simulation? Justify the need for it.
2. What is exchanged between SD and DES (mapping between SD and DES)?
3. How SD and DES models interact with each other over the time to exchange information?

These questions establish requirements for the framework.

4 The Proposed Framework

In order to meet requirements established in previous section, a three-phase generic framework for hybrid simulation has been proposed. Each phase of the framework is mapped to an established requirement and provides guidelines for addressing that requirement.

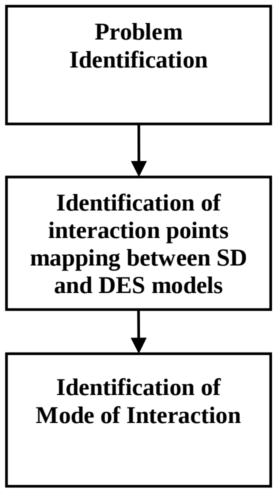

Figure 1: Overview of the final hybrid simulation framework

As shown in Figure 1 the framework consists of three phases. The first phase of the framework provides guidance for identifying that the problem in hand requires hybrid simulation. It has been argued previously that effort and investment in hybrid simulation is only justified if some aspects of the problem require SD and some require DES for analysis and there are strong interactions among the elements represented by SD and DES (Farhland, 1970). Once it is identified the problem requires hybrid simulation, then Phase 2 and Phase 3 of the framework provide detail instructions on how to carry out hybrid simulation. Phase 2 provides guidance for identification of mapping between SD and DES models. Mapping between SD and DES models comprises of identification of interaction points, followed by formulation of relationship and finally the way corresponding interaction points are mapped in both SD and DES models. Phase 3 of the framework assist its potential users in identifying the way SD and DES models are required to interact with each other over the time (mode of interaction) for exchanging information. The following subsections will provide elaborate discussion on each phase.

4.1 Phase 1: Identification of Problem seeking Hybrid Solution

The Phase 1 assists prospective users in identifying whether the problem requires hybrid simulation or not. The framework is based on the assumption that problem is fully understood. Quite a few articles are available on problem understanding. The author encourages potential users to understand the problem thoroughly prior to deployment of this framework. Understanding of the problem is a major task and it requires a framework of its own. Due to the appreciation of importance and effort involved in problem understanding this has not been included in this framework. As shown in Figure 2 Phase 1 consists of the following main steps for identifying problems in need of hybrid simulation:

- Identify overall Objective
- Decompose in to smaller objectives
- Method Selection

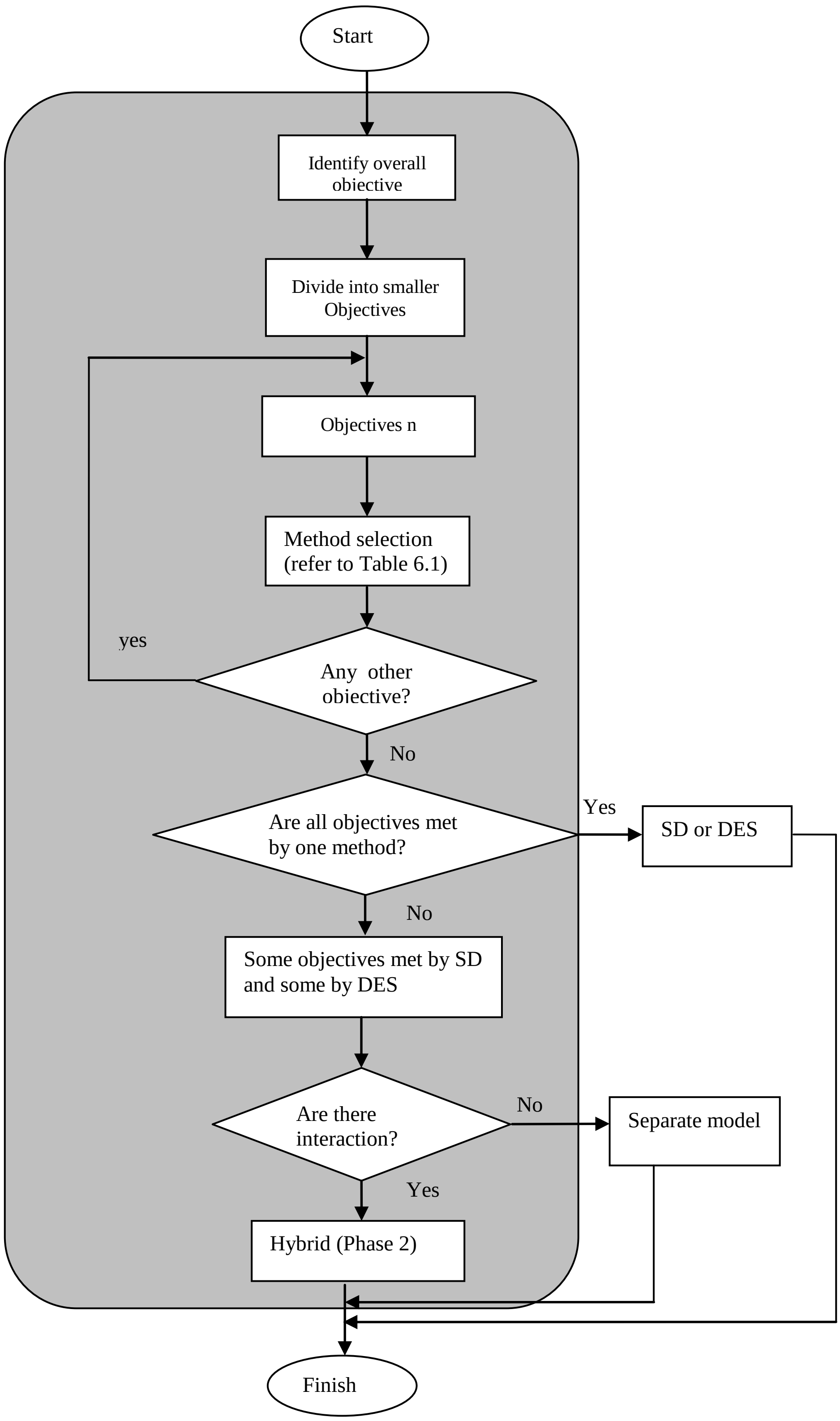

Figure 2: Overview of Phase 1 of the final framework

Identify overall Objective

The framework starts with identification of overall objective (as shown in Figure 2). The following questions help in defining the overall objective:

- What causes the problem owners to seek assistance from analysts?
- What is the goal they are seeking?
- What are the internal and external influences on the goal?

The above questions provoke the potential users of the framework to analyze problem from a wider context. The overall objective is defined in light of both, problem as well as system perspective.

Decompose in to smaller objectives

In accordance with the third principle of modeling (Pidd, 2001), the overall objective is then decomposed into simpler smaller objectives. The broad criteria for decomposition is that if there is a fluctuating variable that is significantly influencing the overall objective and is being influenced by multiple factors then it is crucial to have a model that facilitates in determining the value of that variable in a timely manner, and in order to do so it is needed to decompose the overall objective into smaller components or sub-objectives. Decomposition of overall objective into smaller objectives simplifies both modeling as well as the selection process.

Method selection

The selection process implies selection between SD and DES. Depending upon problem attributes and system context, Table 1 provides the criteria for selection of appropriate method. Upon deciding between SD and DES, it has been argued in the literature that the answer to the question of deciding between SD and DES depends more on the purpose of the model rather than the system being modelled (Brailsford and Hilton, 2001). Contrary to that, this research argues that the system is an integral aspect when it comes to deciding between SD and DES (Chahal and Eldabi, 2008a). Pidd (2004) advises that modellers should think about the nature of the system and nature of the problem prior to modelling, as some models are better suited for certain problems than others. From his argument it is evident that there needs to be close fit between modelling methodology, system and problem. Lorenz and Jost (2006) argued that what (object of simulation study), why (purpose of study) and how (simulation method) are the main criteria for deciding between methodologies (Lorenz and Jost, 2006). The common limitation of previous frameworks for selection is the absence of the system or **WHAT** perspective. Out of all the previous frameworks on selection, Brailsford and Hilton (2001) provided most the comprehensive criteria for selection between SD and DES. In the rest of the selection frameworks SD and DES merely form a fraction of various methods addressed. The limitation of their approach like many others is that their selection criteria are explicitly based only on the alignment of problem purpose with appropriate method. On the basis of the argument that there should be alignment between problem, system (problem context) and methodology, selection criteria provided by Brailsford and Hilton (2001) has been modified to incorporate “system perspective” as shown in Table1. The purpose of this table is to provide guidance with regards to selection between SD and DES. As argued by Chahal and Eldabi (2008b), the decision to select SD and DES for analysing a particular problem context is further subjected to the feasibility constraints such as resources, time and client expectation etc.

Criteria	**DES**	**SD**
Problem 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)

Table 1: Criteria for selection between SD and DES

Once the methods are selected for each objective the next step is to identify whether all objectives are met by SD or DES or by both. If all objectives are met by a single method then the framework terminates (as shown in Figure 2) otherwise the users are asked to identify whether there are interactions between different objectives met by SD and DES. If there are interactions between elements represented by SD and elements represented by DES, then hybrid simulation is required, otherwise the objective can be achieved by independent SD and DES models, in that case the framework terminates there.

4.2 Phase 2: Mapping between SD and DES models

Once it has been identified that the problem requires hybrid simulation then the prospective user is led towards the Phase 2. If the problems do not require hybrid simulation then Phase 2 and Phase 3 are not required. Execution of Phase 2 and Phase 3 depends upon the outcome of Phase 1. As shown in Figure 3 Phase 2 consists of following steps:

- Development of SD and DES models
- Identification of inputs and outputs of both models
- Identification of variables which are accurately captured by the other model
- Identification of variables which are influenced by the other model
- Identification of interaction points
- Formulation of the relationship between interaction points
- Mapping of interaction points in SD and DES models

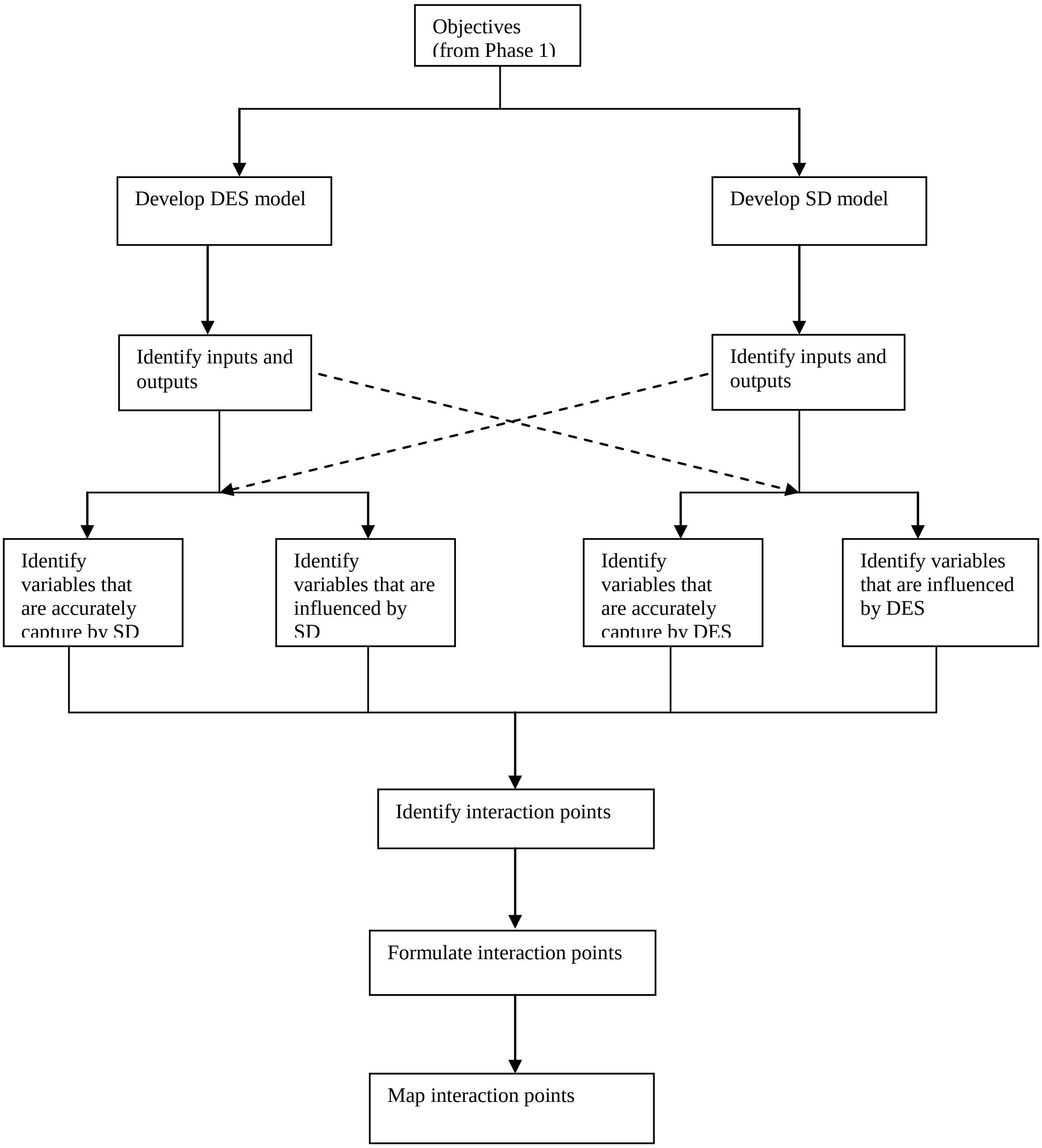

Figure 3: Overview of Phase 2 of the final framework

Develop SD and DES Model

Once it is identified that problem requires hybrid simulation, the next step is to develop conceptual models for SD and DES. As objectives of both SD and DES models are already defined previously in Phase 1, the first step of Phase 2 is development of SD and DES models to meet their respective objectives. Literature is available for providing guidance with regards to building SD (Sterman, 2000) and DES (Law and Kelton, 2000;

Robinson 2004; Robinson 2008a; Robinson 2008b) models. It is important to note that as the purpose of SD and DES models is to aid in identifications of inputs and outputs, the potential users are advised not to indulge in strenuous exercise for data collection. Data is not required at this stage but the models should be capable of representing all variable and interactions among them. SD and DES models provide platforms for identification of inputs and outputs.

Identify inputs and outputs of SD and DES models

The next step is to identify inputs and outputs of the model. The relationship between identification of inputs/outputs and model development is iterative. All the variables whose values are not calculated/ estimated by the model itself but are obtained from outside are considered as inputs. Similarly all the variables whose values can be derived endogenously from the model itself are considered as outputs.

Identify Variables which are accurately captured by other model

After the identification of inputs and outputs the next step is to identify the variables which are accurately captured by the other model (identify from inputs and outputs of SD which of these are more accurately captured by DES and vice versa).

Identify Variables which influence or are influenced by other variables of the other model

The next step is to identify the variables which are influencing or are being influenced by variables of other models (again this implies variables of SD influenced by DES variables and vice versa).

Define Interaction Points

Once these interactions are captured the next step is to define interaction points. Identification of variables is preceded by defining of interaction points. Interact points are variables which actively participate during exchange of information between SD and DES during hybrid simulation. Interaction points comprise of both variables being replaced and influenced as well as variables of the other model which are replacing or influencing values. As the variables whose values are more accurately captured by variables defined in other model and variables whose values are influenced by variables defined in other model are already identified, identification of interaction points is straight forward as it only requires the explicit listing of corresponding variables of both models which are involved in information exchange.

Formulate Relationship between Interaction Points

Once the interaction points are defined the next step is to explicitly formulate the relationship between interaction points. *The relationship between interaction points can be of three different types: Direct replacement of values, aggregation/disaggregation and causal as defined in Table 2.* In Direct replacement of values of variable of one model by values of variable of another model, equivalent variables for representation of corresponding interaction points are defined in both models. During hybrid simulation values of interaction points in a model are simply replaced by the values computed in the corresponding interaction point defined in the other model.

In aggregation/disaggregation, the corresponding interaction points have equivalent representation in both models but the transfer of values between SD and DES for exchange of information is not direct replacement. Value of interaction point represented by SD are disaggregated and passed to corresponding interaction point represented in DES model. Similarly value of interaction points represented in DES model are aggregated and passed to SD model.
In third type the corresponding interaction points do not have equivalent representation in both models but the relationship is of causal type i.e. the variable defined in one model influences the variable defined in other model. These relationships are required to be explicitly understood and represented by a mathematical equation.

Type of relationship	Definition
Direct replacement of values of variables	Direct replacement of values of variables implies that the corresponding variables which have been identified as interaction points are already defined in both models and both represent variables equivalent to each other. During hybrid simulation only values of one variable are replaced by its equivalent variable defined in other model.
Aggregation/ Disaggregation	From this it means that the same thing has been represented in both models but this representation does not have same face value. Mostly SD represents the aggregated version of the variable which is disaggregated in DES and can be represented in DES either by single or group of variables which holds value equivalent to SD variable.
Causal Type Relationship	In this unlike previous two types the corresponding interaction points neither represent equivalent values directly nor represent the aggregated/ desegregated representation of equivalent values. In this type of relation ship corresponding interaction points influence each other.

Table 1: Different types of relations between corresponding interaction points

Map Interaction points between SD and DES models

Once the relationships are formulated then the next step is to map interaction points between SD and DES models. For smooth interactions between SD and DES models it is required that interaction points defined in SD have equivalent representation in DES model and vice versa. Additional mapping is not required in scenarios where relationship between interaction points is of direct replacement of values or of aggregation/ disaggregation type as variables for representing equivalent values are already defined in both models. However it poses challenges where relationship between interaction points is of causal type. The mathematical relationship is required in cases where the variables of DES model are influenced by variable of the SD model and vice versa. In this it is required that the influencing variable have some implicit or explicit representation in the model whose variable is being influenced.

4.3 Phase 3: Identification of mode of interaction

Once the interaction points are defined and explicitly mapped the next step is to identify the way SD and DES models are going to interact with each other over the time to exchange data. The main objective of this phase is to provide guidance with respect to selection of appropriate mode of interaction. It has been identified in this research that there are two types of modes of interactions between SD and DES: Cyclic interactions and Parallel interactions.

Cyclic Interactions: In this mode SD and DES models run separately and the information is exchanged between consecutive runs in a cyclic fashion. There is no interaction during the run time. They interact with each other only after the completion of their run.

Parallel interactions: SD and DES run concurrently and the information is exchanged during run time**.** SD and DES run in parallel. Continuous variables represented by SD causes changes in the variables defined by DES and DES variables cause changes in SD variables.

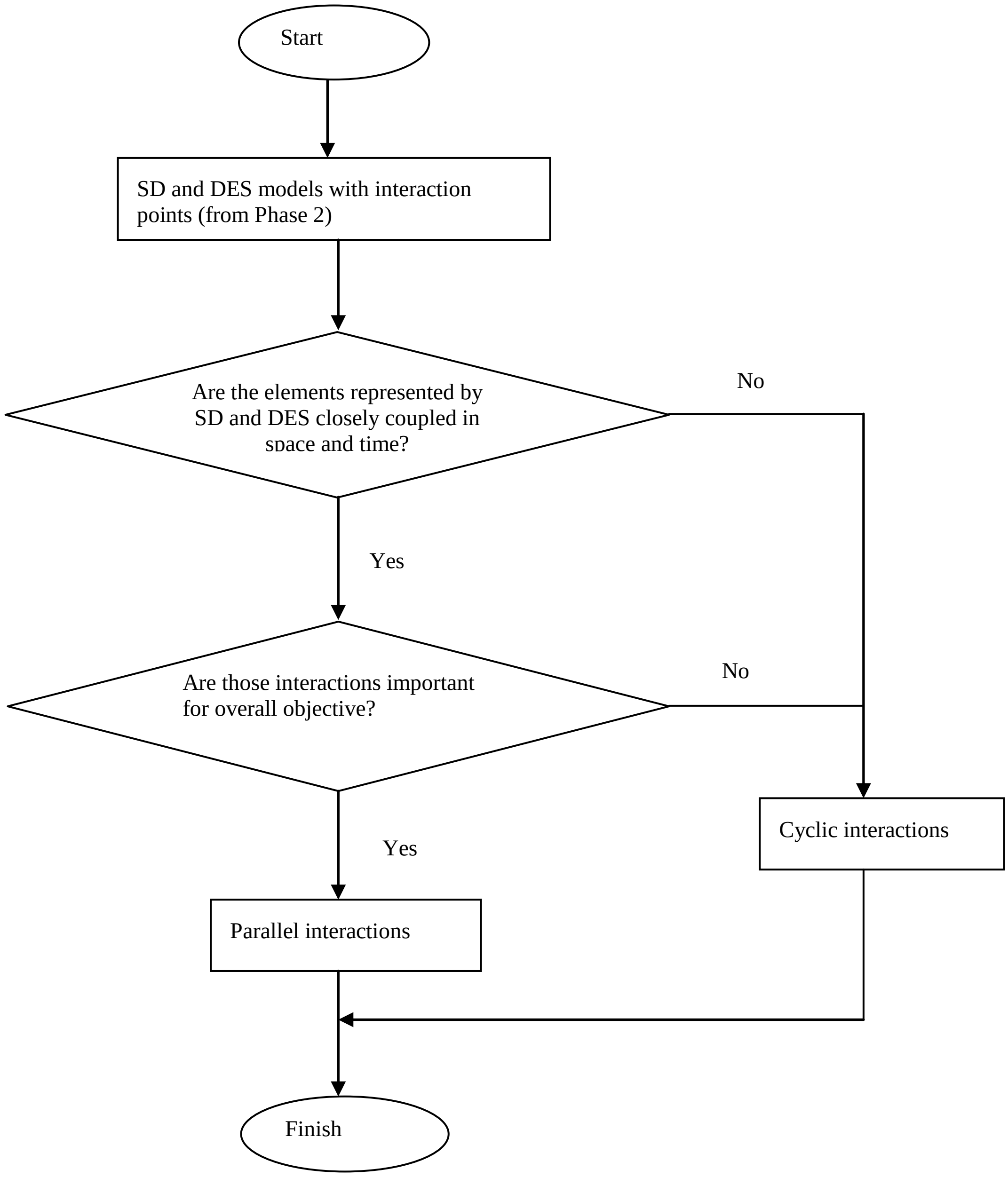

Figure 4: Overview of Phase 3 of the final framework

Guidance regarding situations where these different types of interactions are appropriate will aid in selection. As shown in Figure 4, selection between cyclic and parallel mode of interaction depends upon the answer of following questions.

- **Are elements represented by SD and DES closely coupled in time and space?**
- **Are these interactions important for overall objectives?**

If the elements represented by SD and elements represented by DES are closely linked in space and those interactions are important for overall objective then parallel interactions are required otherwise the objectives can be achieved with cyclic interactions.

5 CONCLUSIONS

In this paper authors have attempted to set a context for the need of generic framework for hybrid simulation which provides guidance to the prospective modellers interested in utilising hybrid simulation for complex healthcare problems. Three requirements for the framework have been established. Based on the literature it was recognised that generic framework should be capable of providing guidance to prospective users with regards to mapping between SD and DES models, and the way SD and DES models interact with each other over the time in order to exchange information. It has been argued in literature that the investment and effort involved in development of integrated hybrid models is wasted if the problem does not require hybrid simulation. Hence the overarching requirement of hybrid framework prior to provision of guidance on mapping and interactions between SD and DES is identification that the problem actually requires hybrid solution. A three phase framework has been proposed to address these requirements.

In future, on the basis of its ability to meet these requirements the proposed framework will be evaluated theoretically as well empirically. The main contribution of this paper is the generic framework for hybrid simulation which can be applied within healthcare context. It is expected that this work will encourage those engaged in simulation (e.g., researchers, practitioners, decision makers) to realise the potential of cross-fertilisation of the two simulation paradigms.

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