# Agent-Based Modelling, a Quiet Revolution in Asset Management

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## Abstract

Over the past 20 years sophisticated technical models of the asset management process have been created, but asset management is a socio-technical process, with the interaction between the social and technical systems directly impacting strategy development and the long-term evolution of the asset. To combine both the social and technical systems into one model a small number of researchers have started to use agent-based modelling. By creating these models, stakeholders' reactions to proposed policies can be explored prior to policy implementation. This ability to explore stakeholder reactions means that, for the first time, asset management strategies can be developed that meet stakeholder expectations, while ensuring the on-going functionality of the asset.

This paper provides an introduction to this new modelling technique. This paper also describes how agent-based models can be used to improve performance measurement and management, thus creating a framework for improved decision making.

## Keywords

Agent-Based Modelling (ABM), Asset Management, Decision Making, Simulation

## Introduction

The asset management process is often depicted in a way which implies it is a simple cycle, with no or limited feedback and with future actions dependent on past experience. This cycle takes the same form as Sterman's (2001) event orientated view of the world, with goals and targets set at the start, problems identified, decisions made and results obtained (Figure 1).

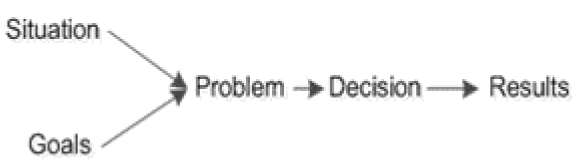


**Figure 1 – An Event Orientated View of the World (Sterman, 2001)**

In this linear view the gap between the desired goal and the current state defines the problem to be overcome (Sterman, 2001). Once this problem is solved another is then identified. This setting of goals and developing solutions to meet these goals is the same as the service level setting exercise that occurs in asset management (INGENIUM, 2006). In reality decisions are not independent of each other and continue to have repercussions that influence the system's future operation (Sterman, 2001). An alternative view, that more accurately reflects the decision making process found in asset management, is Sterman's feedback view of the world (Figure 2). In this view feedback loops are formed between the decision environment, and the stakeholders involved in the decision. This view is an evolution of the event orientated view, as it requires decision makers to actively assess the impact of outside influences on the future state of the system. The expectation that a feedback view should be taken can be inferred from recent audits (NZOAG, 2010, NZDIA, 2013), with auditors all finding that decision makers, while describing operational activities in significant detail, are failing to fully account for stakeholders in the decision making process and to clearly provide these stakeholders with choices. Osman (2012) also believes that to account for stakeholders there should be a paradigm shift in asset management modelling, because the current asset centric viewpoint provides limited understanding of what a stakeholder's future reaction to changes in service levels might be. Similarly, Bernhardt and McNeil (2008) found that asset management decision support tools are predominantly asset focused and that these models have had limited success in accurately simulating the asset management decision making process.

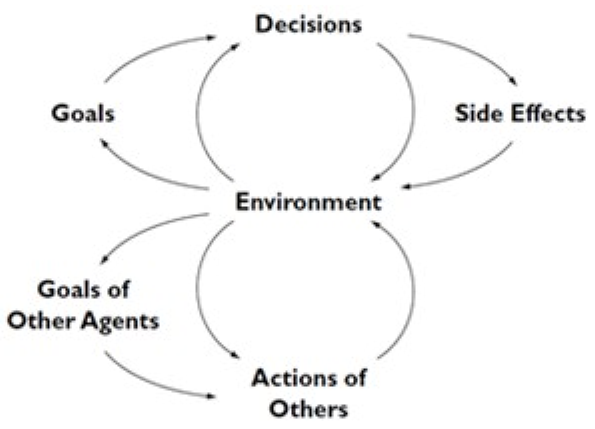


**Figure 2 – The Feedback View of the World (Sterman, 2001)**

To integrate stakeholders into asset management models Dijkema et al. (2013) recommended that models should take a socio-technical viewpoint, rather than the more traditional, asset centric, technical viewpoint. Herder and Wijnia (2012, p33) also found that because assets are embedded in society they are subject to societal changes as well, and as such asset management models should account for these societal influences. This new socio-technical paradigm requires asset management models that are able to account for the interconnectedness between the decision and the stakeholders. If stakeholders are to be included any new modelling approach should also be able to simulate the behavioural attributes of each individual stakeholder and the relationships between these stakeholders. This paper provides introduces Agent-Based Modelling (ABM), a simulation method that has only recently started to be used to model the complexities of asset management decision making. In ABM stakeholders and assets are represented by computer simulations. By modelling both stakeholders and assets in the same environment decision makers can learn about the possible future repercussions of their strategies.

## What are the alternatives to agent-based modelling?

A complex system has a large number of sub-systems that are involved in many loosely structured interactions, the outcome of which is not predetermined (Jackson, 2003). This interconnectedness results in behaviours that cannot be quantified by simply summing the outputs from each system component (Von Bertalanffy, 1972). This greater than the sum of the parts characteristic is known as emergence (Hitchins, 2003). To help describe a complex system, and eventually to simulate the system, a number of techniques can be used including systems-thinking, systems dynamics, discrete event simulation, and ABM (North & Macal, 2007), but not all of them are appropriate for simulating a socio-technical system. These approaches are discussed below.

Godau (1999), and Herder and Wijnia (2012) suggested that a systems-thinking paradigm should be used to model the asset management decision making process. Systems-thinking was recommended as it is commonly used to understand the operation of complex systems. For example, Seddon and Brand (2008) and Skarzauskiene (2010) have used systems-thinking to understand how organisations function and to improve organisational performance. As such, systems-thinking provides a useful starting point for modelling complex systems, as it provides a framework for system visualisation. Nonetheless, to simulate the system mathematical models are required (Nikolic et al., 2013).

Systems-dynamics (Forrester, 1994) is one method of creating mathematical models of the decision making process. In these models differential equations are used to simulate system components. For example, systems-dynamics has been used to model the impact of varying stocks and flows on delivery supply chains (North & Macal, 2007). Systems-dynamics models have also been used to simulate the impacts of a growing demand for construction materials (Suryani et al., 2010). Even so, systems-dynamics models are not applicable for simulating systems that have a strong spatial component (North & Macal, 2007), such as the asset management process. Lewe (2005, p104) also noted that for a systems-dynamics model to be effective the whole system would have to be described in detail, whereas an agent-based model requires comparatively less data before it becomes a useful decision support tool.

Statistical modelling is technique that is frequently used in asset management decision making, but it is not recommended for modelling socio-technical systems, as it treats the decision process as a black-box. By treating the decision process as black box the relationship between the system's inputs and the system's outputs becomes difficult to understand (North & Macal, 2007). In complex systems describing the connections between system inputs and outputs is an important part of understanding how the system functions.

Discrete event simulation (DES) is a process that is used to model complex systems (North & Macal, 2007). DES can also be used to model the feedback view of the world, as it is able to simulate the impact of successive decisions on future scheduled events (North & Macal, 2007). Even though DES is able to simulate these impacts it is not appropriate for modelling socio-technical systems, because it does not focus on agents and their interactions (North & Macal, 2007), which is required in a model of a socio-technical system.

ABM is an approach that can be used to model the behaviours of stakeholders and decision makers, how asset performance changes with time, and the effects of changing asset performance on stakeholder holder satisfactions levels. In fact, ABM has been used to model many types of human-environment systems including coupled human and natural systems (An & López-Carr, 2012) and how human-infrastructure systems evolve with time (Nikolic & Dijkema, 2010). ABM was used, because it is the best method for modelling systems that have a strong geospatial component and where stakeholder behaviours influence outcomes (Macal & North, 2010). As such, agent-based modelling is the recommended method of simulating the asset management decision process.

## What does a model include?

An agent-based model comprises three components: models representing stakeholders, a model of stakeholders and their relationships and a model of the environment for the agents to interact with (Macal & North, 2010) (Figure 3).

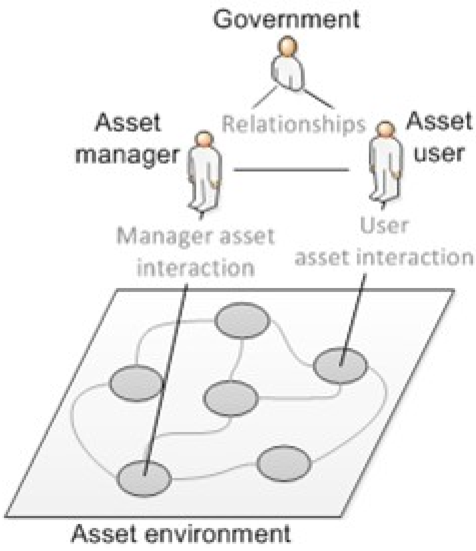


**Figure 3 – An agent-based asset management model**

To simulate stakeholders their behaviours are described by rules, which define how they react to situations and how they interact with each other (Van Dyke Parunak et al., 1998). In an asset management context, the modeller will have to understand who the key stakeholders are and their preferences, how these stakeholders influence each other and how they interact with the asset. For example, how is the asset manager influenced by asset risks, corporate strategic objectives, the asset user, and peers within the working environment? Figure 4 shows a simple framework of how these rules could be structured.

To gather data for the model, stakeholder surveys are still used, but in a much more focused way. At the moment surveys are used either to understand people's preferences for a particular project or whether they are satisfied with the service being delivered. In ABM this data is still required, but new data is also needed. For example, in-order to model agent behaviour the stakeholder survey would be used when the level of satisfaction falls below an acceptable limit and the factors that influence these changes, and how stakeholders interact with each other. To develop these surveys new members will be required in the asset management team including behavioural scientists, economists and operational researchers. This change in team dynamics is a reflection that asset management decision making is a complex process that can no longer be managed by individuals(Frangopol & Bocchini, 2012).


**Figure 4 – An agent modelling framework**

An added benefit of modelling stakeholders and the asset in one simulation environment is improved performance management. This occurs because stakeholder and asset attributes can be extracted from the model and used as performance measures, unlike current methods, whereby measures are created separately from the system. By running the model it is also possible to understand whether defined targets are achievable, finally making it possible to correlate maintenance and improvement costs with stakeholder satisfaction.

## What do I need to develop an Agent-based model?

New skills are required to understand stakeholder behaviour and to collect the appropriate data. Further to these skills, programmers will be required to create the model. The environment the model is created in will range from purpose built through to a specific agent-based modelling packages. Based on comments by North and Macal (2007) rapid pro-typing and simple to intermediate level models are best developed in a specific agent-based modelling package, with more complex models being purpose built for a specific situation. To date asset management models have been created in agent-based modelling packages, but there are in excess of 70 software packages (Wikipedia, 2014) to choose from, which creates the problem of which one to use. The package to use can however be narrowed down by whether it has a geospatial component. Other considerations for using a particular software platform are whether the level of documentation is adequate and the level of activity on the user groups. These are important considerations, as some systems have limited documentation, which leads to difficulty understanding how the system works and this difficulty can be compounded if there is no user group.

## Have agent-based models been used in asset management before?

ABM is only a recent addition to asset management simulations and at this point in time these models describe two types of system. For example, Nikolic and Dijkema (2010) used agent-based models to understand the evolution of complex asset systems. These can be classified as large scale agent-based models. The second model type, created by Osman (2012), Moore et al. (2008), and Bernhardt and McNeil (2008) has fewer agents and is used to develop effective strategies for maintaining locally managed infrastructure assets. These can be categorised as small-scale models, as they have limited numbers of agents.

In the Osman (2012) example, a small-scale model was created to highlight how ABM could be used in road asset management. In Osman's model a statistical deterioration model is used to simulate the change in the performance of a pavement asset and simple behavioural models are used to simulate stakeholders. In the simulation process the road condition deteriorates and because of this deterioration users are exposed to an increasing number of sections that have poor ride quality. As the users encounter more and more poor quality road sections the count of low quality service interactions rises. As a result of this rising count of service interactions more and more complaints are issued to the asset manager and to government officials. Once the number of complaints rises above a tolerance threshold budgets are increased to improve performance and improve satisfaction levels. If no complaints are encountered then budgets are lowered. In the simulation the overall satisfaction is defined by their level of tolerance to poor road quality. In total five user groups are defined with the tolerance of these groups ranging from highly tolerant to intolerant. This simple model represents the ability, for the first time, to directly link asset performance and stakeholder satisfaction. This ability is a major improvement over event orientated asset management models, as asset managers can now assess stakeholder's future reactions prior to a new strategy being implemented.

The Osman model only focused on road condition, but the method can applied to any other public asset, and to performance measures other than condition. All that is required is knowledge of stakeholder's reactions to changing asset performance levels and asset specific technical models.

## Conclusion

ABM has only started to be used as an asset management decision making support tool in the last six years, but these early models have shown that it is possible, for the first time, to link stakeholder expectation and asset performance. The act of creating these new models advances asset management thinking, because it encourages modellers to change from an outdated linear decision approach to the newer feedback view of the world, which is more appropriate for decision making in a complex environment. To create agent-based models is only incremental step, but one which unifies many of the processes that are already being used into one integrated decision support model. For these reasons agent-based modelling presents a major advance on current modelling approaches and as such will become much more prevalent in asset management decision making.

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