Discrete Event Simulation, System Dynamics and Agent Based Simulation: Discussion and Comparison

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1 Introduction

Simulation modelling is an important instrument in Operational Research for a number of reasons. It provides a valuable tool for approximating real life behaviour and hence can be used for testing scenarios. Also the art of constructing the model itself may lead the modeller to greater understanding of the real system. When it comes to simulation there are three main methods in use, this paper will look at these three: Discrete Event Simulation, System Dynamics and Agent Based Simulation. Firstly basic definitions of the methods will be given and then comparisons between them will be discussed.

2 Introducing the Techniques

2.1 Discrete Event Simulation (DES)

Discrete Event Simulation (DES) is probably the most widely used simulation technique in Operational Research. As the name suggests it models a process as a series of discrete events. This means that entities (the general name for what is being considered; e.g. “customers”) are thought of as moving between different states as time passes. The entities enter the system and visit some of the states (not necessarily only once) before leaving the system. Typically DES systems are thought of as networks of queues and servers, such as in the system which can be seen in Figure 1.

Figure 1: Part of a DES model created using SIMUL8 to model an A&E department.

The example considered is a hospital Accident and Emergency Department and it's been modelled very basically using SIMUL8. However even a basic model such as this can prove to be insightful. Using a simulation such as this will help the modeller identify possible areas in the system where problems may occur. DES techniques can especially be used to discover whether it would be advisable to add more server to a service node, or even restructure the system far more radically. For example, in the situation depicted above the modeller may find that after running the model that delays occur up at the final checkup point of the system. It may be that adding more beds to the system would help solve this, however this is not the only solution. A better fix may be to hire more doctors (as they are the resource needed to checkout the patients) or more radically it may be the case that actually in the system some low risk patients can actually be checked out by nurses and the model could be reformulated to consider this. In DES modelling software all these different approaches can be simulated and then using test statistics can be compared against each other.

2.2 System Dynamics (SD)

Another widely used simulation technique is System Dynamics. SD takes a slightly different approach to DES, it focuses more on flows around networks than on the individual behaviour of entities. In SD three main objects are considered; stocks, flows and delays. Stocks are basic stores of objects, an example may be number of patients in a hospital department. Flows define the movement of items between different stocks in the system and out/into the system itself. Lastly delays are exactly as they sound, they are the delay between the system measuring something and then acting upon that measurement. An SD model is a network of stocks, flows and delays which may then depend on some general constants. A typical SD model can be seen in Figure 2.

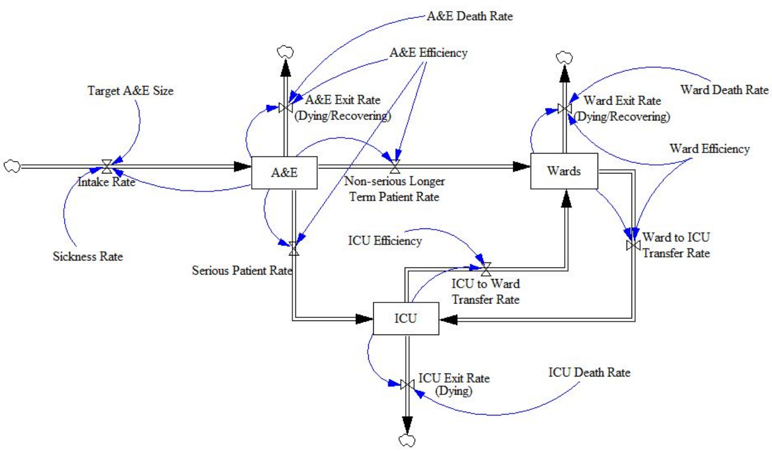
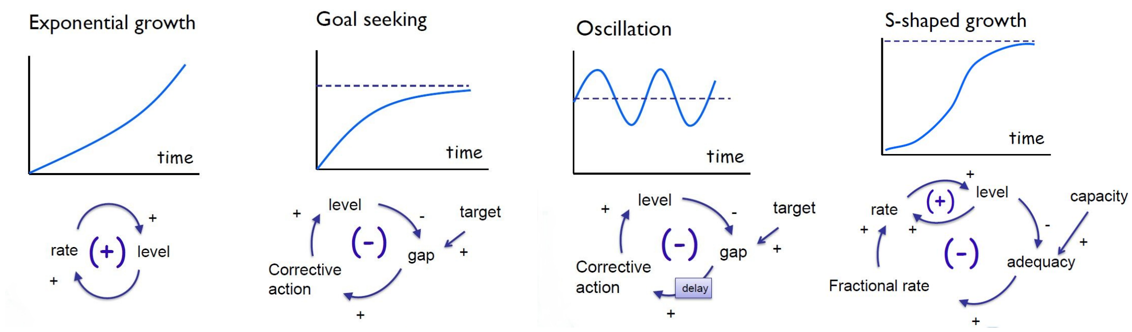


Figure 2: An SD model created using Vensim to simulate patients flow through a hospital.

Figure 2 was produce using Vensim and is typical of an SD model. The A&E, ICU and Wards are all stocks and the flows between them are indicated by the black double lined arrows. In this simple system there are no delays however these could easily be included.

One key feature of SD systems is the ability to predict the behaviour of the system just by looking at the structure. Four different structures are given in Figure 3, however these are definitely not exhaustive. In fact some of this behaviour arises in the example given in Figure 2.



(a) (b) (c) (d)

Figure 3: Diagram showing relationships between feedback loops and the behaviour of the system.

2.3 Agent Based Simulation (ABS)

The final simulation method which will be looked at in this paper is Agent Based Simulation. ABS is a relatively new method, especially in OR where it's often been overlooked in favour of using the more established methods of DES and SD. ABS models systems as being made up of autonomous (self-directed) agents which follow a series of predefined rules to achieve their objectives whilst interacting with each other and their environment. In ABS an "agent" could be a multitude of different things, from people in a crowd to cells in a body and because of this versatility it has been used to model a wide range of situations from flocking behaviour in birds to modelling the emergence and spread of cancer cells throughout a body.

One of the simplest uses of ABS (and most famous) is in Conway's Game of Life (Chan et al., 2010). In this model a $n \times n$ grid is set up where each cell can either be "alive" or "dead". After the modeller sets up an initial state for the process then each cell (which can be thought of as an autonomous agent) proceeds keeping to the following rules:

1. A live cell with at least X and at most Y live neighbours will remain alive in the next time step.
2. A dead cell with exactly Z live neighbours will come to life in the next time step.
3. Otherwise, cell will die either of loneliness or overcrowding in the next time step.

Here a "neighbour" is defined as a cell adjacent to the cell in question, including diagonals.

Various behaviour can be observed using the Game of Life including self replication, reproduction and oscillation and it has many applications especially in computer science. In addition, the values of X, Y and Z can also be changed during the process, for example Figure 4 shows some of the affects of this.

3 Comparisons of the Methods

3.1 Comparing DES and SD

As hopefully has already been made apparent there are many differences between DES models and SD models and as of such these methods are often used for modelling different situations. DES naturally lends its hand to systems which naturally involve queues of some sort, such as in the A&E department example given in Figure 1. However it can also be used in other situations where a queueing structure is not obvious, for example in internet shopping where a customer doesn't have to queue at all can be modelled using queues with a large number of servers (far in

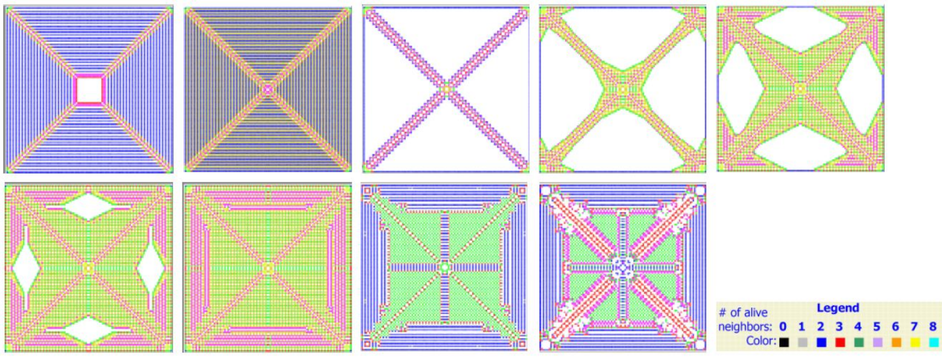


Figure 4: Emergent patterns of variation of Conway's Game of Life: starting with all cells alive, the following sequence of rules was cycled through: (0, 7, 8)-(0, 7, 3)-(0, 7, 6)-(0, 7, 5)-(0, 7, 4)-(0, 5, 4)-(3, 5,4).

excess of any expected user activity). On the other hand SD models tend to used more to model either systems which naturally form flows (such as water pipes) or when looking at more larger systems in a simpler way (such as in the example in Figure 2 where patients "flow" about the hospital departments).

In fact the last situation leads on to one of the key differences between the two methods. DES tends to look at the smaller detail of a system (microscopic), whereas SD tends to take a more overall perspective (macroscopic).

DES and SD are also very different in how they deal with randomness. DES is stochastic in nature and therefore will give different results on different runs. Therefore a DES model will have to be run multiple times to gain full understanding of the system and some sort of statistical methods will have to be used to analyse these multiple runs. In contrast a SD model is deterministic in nature, it will produce the same results run after run, so only needs to be run once.

Although many papers provide general overviews of the differences between DES and SD (Brailsford and Hilton, 2001), there are a couple of papers by Tako and Robinson which provide full empirical studies. The first looks at end users opinions to two different models of the same system (Tako and Robinson, 2009a). "Managers" (which were in reality executive MBA students) are presented with the two models, one DES and one SD, which had been used to model a prison population. Participants were then asked to suggest possible policy changes to solve the problem of overcrowding (while taking into consideration budget constraints). The subjects were then asked to fill in a questionnaire and the results analysed. Tako and Robinson's conclusions were that, in this case, there was very little significant difference in terms of the users opinions of the different softwares. However it was pointed out the particular case study which had been analysed had been set up so that both approaches were equally applicable.

The second paper (Tako and Robinson, 2009b) looked at the techniques and thought procedures used by ten expert modellers to build DES and SD models. In the same way as the previous paper, the example of prison populations was again used. The modellers were asked to speak through there thoughts on how they would model the system and then the transcripts were analysed using Verbal Protocol Analysis. From the interviews it was concluded that there were distinct differences between the way DES and SD models were constructed. The DES modellers spent more time modelling and verifying/validating the model than the SD modellers did, this reflected the belief that modelling in DES tends to be more complex than modelling in SD. In contrast the SD experts tended to spend more time conceptually modelling the system. Both DES and SD modellers tended to switch their attention frequently between the different areas of the modelling process, this backs up previous work done looking at modelling in general.

3.2 Combining DES and SD Models

Both Discrete Event Simulation and System Dynamics have many advantages and disadvantages which are often complementary. Therefore it seems natural to try and combine the two methods to produce an all inclusive hybrid-method.

Many attempts at finding this “holy grail” of simulation (as it’s often called) have been made, however a true hybrid model has never really been constructed. The main problem with this is that at the current moment there are no software packages available which can truly model both DES and SD to their full extent (Brailsford et al., 2010). However there have been many attempts to construct models which utilise two separate pieces of software which then communicate with each other.

In fact a combination of DES and SD could be used to model the A&E example given in Figure 1. In the example a DES model is used fairly effectively to model the A&E department, but of course this department will be affected by what happens in other areas of the hospital. This is not represented in Figure 1, however this is considered in the SD model in Figure 2. What a hybrid model would do is to allow the two areas to communicate and send information between themselves.

Hybrids have been found to be useful to solve problems in a range of areas. One such area was to model a STI clinic in Portsmouth, UK (Brailsford et al., 2010). This modelled the clinic as a DES system and then modelled infections in the local area as a standard SIR (susceptible, infected, recovered) systems dynamics model. These then communicated with each other using an automated system which ran through Excel. The reason for using this hybrid model for this situation was that the managers of the clinic were particularly worried that they wouldn’t be able to cope if there was a sudden outbreak of STIs in the area.

3.3 Comparisons with ABS

As Agent Based Simulation becomes more widely used in OR, the question as to how it compares to both DES and SD has become more relevant. As when comparing DES and SD, it depends a lot on the particular situation which is trying to be simulated.

At first glance SD and ABS seem to be very different techniques. Whilst SD takes a top down approach, ABS is a very extreme example of a bottom up approach. Also whilst ABS is stochastic, SD models tend to be deterministic. However it can be proved that in fact the set of all SD models is a strict subset of the set of all ABS models. This is the Agency Theorem for System Dynamics (Macal, 2010), and quite simply states that every well formulated SD model has an equivalent formulation as an ABS model. Therefore we can model any SD model using ABS. This tends to produce results which perform at least as well as running the SD model, if not better, however it comes at a price as ABS models are a lot more time consuming to model and to run.

Some work has also been done into comparing ABS systems with traditional DES systems (Siebers et al., 2010). DES and ABS differ in a number of ways. Firstly in ABS systems the agents each have their own behaviour and hence are classed as “active”, in contrast, the behaviour of the entities in a DES model is determined by the system and hence these are classed as “passive”. Another key difference is that while DES is built around networks of queues, in an ABS system there is no concept of queues; this can be a problem when modelling many OR problems. In fact some experts feel that, because of this, true ABS models have no use in Operational Research (Siebers et al., 2010), although in reality there’s not much collaborating evidence to back this up. However it is true that some systems are better modelled using a combination of DES and ABS. This is done by creating a DES system in which some of the entities are actually "active" and exhibit self-aware behaviour. Despite their differences, DES and ABS do share some similarities. Both are stochastic in nature and can use input distributions to model random behaviour.

ABS has often been overlooked in favour of the more traditional methods (DES and SD), this is due to a number of reasons. Firstly the software available is still fairly difficult to use and hence puts many modellers off. Also ABS models tend to take a comparatively high amount of time to develop, which means that it cannot produce the "quick and dirty" solutions which simulation is often used to find. Lastly and perhaps most importantly, is the reluctance of OR practitioners to move away from the more established techniques.

4 Conclusions

DES, SD and ABS all have benefits and disadvantages and are applicable in different situations. A problem in simulation modelling is a tendency for a system to be modelled using the technique which the modeller feels most comfortable with rather than the most useful. Instead the problem should determine the method used to model it, and in order to choose the right method knowledge of a range of techniques is needed as well as detailed knowledge of the system and the objectives of the simulation.

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