2

The Usage of Simulation

Introduction

This chapter provides evidence of the current usage of the simulation technique in organisations. This is determined from evidence from published studies and a study undertaken by the author. There follows an overview of application areas of simulation in organisations that do use the technique. Applications of simulation in both manufacturing and service industry are provided. The widespread use of simulation in people-based applications has lead to an increasing interest in the modelling of human behaviour in simulation. A range of approaches to meeting this challenge are presented.

Published Surveys of the Use of Simulation

A number of surveys of simulation use have been conducted. In the USA Christy and Watson (1983) conducted a survey on the application of simulation in industry to members of the Institute of Management Sciences. It found that 89% of the firms that responded used the simulation technique, of which 32% initiated its use between 1975 and 1979. Kirkpatrick and Bell (1989) conducted a survey of visual interactive modelling use by conducting users through the simulation software supplier organisations. System complexity was the most cited reason for using VIM. Groups developing a VIM capability reported an expanding demand for their services and a growth in their prestige and credibility with management. Cochran et al. (1995) conducted a survey to provide information on simulation practices in industrial settings. The report finds that the simulation languages are being increasingly being discarded for simulators (VIMs). Somewhat optimistically the authors predicted that the ease of use and built-in methodology of simulators will mean opportunities for simulation consulting may die out. McLean and Leong (2001) also characterise the implementation of simulation in the US as ‘limited’ and ‘sporadic’. Further studies indicate that the use of simulation is widespread or always successfully implemented in industrial settings (Upton, 1995; Beach et al., 2000).

The first major survey in the UK was by the Simulation Study Group (1991), the results of which can also be found in Hollocks (1992). This found that awareness of the technique in manufacturing industry as very low and some £300 million of benefits were being missed. The survey revealed only 11% of UK manufacturers using simulation as a decision support tool. Other than awareness, the principal obstacles to wider use were found to be lack of skills or training, difficulties in data acquisition, the time taken to build the model and a lack of management commitment. The ESPIRIT working group on Simulation in Europe (SiE) stated that this general picture of proliferation was reflected across Europe (Kerckhoffs et al., 1995). Hollocks (2001) maintained that there has been no evidence to indicate any material shift in the level of simulation use on UK manufacturing since the original survey. Edge and Klein (1993) conducted a survey to assess use of operational research techniques in small businesses in the UK. Out of the 19 firms surveyed, 15 had no familiarity with simulation, 4 had moderate familiarity and 0 had high familiarity. Wisniewski et al. (1994) conducted an investigation into the use of quantitative techniques by business in Denmark, Scotland and the UK. It found 57% of companies surveyed had awareness of simulation and of those 63% actually used the technique. The major factor cited for non-use of a technique was that the firm did not see the technique as being relevant to the organisation's activities. A survey covering non-academic members of INFORMS found only 10% of survey respondents employed simulation as a decision support tool (Abdel-Malek et al., 1999).

Hlupic reports on a study undertaken in 1997 in Hlupic (1999) and Hlupic (2000) on current academic and industrial users of simulation. The report finds that two-thirds of respondents use simulation for manufacturing applications. Other significant application areas are health (18.5%) and communication systems (11.1%). The survey focuses on simulation software and finds that the most requested software features are more assistance in experimental design, packages that are easier to learn and use and improved software compatibility. A survey by Fryer and Garnett (1999) considers the issue of a lack of education and training as a barrier to the wider and more effective use of simulation. They found that many courses within higher education place emphasis exclusively in theoretical and technical issues, and ignore practical skills, which may not be appropriate for modelling relatively simple business processes. Thus the challenge for the simulation education community is to find the right balance between theoretical, technical and practical illustration. Melao and Pidd (2003) conducted a survey among potential business process simulation (BPS) users. BPS is defined as the use of a computer simulation model to mimic a business process so as to consider changes before their implementation. The aim of the survey was to understand the requirements of people engaged in this relatively new area of simulation usage. The survey revealed a low usage in the design, modification and improvement of business processes. There was no evidence of a skills gap found, but rather a feeling that there is no net gain from employing simulation methods when simpler methods will suffice.

A Survey of Simulation Use in the UK

A descriptive survey is presented of the current usage of simulation in UK organisations. The survey sampled approximately 1000 companies from a database of UK organisations across industrial sectors. The survey was designed to gather data using a Likert scale in response to a number of questions regarding the use of the simulation technique. Space is also provided for comments for qualitative feedback. The response to this questionnaire was very low and so the question of non-response bias needs to be addressed. However it was felt likely that the majority of non-responses were non-users of simulation and so the proportion of non-users is greatly understated. From the survey 30 responses were received giving a response rate of 3%. Of these 24 (80%) were from non-users of simulation and 6 (20%) were from users of the technique. The non-users of simulation were asked a number of questions to identify the main reasons why the simulation technique is not used at this time. Users were requested to respond on a Likert scale numbered 0 (not a reason) to 4 (major reason) to questions categorised under the headings of cost, awareness, skills, organisational and limitations of technique. The following analysis was performed on the responses in order to provide a summary of the results. Responses of 0 and 1 on the scale were combined and converted to a percentage of the sample size, responses of 2 on the scale were discarded, and responses of 3 and 4 were combined and converted to a percentage of the sample size. A summary of the responses is provided in Table 2.1.

Table 2.1. Survey Results of 'Reasons for non-use of Simulation'

Reasons for non-use of simulation	Major Reason %	Not a Reason %
Costs		
Initial cost of software, hardware and training	20.83	33.33
Project costs of model developer time	12.5	33.33
Project costs of staff time in data collection	12.5	37.5
Cost of simulation consultancy	20.83	29.17
Awareness		
Lack of knowledge of where technique can be applied	**54.17**	25
Lack of knowledge of benefits of technique	**50**	20.83
Assumption that technique is only used in manufacturing applications	8.33	37.5
Skills		
Lack of staff skills in model building	33.33	25
Lack of staff skills in statistical analysis	20.83	37.5
Organisational		
Lack of confidence that results of a simulation study will actually lead to change	25	**41.67**
Study results takes discretion away from decision makers	8.33	**41.67**
Lack of understanding of technique by decision makers	25	25
Intuitive (non analytical) approach to decision making preferred	25	25

Table 2.1. (continued)

Limitations of Technique		
Lack of ability of simulation to model human-based or ill-defined processes	20.83	25
Other techniques (e.g. spreadsheet modelling) provide sufficient information	**50**	12.5
Time taken to develop model and present results too slow for decision making	16.67	20.83
Lack of flexibility in reusing models	12.5	33.33
Lack of ability to run models in real-time	4.17	**45.83**
Assumptions made in model make it an unrealistic representation of the real system	16.67	29.17
Lack of connectivity of simulation with databases and IT systems	12.5	37.5

It can be seen from Table 2.1 that the most likely reason for non-use of simulation is a lack of awareness of the technique. This is found both in a lack of knowledge of where the technique can be applied and a lack of knowledge of the benefits of the technique. The other major reason given for non-use of simulation is the view that other techniques, such as spreadsheet modelling, provides sufficient information for decision making purposes. The lack of ability to run models in real-time, a lack of confidence that results of a simulation study will actually lead to change and a feeling that study results takes discretion away from decision makers were not felt to be reasons for non-use by a significant proportion of respondents. A space was provided for a qualitative response to how the respondents felt the simulation technique could be used more widely. Responses included the following:

> ‘Whilst in theory a good idea, in the real world it is only appropriate for large companies with complex procedures’
>
> ‘Most of our problems are not complex enough to need simulation modelling’
>
> ‘I have never HEARD of Simulation Modelling’
>
> ‘Simulation techniques are tools used by half witted management consultants who don’t understand business’
> ‘As an ISO 9001 QA service company we track and measure all processes using D/B and s/sheets. Is cost-effective and meets our needs’

These responses point to a lack of awareness of the technique and its perceived non-applicability to companies. The survey also requested responses for current users of simulation. In this case the users of simulation were asked the same questions as non-users but in the context of why greater use was not made of simulation in their organisation. The responses are presented in Table 2.2.

Table 2.2. Survey Results of 'Major barrier to greater use of simulation?'

Major Barrier to greater use of Simulation?	Major Barrier %	Not a Barrier %
Costs		
Initial cost of software, hardware and training	50	16.67
Project costs of model developer time	50	16.67
Project costs of staff time in data collection	**83.33**	16.67
Cost of simulation consultancy	**83.33**	16.67
Awareness		
Lack of knowledge of where technique can be applied	50	50
Lack of knowledge of benefits of technique	33.33	50
Assumption that technique is only used in manufacturing applications	16.67	66.67
Skills		
Lack of staff skills in model building	33.33	16.67
Lack of staff skills in statistical analysis	33.33	0
Organisational		
Lack of confidence that results of a simulation study will actually lead to change	16.67	66.67
Study results takes discretion away from decision makers	33.33	66.67
Lack of understanding of technique by decision makers	16.67	66.67
Intuitive (non analytical) approach to decision making preferred	0	33.33
Limitations of Technique		
Lack of ability of simulation to model human-based or ill-defined processes	16.67	33.33
Other techniques (e.g. spreadsheet modelling) provide sufficient information	33.33	33.33
Time taken to develop model and present results too slow for decision making	16.67	33.33
Lack of flexibility in reusing models	50	33.33
Lack of ability to run models in real-time	16.67	66.67
Assumptions made in model make it an unrealistic representation of the real system	16.67	66.67
Lack of connectivity of simulation with databases and IT systems	33.33	16.67

It would seem from the results that cost is a significant barrier to greater use of the technique. Cost is seen as significant both in terms of staff time required for data collection and the cost of consultancy for outsourced simulation development. Overall the survey results show that while there is scepticism of the applicability of the technique in non-users, actual users of the technique seem to be satisfied with the relevance of the technique, with the main barrier to further use being cost. This suggests that the factors affecting the breadth of use across organisations differ from the factors affecting the depth of use within an organisation. Although difficult to judge from the small response rate, it seems that this survey confirms a low usage of simulation by organisations reported in the literature search.

Where in the Organisation is Simulation Used?

Simulation Modelling is used in various areas of many different types of organisations. Some examples of simulation use are given below, with reference to industrial case studies published by the author.

Manufacturing Applications

In order to remain competitive manufacturing organisations must ensure their systems can meet changing market needs in terms of product mix and capacity levels whilst achieving efficient use of resources. Because of the complex nature of these systems with many interdependent parts, simulation is used extensively to optimise performance. Greasley (2004) provides a case study of using simulation to optimise a line type manufacturing system by ensuring that each stage in the line has an equal capacity level. Greasley (2000c) provides a case study of the use of simulation to test various scheduling scenarios on a just-in-time production system in order to optimise resource utilisation. Greasley (2005) provides a case study of the use of simulation to develop production rules that would reduce work-in-progress and production lead-time.

For large capital investments such as equipment and plant, simulation can reduce the risk of implementation at a relatively small cost. Simulation is used to ensure the equipment levels and plant layout is suitable for the planned capacity requirements of the facility.

A key customer requirement of any delivered manufactured good or service supplied is its reliability in operation which is often a key measure of service quality. Simulation can test the performance of a system under a number of scenarios both relatively quickly and cheaply. Steps can be then be taken in advance to ensure service is maintained under various operating conditions. Greasley (2000a) provides a case study of the use of simulation to ensure that a transportation system can meet demand within a planned maintenance schedule under a variety of scenarios of train breakdown events. Although simulation has traditionally been associated with improving internal efficiency of systems, this is a good example of where it was used not only to prove capability to the maintenance operator, but also to provide a tool to demonstrate to the potential customer that performance targets could be met.

Transportation systems such as rail and airline services as well as internal systems such as automated guided vehicles (AGVs) can be analysed using simulation. Many simulation software packages have special facilities to model track-based and conveyor type systems and simulation is ideally suited to analyse the complex interactions and knock-on effects that can occur in these systems.

Service Applications

The productivity of service sector systems has not increased at the rate of manufacturing systems and as the service sector has increased the potential increase in productivity from improving services has been recognised. The use of BPR and other methodologies to streamline service processes have many parallels in techniques used in manufacturing for many years. Simulation is now being used to help analyse many service processes to improve customer service and reduce cost. Greasley (2003) provide a case study of the use of simulation to analyse a proposed workflow system for a group of estate-agency outlets. The purpose of the workflow system is to automate the paper-flow in the house-buying process and thus increase speed of service to the customer. The simulation was used to assist in predicting demand levels on the system, identifying bottlenecks and thus optimise operation before implementation.

Business Process Reengineering (BPR) attempts to improve organisational performance by analysis of a business from a process rather than a functional perspective and then redesign these processes to optimise performance. Greasley and Barlow (1998) provide a case study of the use of simulation in the context of a BPR project to redesign the custody operation in a UK Police Service. Greasley (2000b) and Greasley (2001) present a case study showing how simulation can be used in conjunction with the technique of activity-based-costing (ABC) to show costs from a cost, resource and activity perspective. The cases show how simulation can be used during most stages of a BPR initiative and how the use of simulation can be prioritised and aligned with strategic objectives through the use of techniques such as the balanced scorecard. They also show the ability of simulation to provide a variety of performance measures such as utilisation of people, speed of service delivery and activity cost.

The emphasis on performance measures in government services such as health care has led to the increased use of simulation to analyse systems and provide measures of performance under different configurations. Simulation is used to predict the performance of the computerisation of processes. This analysis can include both the process performance and the technical performance of the computer network itself, often using specialist network simulation software.

Modelling Human Behaviour with Simulation

The issue of how to incorporate human behaviour in a simulation study has become prominent due to the increased use of the technique in areas where human behaviour has an impact on process performance. These areas include business process initiatives, particularly those in the service industries and the increase in professional service applications, as opposed to mass manufacturing applications dominated by equipment and machinery. However despite the continued use of simulation in organisations and a relatively large skill base of simulation practitioners, the use of the technique to model human behaviour is not widespread. This section suggests a number of approaches to this task within the process of the simulation study. The different approaches have been derived from a literature review and categorised by level of abstraction. The aim is to raise awareness amongst simulation practitioners of the options available for incorporating human behaviour in their studies, show examples of the implementation of each method and provide guidance on when each method should be used.

Methods of Modelling Human Behaviour

From a literature review potential methods of modelling people were identified and classified by the level of abstraction of human behaviour (see Figure 2.1). A classification by level of abstraction (i.e. the level of detail of the modelling of human behaviour) was used because this was identified has having a major impact on the approach used to model human behaviour. Each approach is given a method name and listed in order of the level of abstraction used to model human behaviour. The framework recognises that the incorporation of human behaviour in a simulation study does not necessarily involve the coding of human behaviour in the simulation model itself. Thus the methods are classified into those that are undertaken 'outside' the model, and those that actually involve changes to the

Method Name	Method Description	World View	Model Abstraction	Simulation Method	Abstraction
Simplify	Eliminate human behaviour by simplification			None	Outside the Model
Externalise	Incorporate human behaviour outside of the model			Gaming Expert Systems Neural Networks	
Flow	Model humans as flows	Continuous	Macro	System Dynamics	Inside the Model
Entity	Model human as a machine or material	Process	Meso	Discrete Event Simulation	
Task	Model human action				
Individual	Model individual human behaviour	Object	Micro	Agent-Based Simulation	

Figure 2.1. Methods of modelling human behaviour in a simulation study

construction of the model ('inside' the model). Methods inside the model are classified in terms of world view and model abstraction in order to clarify the different levels of abstraction within this category. The framework then provides a suggested simulation method for each of the levels of abstraction identified from the literature.

The methods shown in Figure 2.1 are now described in more detail.

The simplify method involves the simplification of the simulation model in order to eliminate any requirement to codify human behaviour. This strategy is relevant because a simulation model is not a copy of reality and should only include those elements necessary to meet the study objectives. This may make the incorporation of human behaviour unnecessary. Actual mechanisms for the simplification of reality in a simulation model can be classified into omission, aggregation and substitution (Pegden et al., 1995). In terms of modelling human behaviour this can relate to the following:

Omission: omitting human behaviour from the model, such as unexpected absences through sickness. It may be assumed in the model that alternative staffing is allocated by managers. Often machine-based processes are modelled without reference to the human operator they employ.

Aggregation: processes or the work of whole departments may be aggregated if their internal working is not the focus of the simulation study.

Substitution: Human processes may be substituted by a 'delay' element with a constant process time in a simulation model thus removing any complicating factors of human behaviour.

The externalise approach attempts to incorporate human behaviour in the study, but not within the simulation model itself. The area of gaming simulation represents a specialist area of simulation when the model is being used in effect to collect data from a human in real-time and react to this information. Alternative techniques such as expert systems and neural networks can be interfaced with the simulation and be used to provide a suitable repository for human behaviour. There will however be most likely a large overhead in terms of integrating these systems with simulation software.

The flow method models humans at the highest level of abstraction using differential equations. Continuous modelling has been used for many years and has been integrated in discrete-event simulation software packages such as SIMAN/CINEMA (Pegden at al, 1995) and its replacement ARENA (Kelton et al., 2007). The implementation of the continuous world view has however been usually associated with the use of the system dynamics technique (Forrester, 1961). A benefit of the system dynamics approach is that it provides a way of understanding the underlying structure of a human system in order to explain behaviour. The level of abstraction however means that system dynamic models do not possess the ability to carry information about each entity (person) through the system being modelled and are not able to show queuing behaviour of people derived from demand and supply (Stahl, 1995). Thus the simulation of human behaviour in customer processing applications for example may not be feasible using this approach.

The most basic way to model human behaviour using the process world view is to either represent people by simulated machines (resources) and/or simulated materials (entities). This allows the availability of staff to be monitored in the case of resources and the flow characteristics of people, such as customers, to be monitored in the case of entities. This will provide useful information in many instances, but does not reflect the way people actually work, particularly in a service context where their day-to-day schedule may be a matter of personal preference.

The task approach attempts to model human behaviour without the complexity of modelling the cognitive and other variables that lead to that behaviour. The rationale behind the approach is described by Shaw and Pritchett (2005), 'In this approach models are described as modelling performance rather than behaviour because of their scope – the current state of the art is better at capturing purposeful actions of a human as generated by well-understood psychological phenomenon, than it is at modelling in detail all aspects of human behaviour not driven by purpose.' Laughery (1999) models human performance by breaking down activities into a number of tasks. This method is intended to get closer to human performance than resource modelling by being able to model the individual actions that humans do rather than subsuming many parallel tasks it one generic task. Elliman et al. (2005) uses task and environmental variables, rather than individual characteristics to model individual behaviour. Thus provides a simpler method than using individual differences but still requires the need to operationalise the variables chosen. Bernhard and Schilling (1997) model people using the entity method but separate material flow from people flow. No individual differences are taken into account and the approach uses a centralised mechanism/database to control workers. These examples show the DES method is a suitable platform for modelling humans using a task approach.

The individual approach attempts to model the internal cognitive processes that lead to human behaviour. This has the advantage of not necessarily being task specific, but requires a sophisticated model of human behaviour. The difficulty of implementation of studies on human behaviour by behavioural and cognitive researchers is a significant barrier to this approach. Silverman et al. (2003) state 'there are well over one million pages of peer-reviewed, published studies on human behaviour and performance as a function of demographics, personality differences, cognitive style, situational and emotive variables, task elements, group and organisational dynamics and culture'. However Silverman (1991) states 'unfortunately, almost none of the existing literature addresses how to interpret and translate reported findings as principles and methods suitable for implementation or synthetic agent development'. Another barrier is the issue of the context of the behaviour represented in the simulation. Silverman states 'many first principle models from the behavioural science literature have been derived within a particular setting, whereas simulation developers may wish to deploy these models in different contexts'. Another barrier is that validation of multiple factors of human behaviour is difficult when the research literature is largely limited to the study of the independent rather than the interactive effects of these factors. Silverman et al. (2003) calls for behavioural scientists to provide a fuller representation of factors that influence human performance. Despite these barriers a number of architectures that model human cognition, such as PECS (Schmidt, 2000), Soar (Newell, 1990) and TPB (Ajzen, 1991) are available. Agent based systems are particularly useful when attempting to model autonomous human behaviour which is difficult in a DES, such as decision making and free physical movement around their workplace. There has been work on integrating DES and Agent based models, for example Dubiel and Tsimhoni (2005). This study combines an agent-based modelling of the free movement and interaction of people in a theme park with the discrete-event implementation of a theme park ride.

Choosing a Method to Simulate Human Behaviour

When considering whether to incorporate human behaviour in a simulation study, the major determinant should be the level of abstraction required to meet the study objectives. It may be that a simplification approach may be sufficient or human behaviour can be externalised to data structures such as an expert system. When considering incorporating human behaviour within the simulation there is an association of the technique of system dynamics at a macro level, discrete-event simulation at a meso level and agent-based simulation at a micro level. However these three techniques are capable of modelling at all three levels of abstraction and the skill-set of the modellers, who tend to operate using only one of the three world views may override the categorisation provided. There is also the issue of applications which require abstraction at the micro, meso and macro level within a single model. Ni (2006) provides an example of a traffic simulation which requires traffic flows to be modelled as flows across large distances (macro), as individual vehicles with characteristics (meso) and as autonomous systems modelling driver cognition (micro). The ideal here would be simulation software that provides tools representing all 3 world views and these do exist, for example AnyLogic (www.xjtek.com). Pegden (2005) predicts that the next generation simulation tool will combine the continuous, process and object world views by making the terms model and object interchangeable, so model builders become object builders.

Summary

The surveys confirm a low rate of usage of the simulation technique, partly due to the perceived cost of establishing a simulation capability in the organisation. A number of applications of simulation in both manufacturing and service industries are provided. A framework is presented providing a range of approaches to modelling human behaviour in a simulation model. The framework suggests a modelling approach according to the level of abstraction of human behaviour appropriate to meet the simulation study objectives.

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