Proceedings of the 2001 Winter Simulation Conference
B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds.

A PROPOSED APPROACH FOR MODELING HEALTHCARE SYSTEMS FOR UNDERSTANDING

Tillal Eldabi
Ray J. Paul

Centre for Applied Simulation Modelling (CASM)
Department of Information Systems and Computing
Brunel University
Uxbridge, Middlesex UB8 3PH, UK

ABSTRACT

The use of simulation in healthcare area is not widely spread when compared with other areas. This paper suggests that traditional approaches to modeling may not fully utilize simulation for tackling healthcare problems. Healthcare systems are often complex with multiple decision makers. A modeling approach is proposed in this paper to enhance stakeholders' understanding and intercommunications. The structure of this approach is participative including the stakeholders. The behavior of the approach is iterative rather than step-based. An example is given showing how this approach is used for facilitating the modeling process. It is found that involving stakeholders throughout the modeling process helps them understand their problem coupled with more appreciation to findings from the model. This process is also found useful in enhancing stakeholders' intercommunication.

1 INTRODUCTION

The application of simulation modeling in healthcare sectors is not widely applied when compared to other sectors, such as military, manufacturing and logistics application (Sanchez *et al*. 2000). Even though the use of simulation could be traced back for over three decades, it was not as widely spread as the case might be in other fields (Jun *et al.* 1999). This paper discusses issues related to the application of simulation in healthcare and proposes a modeling approach that is suitable for this particular application area. The paper looks at the nature of healthcare systems and discusses why a water-fall engineering based modeling may not be the most appropriate approach to tackle healthcare application, or most fast changing businesses for that matter. Before discussing such issues the paper will give a brief introduction to the up-to-date uses of simulation in the field in addition to a brief background about the traditional approaches of modeling followed. A critique is given for these approaches paving the way for the alternative approach suggested. It must be noted this paper only advocates a way of thinking about tackling healthcare decision problems using simulation rather than claiming the invention of a new technique.

2 TRADITIONAL SIMULATION MODELING

The use of simulation techniques is now rapidly increasing in healthcare systems modeling (Barnes and Quiason 1997, Jun *et al.* 1999). In fact (Jun *et al.* 1999) have identified two main areas of the use of simulation related to the management of patients flow and resources allocation. Lagergren (1998) adds to that by identifying a number of areas for modeling (in general) in healthcare: *Epidemiology*; *health care systems design*; *healthcare systems operation*; and *medical decision making*. One of the main reasons that simulation is becoming a popular technique in healthcare problem solving is because simulation may be used for dynamic analysis of the situation rather than static analysis. This presents stakeholders with a more realistic picture of the situation (Banks *et al.* 1996). In simulation, assumptions are independent of the model and can be switched *on* or *off* at any time or re-scaled in a probabilistic fashion. This is a great advantage that helps users to examine their assumptions rather than be driven by them in building the model and solving the problem.

Simulation offers good features to cope with problem understanding and solving. However, in practice it is not exploited in the best way to yield greater understanding of the problem. The following subsection presents detailed accounts of the process of the traditional step-down approaches to modeling.

2.1 Overview of the Simulation Process

This paper conveys the simulation process as presented by the main authors in this area. Due to the fact that most authors agree on the process flow, it is more convenient that discussion of the process is represented by one framework presenting the different views available in the subject. A typical simulation process can be shown in Figure 1 (Law and Kelton 1991). Other literature produces similar graphical representations of the simulation process. All steps mentioned in the following discussion are based on Figure 1.

Law and Kelton (1991) define step 1 *problem formulation* as setting the objectives of the study and the specific issues to be considered. Resources available for such a study should also be considered (Law and Kelton 1991). Pedgen *et al.* (1990) agree with that and expand on the importance of clarifying the issues to be considered, such as, hardware design issues and operational issues. In addition to that, measure of performances have to be defined before starting the study. Pidd (1998) defines this phase as the *problem structuring* phase. He suggests that this phase is the attempt to take a 'mess' and to extract from it some agreement about the particular problems which might be amenable to analysts. Other authors, such as Robinson (1994), Paul and Balmer (1993), Nance (1994), Balci (1994) and Banks *et al* (1996), divide this step into two or more stages.

The second step in Figure 1 is *data collection*. Data is collected if it exists based on the objectives of the study (Law and Kelton 1991). Most authors, mentioned in the above paragraph, agree with the importance of data collection and stress the validation of such data which is step 3 in. Robinson (1994) puts the process of data collection at the first phase of his definition of the project phases. On the other hand, Law and Kelton (1991) and Banks *et al* (1996) suggest that data collection should coincide with developing the conceptual model. Paul and Balmer (1993), however, put *data collection* as a separate step after the *conceptual model*.

After data is validated then step 4 is *constructing a computer model*, which is based on the conceptual model. After that a *pilot run* is done in step 5 (Law and Kelton 1991, Paul and Balmer 1993). Banks *et al* (1996), however, suggest translating the *conceptual model* into a *computerized model* before starting step 6 and that is conducting the *verification* and the *validation* steps. It must be noted that most authors agree on the fact that *validation* and *verification* process should be throughout the study.

Steps 7 through 10 are *design of experiments* for defining the different alternatives for experimentation, *production runs* for providing performance data on systems designs of interest, *output analysis* which consists of statistical techniques for analyzing output from production runs, and *implementation* of model's findings (Law and Kelton 1991). All of the above authors agree on two facts: all frameworks are not strictly sequential and the first stage, problem formulation, is an art as much as it is science. Basically it depends on available resources, the problem, the problem owners, and involved analysts.

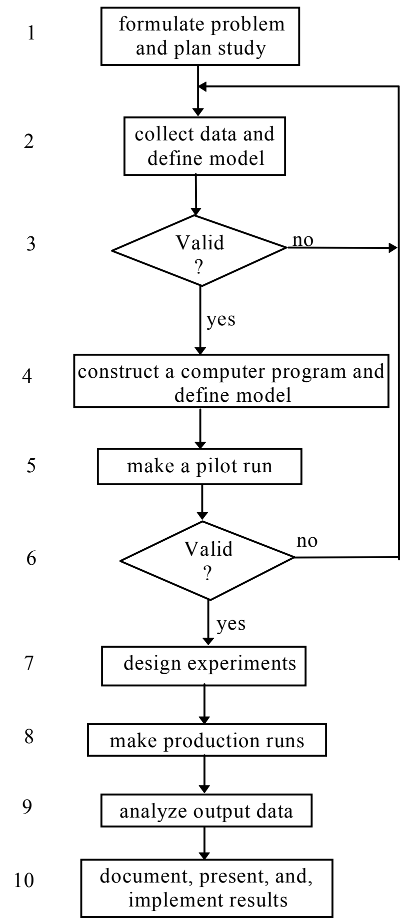

Figure 1: Steps in a Simulation Study (Law and Kelton 1991)

3 A CRITIQUE OF HEALTHCARE SIMULATION

Reflecting on the above discussion, it can be suggested that simulation is a powerful technique for problem solving. However, considering healthcare systems and problem understanding, this may not be the case. Most of the existing modeling approaches do not give much attention to the stage of problem formulation/structuring, which is the most important stage for problem understanding. As mentioned above, this stage is implicitly suggested to be outside the boundaries of simulation model development. Even so, it is part of a simulation project. Some agree on the fact that problem structuring is more of an art than science. Looking at healthcare problems and their complexities, the situation is even worse as the model is only used for modeling well defined problems, while problem definition is the main concern in healthcare problems. Adding to that conducting data collection at this early stage on factors which are defined based on art as much as science is a clear danger. On the other hand, and in healthcare systems particularly, data is not reliable enough to be qualified as the driving force of the model. There are two main reasons for healthcare data to be unreliable. Firstly, in the case of predicting long term effects data has to be collected from records that go well back in history. This type of data will not be reliable because of the changes that may occur in medical technology, policies, and socio-economic values. On the other hand, having data collectors in the premises sometimes may spark some anxiety from the professionals to the extent that they may provide less than 100% truthful data.

4 AN ALTERNATIVE APPROACH TO MODELING

In this section we propose an alternative approach to modeling targeting healthcare systems. The main theme of this approach is related to using simulation to enhance the understanding and intercommunication of the stakeholders (clinicians, managers, health economists etc.). In WSC 2000 a panel discussed the emerging issues in healthcare simulation and gave some aspects and challenges facing the use of simulation (Sanchez *et al.* 2000). The panel came up with three main issues; data as a difficult step, the lack understanding of the decision makers, the conflicting objectives of the stakeholders. From the above discussion it can be argued that data, even though considered necessary, it can serve as an obstacle for achieve the modeling objectives. Pidd (1996) stresses that the modeling should drive the data and not vise versa.

Understanding the problem is one major objectives of every simulation study which means the model should be built to help understand the problem rather than identifying it before the modeling process. Given the stakeholders' issue, the main principle of the proposed approach is that modeling is actually a conversation between the model and the stakeholders, which also helps in enhancing the communication between the different stakeholders involved (each with their different backgrounds). Figure 3 demonstrates the principles of the proposed modeling structure. Ideally the stakeholders should identify a set of requirements or symptoms these requirements are then fed into the model to generate informative scenarios either in terms of the model structure or results. A defining aspect for this approach is the fact that stakeholders are involved in the modeling process from the beginning. Stakeholders are actually most interested in solving the problem and it would be wise to give them full authority over the model rather than reports of results. In this way there will be a higher possibility that findings from the modeling would be implemented. Another important factor to consider and looking at Figure 3 is the fact that the modeling process is iterative rather than sequential. The problem definition is usually based on the stakeholders' understanding of the system, from this process, it can be seen that this understanding could be altered and consequently altering the stakeholders' understanding or perception of the problem based in the information arising from the model, this will result in changing the requirements and specifications to the model as the objectives are changed. This iterative process is continued until the stakeholders achieve acceptable understanding about the problem. The underlying principle of the proposed modeling approach is based on participatory modeling where stakeholders are involved in the modeling process from the beginning in an iterative manner. For simplicity this approach will be referred to as a Modeling Approach that is Participatory Iterative for Understanding (MAPIU).

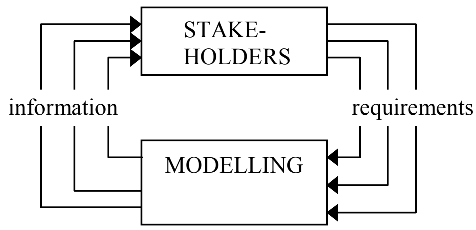

Figure 3: The Proposed Modeling Process

Figure 4 shows the overall structure illustrating the proposed framework (MAPIU) with its new additions. The modeling process for MAPIU is based on two main steps; *initialization* and *processing*. Initialization is about identifying the components of MAPIU whilst processing is about how these components work together given the objectives of modeling. It is worth stressing that MAPIU is an approach to modeling that is not restricted by formal and logical rules, aiming to be adaptive to changing requirements. These guidelines provide overall principles while leaving detailed technicalities flexible based on the particular case for modeling.

4.1 Initialization

The classification of stakeholders remains an important issue in fitting the players to the roles in MAPIU at the initialization stage. This is assuming that the model and the stakeholders are the main players in the process with their mutual feedbacks. It is logical to assume that the identification of stakeholders may not be straightforward. If stakeholders do not understand the problem it is more likely that they cannot fit themselves into their corresponding roles, particularly if they are not familiar with the modeling process. In MAPIU stakeholders are categorized as problem owners, experts, and actual users. Table 1 shows how the different types of stakeholders can be identified using the defining features available in the right hand side of the table. Note that these features are based on the experience of the analysts as there is no specific literature or research findings regarding this issue.

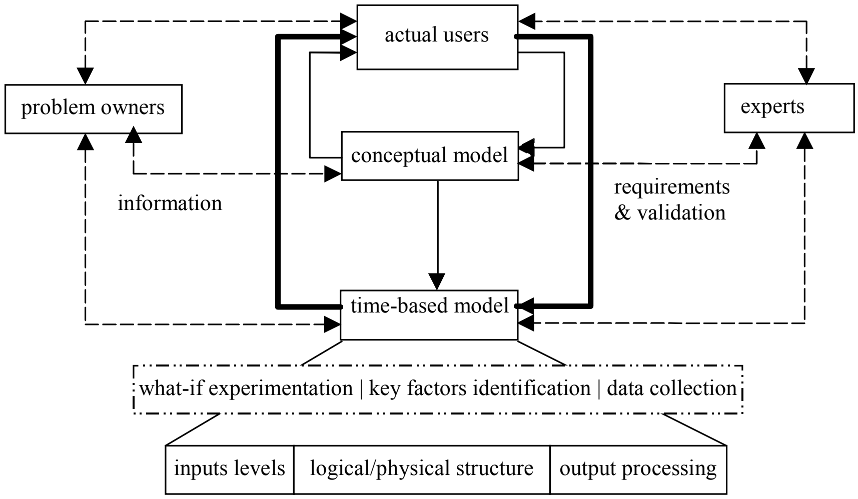

Figure 4: MAPIU Overall Structure

In MAPIU all decisions taken regarding the model's structure are not final and can change at any time to any structure that fits the stakeholders' needs at the time (including stakeholders categories). The classification that takes place at the *initialization* stage is only a starting point and by no means fixed. The main purpose of this classification is to ease the process of collecting the right information based on the needs of the problem owners for a given problem. It is possible to have different requirements for the same problem depending on the problem owners at any given time.

Table 1: Stakeholders' Details in MAPIU

Stake-holders	features
Problem owners	▪ Decision makers (corporate or overall picture) ▪ Pay for the study or the process under study ▪ High interest in solving the problem ▪ High interest in the success of the system ▪ Make use of model's output (one way or another)
Experts	▪ Detailed knowledge of the system ▪ Detailed decision makers (day-to-day)
Actual users	▪ Will directly work with the model ▪ Process and interpret the model's results

4.2 Processing

The modeling process according to MAPIU starts by feeding the initial thoughts and needs for developing the model. Obviously these *needs* are then incorporated in the model. The model then presents the stakeholders with information. For *problem owners* this information is used for enhancing their understanding about the problem, hence, their understanding about the relevant issues in the system regarding the problem, their needs from the model, and the expected outputs from the model. For *experts*, information represents a measure of the validity of the model with regard to the new requirements from the *problem owner*. They use the new information and new needs in specifying which inputs they should use for the model. One may think that the *actual users* are only interested in the latter stages of model building. However, their engagement in the development process from the beginning gives them the opportunity to better understand the model and why it is built the way it was built.

In MAPIU the modeling process is made up of two main factors; *modeling* and *communication*. If we consider stakeholders and the model as the two components in the MAPIU process, then modeling here means any thing to do with the model, such as specifications of the model, incorporation of such specifications, and experimentation. Communication is related to the mutual relationships between the different players: *problem owners*, *experts*, *actual users*, and the *model* itself.

Table 2 explains the different components mentioned here and how they work. The table is divided into three main parts. First, the modeling part which deals with the model itself. Secondly, communication which deals with the interaction between the participants in the process. Lastly, information which explains what is meant by information in the context of MAPIU.

Table 2: Details of the MAPIU Process

Modeling	Features
Specifications	Requirements + validation notes (based on problem owners and experts)
Incorporation _	Building or modifying the model according to requirements and validation notes
Experimentation	Changing model's structure and parameters (sensitivity analysis and data requirements)
Communication	
Stakeholder <–> stakeholder	Communication amongst stakeholders (intercommunication)
Stakeholder <–> model	Communication between any of stakeholder(s) and the model
Information	
Tangible	Quantifiable results or indicators arising from the model (usually after running the time-based model)
Intangible	Non-quantifiable information from the model (during development or use)

4.2.1 Modeling

The modeling component is concerned with all the activities dealing with the model, such as development, data handling, and output processing. The following categories are the main steps taken with regard to the model. These steps are usually taken sequentially in a single modeling iteration, but not necessarily all of them:

- Specifications: the first cycle of modeling specifications represent the initial needs and ideas of the problem owners about the problem. From the next cycle on, specifications represent refined requirements from the problem owners and validation notes from the experts. It should be stressed that requirements are not fixed and they change all the time based on a refined understanding of the problem.
- Incorporation: is for developing the model or modifying it based on the new needs and thoughts from the problem owners. Incorporation also includes validation notes for the experts. Incorporation is concerned with all the activities that add new features or alter existing ones for either the conceptual model or the time-based model (for example, structure, inputs, and outputs).
- Experimentation: is concerned with altering the model's structure and the parameters and reflects on stakeholders' understanding. Experimentation is mainly conducted by the stakeholders or under their direct authorization. It lies at the heart of the iterative process, as it represents a change in the model that has to be seen by the stakeholders. Experimentation is usually about what-if scenarios, identification of relevant variables, and conducting data collection when it is necessary (based on the previous two elements).

4.2.2 Communication

Communication is an important issue in the iterative process as it represents the link between the participants of the process. There are no specific rules of communication, which means problem owners, for example, can feed their needs and ideas directly to the model or via the other two types of stakeholders, and this goes for the rest. That is, the communication process can be carried out regardless of geographical restrictions and making use of any technological enablers of communication. Communication is divided into two categories; stakeholders-to-stakeholders communication and stakeholders-to-model communication. The two categories are defined below:

- stakeholders-to-model: is communication between the stakeholders and the model where the model is either a destination where requirements and needs are fed into the model (such as in the case of incorporation), or it could be a source where information is retrieved form the model as in experimentation results.
- stakeholders-to-stakeholders: is communication that is between the stakeholders and not directed to the model. The model could be used as a means of communication but not a source nor a destination. Note that this communication is mutual. For clarity and to be able to differentiate between the two terms from now on, stakeholders-to-stakeholders communication is named *intercommunication* and stakeholders-to-model communication is named as *communication*.

4.2.3 Information

Information in MAPIU is any feedback that is retrieved by any of the stakeholders from the model. Information here is divided into two categories; *tangible* information and *intangible* information. Tangible information is quantifiable such as output figures from the model or even animated behavior in the model. The main principle for this type is the fact that it is gathered after the model is run (i.e. incorporation of the time factor in the model) and this information is purposefully retrieved from the model. Tangible information is mainly used for evaluative studies and direct experimentation. Intangible is not so easily detectable information or it could be non-quantifiable. This type is not restricted to any modeling stage and usually it is not necessarily retrieved intentionally from the model. Intangible information is about understanding the structure and the behavior of the system under study.

5 AN EXAMPLE

In this section we present an example to demonstrate structure of the modeling process using MAPIU (i.e. an approach to modeling) rather than the detailed architecture of the model and the experimental results. This example illustrates the use of simulation in an evaluative study for the technology of liver transplantation from a cost-effectiveness point of view (Atkinson *et al.* 2000, Eldabi *et al* 2000, Baldwin *et al.* 2000). The main objective relates to finding an optimum strategy for selecting patients in the waiting list for liver transplantation. Selection could be based on a number of criteria, such as age, waiting time, or level of sickness (Jonasson 1989). There are a number of issues that complicate this problem. Firstly, one of the main difficulties is that there is no specific measurement for which the best criteria for selection are. Secondly, there is a number of stakeholders involved (in this case clinicians and health economists) who might have different agendas regarding the best policy to follow. For example, health economists may look at the cost-effectiveness of the process, whilst clinicians may consider provision of care to all patients is more important. The role of the model here is to enable stakeholders to understand the technology of liver transplantation and communicate their understandings amongst each other. The following section shows the structure of the modeling process was conducted based on the description of MAPIU above giving the components of the process.

5.1 Initialization

According to MAPIU the first step is to classify the stakeholders involved. In messy situations an initial conceptual model could be used to assist at this stage, in this case Activity Cycle Diagram (ACD). Based on Table 1 and given the above-mentioned objectives of the project, health economists were decided to be the *problem owners*, which means the model should help them in taking decisions. Their decision in itself represents a recommendation to other healthcare professionals on how to economize their resources. Clinicians represented the *expert* type of stakeholders because of their detailed knowledge of the system and because they are managing the day-to-day operations. On the other hand, clinicians do not use outputs from LiverSim directly in their day-to-day practice, which excludes them from being part of the problem owners. They may, however, be concerned with the economy of the transplant process as a whole. Given the fact that health economists are going to use the model for further analysis then this makes them also *actual users*. Table 3 shows the stakeholders' classification for LiverSim and their corresponding features. Extra care should be taken when different types of stakeholders possess close classifying features.

Table 3: Classified Stakeholders and Corresponding Features

Class	Stakeholders	Features
Problem owners	Health economists	High interest in solving the problem Use model's results for further health economic decisions
Experts	Clinicians	Detailed knowledge of the system Detailed decision makers (day-to-day)
Actual users	Health economists	Will work directly with model Process and interpret model's results

5.2 Processing

According to MAPIU, processing is related to how the stakeholders interact with the model and with each other in an iterative manner throughout the modeling process. It represents the process of modeling during both the conceptual modeling phase and the time-based modeling phase. In this particular case processing is based on interactions between health economists, clinicians, and LiverSim through specified routes of communications. The different components involved in the processing of LiverSim are shown in Table 4. These components are introduced and refined throughout the process and not necessarily in the same iteration of modeling. Figure 5 represents a static structure of the overall modeling process for LiverSim with the specified interrelationships – with reference to MAPIU. Detailed structure of the model is given in Baldwin *et al* (2000).

6 CONCLUSIONS

In this paper we proposed a simulation modeling approach aiming at enhancing two major challenges facing healthcare practitioner: lack of understanding of the healthcare process by the concerned people; the existence of multiple decision makers, hence the conflicting objectives and difficulty of intercommunication. The proposed approach is based mainly on stakeholders participation and iterative processing. It is named a *m*odeling *a*pproach that is *p*articipative *i*terative for *u*nderstanding (MAPIU).

Table 4: Components of MAPIU Process

Modeling	Features
Specifications	▪ Initial *specifications* from Health Economists (HE): building a Liver Transplantation (LT) model and Liver Disease (LD) model for comparison and economic evaluation ▪ Prioritization criteria for the waiting list (for comparison and economic evaluation) ▪ Validation is related to changes of the structure of the model based on HE's changed requirements and views of clinicians with to the model and its relevance to the system
Incorporation	▪ Iterative ACD's for LT and LD as conceptual models ▪ Time-based model for LT and LD based on the ACD – A Simul8 model for the structure (patient flow) – Input variables: durations, costs, prognosis for the interface using Visual Basic (VB) – Output responses (net survival, net cost, and discount) also in VB interface
Experimentation	▪ Variables identification (what criteria to consider for experimentation) ▪ Prioritization criteria (what-if, Sensitivity analysis for different selection policies) ▪ Data collection (some data was needed to assess survival predictions)
Communication	
Stakeholders <–> stakeholders	▪ Communication between HE and clinicians mainly for identifying relevant variables and model's structure
Stakeholders <–> model	▪ Communication between HE, clinicians and LiverSim for debating and experimentation
Information	
Tangible	▪ Results from the each run (Average Cost-effectiveness Ratios)
Intangible	▪ Understanding the behavior of LD and LT ▪ qualitative issues such as fairness of allocation of livers

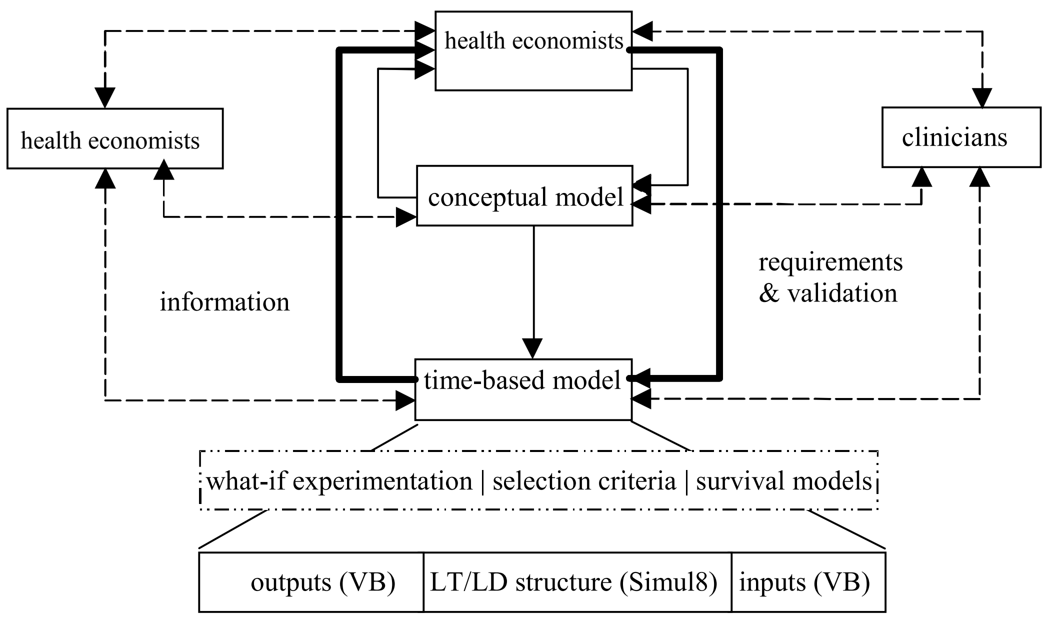

Figure 5: LiverSim Overall Modeling Process

With regard to understanding for – based on the LiverSim experience – stakeholders were satisfied with their level of understanding with regard to the model and the real system. This can be attributed to a set of factors. Firstly, involvement of stakeholders in building the model. This had a considerable impact on gaining more understanding. The benefit was actually twofold, stakeholders' understanding about the system was continually enhanced as more features were added to the model. On the other hand, as stakeholders' understanding about the system was improved, their contribution to the model was more effective. This is a progressive iterative process and can be thought of as spiral behavior; the more the model is answering stakeholders' requirements the more their understanding is increased, which means they contribute more to the model's value and usefulness. In comparison to the sequential approach discussed earlier, MAPIU shows itself to be potentially more valuable. Having the stakeholders engaged in the process of model building produces another lesson, and that is the enhanced confidence of the model by the stakeholders.

It can be seen that an iterative approach is quite valuable for achieving some of the objectives by enhancing the stakeholders' understanding. Yet all of this will not be fully workable without enabling stakeholders to communicate what they have achieved to other stakeholders and to the model. It must be noted that this particular feature was not part of any of the processes in the traditional frameworks. Usually it is represented as additional skills of the modelers for conducting successful modeling exercises (Sadowski and Grabau 1999). Using MAPIU we realized that the stakeholders are continuously communicating with the model. One important issue, however, is the facilitation of the model to ease the process of communication. To make sure the process is flowing, the model must be developed in a way that suites the stakeholders. MAPIU is more suitable for that, as developers get to know more about the stakeholders as they interact, which is unlike the sequential approach where stakeholders start communicating with the model after it had been developed. Intercommunication is a different dimension. Problem owners usually have a problem to be solved and they are looking for specific goals from the model regardless of whether it mimics reality or not. On the other hand, experts will be more inclined to make sure that the model mimics reality. The model can be put between the different types of stakeholders and act as a means of communication. The problem owners will use the model to express their requirements whilst experts will use it to portray the system's constraints. Between this pulling and pushing process and through the iterative behavior both types might reach more conclusive decisions.

REFERENCES

Atkinson, C., T. Eldabi, R. J. Paul, and N. Pouloudi. 2000. The centre for health informatics and computing (CHIC). In *Proceedings of the 22nd International Conference on Information Technology Interfaces*, Ed. D. Klapić, and V. H. Dobrić, 3–21. Zagreb: SRCE University Computing Centre, University of Zagreb.

Balci, O. 1994. Validation, verification, and testing techniques throughout the life cycle of a simulation study. *Annals of Operations Research* 53: 121–173.

Baldwin, L. P., A. K. Burroughs, T. Eldabi, and R. J. Paul. 2000. Using simulation for the economic evaluation of liver transplantation. In *Proceedings of the 2000 Winter Simulation Conference*, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1963–1970. New York: Association of Computing Machinery.

Banks, J., J. S. Carson, and B. L. Nelson. 1996. *Discrete-event system simulation*. Second Edition, New Jersey: Prentice-Hall, Inc.

Barnes, C. D. and J. L. Quiason. 1997. Success stories in simulation in health care. In *Proceedings of the 1997 Winter Simulation Conference*, ed. S. Andradóttir, K. J. Healy, D. H. Whithers, and B. L. Nelson, 1280–1285. New York: Association for Computing Machinery.

Eldabi, T., R. J. Paul, and S. J. Taylor. 2000. Simulating economic factors in adjuvant breast cancer treatment. *Journal of the Operational Research Society* 51 (4): 465–475.

Jonasson O. 1989. Waiting in line: should selected patients ever be moved up? *Transplantation Proceedings* 21 (3): 3390–3394.

Jun, J. B., S. H. Jacobsonand, and J. R. Swisher. 1999. Application of discrete-event simulation in health care and clinics: A survey. *Journal of the Operational Research Society* 50 (2): 109–123.

Lagergren, M. 1998. What is the role and contribution of models to management and research in the health services? A view from Europe. *European Journal of Operational Research* 105 (2): 257–266.

Law, A. M., and W. D. Kelton. 1991. *Simulation modeling and analysis*. Second Edition, Singapore: McGraw-Hill.

Nance, R. E. 1994. The conical methodology and the evolution of simulation model development. *Annals of Operations Research* 53: 1–45.

Paul, R. J. and D. W. Balmer. 1993. *Simulation modelling*. Lund: Chartwell-Bratt.

Pedgen, C. D., R. E Shannon, and R. P. Sadowski. 1990. *Introduction to simulation using Siman*. New Jersey: System Modeling Corporation and McGraw Hill, Inc.

Pidd, M. 1998. *Computer simulation in management science*. Fourth Edition, Chichester: John Wiley & Sons.

Pidd, M. 1996. *Tools for thinking: modelling in management Science*. Chichester: John Wiley & Sons.

Robinson, S. 1994. *Successful simulation*: *a practical approach to simulation projects*. Maidenhead: McGraw-Hill Book Company Europe.

Sadowski, D. A. and M. R. Grabau. 1999. Tips for successful practice of simulation. In *Proceedings of the 1999 Winter Simulation Conference*, ed. P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 60–66. New York: Association for Computing Machinery.

Sanchez, S. M., D. M. Ferrin, T. Ogazon, J. A. Sepúlveda, and T. J. Ward. 2000. Emerging issues in healthcare simulation. In *Proceedings of the 2000 Winter Simulation Conference*, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1999–2003. New York: Association of Computing Machinery.

AUTHOR BIOGRAPHIES

TILLAL ELDABI is a lecturer at the Department of Information Systems and Computing at Brunel University, UK. He received a B.Sc. in Econometrics and Social Statistics from the University of Khartoum. He received his M.Sc. in Simulation Modelling and his Ph.D. from Brunel University. His research is in aspects of healthcare management and the intervention of simulation. His main research also concentrates on the economy of healthcare delivery. He is looking to exploit the means of simulation on the wider healthcare system management to assist in problem understanding. His email and web addresses are `<tillal.eldabi@brunel.ac.uk>` and `www.brunel.ac.uk/~cssrtte`.

RAY J. PAUL is a Professor of Simulation Modelling, Director of the Centre of Applied Simulation Modelling, the creator of the Centre of Health Informatics and Computing, and the Dean of the Faculty of Science, all at Brunel University, UK. He received a B.Sc. in Mathematics, and an M.Sc. and a Ph.D. in Operational Research from Hull University. He has published widely, in books, journals and conference papers, many in the area of the simulation modelling and software development. He has acted as a consultant for a variety of United Kingdom government departments, software companies, and commercial companies in the tobacco and oil industries. He is a co-editor of the Springer-Verlag Applied Computing book series. His research interests are in methods of automating the process of modelling, and the general applicability of such methods and their extensions to the wider arena of information systems. He is currently working on aspects of simulation in the social sciences, in particular in health management. His email and web addresses are `<ray.paul@brunel.ac.uk>` and `<www.brunel.ac.uk/~csstrjp>`.