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WHICH IS MORE APPROPRIATE : A MULTI-PERSPECTIVE COMPARISION BETWEEN SYSTEM DYNAMICS AND DISCRETE EVENT SIMULATION

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Abstract

System Dynamics (SD) and Discrete Event Simulation (DES) are two established simulation techniques for simulating the dynamics of a system. Both have been widely used in modelling business decisions. This paper presents meta-comparison between the two approaches based on literature survey. Upon reviewing the existing literature it has been identified that existing comparisons could be classified under three main perspectives: Systems perspective, Problems perspective and Methodology perspective. The nature of system and nature of problem have been argued as primary factors for deciding modelling methodology. Therefore SD and DES comparisons have been classified on the basis of systems, problems and inherent aspects and capabilities of both modelling methods. It has been argued that development of sound models need fit between system, problem and methodology. The success of model depends on it's technical soundness as well as it's successful implementation. In order to develop successful models this vision has been further extended to incorporate stakeholders, resources and time.

Keywords: System Dynamics, Discrete Event Simulation, Healthcare Decision Making, Comparison

1 INTRODUCTION

Simulation has been effectively applied in enterprise decision making. System Dynamic (SD) and Discrete Event Simulation (DES) are two different branches to simulation modelling. SD offers a methodology to assist businesses and government organizations in strategy development, analysis of policy options, and analysis of dynamic processes, where capturing information flow and feedback are important considerations (Sweester, 1999). DES has capabilities that makes it more suitable for detailed analysis of a well defined system. "DES concerns the modelling of a system as it evolves over time by a representation in which the state variable changes instantaneously at separate points in time"(Law and Kelton, 1991).

Both SD and DES being established simulation techniques and widely used in organizational decision making, one would have expected there to be a strong association between the two. However, there seems to be little dialogue between the two approaches (Sweester, 1999; Lane, 2000; Brailsford and Hilton, 2000; Moorcroft and Robinson, 2006). Both techniques are concerned with modelling behaviour of the system over time, though from different perspectives. Both represent and interpret real systems from different angles (Moorcroft and Robinson, 2006). It has been argued in literature that some models are more suitable for certain problems (Pidd, 2004). All these discussions are feeding towards the growing interest in the question of how to decide which modelling technique is better or more appropriate for a particular situation? This question cannot be answered effectively without having a comprehensive understanding of contrasting and overlapping features of both.

There is a lack of comprehensive comparison between the two. Existing comparisons are either based on differences in philosophical aspects or the way SD and DES represent and interpret models or the way they perceive system or their use. "Most of the comparisons are biased as they are carried out either by DES or SD analyst" (Moorcroft and Robinson, 2006). A comprehensive meta-comparison of SD and DES based on the system perspective, the problem perspective and the methodological perspective is the main contribution of this paper. It has been previously argued that What (object of the simulation study), Why (purpose of the study) and How (simulation method) are the main criteria for deciding between the methodologies (Lorenz and Jost, 2006). In this context, the importance of the nature of the system and the objectives of the simulation study have also been highlighted by Pidd (2004). However, this paper argues that a combined view of the system, the problem and the methodology maybe necessary to make a decision pertaining to the suitability of SD and DES for modelling specific scenarios. As mentioned in the previous section, this research has been fuelled by growing interest in answering the question " which is better or more appropriate". This paper provides a vision which can lead a way forward for development of framework for answering this question.

The paper is structured as follows . The following section provide brief overview of DES and SD. Section 3 presents comparisons and discussion on the outcomes of the findings. Section 4 provides combined view: a vision for development of sound models. Section 5 highlights the difference between sound and successful models. The vision has been further extended to incorporate the importance of clients, resources and time. The last section presents the conclusion.

2 OVERVIEW OF DES AND SD

SD and DES are two simulation techniques widely used in Operational Research. The following subsections will provide brief overview of both.

2.1 Discrete Event Simulation

Arguably, DES is the most popularly used OR technique (Brailsford and Hilton, 2000). DES is probably most well known in its use in the manufacturing industry and healthcare systems. Most modelling techniques were developed in order to solve a specific problem. DES is known for problems with queuing characteristics. The model consists of network of queues and entities. The animations and graphics of DES enhanced its visual interactivity. This makes DES an ideal tool for communication with clients. The general principle of model building remains same regardless of the industry, simulations is applied to. The images and animations provide that tangibility to the factual figures and concepts which help in understanding the system better. e.g. flow of patient depending on severity label. It generates the confidence of the client in the model. The main objectives of these models are prediction, optimisation and analysis of what if scenarios.

As a modelling approach DES model can describe the most complex systems and include stochastic elements, which cannot be described easily by mathematical or analytical models(Venkateshvaran et al., 2005). DES allows one to track the status of individual entities and resources in the facility and estimate numerous performance measures associated with those entities. DES models System as network of queues and activities (Brailsford and Hilton, 2000). Events are the pivot of DES models. Changes in system occur when events happen. Due to this event based focus, changes in system occur at discrete points of time. The activity duration of these events are sampled from probability distributions. DES model building involve identification and representation of resources, entities, logic and flow of entities.

2.2 System Dynamics

SD is an analytical modelling methodology developed by Jay Forrester (1968) at Massachusetts Institute of Technology. The basic idea was taken from feedback control theory. Engineers have been using modelling of feedback systems via differential equation. SD combines two distinct aspects: qualitative and quantitative, with the aim of enhancing the understanding of a problem and improving the comprehension of the structure of the problem and relationships present between relevant variables (Brailsford and Hilton, 2000). Due to this ability of combining both qualitative and quantitative aspects along with the flexibility of process, SD has been used across many fields such as project management, defence analysis and healthcare etc. It has been only recently that people have started appreciating the benefits of qualitative aspect of SD (Brailsford and Hilton, 2000). The interactions between different constituting units and variable affecting system are represented by influence diagrams. Influence diagrams are highly informative and provide insight into the system being investigated. Along with numerical data, SD models are capable of using descriptive as well as judgemental data. The main objective and advantage of modelling comes from the fact that it helps in formulation and understanding of problem. SD fits into this context very well. It helps in in-depth understanding of problem. Jay Forrester (1968) said that SD models are "learning laboratories".

As a modelling approach SD has three characteristics; concept of feed back loops, computer simulation and need to engage with mental models (Lane, 2000). The most important information about these systems is not documented it is held as mental models. The decisions made by the problem owners are influenced by their mental models. SD as a modelling approach has the ability to engage with mental models (Lane, 2000). Therefore it is highly recommended that modelling work should be done in close proximity with the problem owners, who can see reflection of their mental models in the computer models. Due to its engagement with the problem owner's mental models SD generate confidence in the model and hence has impact on decisions made by the problem owner. Due to their problem structuring ability SD models are more used at strategic level (Coyle, 1985; Sweester, 1999; Lane, 2000; Brailsford and Hilton, 2000).

3 COMPARISON BETWEEN DES AND SD

On extensive literature search, it has been found that literature available on comparison of two techniques is very limited. This could be due to the fact that proponents of two fields have very little appreciation of each other (Sweester, 1999; Lane, 2000). This section compares DES and SD modelling approaches on the basis of existing literature. So far Moorcroft and Robinson (2006) paper is the only paper that have compared SD and DES empirically.

SD and DES models have been compared on the basis of technical and philosophical difference in methods, difference in the way they represent and interpret problems and systems and the difference in the way they have been used (Brailsford and Hilton, 2002; Moorcroft and Robinson, 2006; Tako and Robinson, 2006; Lane 2000). There is lack of comprehensive comparison which combined all these separate views. The need to fulfil this gap has been further aggravated with the growing interest in finding answer to the question when to apply which methodology (Brailsford and Hilton, 2002; Lorenz and Andreas, 2006; Moorcroft and Robinson, 2006)

In an attempt to fulfil this gap the authors have taken a combined approach and classified existing comparisons under *modelling methodology perspective, systems perspective* and *problem perspective*.. Here methodology perspective refers to philosophical assumptions, technical capabilities, limitations and inherent characteristics of modelling method. Problem perspective refers to "Why" the reason behind the modelling exercise and the system refers to real world context under investigation. There are two reasons behind choosing system, problem and methodology as criteria for comparisons, first is that all the existing comparisons can be classified under these three parameters providing a comprehensive comparison. And the second reason is that system, problem and methodology have significant influence in answering the major question, which is better for what? In a way by choosing these three parameters, the authors have tried to kill two birds with one arrow. This comparison not only provide a comprehensive comparison but also lead a way forward for answering the question which is better in which situation.

Pidd (2004) argues that modellers should think about 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. There are other factors which are related to a successful modelling practice and hence have impact on deciding between modelling techniques, but the systems, problem and capabilities of modelling methodology have come across as primary factors. It is important to note that the boundaries between these perspectives are much diffused with many overlapping features.

3.1 Methodology Perspective

Quite a few comparisons in literature have been found on the basis of capabilities and inherent aspects of both modelling methods such as how the models represent and interpret what are the modelling elements of the models etc. Dominance of comparisons on the basis of inherent capabilities of methods could be attributed to the fact that most of the comparisons are carried out by academics and academics tend to concentrate more on methodological perspective.

Coyle (1985) identified that SD models represent closed, nonlinear processes whereas DES models represent open linear processes. However Moorcroft and Robinson (2006) argued that DES can model nonlinear closed processes as well. It has been stated that SD and DES differ in the way they represent and interpret (Moorcroft and Robinson, 2006). Differences have been found in their modelling philosophy and underlying mathematics (Coyle, 1985; Mak, 1992; Sweester, 1999; Lane, 2000). Lane (2000) argued that clients find SD models more transparent and easy to understand, whereas though they find DES models convincing, they do not understand the underlying mechanics of the model. Author agrees with Brailsford and Hilton's argument (2000) that Lane (2000)stance might be applicable to qualitative SD models, however quantitative SD models with their differential equations and mathematical formulae lack this transparency. Models have been compared on the basis of their capabilities (Randers, 1980; Sweester, 1999; Lane, 2000; Usano et al., 1996). They have been also compared on the basis of their output, validity and the way they handle data and time (Randers, 1980; Coyle, 1985; Sweester, 1999; Lane, 2002). It has been argued that SD and DES differ the way they interpret and rep[resent system (Moorcroft and Robinson, 2006). David Lane (2000) has argued that both methodologies differs the way they pursue complexity, "dynamic complexity" in case of SD and "detailed complexity" in case of DES. Summary of comparisons on methodological perspective are shown in Table 1.

3.2 Systems Perspective

Upon reviewing literature, System's perspective has also been identified as one of the main criteria which was used as the basis for comparisons. The nature of the system being simulated is an important consideration before deciding between the models because "the model needs to be a close fit, a good representation of the system"(Moorcroft and Robinson, 2006). SD and DES have been compared on the basis of the nature, representation and view of the systems. It has been argued that SD provides a more broader holistic view of the system whereas DES provides narrow, microscopic view focusing on precision and detail (Mak, 1992; Lane, 2000). Sweester (1999) has argued that System Dynamicists are interested in fuzzy ambiguous systems whereas DES modeller focus on clearly defined system. MacDonald (1996) argued that DES is more appropriate for modelling systems where behaviour of the system changes significantly when a specific variable reaches a threshold level, whereas SD is better where the system reacts in a specific way in response to the gradual building up of pressure. Summary of comparison of the two methods with respect to systems perspective is presented in Table 1.

3.3 Problem Perspective

The third main perspective which has been identified as criteria for comparison is the Problem Perspective. Again this has been influenced by the relevant literature suggesting that nature, scope and different aspects of the problem has influence on deciding between SD and DES, as both SD and DES are more capable at modelling certain aspects of the problem. It has been argued in literature that SD is more suitable for modelling strategic problems and DES for operational and tactical (Brailsford and Hilton, 2000; Lane, 2000). Problems which are caused by the structure of the system are better analyzed by SD and problems which are caused due to the randomness are better modelled by DES (Sweester, 1999; Moorcroft and Robinson, 2006). Summary of comparison of the two methods with respect to problem perspective is presented in Table 1.

Modelling Methodology Perspective		
Criteria	SD	DES
Modelling Philosophy	Causal structure of the system causes behaviour and model building reveals this	Randomness associated with interconnected variables leads to system behaviour.
Structure determine performance	SD is based on concept that Performance of SD model over time is determined by it's structure	DES is based on the concept that Performance of System over time is determined by randomness.
Representation	System represented as stocks and flows	System represented as queues and activities, processes
Feedback	Feedback explicit	Feedback Implicit
Relationship	Interested in identification of nonlinear relationships	Relationships can be nonlinear but mostly are linear
Data	SD Models are not heavily dependent on numerical data	DES models are highly data dependent
Complexity	Complexity increases linearly with size	Complexity increases exponentially with size
Resolution of Models	Homogenised entities, continuous policy pressures and emerging behaviour	Individual entities, attributes, decisions and events
Validity	Validation increases plausibility of the model as a theory for the causal mechanism generating behaviour	Validity proves the model to be true representation of system.
System's Perspective		
System	Holistic view; emphasis on dynamics complexity	Analytic view: emphasis on detailed complexity
Focus	Wider Focus: general and abstract system at macro level	Narrow focus with microscopic view on detail
Relation to Outside world	Unisolated continuous system with cross boundary interactions	Isolated discrete system with no interactions with the outside world.
System Orientation	SD focus more on modelling systems	DES focuses more on modelling processes.
Problem Perspective		
Problem perspective	The understanding of the problem lies in analysis of causal feedback effects	Understanding of the problem lies in analysis of randomness associated with interconnected processes and events.
Problem studied	Strategic Level	Operational & tactical Level

Table1. Multi – perspective comparison between system dynamics and discrete event simulation

4 COMBINED VIEW

There is a growing concern in research in understanding which method is better or more suited for a particular problem. It has been argued that the choice of modelling methodology is dictated by the modeller's expertise (Brailsford and Hilton, 2000, Moorcroft and Robinson, 2006). This is typical scenario of fitting nail to hammer. Rather than adopting a tool to problem, analysts try to adapt problem to available tools. However it should be the other way around. This mismatch between problem and methodology could be attributed to the lack of a framework helping decision makers to decide upon methodology.

All modelling techniques are based on certain philosophies and assumptions. Successful choice between methods depends upon understanding the contrasting and overlapping features of modelling methodology. Previous section has given a detailed account on comparisons between SD and DES.

It has been argued in this paper that in order to develop sound models, there needs to be strong fit between system, problem and methodology (Figure 1).

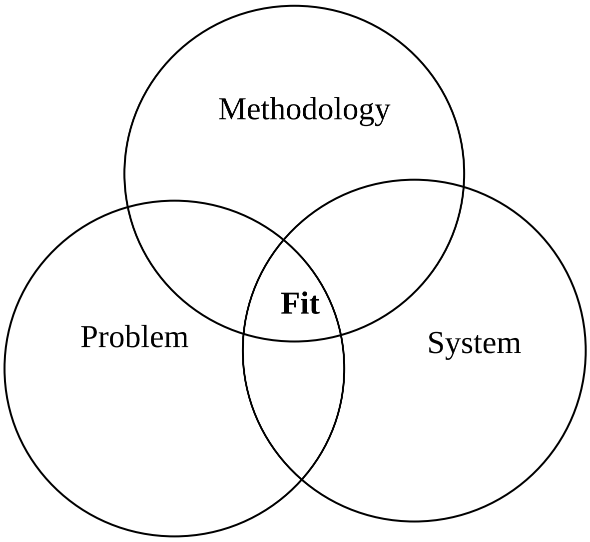

Figure 1. Fit between problem, system and methodology

Upon deciding between SD and DES, it has been argued that the answer to this question depends more on the purpose of the model rather than the system being modelled (Lorenz and Jost, 2006). On the contrary, the authors believe that system is an integral aspect when it comes to deciding between SD and DES. There are quite a few examples of DES models of A&E trying to address the issues regarding the optimization of A&E. Such models are trying to align the purpose with the methodology rather than the system. A&E as a system interfaces with many other departments of a hospital. Its internal processes may therefore influence other departments and vice versa. Here consideration of systems perspective along with problem perspective would have definitely contributed more. On the other hand, if cross boundary interactions have zero impact on the internal processes of the system then perhaps the use of DES to optimize the internal functioning would have been the right choice. These cross boundary interactions can only be addressed if the modeller takes into account system perspective as well. Lane et al (2000) in their study of Accident and Emergency department have highlighted that considering problem perspective alone to measure the effect of bed shortage on A& E waiting time would be misleading. They have emphasised on the point that how a system's perspective along with problem perspective will help in looking at the bigger picture of the problem. The authors agree with Lane et al (2000) that systems perspective will not only represent the connections between the different parts of the system but also highlights how the changes in one part will have ripple effects in other parts of the system. Lane et al have argued that reduction in bed will not affect A&E waiting times directly, but it will affect elective waiting times. Because of the increase in elective waiting times the condition of the patients will deteriorate and hence elective patients will present themselves to the system as A&E patients. This will reinforce the problem of A&E waiting times and bed shortage. As

A&E patients stay in hospital longer than elective, this will further reduce the availability of beds. As a behavioural consequence of long waiting times for elective patients, GPs will refer more patients to A&E. All these factors will additively affect the A&E waiting times. These factors can not be studied without analysing the problem in system's context.

Similarly, taking system aspect alone for deciding between the suitability of SD and DES can again lead to inefficient/incomplete models. It has been argued that if the system is large SD is better choice because complexity of the DES model increases exponentially with size (Brailsford and Hilton, 2002; Rabello et al., 2004). Brailsford et al (2004) have used system dynamics in their study of accident and emergency department of Nottinghamshire. They have used SD as methodology of their choice and reasoned that the size of the system is large and there are not many reported DES studies of large system as the justification behind their choice. However the authors of this paper do not agree with their reasoning as in the same study they have also used DES to investigate the Government's suggestion that waiting times in A& E can be reduced by the provision of fast track system for minor injuries. Brailsford et al (2004) have argued that this investigation required individual details and SD as a methodology is not capable of capturing this detail. From this it is quite evident that as the systems context in both scenarios is same the difference lies in the purpose of problem. Hence use of SD and DES has been governed by the suitability of SD and DES to combined perspective of system and problem. Again authors would like to make a point that size of the system alone without understanding the objectives of the problem is not sufficient for deciding between two.

Like Systems and Problem, using inherent capabilities of methodology on it's own for deciding between two can be misleading. For example it has been argued that SD models require less time to develop and DES models require more time and hence SD should be used when there is not enough time (Brailsford and Hilton, 2002) However it has been well proved that quick and dirty models can be developed using DES.. As argued by the authors, choice between SD and DES should be dictated by the problem and the System The combined view is required in order to make better models and hence better decisions. The authors believe that this combined view of comparisons using system methodology and problem (as shown in fig1) will provide a suitable vision for developing a framework for deciding appropriate methodology.

5 DOES TECHNICALLY SOUND MEANS SUCCESSFUL?

As mentioned in previous section alignment between system, problem and methodology will result in technically sound models but the technical sound models do not necessarily mean successful models. A modelling project is successful if it is implemented successfully. Successful implementation requires much more than technically sound models. The authors argue that stakeholders, resources and time are other parameters which should influence the choice of modelling as shown in Figure 2.

The inclusion of system, problem and methodology fit into this stakeholders, time and resource triangle expresses the dominance of later on deciding between system dynamics and discrete event simulation. There is no point of developing a sound model using discrete event simulation if the stakeholders do not have the confidence in representation of his problem domain in terms of queues. There is high probability that their lack of confidence will result in a technically sound but undesirable product. It is a well realised fact in Information systems community that solution to complex problems not only require technically sound deliverables but also a great deal of investment in relationships with stakeholders. Hence it is very important for the analysts to work in close proximity with stakeholders so that their views, likes and dislikes are addressed in the initial stages of model development. Similar consequences will arise if the process of model development overruns budget and time. Time and cost has been argued as the one of the main barriers for uptake of simulation in industries such as healthcare where quick and affordable decisions are required (Lowry et al 1992, Carter and Blake, 2005).

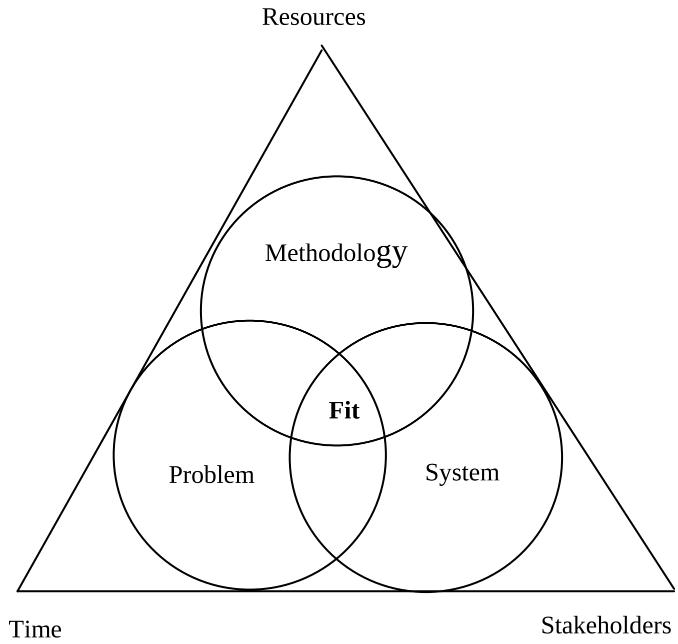

Figure 2. Impact of stakeholders, resources and time

6 CONCLUSION

Modelling Methodology perspective, systems perspective and problem perspective have been identified as the major categories for comparisons. These criteria align with the primary criteria for choosing between models (Coyle, 1985; Brailsford and Hilton, 2000; Lorenz and Andreas, 2006; Pidd, 2004).

Differences in the SD and DES could be attributed towards the fact that they were developed on the different philosophies in response to different problems. Their respective characteristics which make them suitable for different types of systems and different types of problem can also be explained on the basis of their capabilities and limitations, for example applicability of SD to larger systems and DES to small systems can be attributed towards the fact that complexity of SD model increase linearly with size whereas the complexity of DES model increases exponentially (Helal and Rabelo, 2005).

Coming back to the original question of choosing between the two, it has been argued that alignment between system, problem and modelling methodology is the primary recipe for development of sound models. However different authors have viewed these issues separately when it comes to comparisons. This paper contributed by providing comprehensive comparisons and using the perspectives which align so well with recipe for development of sound models. This paper contributes by providing a comprehensive comparison. This is achieved through three perspectives of methodology, system and problem, perspectives previously suggested as necessary requirements for building sound models.

It has been highlighted that sound models does not necessarily means successful model. Authors have argued that success of the model is measured in terms of its implementation. Along with time and resources, engagement and confidence of stakeholders in modelling approach are also included in the vision as they have major impact on the successful implementation of model.

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