USE OF MODELLING PARADIGMS: AN EXPLANATORY STUDY OF SD AND ABM MODELS

Adriana Ortiz, Finn Olav Sveen, Jose M. Sarriegi and Javier Santos

Tecnun – Universidad de Navarra

[amortiz, fosveen, jmsarriegui, jsantos]@tecnun.es

Abstract

Theory informs us of the differences between principles and methods used to build System Dynamics and Agent Based Models. However, little is known about how the paradigms are applied in practice and the subsequent difficulties encountered. In order to assist the model developer in applying methodologies to build models, it is first necessary to examine what occurs in practice. This paper reports the conclusions of an assessment study of four different simulation projects, two of which used System Dynamics, and the other two Agent Based Modelling. Results highlight the methodological issues faced when building models with both paradigms. Furthermore, the results suggest that the more mature modelling paradigm of System Dynamics can assist in improving Agent Based Model building processes.

1. Introduction

System Dynamics and Agent Based Modelling are known simulation paradigms which differ significantly by the extent to which they provide the ability to model different system perspectives (Meadows, 1980). System dynamics is characterised by giving greater importance to the definition of the model structure, and establishes relations between variables of stock, flow and auxiliaries (Forrester, 1961). Agent based models also gives importance to the structure, but are more focused on the definition of rules, events or functions that can potentially modify the state of the agents, and subsequently the behaviour of agents in the complete environment (Bonabeau, 2002).

Literature on these paradigms explains their differences (Schieritz and Gröbler, 2002; Lorentz and Bassi, 2004) and there are published methods and tools on how to build models in both paradigms (Gilbert and Terna, 2007). System Dynamics is a mature paradigm where more methodologies and tools to build models have been developed. Agent Based Modelling is growing with respect to the number of tools and methodologies as seen in the emergence of new software (Anylogic and Starlogo) that make the building of models in these paradigms easier.

However, little is known about how the paradigms are applied in practice and the subsequent difficulties encountered. In order to assist the model developer in the process of building models it is first necessary to examine how models are built in practice, what can be learned from their experiences, and what issues need to be resolved in order to improve their building process.

This paper reports an assessment study that attempts to observe model building in practice, to grasp successful practices and address difficulties experienced.

Results highlight the methodological issues faced when building models with both paradigms. Furthermore, the results suggest that the more mature modelling paradigm of System Dynamics can assist in improving Agent Based Model building processes.

2. Research questions

In this study four modelling experiences are examined to investigate the following questions:

RQ.1. ¿What are the characteristic features of the problems being modelled?

RQ.2. ¿How did the modellers construct the model?

RQ.3 ¿What difficulties were encountered?

RQ.4. ¿What did they consider to be the resulting benefits of using modelling?

By providing answers to these questions, we attempt to be closer to the reality of the modelling methodological problems and be able to assist the model developer in applying and improving the current established methodologies.

3. Study methodology

The study described here is an exploratory study of four modelling simulation projects. Two of the projects applied System Dynamics (SD) and the other two applied Agent Based Modelling (ABM).

Although the number of case studies is not significant enough to make strong affirmations, the findings identify gaps where model building methodologies can be improved.

The four modelling projects were analysed using a guideline of open questions in relation to 14 modelling issues. The information was collected by conducting interviews with the modellers and reviewing papers and reports. As is presented in Table 1, the modelling issues were classified in four groups associated with the research questions:

1. Problem features
2. Modelling process issues
3. Difficulties encountered
4. Benefits of using modelling

The first group explore the problem environment and requests for the model. The second group examines the methodology used for model construction, including how and why modellers chose the paradigm, what kind of data sources modellers used, how they handled the inclusion of soft variables, what support methods were applied and which tests they applied to validate the model. The third group, as its name suggests, asks about sample problems encountered. The last group investigates the benefits acquired during model the building process and model exploitation.

Research Questions		Modelling issues analysed
PI.1	Problem features	1. Purpose
		2. Scope
		3. Aggregation level
		4. Heterogeneity
		5. Handling of space
PI.2	Modelling process issues	6. Paradigm selection
		7. Stakeholders participation (size and group characteristics)
		8. Data sources
		9. Soft variables
		10. Support tools (Brainstorming, causal loop diagrams, documentation, interviews, etc)
		11. Validation methods
PI.3	Difficulties encountered	12. Difficulties encountered
PI.4	Benefits of using modelling	13. From the model building process 14. From the model output

Table 1. Modelling issues analysed

3.1 Limitations of the study

The cases selection for the study has presented two main limitations.

Firstly, the difference in quality varies between the modelling projects. Due to the flexibility in how models are built, the modelling projects differ significantly in their focus, data sources, methods and tools used. It is common to find models that have been built with little awareness of the theory and methods recommended to follow a defined modelling process.

Secondly, it was more difficult to find AB model applications than SD models. One of the reasons is that ABM is an evolving paradigm with fewer known modelling building processes. On the other hand, the existing support tools tend to focus on the technical difficulties rather than the methodological ones.

4. Cases Study Descriptions

The four model building projects investigated, have different topics, purposes, scope and methods.

They all clearly demonstrate what occurred in practice during the model building stages. In practice no two models are the same, and in this study each model selected was built to examine different topics with different purposes, even the modellers' expertise varied significantly. The aim of this research is not to compare similar models, but examine the methods of construction and the issues faced by their builders.

The cases coincide on following modelling phases described by theory of the paradigms and their result have been presented and evaluated for users and researches of the topic.

The cases are:

- ABM.Case 1: Urban Water Management–FIRMABAR
- ABM.Case 2: Technological change and diffusion modelling-TCDM
- SD. Case 3: Consciousness of information security-InfSec
- SD. Case 4: Inmune Systems in Multiple Sclerosis patients – ISMS

The first case represents a system to try different strategies to improve urban water consumption planning. The second case shows a complex view of a technological change process. The third case is related to the analyses of factors affecting the effectiveness of incident reporting systems. Lastly, the ISM case focuses on creating awareness of critical aspects of information security management.

4.1 Case 1: Urban Water Management–FIRMABAR

4.1.1 Problem features

The purpose of this project was to improve the planning of urban water consumption by applying an agent based model where physical aspects, and hydrologic, social and economic perspectives were integrated. The objective was to build a model which stakeholders could use to evaluate different strategies.

Initially the modeller's intention was to have a general model for five different regions in Spain, however the individual characteristics of each region forced the requirement to build five separate models.

The principal assumption is that social activity has an important influence on water consumption behaviour. Hence actors such as families, organizations, municipalities and regional government are all represented in the model (Lopéz-Paredes et. al. 2005).

The model is divided into two sub-models; a social model and a territorial model.

The connection between population life cycle and migratory process is simulated.

4.1.2 Modelling process issues

- Paradigm selection: Modellers explained that their decision to use the ABM paradigm approach was due to its suitability for modelling:

  a) Geographical space, which can be extremely influential in the process of water consumption.

  b) Social actor's characteristics, which diverge between actors, some of which can occasionally evolve in time.

  c) External processes, such as climate profiles, housing preferences or social attitudes which affect the system.

  Another important reason mentioned by the modellers is that although they have experience with other paradigms, they believe that the abstraction structure of the system permits stakeholders to explain easier the hypothesis of the model.

- Stakeholders participation: Based on participatory methods theory (Van der Sluijs, Jeroen, 2002) and role play games (Barreteau et. al, 2001), a platform of social entities was created in order to develop the model (for more details see Galan et. al., 2008). Nine representative organizations of the water sector participated in the interactive process through individual interviews and questionnaires.

- Data sources: In addition to the information obtained through the interviews, the model construction was based on previous research works such as statistical studies, water price studies and water demand studies.

- Handling of soft variables: One the most problematic aspects to consider and measure was the "dissatisfaction level" of a person with respect to his residential conditions. This variable was very important to determine the decision of a person or family in the model immigration processes. The stakeholders´ platform were unable to measure dissatisfaction level, and thus modellers decided to use the "stress-resistance hypothesis" to explain residential choice and movement (Phipps, 1988, Benenson 1999). According to this hypothesis an agent decides to change residence by evaluating criterions as context richness, neighbourhood and social spaces among others.

- Support tools: Different tools were used during the modelling process.

  Step 1. Problem conceptualization: a series of individual interviews was made with the aim of understanding the attitudes, preferences, roles and objectives of the organizations in relation to water consumption. Subsequently a questionnaire aimed at the study of the hydrologic cycle was prepared.

  Step 2. Parameters definition: in a second set of interviews, the stakeholders´ platform was asked about the main variables of the system and how they could be calculated.

  Step 3. Sceneries estimation: modellers projected the stakeholders opinions and created the evolution of the parameters. The results (evolution of 36 parameters) were evaluated by the stakeholder's platform using the Delphi method.

  Step 5. Conceptual model design: the initial version of the model was implemented in *Strictly Declarative Modelling Language, SDML* (Moos et al. 1998). In the second model a graphical user interface *(GUI)* was added at the suggestion of stakeholders.

  Step 6. Programming the model: the program of the model was implemented in Java using Swarm libraries.

- Validation: Before the validation, the model program needed to be verified in order to demonstrate that the computational program of the model accurately represented the modeller's conceptual description. In this stage, theoretical parameters were applied in a debugging mode to detect errors at each progressive step of the model simulation.

  Due the lack of real data to validate the model, the social platform of stakeholders was able to validate the model by analysing its structure.

4.1.3 Difficulties encountered

Modellers explained that during the modelling process a number of difficulties were encountered, the biggest being the lack of data available to define the parameters. This problem is typical in complex situations with a large social component.

Another mentioned difficulty arose at the transformation of the conceptual model to a programming model. Firstly, modellers mentioned the need of a metamodel in agent based to help convert from one model to the other. They considered the integration of the programming model with geographical and economical databases to be a difficult process. Additionally, the computing power required to perform the statistical analysis was not sufficient.

Also, modellers mentioned that they found it difficult to analysis the model outcomes, as in the agent based models (a bottom up approach) the rules defined for the interaction between agents.

4.1.4 Benefits of using modelling

The resulting model has been used (the same as other statistical models) in the Agencia Catalana del Aigua (ACA) to help decision makers evaluate policies of water demand and supply using different climate and technological scenarios.

Furthermore, it was possible to identify the main factors involved in the water cycle and to integrate the human dimension to improve the system.

4.2 Case 2: Technological change and diffusion modelling – TCD

4.2.1 Problem features

The aim of this case was to understand how change between competing technological standards can be initiated endogenously within an industry. Traditionally, the technological diffusion models tend to consider individual technologies entering a market and their stability according to a diffusion rate.

The model attempts to show the complexity of the technological change. In this context, different technological alternatives compete in the market and their success is influenced by social, economic and political entities.

The model represents two different populations. Firstly, organizations which adopt the technologies to produce a good or a service X, and secondly, technologies which are the possible alternatives that an organization can adapt to manufacture their product.

4.2.2 Modelling process issues

- <u>Paradigm selection</u>: Modellers explained that they chose to use the ABM paradigm at it provides a suitable approach to illustrate the interaction between two populations. Additionally, it is possible to distinguish different characteristics between the actors. For example, for the technologies population it was necessary to differentiate each actor according to treatability, relative advantage, complexity, compatibility and sustainability.

- <u>Stakeholders participation and data sources</u>: In this case stakeholders participation was not used to create the model. It was designed and programmed based on theory. The technology adoption behaviour was based on “informational cascade” models

(Carrillo-Hermosilla, 2005). This theory is traduced in the model to the assumption that as more organizations adopt a technology, more organizations start being interested.

To calibrate the model, modellers opted for a set of theoretically acceptable parameters obtained from literature, but which were not intended to represent precisely any particular situation or industry.

- Handling of soft variables: It was especially difficult to measure the impact of communication amongst the organizations adopting technologies. Modellers opted to represent this impact as "informational cascade" models (used in epidemiologic studies) to explain this kind of phenomena. As a solution, a function between the variables "communication rate" and "the contagion probability" was established. As shown in Figure 1, the problem was to know what type of function best corresponded to reality, e.g. whether it was linear, exponential, saturation or other.

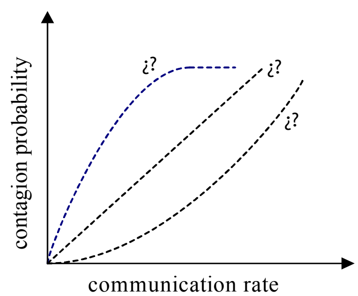

Figure 1. Impact of communication

- Support tools: Four stages were applied to build the model: definition, modelling, calibration and result analysis.

  Step 1. Definition: a conceptual model was based on literature on technological changes. Stochastic functions like Poisson distribution were employed to calculate some parameters.

  Step 2. Modelling: Due the modellers interest in dynamic properties and the difficulty of its mathematical treatment, the agent based model was developed in MATLAB™ (a mathematics-oriented programming language). However, the modeller was not familiar with MATLAB and thus an engineer was required to do the programming.

  Step 3. Calibration: In this phase a base scenario was defined of theoretically acceptable parameters, obtained from literature. Multiple sensitivity analyses were performed on the various parameters of the model to statistically evaluate the effect of modifications on this base scenario. (Carrillo-Hermosilla, 2003).

  Step 4. Result analysis: To check the hypothesis formulated in the study, an experiment was implemented using the base scenario. The experiment involved 150 simulations, each of 50 interactions, using different random seeds in each simulation.

- Validation: As mentioned, the structure of the model was based on literature and it not on the participation of stakeholders. Consequently, the validation method consisted of publishing the model and the results, and presenting in conferences of economic and ecological topics. It is worth mentioning that from the economic perspective, the model created controversy as the social modelling approach and the complexity study of systems was not familiar to economists. However on the ecological side, the model was well accept, and researches received positive comments for having considered the complexity of the topic.

4.2.3 Difficulties encountered

Three main difficulties during the modelling process are mentioned. Firstly, the lack of previous experiences studying the technological change by using social simulation. Modellers had to learn how to use and how to build a model in the AB modelling paradigm. Secondly, it was difficult to make a simple and concrete model without loosing reality. Lastly, the programming of the quantity model was difficult because it required a high level experience in programming.

4.2.4 Benefits of using modelling

The model examines the hypothesis on the adoption and technology standardization in an industry characterized by increasing returns. In addition, the analyses results of the model suggest other areas of future research.

Observing the problem as a complex system, amplified the knowledge of the problem and permits identify interrelationships unperceived before.

4.3 Case 3: Consciousness of Information Security - InfSec

4.3.1 Problem features

The purpose of this modelling project was to create a simulator for security information management in a business context. The project was financed by the Spanish Ministry of Industry, Tourism and Commerce.

The model represents three subsystems, one for each type of control directed to improve the security information systems. They consist of technical controls, formal controls and informal controls or human factors. Each subsystem consists of a number of variables actuating in the system.

4.3.2 Modelling process issues

- Paradigm selection: The Systems Dynamics paradigm was used to build the quantitative model. One of the main reasons for modellers to select SD was the ability of the paradigm to build a model involving stakeholders in the process and because of the modellers proficiency to direct the project.

  Another important reason was the ability of the paradigm to represent a complex system with interrelations and the facility to analysis the results behaviour observing the relations between the variables.

- Stakeholders participation: A consultancy company 'A', a university 'B' and a private company 'C' participated in the modelling process. The consultancy, specialised in information security, directed the project. They proffer their experience in the topic.

  The participants from the university provided their modelling expertise and the private company was interested in improving their security information system.

- Data sources: At the time of project execution, the private company was implementing a security information management system based on the ISO17799 standard. Thus their experience was directly transmitted into the model. Reports and numerical data bases of the private company ‘C’ was also used in the model building process. When more information was needed and was not available, the stakeholders were asked to estimated the behaviour of variables over time.
- Handling of soft variables: Some of the important and required soft variables in the model included; management commitment and risk of internal and external events which could affect the security system. Due to the difficulties to measure these variables, the modelling team asked stakeholders to suggest indicators related to these variables which cannot be quantified.
- Support tools: In this project, the modelling team applied the Group Model Building approach defined in System Dynamics (Richardson Y Andersen, 1995), (Andersen y Richardson, 1997) y (Andersen et al, 2004).

  Step 1. Stakeholders definition: The stakeholders mapping graph was used to identify and classify the stakeholders according to their interest in the topic and their influence capacity.

  Step 2. Causal loop diagrams: In order to explain the complexity of the problem, causal loop diagrams were also used.

  Step 3. Quantitative model: Considering the ideas and suggestion of stakeholders the quantitative model was defined.

  Step 4. Calibration: A sensitive analysis was applied and evaluated with the stakeholders collaboration to improve the model.
- Validation: The model was tested in extreme conditions and experiments with different policies. Due the lack of real data the realistic behaviour of the results was evaluated with stakeholders’ participation.

4.3.3 Difficulties encountered

One of the main limitations encountered during the modelling process was to define the scope to use in the model. The consultancy and the university team preferred to consider the security system from a general point of view, without representing specific cases. However, as the private company was interested on improving their system they put emphasis on their case.

Another constraint of the modelling process was the lack of historical data to evaluate the resulting behaviour of the model.

4.3.4 Benefits of using modelling

At the beginning of the project, the team from the consultancy and the private company, did not have any knowledge about using System Dynamics and its benefits. This was an interesting benefit of their participation in the process as they could interact with the model, creating a commitment to the problem and learning how to use the paradigm.

On the other hand, the process followed by meetings with the stakeholders helped significantly in the communication between participants, sharing their ideas and perceptions. Consequently, understanding the different points of views involved in the problem amplified the knowledge of participants.

The resulting model was also applied to experiment different strategies in information security system. Currently, the idea is to use the model to build a flight simulator that can be used by security managers to experiment policies and create consciences of the important factors.

4.4 Case 4: Immune Systems in Multiple Sclerosis patients – ISMS

4.4.1 Problem features

The aim of this case was to investigate the interrelationships between the changing causes and effects within the immune system. The interrelationships of factors affecting the immune system in patients with Multiple Sclerosis (MS) were simulated. The work was conducted by the Department of Neuroscience in CIMA (Centro de Investigación Medica Aplicada).

4.4.2 Modelling process issues

- Paradigm selection: Before modellers decided to use System Dynamics, they had applied temporal series models, as they had historical data about incidents and fatalities in MS patients. However they preferred to use System Dynamics because the use of temporal series was not sufficient to explain the causes of some behaviours.
- Stakeholders´ participation: A medical researcher and a computing engineer from the multiple sclerosis department participated in the modelling process. The medical researcher was an expert concerning the disease factors and the treatments. The engineer was not an expert in System Dynamics paradigm but had the most experience of the participants.
- Data sources: Historical data about incidents and fatalities in multiple sclerosis patients was available. Nevertheless, more data was needed, and thus modellers decided to undertake laboratory experiments to improve the model and at the same time produce more data to validate the model structure.
- Support tools: Due to the fact that it was the first time the modellers had applied modelling paradigms to investigate their topics, they were not familiar with the tools and methods available in System Dynamics.

  Step 1. Definition: The modelling team defined the conceptual mode by investigating theory and using the analysis of the time series applied before System Dynamics.

  Step 2. Modelling: Using the historical data of incidents and fatalities in multiple sclerosis patients the model was formulate. The interactive and iterative process took approximately a year to complete.

  Step 3. Calibration: Modellers decided to undertake laboratory experiments to collect more data to improve the model.

  Step 4. Result analysis: Modellers were able to design medical treatments and medicine doses for multiple sclerosis patients.

- Validation: Behaviour results from the model were compared with the time series simulation. Experiments in Matlab were undertaken in the sensibility analysis to applied statistical analysis. It is worth mentioning that due the higher interest in the model, there was more effort required to build a valid model for their knowledge.

4.4.3 Difficulties encountered

The main difficulties encountered were:

- Using modelling paradigms was a new activity for the modelling team, thus forcing them to learn how to build a model in this paradigm.
- There was a high expectation to use the model to estimate different treatments, but to improve the model they had to undertaken more laboratory experiments than they planned.
- The Vensim program was not sufficiently powerful to perform a large number of simulations experiments and undertake the mathematical calculation required, thus the modellers employed Matlab™ to perform the calculations.

4.4.4 Benefits of using modelling

Modellers underlined that System Dynamics has the potential of promoting a holistic view of the problems, identifying the complex interrelationship between the factors of a system taking part in a unique whole system. This is considered favourable in the medical area as it explains the complexity of the human body. For example, the occurrence or change in a particular body system can be reflected in consequences (often unexpected) in another completely different body system. (Villoslada and Oksenberg, 2006)

5. Cases Analyses

In the next sections the findings of the study are presented.

5.1 Particularidades del problema

From these case studies it is demonstrated that SD and ABM modelling paradigms have been applied to very different applications. Their common characteristic is that they all model complex systems, in other words, the model outputs are an evaluation in time of results of interrelations between factors that act within the system. Therefore it is often difficult to understand how and why the system behaves as it does.

As well as the variety in the application of the case study, the reason for using the models differs between cases. The FIRMABAR and ISMS cases use modelling to investigate the system and experiment with different policies. In the InfSec case there was interest to use modelling as a tool for learning and appreciation of the system, whilst in the CTS case the aim was to expose different perspectives of the problem.

The model scope, understood as the area of the problem that is considered in the project, is considered to be broad in the majority of the cases. The FIRMABAR and CTS models take into account the different perspectives that affect the system. For example the FIRMABAR model considers the geographical, social and economic perspectives.

The InfSec case is different however in that is has a narrower scope. It centres on the management of the different type of controls affecting the information security system.

The aggregation level is associated with the level of zom that is used to represent system actors. For example, the population, control types and organisations can be modelled as a group or as individuals. The case study results indicate that SD and ABM differ with respect to aggregation levels. SD models tend to use higher aggregation levels whilst AB models tend to consider individuals rules of behaviours.

Figura 1 represents the combination of scope and aggregation in the four cases analysed.

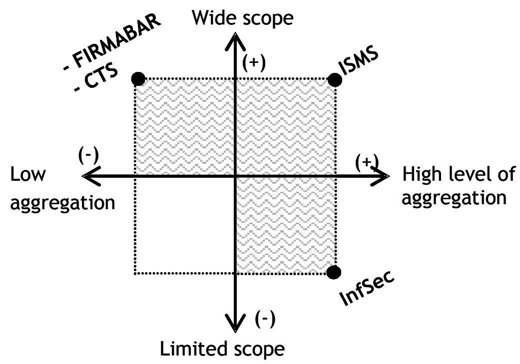

Figura 1. Scope and level of agregation

Heterogeneity and handling of space are particular characteristics that can only be represented if low aggregation levels are modelled. FIRMABAR and CTS are the models which comply with this condition. However only in FIRMABAR case modelled handling of space.

5.2 Modelling process issues

5.2.1 Paradigm Selection

It is observed that the selection of the paradigm doesnot only depend on the characteristics of the problem, but on other circumstances such as the experience of the modellers involved and their knowledge and preference for one particular paradigm over another.

The paradigms chosen for the cases of FIRMABAR and ISMS (SD and ABM respectively) adjust well to the project scope. However, it is not clear with the InfSec and CTS cases, the reasons for having worked with SD and ABM respectively.

The InfSec problem could have been planted as an agent system (control types for example) in a context (system security). In a similar manner, the CTS problem could have used the SD paradigm to demonstrate the process of technological change as a a process affected by other factors such as the arisal of new companies and technologies.

Therefore the question remains as to what does the contribution of each paradigm? This will depend on the problem characteristics and the scope of the problem that is to be studied.

5.2.2 Stakeholder participation and data sources

There appears to be a tendency to involve stakeholders in the modelling process, not just as sources of information, but also as an important validation tool. In three of the four cases this took place with very good results. In InfSec (SD) workshops and meetings were held to construct the model amongst the participants. In FIRMABAR(ABM) a social platform was created with representatives of the principal organisations involved in the project. Interviews and meetings supported the model development.

The participative process using workshops is of particular interest as apart from the advantages of uniting ideas of the stakeholders, the fact that participants physically met and interacted with each other meant that the different perspectives of the problem could be integrated.

The models were supported by information sources such as theory, statistics and related studies in the field of interest. Additionally, companies participating in the InfSec case were able to contribute real data and practical experience related to the problem.

5.2.3 Soft Variables

In all cases the modellers came across variables that were not possible to quantify. In general this was resolved by participants who, through their own experiences, were able to estimate better variable values. In other cases it was opted to select established theoretical values. All cases coincided in recognising that it was a critical issue to find a method to measure such variables and to search for the most acceptable method possible.

In both the ABM simulation models it is brought to attention that one of the critical variables used is a soft variable as follows:

- FIRMABAR: The dissatisfaction level
- CTS: The communication rate

The first variable influenced the decision to change residence, which in turn had important consequences in the consumption of water. The second variable controlled the propagation process of technologies.

5.2.4 Support tools

Guides recommended by the GMB were used for the SD cases and theory of the paradigm and what to do in each stage of the modelling process.

5.2.5 Validation

In reference to the validation, it is of interest to note the different concepts used but the similarity of meaning. In general three different types of validation were used; conceptual, structural and behavioural. For example, in the FIRMABAR case it is named as assumptions validation, programme validation and results validation.

However, there is a significant difference in the validation methods support suggested in the paradigms theory. ABM is an immature paradigm and tends to focus on verification instead of the validation.

5.2.6 Difficulties encountered

Even though stakeholder participation has been very helpful, it also produced difficulties. For example in the InfSec case, the modelling team spent time to reach an agreement with regards the scope of the model.

Time availability, was another constraint in some modelling projects as it determined the number of meetings or workshops that could be held.

All cases have agreement in that one of the more important limitations was the unavailability of data. Even in the cases where organisations were able to help the modelling process with their reports and information, it did not provide all the required information.

Both ABM models agree in the difficulties in translating the conceptual model to a programming model.

5.2.7 Benefits of using modelling

Two groups of benefits can be defined, the first derived from the model construction process, and the second from the application of the completed model to experiment with changes, strategies and policies.

The benefits of the modelling building process are clearly demonstrated in the FIRMABAR and InfSec cases. The process was used as a tool to improve the communication amongst participants and to integrate different viewpoints into the problem.

Additionally, participation in the process of model construction resulted in the participants gaining further knowledge of the problem. In the InfSec case for example, it was commented that the consultancy A and the company C were unaware of the benefits of modelling paradigms such as SD. At the end of the modelling process, as well as being more aware of their contribution, their interest in the model increased their overall awareness of the problems to be resolved.

In the four cases the completed models produced significant benefits for the participants, predominantly in the ABM models, in which a large number of experiments were made by varying determined model parameters and extracting conclusions and the sensitivity analyses.

6. Conclusions

In this paper we investigated issues of building models in practice. Four modelling projects were examined using a qualitative evaluation of fourteen aspects related to the features of the problem being analysed, modelling process issues, difficulties encountered and benefits of modelling. The information from each case was obtained by conducting interviews with the modellers and collecting information from papers and reports of each case.

From the analysis we conclude that simulation models can be used for a variety of purposes and topics. The more important matter is selecting the more accurate model to the purpose, scope and level of aggregation required by the problem in question.

Furthermore, it was observed that even in cases were there was limited data available; it was possible to build a successful models. In these cases, the model can be made as realistic as possible by using additional sources of data such as holding interviews with stakeholders, making experiments, quantifying the information needed through other indirect variables and using available documentation.

Stakeholders participation and awareness contribute significantly to encourages communication, creating consensus and gaining understanding between modellers and stakeholders. This contributes strongly to the creation of an important knowledge base for decision makers.

Although it is not possible to make accurate predictions when there are data limitations, the model can be made as realistic as possible by using additional sources of data such as holding interviews with stakeholders, making experiments, quantifying the information needed through other indirect variables and using available documentation.

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