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VERIFICATION AND VALIDATION AND COMPLEX ENVIRONMENTS: A STUDY IN SERVICE SECTOR

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ABSTRACT

Verification and validation are two very important steps in simulation modeling. Consequently, they are under constant review and examination from many different perspectives. Researchers have identified several modes of conducting verification and validation and proposed taxonomies for techniques used in their execution. This paper visits the issues in the light of a case study being carried out specifically in the health sector. The paper argues that the health sector is characterized by a level of complexity in handling "resources" (as understood in simulation modeling) which is not frequently found in the manufacturing sector. This complexity makes validation and verification of simulation models a difficult and challenging task. While the earlier articulation of modes of verification and validation and their taxonomy are generally helpful, there is still some work which could be fruitfully undertaken in understanding various situations and, especially, the perspectives which the "end-users" or clients bring to bear upon any modeling exercise.

1 INTRODUCTION

The use of models is an essential part of the decision making process. These models range from the mental models buried in the mind of the decision maker and not necessarily visible, to the explicit large scale models used to explore the consequences of specific decisions or phenomena affecting outcomes of a given model. To some extent perceived utility of the model will be influenced by the complexity of the model and it then follows that the drive for increased utility and complexity in the model will lead to the situation where the person making the decision is unable to understand the processes followed by the model in producing its outcomes. The need to establish validity and the process of model verification have been debated in the simulation area for many years, and with the development of animated interfaces it is now possible to adopt more comprehensive processes of validation and verification to be followed leading to higher levels of credibility for the model. Simulation therefore could occupy a more prominent position in the tool-kit of decision makers as the animation interface and ease of model development continues to advance over the next ten years. Development of simpler and more powerful interfaces, often referred to as simulators, (Banks, Aviles, McLaughlin and Yuan 1991) has led to the situation where simulation is no longer the technique of last resort but is a technique which is available to engineers, designers and managers. (Pegden, Shannon and Sadowski 1990)

In this paper we modify slightly the views of Pegden et al. (1990) to define simulation as the process of designing a computer based model of a reference system, which may be real or proposed, and conducting experiments with this model for the purpose of understanding the behavior of the reference system and/or evaluating various strategies for the design or operation of the reference system.

The specific area of simulation which is the focus of this study is discrete-event simulation (DES) which is 'the modeling of systems in which the state of variable changes only at a discrete set of points of time.' (Banks et al. 1996) This paper uses the following terms:

System, Model, Scope, Process, Entity, Resource, Workcentre, Policy.

The terms have been used in a manner consistent with that described by Banks et al. (1996) and have been found useful in developing models in the Witness and ProModel environments.

2 SCOPING THE MODEL

In this paper we propose that the level of interactions among the three key modeling constructs, Entity, Resource and Workcentre, can be described, and can be used to gain an improved understanding of the likely level of complexity of the model.

Our modeling environment assumes that entities will move from workcentre to workcentre depending on the attributes of the entity, the state of the workcentre and the state of resources. The entity is essentially passive and does not take decisions about routes and destinations. These decisions are dictated by the character of the entity and the state of the system.

The perspective of the modeler is not necessarily congruent with the modeling environment. For example in the ProModel environment, the workcentre makes decisions about which entity will be the next object to be served. In our system the workcentre is a passive object. Active decisions on which entity occupies a workcentre, and which resource services the need of the entity/workcentre combination is a result of rules which exist in the policy domain.

In order to arrive at a value of the scope of the system we propose a scale which can be applied to the degree of alternatives which can be exercised by entities and resources. When these two dimensions are quantified the position of the model on these two axes will be a useful indicator of the required scope of the model. Table 2 proposes five levels of complexity in scoping a simulation model, based on the two dimensions, Entity and Resource. As the scope of the model increases by this metric, it is likely that the number of workcentres will also increase. As resources and entities have increased options, more workcentres will be contained within the model if all of the dynamic behavior of the entities and resources are to be captured. It is generally accepted that the simplest possible model which can do the task will be the most appropriate model.

We do not propose to include policy as a dimension in this metric. We suggest that it is the value of the range metric for the entities and resources that will create the need for a given policy level in the model. Models that only use few entities and no resources are likely to have simple rules governing the flow of the entity through the process. Policies in this context, articulated as lines of code in the model, are likely to be simple and short.

3 VERIFICATION AND VALIDATION

A key area of the model development process in the simulation area is the development of verification and validation (V&V)stages in the process. In an early paper on this topic Naylor and Finger (1967) were able to say that ' management scientists have had very little to say about how one goes about "verifying" a simulation model

Table 1: Scoping the Model

	Description	
Range	***Resource***	***Entity***
1	The system has been modeled without the use of resources.	No entities are required for execution of the model. This is likely to be a trivial case.
2	The system has been modeled using resources which are able to be called to single workcentres by whatever entity is being processed at a particular time. These resources will not have time constraints placed on them.	Entities pass through the various workcentres with a fixed route, with no choice of path.
3	The system has been modeled using resources which are able to be called to single workcentres by whatever entity is being processed at a particular time. These resources may have time constraints placed on them	The entity will pass through the process, choices on the particular route will depend only on attributes of the entity. The state of the workcentre, and the state of the resources will not impact on the route of the entity
4	The system has been modeled using resources which are able to be called by multiple workcentres. The resources may have downtimes, and shift structures which also influence their availability for tasks at the workcentre.	The entity will pass through the process, choices on the particular route will depend on attributes of the entity and the state of the workcentre. The state of the resources will not impact on the route of the entity. The pattern of resource requirement by the entity will remain constant.
5	The system has been modeled using resources which are able to be allocated to multiple workstations and multiple entities. The resources are able to be pre-empted from a workcentre and are able to work in teams with variable composition.	Entities are able to use multiple workstations, and multiple combinations of resources in order to effect the transformation required to pass through the full process.

or the data generated by such a model.' Mihram (1972) proposed that the modeling process has the following five steps:

1. Systems Analysis
   The study of a system in order to ascertain its salient elements and to delineate their interactions and behavior mechanisms;

2. System Synthesis
   The construction of a complete, logical structure in order to provide a reasonable symbolic mimicry, or model, of the system's elements and interactions, including the determination and collection of data required to support the model's structure;

3. Verification
   The determination of the rectitude of the completed model vis-à-vis its intended algorithmic structure;

4. Validation
   The comparison of responses emanating from the verified model with available information regarding the corresponding behavior of the simulated system; and

5. Model analysis or inference
   The contrasting of model responses under alternative environmental specifications (or input conditions)'

More recent work (Robinson 1997,Balci 1997, 1995, 1994, Banks et al 1996, Pidd 1992, Carson 1986, Gass 1983 and Schechter and Lucas 1980) have maintained the use of the concepts of validity and verification and Banks, Carson II and Nelson (1996) define the terms as:

'Verification is concerned with building the model right. It is utilized in the comparison of the conceptual model to the computer representation that implements that conception. It asks the questions: Is the model implemented correctly in the computer'

'Validation is concerned with building the right model. It is utilized to determine that a model is an accurate representation of the real system.'

The general level of agreement on the definition of V&V should not however be taken as evidence to suggest that this part of the model development process is either simple or straightforward. Balci (1997) reports 77 techniques which can be used in the process of V&V and testing. Whilst a taxonomy for these techniques is proposed it is still a complex task to define what techniques could be used at each part of the process. Robinson (1997) discusses some of the issues related to V&V testing which indicate where some of the sources of complexity lie. The reference system may or may not exist. Furthermore, the perceptions of different participants in this reference system will be quite different. The perceptions for example of a scheduler in a factory are likely to be quite different to the perceptions which a process operator, or team leader are likely to have. Yet all of these participants may be part of the process of validation. If we also accept that the structure or approach to validation will be influenced by the goals which the model must facilitate, then we have added a further degree of freedom to the choice of the technique. With this level of complexity which exists for the technique it would not be surprising then if this part of the model development process was often executed inadequately.

The general level of agreement on the meaning of the V&V is matched by the general level of agreement on the importance of verification and validation. This general level of acceptance of the concept however has not been translated into a general level of application. The nonexistent or weak validation efforts in three cases studied as part of a review of models used by the US Govt. was cited as a major threat to the credibility of the models. (Fossett et al. 1991) It is a significant weakness in the reports and if it accurately reflects the use of the models in the business environment then it will constitute a significant barrier to the acceptance of the technique and the decisions reached in the decision making process. The need to convince the client of the validity of the model lies outside the scope of the earlier approaches to the model development process (Naylor and Finger 1967, Mihram 1972) but has been recognized as important in recent works. (Carson 1986, Fossett et al. 1991, Hale and Greenland 1994, Gass 1983)

4 CAMPBELLTOWN PUBLIC HOSPITAL

Campbelltown Public Hospital (CPH) is a modern and expanding hospital, in a fast-growing part of Australia. The hospital has 210 beds currently in use and offers a wide variety of services which include Medical, Surgical, Maternity, Pediatric, Intensive Care, Coronary Care, Orthopedics etc. These services are supported by modern Pathology and X-Ray services, Operating Theatres and an Accident and Emergency Department. CPH is an associate teaching hospital and is expected to have a capacity of about 400 beds by the turn of the century. The simulation modeling project whose verification and validation will be discussed below is confined to modeling the Emergency Ward. Details of the project will be found in Ramani et al (1998).

4.1 Identifying goals

The public health system in Australia, and New South Wales is under increasing pressure to increase levels of service, with levels of financial support which do not match the levels of increasing demand on the service. One such measure is the service time for clients categorized according to the level and urgency of attention required.

Within the emergency treatment ward, the patients enter the ward and are assigned a category by a triage nurse. This category is used to prioritize the patient in most subsequent operations in the system. Funding for the hospital is influenced by the promptness of service for each of the five categories of the patients. This model is designed to explore the impact of different management strategies on the level of service by category of patients. The initial range of management strategies assumes relatively constant levels of human resources in the department. The strategies are mainly directed at rescheduling of these resources.

4.2 The process of developing and using the model

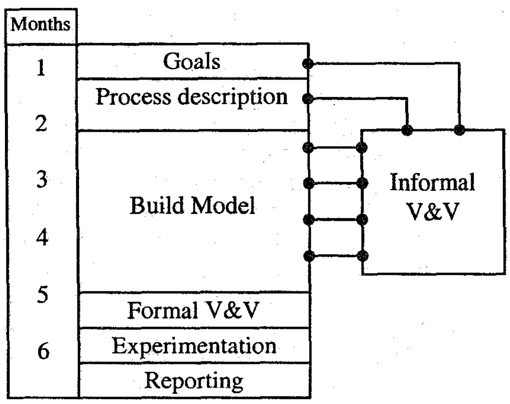

Figure 1: Model development process

4.2.1 Process description

The model of this process has been constructed using one entity, i.e. the patient. The patient is characterized with triage category, and with age. This characterizes the major attributes of the patients given the scope of this model. The triage category is determined either by the triage nurse at the triage workcentre or prior to arrival at the hospital, depending on the seriousness of the patient's condition. The age of the patient is used to categorize the patient as pediatric or adult. This will require different policies to be exercised at different positions in the model.

The model contains six types of workcentre; Waiting Room(1), Clerical office (1), Traige (1), Cubicles (5), Resuscitation (2) Observation (6) and Overflow (7). Patients can move from various workcentres to others depending on the state of the workcentre, availability of resource, category of injury and age of patient. The number of alternative paths through the set of workstations is too numerous to enunciate in this paper.

The model contains six types of resource. All resources in this model are people. Resources are; clerks, triage nurse, senior doctor, doctor, registered nurse team leader, registered nurse. The number of resources available at any particular time in the execution of the model is variable, depending on the shift structure chosen for that model.

Complexity in this model exists in the policies which are used to guide prioritization of patients and allocation of resources to patients in workcentres. Detailed flowcharts were prepared to record policies during initial interviews with hospital staff. policies such as pre-emption logic for doctor or senior doctor on arrival of a category 1 patient (a patient who has been triaged and found to have a life threatening injury) have been described in model documentation.

4.2.2 Building the model

The process of developing and building the model of the emergency ward was a team effort which included an experience staff member from the hospital. Throughout the model building phase successive models have been placed before other stakeholders within the reference system. In general the concerned hospital staff have been asked to comment, or react to the animated interface. At times, they have been asked to comment on flowcharts and verbal descriptions of policy rules. The use of flowcharts was a key aspect of the early stages of developing the model as it enabled the system experts to articulate the system in terms which they understood, and which were readily able to be translated into discrete event simulation concepts . During the model building process validation and verification techniques were used at many points, and the techniques could be described as both informal and dynamic in the taxonomy as proposed by Balci (1997).

4.2.3 Verifying the model

Two techniques were used to achieve acceptable levels of verification for this project. As previously noted, flowcharts were prepared for the system prior to the model building phase of the project. The model builder was a part of the flow-charting team. As the model has been developed, the builder has subjected the model to special input testing. The most challenging aspect of verification for this model is in the pre-emption strategies which take place for various resource/entity combinations. Verification has been conducted by close observation of the animated interface during extended runs of the model. Conflicts or inconsistencies in the behavior of the icons have led to examination of the code and to the correction of incorrect code and, more commonly, to the inclusion of further policy rules.

At a number of times during the model building phases the model was shown to system experts. They were asked to observe the flow of entities and resources throughout the workstations during extended runs of the model. This did not lead to significant levels of feedback which might have contributed to model verification. This was despite the presence of errors in the code, errors which led to visible inconsistent behavior of the entities and resources. Inconsistencies which were noted by system experts were often a result of verbal description of inconsistent behavior of the model. These inconsistencies were noted, not by design, but by chance. In general the discussions were prompted by problems with the model which caused the model builder to provide a general description of policy and rules for that particular part of the system. It was often in providing background to what the model was doing that these inconsistencies were noted.

As the model building stage neared completion a structured walkthrough of the code was conducted. This led to the identification of some code which was redundant and therefore confusing, but not to errors in the execution of policy.

4.2.4 Validation

Two broad techniques were used to validate the model. The first of these, and the most extensively used, was visualization/animation. A typical and repeating pattern of a typical day's arrivals for patients was used as the basic model platform. The model was run for extended periods and system experts and members of the modeling team observed the pre-emption behaviors of entities and resources. They have also been asked to carefully observe the behavior of queues in front of the various workstations.

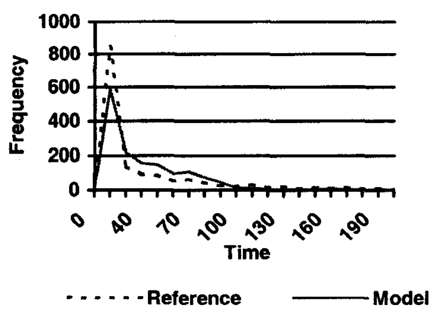

Figure 2: Waiting Times

The model generally satisfied these groups with respect to its broad, informal dynamic behavior. The number of people in the waiting room generally conformed to the expectation of the system experts. Queues were seen to be sensible, given the arrivals of different categories of patients. To facilitate this stage of validation, patients with different categories were represented with different colored icons, and substantial reporting of quantitative was appended to the animation interface. This provided observers of the model with a detailed narrative of the state of each resource, entity and location workcentre.

The second validation strategy technique was a graphical presentation of the models behavior. The goal of the model was to provide decision makers with a tool to examine strategies to achieve better service provision, particularly for patients with non-critical injuries. The model therefore had to be valid within the domain of these goals. Statistical data was collected for extended periods of hospital history, and this data was analyzed by patient category. The model was instrumented in order to provide data in the same format. A simple comparison of frequencies of service levels by patient category was used to establish validity levels for the model. A sample of this report is shown in Figure 2: Waiting Times. The consistency between hospital historical data and model outputs at this stage have provided the model development team and the client team with the confidence to provide resources for further development of the model.

4.2.5 Model Behavior

The model is currently in the model analysis or inference stage. Hospital management have accepted the validity of the model, and have proposed a number of scenarios which the modeling team are currently experimenting with. The scenarios are directed mainly at resource allocation options. One scenario, however illustrates the benefit of animated discrete event simulation. The potential to introduce a para-medic for patients with low priority had been dismissed during previous discussions of emergency ward management. The model has enabled the client team to quantify the benefits which could flow from this strategy and thus it has enabled them to give this strategy a more considered response.

5 DISCUSSION

Work on this project is still in progress. The model is nominally in the experimentation/application phase. It is possible as this phase proceeds that the client will change part of the focus of the model, thus leading to some local rebuilding of the model with consequent verification and validation issues. During the progress of this project we have been exposed to three issues which we believe are important when trying to understand the difference between model in the manufacturing sector and modeling in the health care sector.

5.1 Craft Paradigm

In discussing flow of patients through the emergency department we were struck by the intense complexity of the process. When a category one patient arrives, the triage nurse will immediately transport the patient through the department, literally calling for a registered nurse and for a doctor. This call will cause these two resources to be pre-empted from other workcentres which have captured them. The structure of this process is very complex to model. The overwhelming impression of the modeling team, most of whom were used to operating in a manufacturing environment was one of a craft culture. This culture is characterized by a high level of variation in task structure, low levels of repetition of tasks in the process and a very flexible, team orientated resource organizational structure. In a conventional manufacturing environment, after a century of scientific management, we have become accustomed to thinking of processes, specialization of resources and allocation of tasks to a process. The emergency ward at Campbelltown District Hospital has not been afforded the luxury of being able to choose its patients, or being able to establish a separate process for each complaint. The load on the system is unreservedly chaotic and in response, the system has developed high levels of interconnectivity of its resources, high levels of complexity in its policy and rules infrastructure, and high levels of versatility in its workcentre functions. We found this to be a challenging task to model. Initially the conceptual model was complex and difficult to elicit from system experts. The subsequent development of code to capture this complexity was very complex, not a difficult problem in itself but with consequent problems for verification and validation which are very significant.

5.2 Environment

The nature of the work environment causes the system experts to be unfamiliar with the concepts embedded in the discrete event simulation paradigm. Thus, when confronted with the animated interface, the system expert found it difficult to focus on the general behavior of the model, preferring to follow the path of single entities through the process, sometimes missing quite significant instances of non valid behavior. This has led to the team finding that the informal verification process using system experts and visualization/animation has been fairly unproductive compared to that which we would have expected in a manufacturing environment.

5.3 Scope of the Model

We believe that an understanding of the scope of the system is useful at the start of the model project. For models in the manufacturing sector we would expect to find a range of values for entities and resources to define the scope, but our conjecture is that the models would tend to cluster towards lower values for both the entities and the resources.

Lanner Australia provide case studies from two companies which can be used to illustrate this point. The first case describes the approach taken by Massey Ferguson in organizing the configuration of an existing cellular manufacturing process. Substantial problems had been experienced with the cell not performing to design. Discussions with engineers and managers had produced a range of potential problems ranging from the usual man, materials, tools to the changing volume mix, and to the introduction of MRP II which had led to smaller batch sizes on the plant. In this analyses it appeared that anything that went wrong was used as the reason to explain the low throughput of the cell. The company decided to use discrete event simulation because a significant level of capital expenditure was implicated in early analysis, but static analysis using spreadsheets was felt to be inadequate as it ignored interactions between product mix, machines, operators, setters, and other factors associated with cellular flow and wide product mix. The model was built by a company employee in one month with support from the software supplier. The model considered routing of entities, cycle times (machines and men), breakdowns, buffering, priorities and logic and scheduling rules.

The second company which was used to provide case material to demonstrate the benefits of simulation took a very different approach to the technique. In this company an industrial engineer with two years experience with the technique approached the modeling task with the objective of insuring models were able to be developed quickly and with tangible benefits. Three models are discussed in the publication:

Model 1, grinding mill refurbishment took 45 minutes to develop, used entities which essentially flowed from workstation to workstation with no alternative paths, and essentially used no resources. The tangible benefits of the model were£10,300 pa.

Model 2 a FMS conveyor system where the objective was to determine the total number of pallets required. Modeling time was three hours, and experimentation took a further three hours. This model again used entities which were following a predetermined and single path with resources, pallets, flowing through a conventional loop. Benefits were in the order of avoidance of £50,000 capital cost.

Model 3, size of buffers between 3 assembly lines. Model development took eight hours, and experimentation took four hours. Entities flowed down the assembly line with no alternative paths and the system used no resources, buffers are treated as an additional workcentres.

Sydney water

This simulation model was developed as part of post-graduate program and modeled a group of software.

Table 2: Model Characteristics

	Entities		Resources	
Case	Description	R	Description	R
CPH	Entities are able to use multiple workstations, and multiple combinations of resources in order to effect the transformation required to pass through the full process.	5	The system is modeled using resources that can be allocated to multiple workstations and multiple entities. Resources can be pre-empted from a workcentre and can work in teams with variable composition.	5
Rover	Entities constrained to flow through single route.	2	Systems were modeled without the use of resources	1
Simplot	Entities flow through process with single route, delays depend on attributes.	2	Modeled without resources	1
Massey Ferguson	Entities are able to use multiple workstations, and multiple combinations of resources in order to effect the transformation required to pass through the full process.	4	The system has been modeled using resources which are able to be called by multiple workcentres. The resources may have downtimes, and shift structures which also influence their availability for tasks.	4
Sydney Water	Entities are able to use multiple workstations, and multiple combinations of resources in order to effect the transformation required to pass through the full process. The state of the resource has an impact on route.	4	The system has been modeled using resources which are able to be called to single workcentres by whatever entity is being processed at a particular time. These resources may have time constraints placed on them	3

developers who worked on ad-hoc and regular requests for work from various clients. The problem, as described by the client, was that there were complaints about delays from the users who had submitted these requests for further work. It was felt that the workflow could be improved through the use of a simulation model. The entity in the model was incoming work, regular or ad-hoc. The resources were staff with specific skills with a generalist among them

Simplot

This model was prepared by a final year student in the manufacturing program at UTS. The model used a single entity, with attributes identifying product type, to pass through a single process. Processing times, set-ups and downtimes were a function of the product type of the entity. This project was completed without the use of resources on the line, however plant management are interested in extending the scope of the model.

The five models described above can be analyzed according the two dimensions, entity and resources, proposed earlier. Table 3 shows the complexities of each model in terms of the levels described in Table 2.

6 CONCLUSIONS

The problem of validation and verification is a difficult problem for model Development. The most reliable means of managing the verification and validation problem is to develop simple models. Simple models such as those used at Rover are not simple to build. We conjecture that novice programmers will tend, where options exist, to build more complex models. This tendency may be accentuated by the presence of the animation function on modern simulation packages. The lure of being able to place mobile resources on the animated interface, thus improving the impact of the model on management is difficult to resist. Our work, and proposition suggests that when complexity with entities, which is often unavoidable, is combined with complexity on resource design for inclusion in the model, an overall model complexities are dramatically-increased.

The matrix structures in which entities operate, the craft approach and versatility of workcentres are characteristics of the health sector in general. Our work suggests that modelers must beware. We are suggesting that if the system has entities and resources which interact across the whole system then it will be difficult to identify and isolate sub systems which can be modeled with relative ease. Models for this system will be large, complex and highly interactive with very high numbers of potential events or combinations in the models scenarios

Conventional informal validation and verification techniques may not be adequate to cope with the range of potential combinations in the animated process. The burden of verification will pass back into code verification rather than screen based. The importance of black box validation will probably be increased, as it will be very difficult for system experts to make competent judgements on the validity of the dynamic behavior of the model based on animated observations and also to observe the full range of combinations which may occur over long periods in the actual system.

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