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Abstract:	This paper presents a framework for understanding and improving the process of simulation model building involving a group of domain experts, classifying the different roles the model may play at various stages of its development. We argue that a consideration of these different roles will help modelling consultants to better design modelling processes to meet the needs of their clients and clients to better understand what a modelling project can achieve, so that ultimately projects are more successful. The framework consists of four different "object roles," defined along two dimensions: firstly a functional dimension (boundary object vs. representational object) and secondly, a knowledge dimension (epistemic object vs. technical object). We show how the same simulation model can take different roles at different stages during the group model development process according to the needs of the group. For example, the model could be used for facilitating communication, gaining understanding and insight into the real-world system, or for experimentation and policy evaluation. The use of the framework is illustrated by two case studies in health care, based in the UK National Health Service (NHS). Its relevance and applicability are then examined through a survey on model use in expert group model building exercises. While both case studies used system dynamics, the framework is applicable across a range of modelling techniques. The survey on model use was conducted among a group of modelling consultants with experience of using both discrete-event simulation and system dynamics within the NHS, and indicated the usefulness of the framework in describing group model building processes.

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Keywords: group model building, simulation, project management, health care, practice of OR

Introduction

Context

There is an extensive literature on the process of model development. The modelling process is often described as starting with a problem structuring phase, moving through a conceptual model development phase to an "encoding" phase, which normally involves the use of software, and also includes data collection for model parameterization. Finally, after a verification and validation phase, the encoded model is used for experimentation, the results are documented and, hopefully, the model recommendations are implemented by the client. Of course, this description is over-simplistic: in practice this process is far from sequential and may involve numerous iterations, consultations with stakeholders and backward loops between stages.

During this process, the model itself evolves dynamically from a conceptual model, which may be simply a mental model, a verbal description or a rough drawing, through to the final model, which may be relatively simple or a vast, sophisticated computer program representing many person-years of coding and data analysis. Although there appears to be an implicit assumption that the main deliverable of the project is the final model (and its results), and the earlier phases are merely stepping-stones on the path towards this goal, many authors (Lehaney and Paul, 1996; Pidd, 2009; Williams, 2008; Robinson, 2001, 2004; Brailsford et al., 2004) argue that the process of model development and the discussions which arise during it can be equally, if not more, beneficial. This paper is not directly concerned with this evolutionary process as such, but much more specifically, with the way in which the evolving model is used by the various participants in the process of group model-building.

The paper builds on a continuing discussion within the disciplines of knowledge management and philosophy of science on the role of artefacts in human communication and decision-making (Rheinberger, 1997; Cetina, 1997; Zagonel, 2002; Carlisle, 2002; Dodgson et al., 2007; Ewenstein and Whyte, 2009; Ackoff, 1979; Pidd, 2010; Waisel, et al, 2008). Past research has investigated the role of artefacts (as repositories of knowledge, representations of cognition and expressions of culture) and examined the effect of these artefacts on social processes (Wilson et al., 2007; Nemeth et al., 2006; Becky, 2003; Carlile, 2002; Norman, 1991). Studies have also examined how artefacts support future-oriented sense making, cognitive sculpting (Doyle and Sims, 2002), the interpretation of tasks (Ewenstein and Whyte, 2009) and expressions of personal interpretations (Heracleous and Jacobs, 2008). Generic boundary objects such as maps, diagrams, plans etc, have been investigated as a means of promoting learning between diverse groups (Brown and Duguid 2001; Yakura 2002).

Our research continues this research strand and focuses on the role which simulation models and group model-building activities can play in addressing system understanding, exploration of options and creation of specific policy decision tools. Building on the existing literature, we have developed a framework designed specifically to enable modellers engaged in group model-building to understand the role played by the model at different stages in the model development process. The insights gained from this framework not only add to the understanding of the model-building process, but will also have practical implications for modellers in terms of improving the model development process and client acceptance of the models and their results.

The application of the developed framework is examined in two applications of system dynamics in the domain of healthcare as well as in a survey of, and interviews with, healthcare modelling consultants. In this domain simulation modelling has been widely applied since the 1970's (Wilson, 1981; Fone *et al*, 2004; Brailsford *et al*, 2009). Healthcare is a fertile application area for group model building, due to the need for client and expert engagement widely cited in the literature (Harper and Pitt, 2004; Brailsford *et al*, 2013). Healthcare is characterized by "messy" or "wicked" problems, as first defined for the Management Science community by Rittel and Webber (1973) with the need to address this in health services research raised by Rosenhead (1978), Pidd (1997) and others, due to the complex financial, cultural and political constraints and multiple stakeholder groups common in this domain. These stakeholders often have conflicting objectives (for example, minimizing cost while simultaneously maximising quality of care) and the system performance indicators may be difficult to measure quantitatively (for example, health outcomes, staff morale or patient satisfaction). In many healthcare modelling applications, it is standard practice to engage collaboratively with end-users, and frequently domain experts – clinicians, managers and sometimes patients – are involved not only in the problem structuring phase but also throughout the whole modelling process, providing input and feedback on model structure and parameterization. For system dynamics modelling, in particular, user engagement is seen as essential when developing causal loop or influence diagrams in order to ensure that the model is acceptable to all stakeholders, fit for purpose and captures all the necessary complexity.

The Research Question

The aim of this paper is to describe and then evaluate a framework to help understand the different roles a model can play in the model-building process. We focus on group model-building, involving the participation of domain experts in the problem area who are not necessarily familiar with modelling techniques or approaches.

Approach

The conceptual framework presented here was developed as part of the EPSRC-funded HaCIRIC project and presented at several conferences (Bayer et al., 2009, 2014; Kapsali et al., 2010, 2011). In this paper, we examine the framework through two case studies of modelling projects and a survey of expert modellers. We conducted over 30 hours of observation of two modelling interventions and 22 follow-up interviews with the modellers, clients and domain experts involved in these projects for the case studies. The survey collected the views of ten expert modellers using an online questionnaire and was complemented by follow-up interviews with some of the respondents.

The framework

A simulation model is constructed typically by simulation experts. As a constructed object it is an artefact. Similar to a scale model, or the drawings of an architect, it represents some aspect of the "real world" or something which is intended to be realised in the "real world". Artefacts of this type can fulfil different functions for different audiences: within the same profession or scientific discipline, across disciplines, or for lay audiences (Rheinberger, 1997; Cetina, 1997).

Our framework describing the roles of the artefact "simulation model" is constructed as a

2-by-2 matrix. The first dimension (the *y*-axis) of the framework addresses the *functional role* or purpose of the model. On this axis the first category is the familiar role of the model as a *representation* of a real-world system. The model is a simplification of the real world which captures the essential features of the problem setting which will enable the problem at hand to be addressed. The process of identifying both the "essential features" and "the problem at hand" is a crucial aspect of problem structuring and modelling (Pidd, 2009). Frequently, there is a tension between the client's desire to capture the full complexity of the real world, and the modeller's desire to keep the model simple. The second category of functional role is the concept of a *boundary object*, whose purpose is to facilitate communication across disciplinary or specialist boundaries (Star & Griesemer, 1989; Carlisle, 2002; Dodgson et al., 2007). A boundary object can be understood by all parties, no matter what their scientific background or previous experience. It also serves to link communities of practice who have their own communication patterns and codes (Star & Griesemer, 1989; Sapsed & Salter, 2004).

A visual animation of a discrete-event simulation (DES) model is a good example of a boundary object. It provides a common language which enables stakeholders with differing knowledge bases, problem owners, domain experts and modellers to discuss a scenario or some process in the real world system (and its representation in the model). The visibility of the model behaviour can make processes widely accessible in a way which the coded algorithm or the verbal description of the real world system might not easily achieve. The modeller has only to experience the "lightbulb moment", such as when a client watches a visualization of their production system or Emergency Department on the computer screen and says "Now I understand" or says "You've got that part totally wrong", to appreciate the power of animation as a communication aid.

An influence diagram in system dynamics (SD) can also be a boundary object: once the very simple notation has been explained to the clients, the diagram provides a focus for discussion of the key issues in the real-world system, as well as a mechanism for the modellers to extract domain knowledge from the client. The visual interface of an SD stock-flow model acts as the boundary object or common language which enables client and modeller to communicate (Black, 2013). Zagonel (2002) explores these two alternative functional roles in the context of SD, labelling the representational role the “micro-worlds” function which represents the salient features of the real-world system selected for the model.

Ewenstein and Whyte (2009) subdivide boundary objects into two classes, *epistemic* and *technical*. Epistemic objects help to create new knowledge across disciplinary boundaries and are flexible and dynamic, while technical objects are essentially static, unchanging “knowledge transfer” tools which exist solely to make knowledge from within one discipline available to another. An influence diagram is generally used as an epistemic boundary object, as it is normally developed through an interactive, evolutionary process and the diagram changes all the time until a final agreed diagram is settled upon. However in DES, animation is more commonly used as a technical boundary object, providing a “user-friendly” mechanism of depicting a given encoded model (and its assumptions) in a format which is immediately understandable to the client.

This useful classification of the two types of boundary object provided the other dimension (the *x*-axis) of our framework, the *knowledge role*. Epistemic boundary objects create new knowledge, insights and understanding through dynamic interactions between different stakeholder groups, whereas technical boundary objects serve essentially as a static communication mechanism to "translate" knowledge from the language of one stakeholder group into the language of another group. The same distinction between epistemic and technical objects can be drawn for the representational role. The purpose of an epistemic representational model is to enable users to explore and learn about the real-world system (or a system designed to be implemented in the real world) by "playing with" the model. On the other hand, the technical representational role of a model is defined by the extent to which it captures and encodes the complexity of the (actual or potential) real-world system. The four distinct roles defined through the two-by-two matrix combination of these functional roles and knowledge roles for the basis of the framework, displayed in **Error! Reference source not found.**.

(Table 1 about here)

All combinations of the two dimensions are theoretically possible. A model could be used by a group to collectively learn about a system (epistemic boundary object), formalise collective understanding (technical boundary object), explore and learn about the (actual or potential) real system (epistemic technical object) or to codify and represent the behaviour of the (actual or potential) real system (technical representative object). A model would not necessarily have only one role; indeed it is quite likely that a model (or different versions of a model) could take on different roles over time as user engage differently with it or use the model for different purposes.

Case Studies

Selection of the case studies

The framework was evaluated through direct in-depth observation of two parallel expert group modelling projects, undertaken by the same modelling consultancy company. This consultancy specialises in system dynamics and has a long track record of successful projects in healthcare. Both models addressed the same complex public health issue involving multiple stakeholders. Each project lasted about six months, and although they both covered the same problem domain, one was conducted at a national level, commissioned by the Department of Health (DH), and the other was undertaken at local level, on behalf of the organisation responsible for purchasing healthcare services for a locality. The local project started slightly earlier than the DH one, and was smaller in scope. However, both projects followed a similar pattern, consisting of a number of facilitated meetings between the modellers and a group of expert participants. One of the consultants acted as facilitator, and the other did the actual hands-on modelling. At the initial meeting a draft conceptual model was built, and then refined and developed into a stock-flow model at subsequent meetings. This stock-flow model was further refined and parameterised over a period of months. The technical aspects of the modelling, i.e. the encoding of the computer model and any necessary data analysis, were carried out between meetings. Typically, meetings lasted a couple of hours and consisted of a walk-through of the latest version of the model, followed by discussion of any issues, and finally any required changes were agreed.

As shown in the case comparison in **Error! Reference source not found.**, the two case studies obviously had a number of similarities, but also differed in several ways. The main purpose of both models was to assist in commissioning services by evaluating the effects of different interventions, but the national DH model was intended to be generic and widely applicable, and ultimately made available to any NHS organization with an interest in the problem, whereas the local model was obviously specific to that particular locality and was intended for use in local commissioning decisions. Therefore, the DH model was inevitably more high-level and "broad-brush" in scope, and used aggregated national data, whereas the local model was tailored very closely to the particular population, local hospitals and community healthcare services in that area. The two projects also differed in terms of the pool of participants in the modelling engagements; in addition to a number of DH staff, the DH model had a large expert panel of academics, healthcare researchers, epidemiologists, statisticians and clinicians, many well-known internationally for their expertise in the field, whereas the local model used a much smaller panel of local managers and clinicians who were directly involved in commissioning and delivering care services.

(Table 2 about here)

Methodology

Each of the two case studies used direct observation of all the group modelling sessions, combined with text analysis of all group-wide correspondence, namely emails and other documentation, such as minutes of meetings. All four authors attended some meetings and although no one person observed every single meeting, in several cases there were two or three researchers present. The observers' case notes from each of the modelling meetings were coded for those factors which related to the framework in Table 1. These included factors relevant to the participants' engagement with the model, the type of interaction among participants, and factors related to the participants' expectations, understanding and use of the model. This analysis was followed by 22 semi-structured interviews with the participants, the modeller, the facilitator and the client at the conclusion of both modelling exercises. The aim of each interview was to capture the participant's experience with the model and modelling process, and to elicit details of the model's role at various stages. All interviews were recorded and transcribed. The content analysis of the interview data was undertaken in NVivo 8 (QSR International, 2008).

The interviews covered practical issues with the organisation, group model building, engagement within the modelling process, participant interaction as well as views on the resulting model. The specific interview question template is presented in Appendix A and the coding nodes used for the interviews and project meeting observations are provided in Appendix B. Two researchers carried out the first coding independently before the research team agreed upon final codes. After all the coding had been completed, all investigators participated in the comparative analysis of processes and model use across the case studies.

Case Study Findings

Two main patterns were observed in the functional and knowledge roles of the model and the model-building processes. These were a) the changes over time observed within each project, and b) the differences between the two projects based on the intended model usage and the expert participants. The framework for the analysis is that which was presented in **Error! Reference source not found.**, the functional role and knowledge role usage matrix for the models as artefacts. Based on this analysis, we concluded that broadly, the two models fell into different quadrants of the framework, as shown in Figure 1. This is discussed further in Sections 3.3.1 – 3.3.3. Where we have included direct quotes from participants, these are labelled “DH*n*” and “LOCAL*n*” where *n* denotes an anonymous participant ID.

(Figure 1 about here)

Distinctions between the two models

While in both engagements there was an observed shift to becoming a more technical, representative object for the model as the modelling process proceeded and the group came together, the rate at which and the extent to which this happened clearly differed. This was driven by two key distinctions, the composition of those participating in the model building process and the intended end user of the model. The local model was developed by a group that included the people who would ultimately be using it for decision-making or whose services would be affected by the decisions made with the model’s help, whereas the DH model was intended for potential roll-out to numerous localities. While this led to relatively similar models, the DH model had to be flexible enough for use across a wide range of local circumstances, and moreover, was designed to be used by decision-makers who were not involved in the model-building process. Ultimately this affected not just the final model but the dynamics within the expert groups brought together for the model building.

Purpose of the Modelling Exercises

The locally-built model for internal use by the commissioner was characterised by more of a knowledge-sharing and knowledge creation role. This was typified by discussion of "*the conversations we had along the way and the extra research it made us go out to do"* (LOCAL003) and the explicit reference to the "*group learning process*". The technical and representational focus of the DH model was found in statements such as an individual's motivation for joining being to "*influence policy*" (DH002) and the repeated idea that they wanted to "*provide a tool for local authorities to make a robust business case*". Furthermore, the focus was on "*communicating this to others*" who are external to the group. For the local group which was less focused on the codification of the expert knowledge, there was agreement that in retrospect the *"outcome of the project is that you learn more about the system than the model representing the system"* (LOCAL003). The debriefing with the local group members also included more discussion of these communication and knowledge creation roles with reflections from participants that *"the interaction helped participants understand each other"* (LOCAL004).

Respondents indicated that the System Dynamics modelling approach was of interest to them as they expected to contribute to a "*model that in some ways sensibly reflected the world, but was also able to take account of changing things in the world*" (DH004). However, the expectations expressed by the clients and participants also clearly indicated the goal of ultimately developing a relatively technical, fixed 'micro-world' representational model which would serve to improve decision making and other concrete objectives. In both case studies, the final product at the end of the project was both a representative object – a model which was agreed by all participants to be a realistic depiction of the real-world system – and a technical object, which could be used for commissioning, planning and policy-making. In the national project this purpose was directly mentioned: *"I think the key reason for it was to give Commissioners at a local level, a tool for which they could build business cases"* (DH005). Another participant stated "*it seemed fairly clear in broad terms what we were expecting, in that we were expecting a tool that people could access locally, use locally, feed data in and press a button and get some predications out and that it was fairly clear what the information was that people would be looking to get out of the model*" (DH009).

Composition of the Expert Groups

Much of the early knowledge-exploration observed in the local modelling engagement was largely due to the fact that the model was intended for use by the client organisation. In fact the model was predominantly designed for use by a key member of the local expert group. This expert group was largely composed of those same people who would be making or implementing the resulting policies, but who were not necessarily experts in the relevant clinical area, nor in all the intervention options being considered by the model. The differing functional backgrounds of this group not only brought potential local political and financial conflicts into the room, but also meant that the participants differed in their understanding of the system. Various communities of practice and interest groups were represented, requiring use of the model as a boundary-object. Hence this group used the model building to address the problem area in a more exploratory way. Furthermore, since the model was intended for the group's own use in decision making, many of the possible options available were already known to the group members, and these were explicitly modelled, explored and communicated during the modelling process.

For the national expert group which had been brought together to develop the DH model, the participants' prior experience within the problem area and professional knowledge of one another tended to mean that, although drawn from a wider variety of organisations and regions, their shared understanding of the problem was strong and they primarily directed this to the development of the model tool. Although they had not necessarily all worked together before, they were nationally recognised experts who had developed a shared language and understanding of the problem, even if focusing on differing aspects or interventions. Respondents recognised this themselves, with many statements such as "*we were in a very good situation there, because this is a reasonably small field; we all know each other really well*" (DH002) and "*I knew many of the people round the table; it's a relatively small field and there are you know, key experts, and we're used to seeing each other interacting relatively, sort of, happily and freely and challengingly and all that kind of stuff*" (DH004). In practice, this meant that typical feedback included "*Certainly from the first meeting, you know, the people sitting round a table; I think people interacted pretty well. … they are likely to be respectful to each other and listen to each other's views"* (DH003).

On the other hand, the local modelling expert group participants, who all had different roles within the local organisation and other local services not all engaged directly as experts in the problem area, showed more awareness of issues such as *"managing between different types of professionals"* (LOCAL001) and that *"this group, I think, had a lot of different issues largely led by the organisations that they work for"* (LOCAL002). This participant then went on to list four organisations and their specific agendas. Engaging with the model building process required and allowed the participants to develop a broader understanding of the local care system: "*And there were* *also the various bits and pieces that I wasn't aware of, the different groups of... kind of were in the healthcare system that were available, that were looking at the different things. So, that was the difficult part as well, was trying to get my head round all these different groups that were all sat round the table I'd actually never heard of before"* (LOCAL005). The different backgrounds and functional roles of the participants in the local expert group meant that building a shared understanding was a time-consuming challenge since *"every member in that group had a different definition for every word that you could possibly come up with"* (LOCAL003). This was less of an issue for the shared domain expertise of the national group. "*I think the link in with the different services was helpful to me because it allowed them to understand where we could action things from the front*" (LOCAL005).

There was evidence that the model was used to codify existing shared understanding among the national domain expert group, as opposed to primarily being used to create new shared understanding, as was observed within the local expert group. This was, at least in part, because they were "*all used to communicating with each other in those types of meetings, and that environment.*" (DH002) The national expert group also experimented with using the simulation model as a tool during the model development process. Much of this experimentation was intended to assess the performance of the tool as a 'micro-world' representation and technical object, reflecting their existing knowledge of the system and problem area, rather than to develop new insights. The focus in the national group was more explicitly on tool creation than on developing (their own) understanding. "*It's intended to give effect to the evidence in a way that provides useful guidance for the field.*" (DH007) "*So if we had, over the lifetime of this project, developed a relatively simple, useable, understandable systems tool, the NHS could then* *use* [it] *to make the right decisions to commission the right services*" (DH010). The model was recognised as a tool for policy outcome, as in statements like: "*… so we need tools and models to say "if you do nothing, this happens; if you do something that will happen*" (DH010). "*It is a more simple planning tool which I think actually could be relatively helpful ... it's a good way of illustrating that for people*" (DH009).

Nevertheless, the participants in the national model were also able to create new knowledge (an epistemic tool) through using the model to evaluate hypothetical interventions which went beyond the effects of real-world studies of which they were previously aware. This was particularly relevant in regards to the broad scope of the interventions and the systemic interactions in the system: the national project members were more used to thinking about individual interventions in isolation than considering the combined effect of several interventions.

In both groups, participants varied in the extent to which they were comfortable with the visual representation of the SD models that were developed. However, the familiarity of the national modelling group experts with the problem area and the shared vocabulary for describing this which could be translated into the model seemed to enable the DH model to take on a representative role (micro-world) more quickly than the LOCAL model.

Survey study

Aims

To further examine the value and usefulness of the framework and understand its wider applicability, a survey of simulation modellers working in the UK health sector was undertaken. The focus of the survey study was again simulation model development involving groups of domain experts in the problem area who were not themselves modellers. The aim of the study was to investigate whether any of the four identified roles could be observed in their work and if so, what factors tended to lead to any specific role dominating at particular points in the group model building process.

Included among the respondents were modellers using different forms of simulation modelling, and in particular discrete-event simulation (DES) and system dynamics (SD) which have been identified as the main simulation techniques used in healthcare (Brailsford *et al*., 2009). We were interested whether our framework would shed light on some of the differences in the modelling process and in the model use, e.g. whether there was any tendency for a particular approach to lead to any specific type of model use. While the differences between DES and SD models and modellers have generated research interest for several years, there has not been any work prior to this study which has considered the different roles played by the model itself in the process of group model-building. Tako and Robinson (2009) compare the way that expert DES and SD modellers conceptualise and build a model, but in their study the modellers are working as individuals, in isolation, on a well-defined problem they were previously given. Bayer *et al* (2014) consider the social roles models can play at various stages of the model-building process.

Methodology

Modelling analysts and business consultants using different forms of simulation modelling in health sector projects were recruited through the UK Network for Modelling and Simulation in Healthcare (MASHnet: http://mashnet.info/) and through personal contacts to participate in an anonymous web-based survey. The 20-minute online survey (Appendix C) covered respondents' experience of health modelling and participant expectation/engagement. All online respondents were also asked to participate in follow-up interviews in which more detailed explanations and examples were elicited. The online survey produced ten valid responses from active business consultants using simulation modelling in health service projects. Of these, six respondents agreed to in-depth follow-up and were subsequently interviewed. The follow-up interviews covered the same issues as the post-modelling observation interviews carried out in the two case studies (see Appendix A). In the following, direct quotations from respondents are labelled M*n*, where *n* denotes the unique participant ID.

Survey findings

Modelling process

Respondents reported that the number of participants in group modelling exercises varied considerably: typical projects had between 5-10 participants in the group modelling building process, but a few had as many as 30 participants. Most projects involved three or four sessions spaced over a couple of months, with a fairly formalised set of stages for introducing, building and releasing the model. Generally, most modellers described applying similar basic processes, resources and time scales, depending on the project goal, size and resources, regardless of which modelling approach was applied. However a difference was observed in the sources of data used to populate the model, with DES models relying on more formal documentation of processes and established pathways.

Object use and modelling approaches

In the questionnaire, two questions were set out explicitly to examine the importance of the object use roles identified in the framework presented in **Error! Reference source not found.** during the group model building process. This was done for each of the two axes and also separately for each of the four quadrants. The basic constructs in the framework were described to respondents in plain language, as shown in Table 3.

(Table 3 about here)

In general, all four roles were considered important by all respondents, although use as a technical object for codifying knowledge received the lowest score. Questions were also presented to indicate the quadrants of the framework in which the combinations of functional object roles (boundary and representational) and the knowledge roles (epistemic and technical) were reflected. The plain language descriptions of these are given in Table 4.

(Table 4 about here)

This more detailed quadrant distinction revealed more differences between the two modelling approaches, as reflected in **Error! Reference source not found.**. SD modelling consultants scored the two quadrants with communication functions (boundary objects) higher than the other two, which are more focused on the creation of realistic representation of the system. This is particularly revealed in the difference in scores for "formalise a collective understanding of the system" (boundary/technical object) in the group model building exercises. DES modelling consultants scored "Explore and learn about the behaviour of the real system" and "Codify and represent the behaviour of the real system" higher than their SD counterparts did.

(Figure 2 about here)

The distinction between the "process of building" and the actual "final simulation model" in their perceived use was also addressed in the study. When asked which of these (the process or the final model) contributed more to the participants achieving the following aims, the general answers were as presented in Table 5. While the responses were mixed, SD consultants put in general more emphasis on process than DES consultants,:

(Table 5 about here)

Object use throughout the modelling process

A key change we were interested in understanding was the change in expectations and objectives on the part of clients and participants over different stages in the modelling process. The same broad trends were observed in how the engagement and the resulting model were perceived in both SD and DES projects. The interviews with expert modellers tended to emphasize the role the model building had in bringing various stakeholders together and directing communication. Among topics for early discussion in the group modelling process was the regular need to address "*the political angle*" in inter-organisation group model building, with standard practice including a formal assessment of these issues (M1: SD user).

In general, respondents felt that clients and participants tended to focus initially on the goals related to "*exploring options to change system*" and also, although to a lesser extent, on "*helping planning and decision-making*". These goals remained important throughout the entire modelling engagement. However, the goals of "*understanding how the system works in reality*" and "*helping planning and decision-making*" did not typically receive as much initial attention from clients, although these were still considered important outcomes. Maybe unsurprisingly, the modelling consultants generally felt that the expectations and needs of clients and participants were met as a result of the group model building process. In those (few) cases where the modellers felt that expectations had not been met, the explanations provided included the fact that knowledge gaps made the question unanswerable within the scope of the project, or that participants did not engage fully with the modelling process due to competing priorities and/or the lack of a champion to drive the modelling forward. This is in keeping with findings from the literature (Harper and Pitt, 2004; Brailsford *et al*, 2013).

The recognition of the modelling experts of the value gained by group modelling clients from starting in the boundary object - epistemic object quadrant was reinforced with observations such as: *"They can use the model to explain or to understand how the whole business fits together and how the different areas are put together.*" (M4: user of both). Similarly, respondents stressed their view that their clients "*value the opportunity to listen to each other about bits of the system, I mean people don't really get the opportunity, other than these sort of experiences of really finding out how another bit of the system works.*"(M2: SD user).

The respondents were also asked to judge the relative importance of "*capturing existing knowledge from domain experts*" versus "*creating new knowledge*," reflecting the technical object versus epistemic object axis. The pattern for both DES and SD were very similar with capturing existing knowledge deemed more important. However, in the prioritisation of "*facilitating exchange of knowledge and information between project participants*" versus "*creating an accurate representation of reality*" (boundary object versus representative object), the responses differed: consultants using DES had a slight tendency towards prioritising the creating of accurate representation while SD consultants had a slight tendency towards prioritising the exchange of knowledge. Respondents who were SD experts saw a more significant role of the model in facilitating internal communication and exchange of ideas than external communication of these ideas to others via the model.

One modeller stressed that "*we believe a client will get, let's say, half the value in going through the modelling process, generally, on most projects. They will get as much value from doing the modelling as they will get from the model itself, and that is something they learn as a consequence of our engagement. They don't actually realise at the beginning that that's going to be true.*" (M6: DES user). Although this was a widely shared experience amongst the respondents, it was also noted by one expert modeller in the interview that s/he perceived a fairly recent shift away from an emphasis on the learning during the model building process towards the need to develop a realistic tool. The respondent commented that "*just reflecting on where we are today in terms of health and social care, there is less appetite now for benefitting from the process and people want the answers because they know that they have got to pay however many millions it is from their budget, to do the comprehensive spending.*" (M2: SD user)

The results of the model building engagements were discussed in terms of the generating of a tool for answering the client's real world questions (reflecting the expected final destination of a representative object - technical object). However, this can be embedded within "*part of a wider sort of learning set access*". (M2: SD user).

Discussion

The application of a boundary object - representative object distinction (defined here as the 'functional role') and an epistemic object - technical object distinction (defined here as the 'knowledge role') is useful in observing and understanding the group dynamics in the model building process and in assessing the group cohesion and transition in the model building. The general trend for solidification of the model into a technical, representational tool from a more in-flux communication and knowledge creating artefact was observed in our two case studies, though also shaped by other features of the expert groups in these case studies. This solidification into a technical and representational tool was also related to the use ultimately envisaged for both models – supporting decision-makers (who were not necessarily part of the group) by providing them with a tool to predict the impact of their decisions in the real world based on the knowledge codified in the model. The differences between the groups have also helped in understanding to what extent such a transition could be expected and the factors leading to this.

The wider group of modelling consultants interviewed and surveyed also perceived the models and group model building fulfilling roles in all four object uses and the intersection of these (the four quadrants). The survey results about typical and specific modelling projects indicate that the usage trends based on the composition and goals of the expert groups match those of the observed case studies. This may be a more significant factor than the choice of modelling approach, i.e., whether they were discussing SD or DES projects, was less relevant for the role of the model than group composition and goals.

Changes in model role over the stages of modelling projects could not only be observed across the two case studies, but also be deduced from the respondents of a larger group of modellers in our survey. Initial expectations and goals of model building groups were reported to be typically more target and decision-making driven, while during the projects typically ‘exploring’ and ‘understanding’ became prominent.

Several of the simulation modelling consultants surveyed emphasized that their clients frequently are surprised by and appreciate the systems exploration and learning they can gain during the process. Indeed, the learning process and discussions during model-building is often seen to be as, if not more, important as the insights gleaned from the resulting model. This can be summarized using the words of one of the interviewed modelling participants in one of the case studies: “*the most useful part of the whole process wasn’t what we had at the end, it was the conversations we had along the way and the extra research it made us go out to do to find out answers to questions and ask more questions along the way*” (LOCAL003). This aspect of the process is where the varying observed roles and uses of the model become key: it is not only the resulting artefact at the end (as a representative object) which matters, but the engagement of the participants with the developing model in its changing roles along the process. Collective learning in the stakeholder group, the formalisation of shared insights into the system (as well as the sometimes tortuous process of developing shared understanding and shared insight) are valuable. The exploration and experimentation afforded by a model is a learning opportunity which is almost unique to a model and not enabled in this way be most other types of artefacts.

Conclusions

This paper has introduced a framework to examine the different roles a model can have during the modelling process. Distinguishing the roles of models according to a functional dimension (boundary object vs. representational object) and a knowledge dimension (epistemic object vs. technical object) allows a classification of the varied uses of a model which goes beyond a simplified view as a mere representation of an aspect of reality. Our suggested framework refines the understanding of artefacts in the literature by distinguishing epistemic and technical roles not only for boundary objects (in the manner of Ewenstein and Whyte, 2009) but also for – in our nomenclature – representative objects. Our case studies and surveys illustrate how both a functional and knowledge dimension can be distinguished in examining simulation models in a group model building situation.

The two case studies of SD group model building showed how this framework is applicable to the analysis of modelling engagements. A simulation model can take different roles at different stages during the group model development process, including facilitating communication, gaining understanding and insight into the real-world system, or for experimentation and policy evaluation. The case studies highlighted the influence of the intended final usage of the resulting model, the composition of the model-building group, and the stage of the modelling process, on the evolving roles of a model in a group modelling process.

We found that in one case study the focus during the modelling process was more on the epistemic/boundary role while in the other the focus was on the technical/representative role. Two other dominant roles are theoretically feasible: a model's use could also focus on formalising the shared understanding (technical boundary object) or on learning by experimenting with representation of the real world (epistemic representative object). Further research investigation a larger number of modelling case studies would be required to understand which combinations are predominant in different contexts.

That a characterization of model roles might be more widely applicable beyond the two SD projects examined here is shown by a survey and consultant interviews. The model roles might also be influenced by the simulation modelling approach adopted (SD vs. DES) with DES practitioners giving somewhat more emphasis on the representative role of the model than SD practitioners, and somewhat less emphasis on its role as a boundary object. While the survey and the interviews with modellers show that the framework is useful to map out uses of models both in DES and SD, any conclusions about differences between modelling approaches are tentative since the number of respondents was small. Further research is desirable.

While experienced consultants will be aware that a model has roles beyond representation of an aspect of reality, we suggest that making these roles explicit as our framework does will have value in designing project processes which best meet the needs of specific clients. Clients (and maybe inexperienced consultants) tend to focus on the representative role; clients' initial expectations might be at odds with the experience of the modelling project they will have later. An explicit acknowledgement of these roles at the outset of the project will help to ensure that the needs of the client are met and that most of the benefits can be reaped. Such explicit acknowledgement will ensure that enough time (and attention) is allocated for the group to engage with the model as a boundary object to develop a shared understanding in a diverse group, to work with a model as an epistemic boundary object to learn together about the whole system and its components, or to experiment with the coded model to understand the system behaviour. Since clients without prior experience of modelling projects are often less aware of these model roles, a consultant might want to highlight at the beginning of the project the value of modelling in facilitating the development of a shared understanding as well consider drawing attention to any lack of such a shared understanding within the group.

In our case studies we noticed the impact of the stakeholder group composition on the model roles; clearly modelling roles can also be taken into account at the outset when planning the modelling project. For example, decisions about the composition of a stakeholder group, the importance or otherwise of constancy of attendance, the attention which needs to be paid to the relationships among the expert group, or the comprehensive inclusion of all stakeholders, will be different if the main emphasis is intended to focus on the model as boundary/epistemic object or as a representative/technical object. Improved communication in the stakeholder group may or may not be a valuable outcome in its own right. Even if a similar outcome is desired depending on the diversity of the group (in regards to knowledge bases and or roles in the system), the importance of different model roles during the modelling process is likely to be different. The use of the model as a boundary object is likely to be greater if communication across differences needs to be facilitated in order to elicit knowledge and to generate an understanding of the whole system. So if even if as Rouwette et al. (2002) observe the context of a modelling project influences the models used but not the outcomes, the modelling process and the prominence of model roles are likely to be different depending on project context.

Similar considerations can inform the choice of modelling approach (SD vs. DES). Arguably, these considerations remain somewhat tentative since the research underlying this paper was not a large statistical analysis of differently designed projects. In the absence of such research (which would be both desirable and not easy to do), we can however confidently suggest that the roles of a model are given explicit attention from the outset of a modelling project.

References

Ackoff, RL (1979) "The Future of Operational Research is Past". *Journal of the Operational Research Society,* 30,,93-104

Bayer S, Bolt T and Brailsford S (2009) Examining the role of simulation models in health planning. *Proceedings of the 27th International Conference of the System Dynamics Society*, 26-30.

Bayer S, Bolt T, Brailsford SC and Kapsali M (2014) Models as Interfaces. In, Discrete-Event Simulation and System Dynamics for Management Decision Making, Eds. Brailsford SC, Churilov L and Dangerfield B. John Wiley and Sons, Ltd. Chichester, England, 125-39.

Bechky BA (2003) “Sharing Meaning across Occupational Communities: The Transformation of Understanding on a Production”. Organization Science, 14(3): 312-330.

Black L (2013) When visuals are boundary objects in system dynamics work. *System Dynamics Review*, Vol. 29, No. 2, pp 70-78.

Brailsford S and Hilton N (2001) "A Comparison of Discrete Event Simulation and System Dynamics for Modelling Healthcare Systems" *Proceedings of the 26th meeting of the ORAHS Working Group 2000*, Glasgow Caledonian University, Glasgow, Scotland.

Brailsford SC, Lattimer VA, Tarnaras P and Turnbull JA (2004) Emergency and On-Demand Health Care, Modelling a Large Complex System, *Journal of the Operational Research Society*, 55, 34-42.

Brailsford SC, Bolt TB, Bucci G, Chaussalet TM, Connell NA, Harper PR, Klein JH, Pitt M, Taylor M (2013) "Overcoming the barriers, a qualitative study of simulation adoption in Primary Care Trusts in the NHS" *Journal of the Operational Research Society*. 64,157-168.

Brailsford SC, Harper PR, Patel B and Pitt M (2009) “An Analysis of the Academic Literature on Simulation and Modelling in Healthcare”. *The Journal of Simulation*, 3, 130-140.

Brown JS and Duguid P (2001) ‘Knowledge and organization: A social–practice perspective’. Organization Science, 12(2): 198–213.

Carlile PR (2002) "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development". Organization Science, 13(4): 442-455.

Cetina KK (1997) "Sociality with objects, Social relations in postsocial knowledge societies", Theory, culture & society, US-based international Society for Social Studies of Science, 14(4),1-30.

Chahal K and Eldabi T (2008) System Dynamics and Discrete Event Simulation, A Meta-Comparison. *Proceedings of Simulation 2008 Conference*.

Department of Health, UK (2007) *World class commissioning, competencies*. Gateway reference, 8754

Doyle J and Sims D (2002) "Enabling strategic metaphor in conversation: a technique of cognitive sculpting for explicating knowledge". In A. Huff and M. Jenkins (Eds.), Mapping strategic knowledge. London: Sage.

Ewenstein B, Whyte J (2009) "Knowledge practices in design:The role of visual representations as 'Epistemic objects'", *Organization Studies*, 30 (1):7-30.

Fone D, Hollinghurst S, Temple M, Round A, Lester N, Weightman A, Roberts K, Coyle E, Bevan G, Palmer S (2003) "Systematic review of the use and value of computer simulation modelling in population health and healthcare delivery", *Journal of Public Health Medicine*, 25(4): 325–335.

Harper PR, Pitt, MA (2004) "On the challenges of healthcare modelling and a proposed project life cycle for successful implementation", *Journal of the Operational Research Society,* 55: 657–661.

Heracleous L, & Jacobs CD (2008) Understanding Organizations through Embodied Metaphors. Organization Studies, 29(1), 45–78.

Kapsali M, Bolt T, Bayer S and Brailsford S (2010) The boundary role of simulation models and the influence of the modelling approach, British Academy of Management Conference, Sheffield, 14-16 September 2010.

Kapsali M, Bolt T, Bayer S and Brailsford S (2011) The materialization of simulation: a boundary object in the making. HaCIRIC International Conference, Manchester, 26–28 September.

Lane DC (2000) "You just don't understand me: Modes of failure and success in the discourse between system dynamics and discrete event simulation". *LSE OR Dept Working Paper* LSEOR 00-34, London School of Economics.

Lehaney B and Paul RJ (1996) The use of soft systems methodology in the development of a simulation of out-patients services at Watford General Hospital. *Journal of the Operational Research Society*, 47, 864–870.

Morecroft J and Robinson S (2006) Comparing Discrete-Event Simulation and System Dynamics: Modelling a Fishery. Proceedings of the Operational Research Society Simulation Workshop 2006 (SW06) (J. Garnett, S. Brailsford, S. Robinson and S. Taylor, eds.). *Operational Research Society*, Birmingham, UK, pp.137-148.

Nemeth C, O'Connor M, Klock A, Cook R (2006) "Discovering healthcare cognition: The use of cognitive artefacts to reveal cognitive work". Organization Studies, 27(7): 1011-1035.

Norman DA (1991) Cognitive artefacts. In J. Carroll (Ed.), Designing interaction. Cambridge, U.K. Cambridge University Press. Pidd, M (2009) *Tools for Thinking: Modelling in Management Science*, 3rd Ed., John Wiley and Sons, Ltd. Chichester, England.

Pidd M (2007) "Making sure you tackle the right problem: linking hard and soft methods in simulation practice", In *Proceedings of the 2007 Winter Simulation Conference*, ed. Henderson, S.G., Biller, B., Hsieh,M.H., Shortle, J.D.T. and Barton, R.R. Piscataway, New Jersey: Institute of Electrical and Electronic Engineers, Inc.

Pidd M (2010) "Why modelling and model use matter" *Journal of the Operational Research Society*, 61:1, pp.14-24

QSR International Pty Ltd (2008) NVivo qualitative data analysis software, Version 8

Rheinberger HJ (1997) Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube, US: Stanford University Press.

Rittel H and Weber M (1973) "Dilemmas in a general theory of planning", *Policy Sciences,* 4,155-169.

Robinson S (2001) Soft with a hard centre: discrete-event simulation in facilitation. *Journal of the Operational Research Society*, 52(8), 905–915.

Robinson S (2004) Simulation: The Practice of Model Development and Use, John Wiley & Sons, Ltd, Chichester.

Rosenhead J (1978) "Operational research in health services planning", *European Journal of Operational Research*, 2:2, 75-85.

Rouwette EAJA, Vennix JAM and Van Mullekom T (2002) Group model building effectiveness. A review of assessment studies. *System Dynamics Review*, 18(1), 5-45.

Sapsed J and Salter A (2004) “Postcards from the edge: local communities, global programs and boundary objects”. Organization Studies. 25: 1515-1534.

Star S, Griesemer J (1989) “Institutional ecology, ‘translations’, and boundary objects: amateurs and professionals in Berkeley’s museum of Vertebrate Zoology”. *Social Studies of Science*. 19:387-420.

Sweetser A (1999) "A Comparison of System Dynamics and Discrete Event Simulation." *Proceedings of 17th International Conference of the System Dynamics Society and 5th Australian & New Zealand Systems Conference*: Wellington, New Zealand.

Tako AA and Robinson S (2009) Comparing Discrete-Event Simulation and System Dynamics: Users’ Perceptions. *Journal of the Operational Research Society*, 60 (3), pp. 296-312.

Waisel LB; Wallace WA and Willemain TR (2008) "Visualization and model formulation: an analysis of the sketches of expert modellers", *Journal of the Operational Research Society* 59:3, pp.353-361

Williams T (2008) Management Science in Practice. John Wiley and Sons, Ltd. Chichester, England.

Wilson JCT (1981) “Implementation of computer simulation projects in health care”, *Journal of the Operational Research Society*. 32(9): 825–832.

Yakura EK (2002) “Charting time: Timelines as temporal boundary objects”. Academy of Management Journal. 45(5): 956–970.

Zagonel A (2002) “Model conceptualization in group model building: A review of the literature exploring the tension between representing reality and negotiating a social order”. *Proceedings International Conference of the System Dynamics Society*, Palermo, Italy.

Table 1: framework for classifying the roles of simulation models

<table>
<tr><td colspan="2"></td><td colspan="2">Knowledge Roles</td></tr>
<tr><td colspan="2"></td><td>Epistemic Object
(create new insights)</td><td>Technical Object
(codify expert knowledge)</td></tr>
<tr><td rowspan="2">Functional Roles</td><td>Boundary Object
(communicate & share ideas among participants)</td><td>Collectively learn about system</td><td>Formalise collective understanding</td></tr>
<tr><td>Representative Object
(create realistic representation)</td><td>Explore & learn about real system</td><td>Codify & represent behaviour of real system</td></tr>
</table>

Table 2: Comparison of the features of the two case studies

Similarities	Differences
Both used System Dynamics	**Scope**: the DH model was generic and intended for national roll-out; local model was specific, tailored for local commissioning decisions
Both addressed the same problem and decision area	
Both had essentially the same purpose, although at different levels	**Participants**: the DH model used a large panel of domain experts and national data; the local model used a smaller group of functionally-relevant decision makers
Both used a facilitated multi-meeting expert group model-building process	
Both studied by parallel modelling observations and follow-up interview data collection	

Table 3: Object Use Descriptions

Object Use	**Description used in Questionnaire**
Boundary Object	Communication & sharing ideas among participants
Representative Object	Create a realistic & accurate representation of the system
Epistemic Object	Create new insight in the real system
Technical Object	Codify expert knowledge about the real system

Table 4: Quadrant Object Use Descriptions

Object Use Quadrant	**Description used in Questionnaire**
Boundary Object - Epistemic Object	Collectively learning about the behaviour of the real system
Boundary Object - Technical Object	Formalise a collective understanding of the system
Representative Object - Epistemic Object	Explore and learn about the behaviour of the real system
Representative Object - Technical Object	Codify and represent the behaviour of the real system

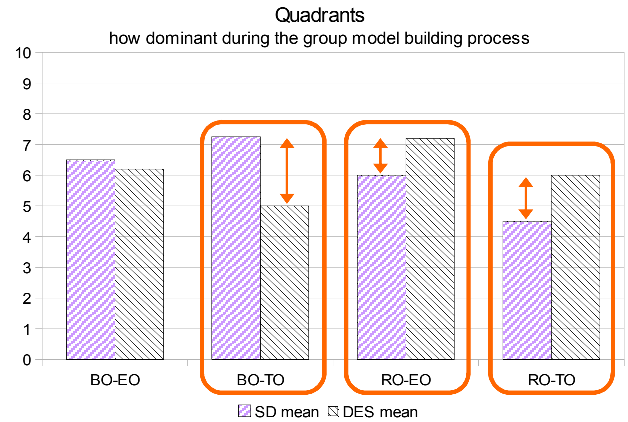
Table 5: Distinction between "process" and "model" in achieving specific aims

Aim	**Response**
Making better decisions	Completely mixed responses: neither process nor model dominated
Understanding system	Both DES & SD consultants placed much more emphasis on process
Exploring known options	Mixed response, small tendency towards final model, particularly among DES users
Creative thinking and new ideas	SD users hold strong views that process contributed more, while DES consultants were equally mixed

Figure 1: The primary tendency in the observed model usage for the two observations

DOMINANT PATTERNS OF OBJECT USE		*Knowledge Roles*	
		Epistemic Object (create new insights)	**Technical Object** (codify expert knowledge)
Functional Roles	**Boundary Object** (communicate & share ideas among participants)	PRIMARY WORKING SPACE OF LOCAL MODEL	
	Representative Object (create realistic representation)		PRIMARY WORKING SPACE OF DH MODEL

Figure 2: importance of object use during model building process



Appendix A: Case study interview outline

Post Model-building intervention: semi-structured interview quidelines

First, we would like to understand your background & role in the modelling…

Points to address:

- organisational role & role in modelling exercise
- experience in using this modelling / other modelling approaches
- initial expectations of the modelling engagement (what would happen, the outcome, the usefulness of the modelling approach)
- initial expectations of the model
  {for consultants, also: their perception of the client's expectations of the resulting model}
- how involved they were in the group model-building process
  Cover involvement at the meetings and outside these (including data provision)

Second, we would like your views on the organisation of the project

Points to address:

- scope and deliverables: initial agreement and changes over time
- availability of information: data and participation of relevant stakeholders
- What do you think about the organisation, management and control of the project? (incl. meeting timescale, meeting frequency, meeting structure, and meeting facilitation & contact outwith meetings)

Thirdly, we would like your views on the participant interactions…

Points to address:

- Did the group modelling process help participants to communicate? In what way? Which role did the model play to help you to express your views?
- Did the interactions at the meeting help participants understand each other? Did they resolve any differences in the views of participants? Which role did the model play in this?

- Has the process helped you to get a better understanding of each other's role and of the whole system? How?
- Did the model and the visual representation of the model and its output encourage involvement and interaction?
- Do you feel participants faced any cognitive/emotional challenges, such as biases, power dynamics, difficulty with abstraction, difficulty in persuasion, political behaviour or other?
- What was the role of the client in the process?
- Did you feel at any point that the project or the model was used by any participant to justify a decision or in pursuing other interests? Which are these interests?

Finally, your views on the resulting model…

As well as providing a general opinion on the usefulness of the model, points to address:

- Did the model represent the insights of participants accurately? Is the resulting model an acceptable synthesis of all views?
- Do you trust the model? - structural accuracy, reflection of reality, trust in any forecasts it may generate. (Try to identify whether this relates to the model or the data used for it.)
- Did the model serve to stimulate creativity in exploring new ideas and solutions? If so, in what way?
- Do you consider that model experiments are useful in understanding the consequences of different decisions/policies?
- Do you find the way the model and its outputs are presented visually helpful? In what way? What could make it easier to understand?
- Is the model (or any particular features) useful to decision makers who were not at the modelling exercise? (Why / why not? What would make the model more useful?)

In summary, any further reflections or points to note on the model building process or outcome?

Further points / questions to include for specific respondent groups:

Consultants:

- Did the *client* know what they wanted at the start of the modelling process?
- Was there anything the *client* could have provided early on to improve the modelling building / planning?
- Were there formalized plans as to how to run the project (phases, deliverables)? What form was the agreement between client and modeller?
- How typical was this observed engagement process and project from others. What impact did any differences have?
- Did you attempt to persuade the *participants* as to the usefulness of the modelling approach / accuracy of the model? If so how? Was there any difficulty in this?
- What is your perception of the *client*'s opinion of the model? Are you aware of the *participants*' opinions of the model?

Client / Commissioner:

- What was your primary motivation in commissioning this work? Your expectations at the time?
- On what basis did you chose the modelling technique and the consultants brought in to do this?
- How did you select the range of people invited onto the expert group? What was the perceived attitude of people approached to serve on the expert group?
- How did you motivate them to participate? Were potential benefits to other groups / organisation a motivation for the modelling?

Expert Group Participants:

- At what point did you understand the modelling technique and how the model would function?
- What was you motivation for participating in the exercise?

Non-participant, end-users:

- How was the model presented to you and how was it explained to you?

- Please explain what you perceive the model to be intended to do. Is this achievable?
- How do you expect to use the model which has been presented?

Appendix B: Coding Terms (Interviews and documents)

Background

- Choice of Modelling Technique
- Clinical experience
- Ownership of model
- Participant & Invitation Decisions
- Past Experience of Modelling

Modelling Process & Meetings

- Data collection
- Decisions in the modelling
- Dissemination of Model
- Expectations
- Exploring options & decisions
- Facilitation Techniques
- Model building activity
- Motivation for modelling
- Outwith meetings
- Participant's engagement & attitudes
- Participants' Understanding of Model
- Practicalities of group model building
- Simplicity & Complexity

Resulting Model

- Boundaries of model
- Dissemination of model
- Influences & Politics
- Training & Documentation
- Trust in Model - Accuracy of
- Visualisation

Use of the Model

- Communications function
- Cost-Benefit Analysis through modelling
- Motivation for Modelling
- Usage of model discussion
- Users of the model

Object Use Codes

- Boundary Object
- Epistemic Object

- Representative Object
- Technical Object

Appendix C: Modellers' survey

The survey was administered online. The question types were as follows:

- selecting one from a small set of options, listed below in italics;
- selecting one choice on a Likert scale of 1 to 5;
- ranking a number of options;
- free text (a very small number of questions).

BACKGROUND

1. To what extent do you use DES and other simulation / modelling techniques in your health sector consultancy? *(Primarily DES; Primarily SD; Mix of simulation methods; Mostly non-simulation approaches; Only other approaches; Unknown)*
2. What are some of the types of issues typical addressed in your health sector modelling?
(*Policy; Strategic (overview); Managerial; Operational; Detailed*)

A TYPICAL PROJECT

Please answer these questions with reference to a recent, fairly typical health-sector simulation modelling project using your primary choice of simulation methods you have engaged in.

3. How long do the typical projects usually last?
4. Please state technique for this "typical project" (*DES; SD; Other*)
5. What are your usual sources for data used to **structure** the model? *(Free text)*
6. What are your usual sources for data used to **parameterise** the model? (*Free text)*
7. Do you normally develop models collaboratively with the participation of expert groups? (*on a scale of 1 to 5 where 1 = Never and 5 = Always*)
8. Did the clients have the following aims before the modelling engagement and did their expectations change? (Y*es/No responses for Prior, During and Expectations Met)*
    a. How system works in reality
    b. Options to change system
    c. Helping planning and decision-making
    d. Others (please add)

9. Which of these is more important in a typical project? (*on a scale of 1 to 5)*
    a. where 1 = Capturing existing knowledge from domain experts more important, and 5 = Creating new knowledge is more important;

   b. *where 1 = Facilitating exchange of knowledge and information between project participants is more important, and 5 = Creating an accurate representation of reality is more important*

10. On a scale from 1 to 5, where 1 = "Very little" and 5 = "Very much", how important are the following uses of the model in a typical modelling project:
    a. Facilitate learning during the project within expert group or by the key client;
    b. Explore new ideas about the system;
    c. Experiment with the system to understand its behaviour;
    d. Predict system behaviour.

11. On a scale from 1 to 5, where 1 = "Very little" and 5 = "Very much", to what extent do you feel the final released model typically facilitates the communication of ideas and suggestions ..
    a. Within the client organisation?
    b. Among other interested organisations?

EXPERT GROUPS

Please answer the following questions if you use expert groups in model building, again thinking about a fairly typical recent project using your primary choice of simulation method.

12. How many members does such an expert group have?
13. What is a typical number of group consultations / group modelling sessions?
14. Does the client participate in expert consultations? (*Yes/No)*
15. Please use the table below to identify the participants' involvement at the various stages of the modelling process. (*Yes/No*)

	Modeller (you)	Clients	Clinicians	Managers	Data Analysts	Policy Makers
Defining the project goals / scope						
Structuring the model						
Parameterising the model						
Validating the model						
Experimentation with model						

Implementation of model results						
Evaluation & reflection						

16. On a scale of 1 to 5, please assess how dominant each of the following activities was during the group model building process (*where 1 = "Not at all" and 5 = "very dominant")*
    a. Collectively learning about the behaviour of the real system;
    b. Formalise a collective understanding of the system;
    c. Explore and learn about the behaviour of the real system;
    d. Codify and represent the behaviour of the real system;
    e. Communication & sharing ideas among participants;
    f. Create a realistic & accurate representation of the system;
    g. Create new insight in the real system;
    h. Codify expert knowledge about the real system.
17. On a scale of 1 to 5, where 1 = Become more engaged and 5 = Become less engaged, do you feel the willingness of participants to engage changed over the course of the project? Please comment on any changes in attitude of participants.
18. On a scale of 1 to 5, where 1 = Very and 5 = Not at all, could the model be competently used by a decision-maker with good understanding of the real-life system who was not involved in its development?
19. According to the level of importance, please rank from 1 to 5, where 1 is the most important and 5 is the least important, your perception of which of the following factors help your participants to understand simulation models:
    - Explanations from modeller & facilitator;
    - Discussions with other participants about the modelling;
    - Presentations and written documentation for the model;
    - Visual display of the model;
    - Animation as the model runs.
20. On a scale of 1 to 5, where 1 = Modelling process and 5 = Final computer model, what contributed more to the participants achieving the following aims:
    a. Making better decisions;
    b. Understanding the system;
    c. Exploring known options;
    d. Creative thinking and new ideas.
21. What would you describe as the most significant challenge in your typical simulation projects? (*free text)*