Maximising Stakeholder Learning by Looping Again Through the Simulation Life-Cycle: A Case Study in Public Transport

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ABSTRACT

Building a simulation model of a complex system requires significant investment of expertise, time, and expense. In order for an organisation to realise the greatest return on this investment, it is advantageous to re-use a model or extend the simulation model's life-cycle to maximise learning generated from it. Existing studies typically end after a 'single loop' of the simulation life-cycle, with the computer model produced at the end of it suitable for addressing the initial requirements of stakeholders. Here we explore how to further extend the modelling life-cycle by adding a 'second loop' in which an existing simulation model is introduced to a new group of stakeholders and then enhanced to capture additional features of the system that are of interest to this new group, but were not identified as requirements by the first group. Developed from real-world experience working with the large train operator Eurostar International Limited, we present details of our proposed methodological framework and highlight the tangible benefits of adding a second loop to the simulation life-cycle. We discuss the roles of modellers and stakeholders in the two loops of the life-cycle and compare and contrast the relationship between the two parties in each.

KEYWORDS

simulation, stakeholder engagement, simulation life-cycle, multi-methodology, hierarchical process modelling, model re-use

1. Introduction

Simulation model development is known to be a highly iterative process (Balci, 1994; Robinson, 2013; Willemain, 1995). As the modeller progresses through the simulation life-cycle loop (i.e., conceptual modelling, model coding, experimentation, and implementation) and begins to test out the model, the modeller may be required to repeat some or all of these steps (Robinson, 2004). Existing studies typically end after a full loop of the life-cycle, with the computer model produced at the end of it suitable for addressing the initial requirements of stakeholders. In large, complex organisations, inevitably not all stakeholders can be involved in the modelling process. Furthermore, stakeholder needs and interests often change over time. In this study, we examine the value of performing two complete loops of the simulation development life-cycle with two different groups of stakeholders in order to extend the lifetime of a simulation model.

By way of example, we discuss a study undertaken in collaboration with Eurostar International Limited (EIL), the high speed rail company connecting London with

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continental Europe. Due to growth in demand in recent years, EIL has on occasion seen significant congestion at security screening and boarder controls within its terminals and the formation of long passengers queues. A number of initiatives are underway at EIL to address this issue. We discuss one such project in which a team of academics worked in partnership with EIL to develop simulation models of each main terminal. These models were developed with input from key stakeholders at EIL, including both frontline staff and senior management, to explore new ideas and test proposed changes to terminal layouts and or operational procedures prior to implementation.

We focus specifically on development of a hybrid simulation model of EIL's St Pancras International Station, located in central London. This hybrid model, developed in AnyLogic (2019), was originally designed to simulate passenger flows at the London terminal and assist with identifying and mitigating bottlenecks in the system. Its development began following a facilitated workshop to identify EIL stakeholder requirements. The model was subsequently extended by engaging a new group of stakeholders for the purpose of trialling the combined use of email messaging and dynamic adjustments to check-in opening times in order to actively control peaks in passenger arrival rates and reduce queuing.

In previous work (Jones, Kotiadis, & O'Hanley, 2019), we provided an overview of a hybrid model of EIL's St Pancras International Station and highlighted some of the challenges of engaging new stakeholders with an existing model and the benefits of doing so. Details of the model's design and empirical results can be found therein. In the current study, we provide methodological details of developing this hybrid simulation model in collaboration with stakeholders and then extending it by performing a second loop of the simulation life-cycle with a new group of stakeholders. A methodology for performing a second loop of the simulation life-cycle with a new set of stakeholders is, to the best of our knowledge, not present within the existing literature.

The work here contributes to the simulation life-cycle literature and practical understanding of the modelling process by proposing a methodology for extending a model's life-cycle via a second loop. The study also contributes to the stakeholder facilitation and hybrid simulation literature through a discussion of the advantages a hybrid simulation model can provide in terms of facilitating stakeholder engagement in the simulation life-cycle. Further, our study contributes to the conceptual modelling literature by demonstrating how Hierarchical Process Modelling, a method for modelling complex systems using hierarchical process decomposition (Davis, MacDonald, & White, 2010; Hall, Blockley, & Davis, 1998; Jones, Sooriyabandara, Yearworth, Doufexi, & Wilson, 2016; Marashi & Davis, 2007; Marashi, Davis, & Hall, 2008), can be used as a problem structuring method (PSM) to support conceptual model development and experimental design. Of note, this study is among the few focused on the simulation life-cycle applied outside the healthcare sector.

The remainder of the article is organised as follows. First, we discuss relevant background literature (Section 2). Next, we provide a high-level overview of our methodology (Section 3) before discussing in detail our methodology for engaging stakeholders in the first and second loops of the simulation life-cycle using the case of EIL as an example application (Sections 4). We then identify key challenges of each loop of the simulation life-cycle, comparing the roles of the modeller versus stakeholders, as well as the importance of PSMs and stakeholder facilitation (Section 5). We end by offering a few concluding remarks (Section 6).

2. Literature Review

2.1. The Simulation Life-Cycle and Model Re-use

There is an extensive literature describing and categorising the various steps undertaken as part of a simulation study (Balci, 2012; Banks, Carson, Nelson, & Nicol, 2010; Hoover & Perry, 1989; Kreutzer, 1986; Law, 2007; Nance, 1994; Pidd, 1988; Robinson, 2004; Sargent, 2001). These frameworks for the so called *simulation life-cycle* primarily vary in their level of granularity. For example, the framework of Pidd (1988) has just three stages, but, Kreutzer (1986) divides his into nine. However, the process is generally very similar in each. Robinson (2004) depicts a life-cycle with four stages: 1) conceptual modelling, 2) model coding, 3) experimentation, and 4) solution implementation. He goes on to elaborate how the first two steps of the life-cycle loop consist of a series of substeps (description, conceptual model, design, coding). For the purposes of the present study, we will rely on the life-cycle description of Robinson (2004).

Model re-use has also received significant attention in the literature (Arons & Boer, 2001; Balci, Arthur, & Nance, 2008; Balci & Ormsby, 2007; Bell, Mustafee, De Cesare, Lycett, & Taylor, 2006; Brown & Powers, 2000; Fletcher, Halsall, Huxham, & Worthington, 2007; Gunal & Pidd, 2006; Hurrion, 1976; Kaylani et al., 2008; Malak & Paredis, 2004; Paul & Taylor, 2002; Pidd, 1992; Pidd & Carvalho, 2006; Pierce & Drevna, 1992; Sinreich & Marmor, 2004; Spiegel, Reynolds, & Brogan, 2005). Re-use can provide a range of benefits, such as enhancing study feasibility and efficiency by reducing the time and cost involved. Time saved, in turn, can instead be used to extend the scope of the project (e.g., simulating more scenarios). On the other hand, while the time and cost implications of developing a simulation model from scratch can be off-putting for many organisations, various authors suggest that time spent developing a model is an important factor in generating learning (Monks, Robinson, & Kotiadis, 2009). The process of model development is key to understanding the problem and, to an extent, solving it (Robinson, 2004). Although new stakeholders involved with extending a simulation model may not achieve the same level of learning due to lack of time spent developing the original simulation model (Monks et al., 2009), this can be ameliorated to some degree through structured engagement (e.g., live demonstrations, facilitated discussion, and follow-on presentations).

Our current work relates to model re-use by taking an existing model and extending it by adding a second loop of the simulation life-cycle. Our specific example involves extending a hybrid simulation model. Hybrid simulation, in which a single conceptual model is coded using more than one simulation paradigm (Brailsford, 2015; Brailsford, Eldabi, Kunc, Mustafee, & Osorio, 2018; Mustafee et al., 2017), has gained popularity in recent years. Hybrid models that blend agent-based modelling (ABM) with discrete-event simulation (DES), such as the one presented in Jones et al. (2019), are most prevalent in the service industry (Brailsford, 2014) because, as Siebers, Macal, Garnett, Buxton, and Pidd (2010) remarks, the application of ABM is often appropriate "*when the goal is modelling the behaviours of individuals in a diverse population*". There are a few examples of hybrid simulation being used to model passenger movements in the transport industry. Bakar, Fauzan, Majid, Allegra, and Fakhreldin (2018), Majid, Fakhreldin, and Zamli (2016) and Félix and Reis (2016), for example, consider passenger movements in airport terminals through security controls using hybrid DES and ABM simulations. Independently, each study concludes that a hybrid approach provides a closer match to the real world compared to any single simulation paradigm.

It would appear that the simulation life-cycle and model re-use literature has not kept pace with the growth of hybrid simulation. All of the previously mentioned studies on the modelling life-cycle and model re-use consider a *single* simulation paradigm; none reference hybrid models. It has been noted that the increased likeness to the real world associated with hybrid simulation can facilitate greater stakeholder engagement with the model (Jahangirian, Borsci, Shah, & Taylor, 2015). The potential benefits this might provide throughout the simulation life-cycle has not been addressed in the existing literature.

2.2. Problem Structuring Methods and Facilitation

Stakeholder involvement throughout the simulation life-cycle is generally considered vital to the success of a simulation study (Eldabi, Paul, & Young, 2007; Fone et al., 2003; Gunal & Pidd, 2005; Jun, Jacobson, & Swisher, 1999; Lowery et al., 1994; Wilson, 1981). Neglecting to engage stakeholders in the life-cycle of a simulation study will likely lead to findings not being acted upon (Brailsford & Vissers, 2011; Fone et al., 2003; Young, Eatock, Jahangirian, Naseer, & Lilford, 2009). At the same time, involving all relevant decision makers in a large organisation throughout every step may simply be unrealistic.

Various studies have explored the advantages of engaging stakeholders in the modelling process (Kotiadis, Tako, & Vasilakis, 2014; Robinson, Worthington, Burgess, & Radnor, 2014). Tako and Kotiadis (2015) present a framework for involving stakeholders throughout the simulation life-cycle using facilitated workshops and problem structuring methods (PSMs). Most studies typically end after the first loop of the life-cycle. The desired outcome at the end of this is the delivery of a computer model suitable for addressing the initial requirement of stakeholders. Little work exists about exploring the possibility of extending the modelling life-cycle to capture changing stakeholder requirements or including new requirements based on input from a different group of stakeholders.

PSMs have evolved considerably over the past decades (Mingers & Rosenhead, 2001). PSMs contrast sharply with traditional 'hard' operational research (OR) techniques (Mingers & Rosenhead, 2004). Their aim is to provide a structured approach to dealing with unstructured problems involving multiple actors and perspectives, often involving conflicting interest, significant uncertainty, and factors which are not easily quantifiable. To achieve this, they must be able to account for alternative perspectives, be accessible to the actors involved to facilitate genuine participation, be flexible and iterative, and allow local rather than global improvements. Common PSMs (see Franco and Montibeller (2010); Kotiadis and Mingers (2006); Mingers (2001a)) include soft systems methodology (SSM), strategic options development and analysis (SODA), strategic choice analysis (SCA), drama theory, group model building (GMB), and multi-criteria decision analysis (MCDA). These methods provide subjective problem analysis, incorporating many views, and aid researcher-client engagement in the modelling process (Franco & Montibeller, 2010). Of the methods described by Franco and Montibeller (2010), SSM appears to be the most frequently used in DES studies (e.g., Kotiadis and Mingers (2006); Tako and Kotiadis (2015)). GMB is traditionally linked to system dynamics (SD) models (Andersen & Richardson, 1997; Peck, 1998; Richardson & Andersen, 1995) but the afore mentioned SSM+DES studies take inspiration from this literature in developing their methodologies.

The need for increased transparency in the modelling process is identified as one of the key challenges in the adoption of PSMs (Checkland, 2006; Eden & Ackermann, 2006; Rouwette, Vennix, & Felling, 2009; Westcombe, Alberto Franco, & Shaw, 2006). PSMs produce models, however, these are not usually intended to lead to prescriptive, let alone optimal solutions. Rather, they are intended primarily to facilitate negotiation and agreement. The model plays a key role in enabling negotiation among stakeholders and finding agreement through debate and the emergence of shared understanding. PSMs apply formal methodologies to construct models whilst ensuring there is sufficient ambiguity to enable participants to consider and change their views (Eden & Ackermann, 2006). The resultant model of a PSM is a transitional object designed to capture stakeholders understanding of the system in question (Eden & Sims, 1979). It is a natural extension to take the model and understanding derived from a PSM and develop this into some sort of simulation model.

In the study that follows, HPM is used. HPM was developed as a method for modelling complex systems using hierarchical process decomposition (Davis et al., 2010; Hall et al., 1998; Jones et al., 2016; Marashi & Davis, 2007; Marashi et al., 2008). The method produces a tri-valued representation of process performance based on interval numbers, thereby allowing for explicit representation of process performance and uncertainty. The value of HPM has been demonstrated through application to numerous complex socio-technical systems problems in areas as broad as flood defence systems, oil exploration projects, telecommunications research investment planning, asset management, and performance management (Davis & Hall, 2003; Davis, MacDonald, & Marashi, 2007; Hall et al., 1998; Jones et al., 2016; Marashi & Davis, 2007). The methodology is closely related to 'purposeful activity modelling' that is central to SSM (Checkland, 2000; Mingers, 2011). In short, HPM begins by focusing on a top-level (transformational) process. Then, by repeatedly questioning 'how' this process works or can be achieved, the top-level process is decomposed into a set of sub-processes and a model consisting of several layer emerges. This simple language game continues until hitting upon specific actions or unresolved issues. For presentation purposes, the diagram is illustrated as a hierarchy in which sub-processes are considered conceptually to be contained within the above level. The higher level processes can be though of as consisting of each lower level processes on the basis of a "part-of" relationship. The final model provides a representation of all known processes that make up the top-level process (Jones et al., 2016). To our knowledge, there are no existing examples of HPM being used in combination with simulation modelling.

To successfully use PSMs, the modelling team needs facilitation skills to effectively enable stakeholders to engage with the model building process and reach agreement (Ackermann, 1996; Andersen & Richardson, 1997; Richardson & Andersen, 1995). The modelling team must demonstrate both process skills and content skills. Sufficient expertise in the chosen PSM is also essential. Often, the modelling team must cycle between different stages of the PSM to best address the group's needs, as opposed to simply following a linear process (Eden & Ackermann, 2006). This allows the modellers to seamlessly assist the group in developing a conceptual model. It is worth pointing out, however, that discussion in the literature of PSMs and effective facilitation is limited exclusively to a single life-cycle loop and does not cover cases when the life-cycle is extended or models are re-used.

Multi-methodological approaches have been widely investigated (Jackson, 1999; Midgley, 1997; Pidd, 2004; White & Tacket, 1997), although sometimes under different names (e.g., coherent pluralism, creative design of methods, pragmatic pluralism, complementarity). The authors of these studies argue that significant benefits can be realised by combining different methodologies together, primarily for their ability to tackle complex problems from a range of perspectives, which can generate new insights

(Mingers, 2001b). While combining several PSMs together is relatively unproblematic, combining PSMs with more traditional hard OR techniques, such as simulation, is known to be more challenging (Munro & Mingers, 2002).

3. Problem Overview

Here we present details of the process of engaging stakeholders and extending the lifetime of simulation model by iterating through the simulation life-cycle a second time. Our multi-methodological approach combines traditional 'hard' OR with 'soft' methods for incorporating stakeholder involvement in the simulation life-cycle (Robinson, 2004). In particular, we rely a number of prescribed stakeholder activities to ensure proper engagement throughout two different loops of the simulation life-cycle.

In both life-cycle loops, the simulation model was translated into a computer model (i.e., model code and post model coding) and followed by extensive experimentation with the model. Specific details of the model and summary results can be found in Jones et al. (2019). That study mainly focused he 'hard' technical details of EIL's station and solutions to address passenger throughput problems. Here we present the 'soft' challenge faced by EIL around stakeholder agreement on the source of the problem and reaching a set of proposed actions. Our discussion focuses on the stakeholder engagement activities of each life-cycle loop. Below we provide a summary of the stakeholder engagement problem.

3.1. Stakeholder Engagement

EIL's challenge can be summarised by what Rittel and Webber (1973) describe as a 'wicked problem'. While highly cited and influential across many disciplines, the principles introduced by Rittel and Webber (1973) are captured succinctly in the more recent work of Mingers (2011) in a way that is relevant to managing complex systems. The following embellishes Mingers' definition with characteristics of the EIL problem context to illustrate the relevant point:

(1) *Stakeholders in the problematic situation have different worldviews.* Improving the management and operation of such a complex system as EIL's terminals requires both a shared understanding and shared commitment to action through a process of deliberation that is likely to start with disparate and possibly conflicting views. For example, those stakeholders responsible for customer experience likely see the problems associated with station throughput differently from those responsible for revenue management. Further, front-line staff may have ideas on actions that could be taken to improve the throughput, however, these will be heavily influenced by their individual experience and the impact they will have on their role and will likely be very different from the views of their managers who maintain a wider system perspective.

(2) *There is no clear definition of the problem from the stakeholders.* Although the long queues of passengers are clear to all, the differing priorities of EIL stakeholders (those mentioned and several others) in the system makes them view the situation differently, hence, making defining exactly what the problem is and its true source, highly ambiguous. As an example, the security contractor may see a risk of failing to maintain security standards when faced with the pressure to deal with such high numbers of passengers, while station staff see the problem as

having to manage frustrated passengers and revenue management see the problem as having to compensate passengers who missed their train as a result of the queues.

(3) *The objectives of any interventions require agreement that is difficult to obtain.* The existence of multiple different priorities poses a significant challenge for EIL stakeholders to agree where best to direct effort to and improve the situation. However, agreement must be obtained in order to implement effective action. For example, the station managers need the buy-in of front-line staff in order to effectively implement any process changes. Similarly, although revenue management may see an opportunity to increase profits, customer experience personnel may worry about the long term impact on the organisation's reputation. When evidence of the long term impacts of a decision like this is unclear, considering it against short term gains presents a topic of debate for senior leaders representing these respective parts of EIL.

    Further, different groups of stakeholders involved in the problem, although under contract from EIL, come from other organisations (e.g., the security provider, UK and French boarder control). The structure and culture of these organisations differs from EIL and they are influenced by other organisations and factors (i.e., government and auditors). Although regular communication exist between all of these parties, the set of different worldviews and interpretations of the problem make agreeing on actions difficult.

(4) *Definitions of success for interventions require agreement between stakeholders.* In parallel with defining the problem, defining a measure of success is equally challenging. As mentioned, some of EIL's stakeholder priorities conflict and in order to satisfy one, inevitably, others must lose out.

(5) *The problematic situation is characterised by high levels of uncertainty.* Each group of stakeholders may identify a preferred course of action, but it is likely even they will recognise risks with this choice. Other groups of stakeholders are likely to view the risks as greater than the rewards and so oppose the actions. Disruptive events always lurk to disrupt the best-laid plans of EIL's station teams. Being aware of the vast range of possible disruptions is central to selecting among possible interventions.

A shared understanding among all stakeholder of each group's worldviews, preferred actions, and associated uncertainty is key to addressing the problem situation. To help address this, EIL began in late 2018 a collaborative research project with the authors of this study to bring new expertise in simulation modelling into the business in an effort inform its operational and strategic planning processes. Over the course of a year, one of the academic team (WJ) worked on a daily basis with EIL staff to develop a number of bespoke simulation models, including detailed models of individual stations.

3.2. Simulation Life-Cycle Loops

The first and second loops of our study follow the life-cycle structure of Robinson (2013). Fig. 1 provides an overview of the two simulation life-cycle loops we completed. In this study, we focus on step one of each life-cycle loop, conceptual modelling and the process of engaging stakeholders in this activity.

We adopt a similar approach to Tako and Kotiadis (2015) by engaging stakeholders throughout the life-cycle. This involves using structured workshops to initiate engagement with stakeholders, aiding conceptual model development and ensuring that they

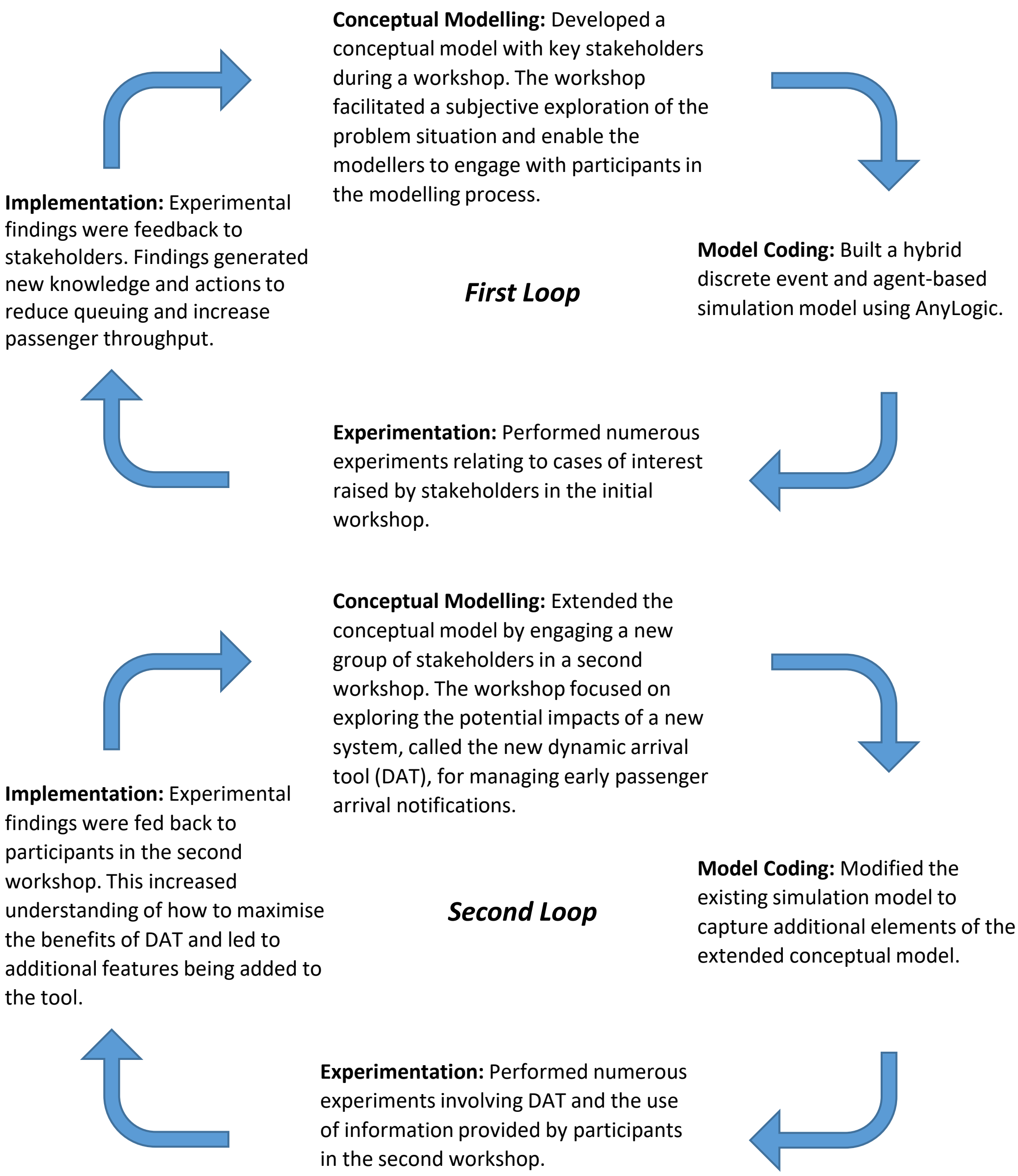

Figure 1. A high-level summary of the methodology used in this study. Shown are the sequence of steps for the first and second simulation life-cycle loops.

are willing to act on simulation findings later on (Brailsford & Vissers, 2011; Fone et al., 2003; Young et al., 2009). The basic aim of these workshops was to explore subjectively the problem situation (i.e., by incorporating many different viewpoints) and enable the modellers to engage jointly with workshop participants in the modelling process (Franco & Montibeller, 2010). More specific objectives of these workshop were several fold. The first was to define the system to be modelled and identify its boundaries. Second was to decompose the system into its constituent processes and activities and map their interconnections within the system. From this, a simulation model can then be proposed (Tako & Kotiadis, 2015). Third, workshops are useful in identifying areas for further exploration using simulation and opportunities for a simulation study to add value.

Tako and Kotiadis (2015) suggest using Soft Systems Methodology (SSM) as a tool to collaboratively develop a conceptual model with stakeholders. Here we use Hierarchical Process Modelling (HPM) as an alternative (see Section 4.1). The modelling team had experience using this technique and judged the situation a good opportunity to experiment using HPM as part of the simulation development process. There is extensive literature on defining PSM characteristics (e.g., Ackermann (2012); Yearworth and White (2014)) and evidence demonstrating they are well suited to dealing with wicked problems in many domains (e.g., Davis et al. (2010); Jones et al. (2016)). Some studies even claim that problem structuring is an essential activity in relation to planning within complex systems (Yearworth et al., 2015). The current study considers the key properties of a PSM as articulated by the 'generic constitutive' definition of Yearworth and White (2014). HPM was used as a structured way to support conceptual model development by mapping the system and different processes involved and identify possible changes to improve the system.

For any highly complex and evolving real-world system, it is unrealistic to expect one will be able to capture all of its features and requirements in a single loop of the simulation life-cycle. Invariably, stakeholder requirements and features of the system that are considered important may change over time as the system or the environment change. To address this, a second loop of the simulation development life-cycle may be required to extend an existing simulation model.

As a case in point, we explained in Jones et al. (2019) how additional requirements for EIL's London simulation model came to be known after the initial model was built by involving a second group of stakeholders. We described how, from a technical perspective, the simulation model was extended to capture additional requirements, in particular a proposed 'dynamic arrival tool' (DAT) that would allow EIL to modify arrival time information on passenger tickets in order to shift/extend the passenger arrival distribution ahead of any train. We presented experimental results of model extensions and explained the impact of those on the DAT implementation. Here, we give details about how the first and second groups of stakeholders were engaged through structured workshops and how this was used to develop an initial and then an extended conceptual model.

4. Methodological Approach

4.1. First Loop Workshop

A two-hour workshop was held with 12 key stakeholders involved in the operation of EIL's London terminal. Participants included station and service managers, terminal duty managers (TDMs), and front line staff. The group also included representatives of the strategy, communications, and customer care teams. The aim of the workshop was to facilitate a subjective exploration of the source of congestion and queues at the London terminal and enable the modellers to engage jointly with the EIL representatives in developing a conceptual model. Main objectives of the workshop were to define the London terminal system and its boundaries. This is an essential first step in conceptual model development (Tako & Kotiadis, 2015). Additional objectives were to decompose the system into its constituent processes and activities and map their interconnections. The modelling team wanted to understand from the stakeholders the range of issues that occurred in the station and their thoughts on how the operation could be improved.

Led by two facilitators and supported by two assistants responsible for timekeeping and note-taking, the workshop consisted of five distinct parts (see Tab. 1). The workshop was highly interactive, with the stakeholders involved doing the majority of the talking and facilitators providing guidance as necessary. Throughout, simple presentations with images and open-ended questions were used to prompt group discussion. Below, we elaborate on the different parts of the workshop.

Part 1: Introduction

The lead facilitator provided an introduction. This included practicalities of the session (i.e., personal introductions and format of the workshop), but the main objective of the introduction was to 'set the scene' and ensure participants were comfortable with sharing ideas and felt confident their contributions would be valued. The facilitator pitched the idea that EIL (as a whole) is a complex system of systems whose purpose is to carry customers between destinations. To run smoothly, those systems need to work in harmony. If any system or part struggles, the other systems and parts must support it. Further, the facilitator suggested that the London terminal itself is a very complicated system and all the participants attending the workshop are an integral part of that system. The facilitator specifically highlighted the importance of the roles of each participant within the organisation. The facilitator highlighted the problem of long passenger queues sometimes experienced in the terminal, emphasising that queues are a result of the system struggling to cope with the demands put on it, rather than the fault of any particular person or group.

The facilitator concluded the introduction by explaining the aim of the workshop was to explore and understand what "we" (i.e., the group of participants and facilitators) could do to ensure the part of the system we have control over (i.e., the terminal) performs as best as possible, even when there are factors outside our control and parts of the wider EIL system may be struggling.

Part 2: Initial group discussion focusing on frustrations

Table 1. Overview of the workshop for the first simulation life-cycle loop.

Part	Description	Time (mins)
1	Introduction	20
2	Initial discussion focusing on frustrations	20
3	Continued discussion focusing on improvements	20
4	Group activity — HPM	50
5	Wrap up	10

A structured brainstorming session was conducted to gather perspectives on frustrations stakeholders have with the current system. The session further helped set the tone of the workshop, encouraging honest discussion on the challenges faced by stakeholders and EIL and promoting the sharing of ideas. This followed preset format. For five minutes, the group was asked to brainstorm individually on a specific question and write his/her ideas on post-it notes. Afterwards, the facilitator led a five-minute group discussion in which participants shared their ideas. This was subsequently repeated with a second question. This time, for variety, participants were asked to brainstorm in pairs. Then, as previous, ideas were shared. Each time ideas were shared, a second facilitator collected the post-it notes and collated them on a display board. Common themes were identified and related post-it notes grouped together.

Part 3: Continued group discussion focusing changes

The structured brainstorming approach was repeated, but facilitators moved the focus of the discussion to possible changes (i.e., interventions) that could be made to improve the system. Facilitators variously assigned participants into pairs or small groups and ensured that participants worked with different people each time. Again, ideas were collected and displayed and common themes identified.

Part 4: Facilitated model building

This stage of the workshop was divided up as follows. For approximately 10 minutes, facilitators explained what HPM is and how it works (see more below). Then, for 25 minutes participants worked in two different groups to develop an HPM, followed by 10 minutes for the groups to give feedback on the models they had developed and another five minutes of discussion on how the models they had produced aligned with wider EIL objectives.

HPM was employed in this study as a tool for managing the complexity of problem structuring and to understand how EIL's transformational process of 'improving customer experience on busy days in the short- and long-term' could be achieved. Workshop attendees were divided into two groups, with one group looking at short-term improvements, the other long-term improvements. Implementation of short- and long-term improvements are core elements of EIL's overarching business strategy and better understanding of them necessarily impacts on decisions about where best to focus effort and resources. The facilitators explained, citing examples from other applications, how the HPM methodology works. Within each group, workshop participants were asked to apply HPM for the transformational process they were tasked with analysing. A facilitator was on hand for each group throughout the activity to answer any questions the participants had regarding the modelling process. Further, if progress of model development slowed, the facilitators would prompt the participants by asking questions that encouraged further decomposition of specific processes in order to produce a more detailed model. Fig. 2 shows an example of a partially complete HPM for EIL's transformational process of 'improving customer experience on busy days in the short-term'.

The HPM models produced out of the group model building session aided in understanding of what improved customer experience in the terminal might encompass and the actions on which this might depend. The models evolved through several iterations and continued discussion with the group. At various points, individuals would propose additions to the model and the group would debate them.

After 25 minutes, the groups had both produced detailed models and where satisfied that their models captured all the main ideas and issues they believed were relevant. A representative of each group presented their model to the rest of the workshop par-

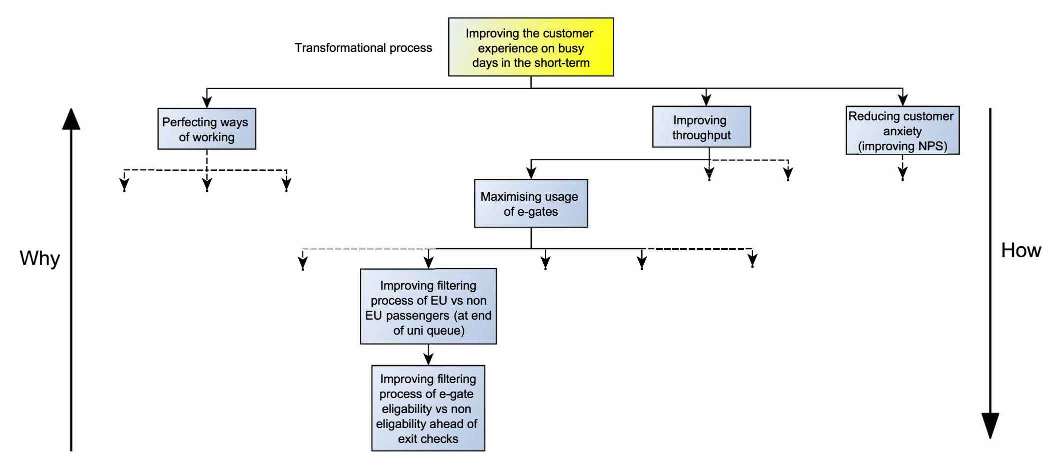

Figure 2. Partially complete hierarchical process model (HPM) produced by EIL workshop participants. Higher level processes can be viewed as consisting of lower level processes on the basis of a "part-of" relationship.

ticipants and there was an opportunity for the other participants and facilitators to make comments. All workshop participants agreed that both models decomposed the top-level transformational process well and that the resulting models were representative of both the system and the possible actions that could be taken to actualise improvements.

As a final activity of the workshop, participants were asked to look again at their HPMs and extend the models by adding a layer above the specified transformational process. The statements they produced represented how the workshop participants understood their system model addressed the wider organisation's objectives.

Part 5: Wrap up

The facilitators thanked the participants for their contributions, outlined next steps of the project, and provided a rough timeline. The facilitators emphasised the importance of workshop participants being involved throughout the project. In particular, their continued involvement with and feedback on the development of the simulation model were essential for the project's success.

4.2. Analysis of First Loop Workshop Findings

For the transformational statement 'Improving customer experience on busy days in the short-term', the groups final HPM broke the highest level statement into three statements representing the three main forces driving improved customer experience: 'perfecting ways of working', 'improved throughput', and 'reducing customer anxiety'. These were further broken down into lower level processes until the high-level requirements could be linked to specific actions or unresolved issues. Fig. 2 provides a reduced version of the full model, which grew to include twenty actions in the lowest level. For the transformational statement 'Improving customer experience on busy days in the long-term', the groups final model broke the highest level statement into five statements (results not shown). This was further expanded to twelve actions in the lowest layer. The full HPM diagrams cannot be published for confidentiality reasons.

The process models produced from the workshop helped define the system and its boundaries from the perspective of key stakeholders. The links drawn between processes captured in the model expressed the stakeholders' understanding of how

Table 2. Overview of the workshop for the second simulation life-cycle loop.

Part	Description	Time (mins)
1	Introduction	10
2	Discussion on influencing passenger arrival times to minimise queues	30
3	Group activity. TDMs asked to demonstrat on real timetables how they would modify passenger arrival times.	30
4	Explanation of existing simulation model and discussion of proposed extensions	20
5	Wrap up	10

parts of the system or actions influenced the system as a whole. Capturing stakholders' shared vision of the system was key to developing an underpinning conceptual model, which could later be translated into a simulation model by the modelling team (Tako & Kotiadis, 2015). After the workshop, the HPMs were reproduced electronically and shared with the workshop participants along with an e-mail again thanking them for their contributions. Participants were invited to contact the modellers at any time with further questions or to raise issues/ideas they feel should be captured by the modelling process.

4.3. Second Loop Workshop

After an initial model was developed and a full loop of the simulation life-cycle completed, a second workshop was held with eight TDMs to explore the possibility of extending that model to evaluate the impact of the proposed new DAT. Also present were two representatives of the software team that developed the DAT and two members of EIL's operations staff who manage it. Within this group, just one of the TDMs had been present in the first loop workshop. The group's objective was to develop a conceptual model (Robinson, 2013) that incorporated the potential effects of the new DAT system. Two facilitators led the workshop, which consisted of five parts. The different parts of the workshop are summarised in Tab. 2 and discussed in more detail below.

Part 1: Introduction

The lead facilitator briefly outlined the workshop format before moving on to introduce DAT. Participants in the workshop were already aware of the tool, however, the facilitators were keen to reiterate why it was being introduced and how it could benefit the business (specifically, clearer instructions to passengers at lower cost).

Part 2: Group discussion

The facilitators led a group discussion. The TDMs gave shared opinions on the effectiveness of encouraging passengers to arrive early (EIL already did this via SMS (text message), a system which the DAT intended to replace) in terms of passenger behaviour, queue lengths in the terminal, passenger satisfaction, potential problems that might arise, and so on. They further indicated the factors that influence their choice of days and particular services to target passengers with these notifications.

A structured brainstorming approach was used asking TDMs to note their ideas on post-it notes, which were then shared and collated into similar themes (like in the workshop of the first loop).

The facilitators then moved the discussion to the TDMs' experience of the current SMS system. They were asked to explain what impact they thought it had on the system. Here, an open discussion format was used in which TDMs took turns to share their thoughts with the group. In brief, TDMs were in agreement that it is beneficial to notify some passengers to arrive early on busy days, however, they admitted that sometimes it seemed to have no tangible benefit and that it probably was not being used to maximum effect.

Part 3: Facilitated group activity

The participants were subsequently divided into three groups. A sample day's timetable with service times, corresponding passenger numbers, and profile information, in a format familiar to all participants who deal with this sort of data each day, was given to each group. The sample was representative of a high passenger volume day, with the number of passengers similar to those EIL would expect on the busy days of the year. The groups were invited to mark-up the timetables indicating which departure times and corresponding groups of passengers they would like to notify to arrive earlier than the typical 45 to 60 minutes and by how much (i.e., 60-75 or 75-90 minutes ahead of the scheduled departure). Finally, they were questioned if and by how much they would modify check-in times. Interestingly, each group applied different strategies for this task, applying notifications to different services and providing conflicting justifications. A fuller discussion of workshop findings is provided in Section 4.4.

Part 4: Simulation explanation

The facilitators proposed the idea that due to the highly congested timetable and many possible options for changes, adjusting the passenger arrival times to minimise queue length is very difficult. Adjusting the arrival information for any service changes the behaviour of those passengers and has a ripple effect throughout the full day's timetable.

The existing simulation model, which did not incorporate the existing SMS system or DAT, was presented to workshop participants along with the original HPMs (see Fig. 2) produced in the first life-cycle loop. The facilitator explained the advantages of the simulation methodology employed, how it had been utilised to support EIL so far, and how the scope of the work could be extended to capture the proposed DAT systems and its impact on passenger arrival times. The modeller/lead facilitator discussed with the group how this additional extension might fit into the HPM models. The modeller explained that, further to some additional model development, the timetables marked-up by the groups during the workshop could be captured in the model and simulated, including the impacts of the passenger profile, to test the impact of early passenger arrival notifications.

One of the key objectives of explaining simulation was to create buy-in from the stakeholders and build trust in the model, such that TDMs would be willing to trust findings and act on them. We discuss the process of developing buy-in in greater depth in Section 5.

Part 5: Wrap up

The facilitators thanked the participants for their contributions to the workshop, outlined next steps of the project, and provided a rough timeline. Like in the first loop workshop, the facilitators emphasised that the modelling team wanted to maintain the involvement of workshop participants throughout the second phase of the project and how their feedback on the extended simulation model would be essential for the project's success.

4.4. Analysis of Second Loop Workshop Findings

TDMs were in general agreement that notifying passengers to arrive early did have an impact on the systems and that this could be used as a tool to reduce queues. Notifications encouraged the majority of passengers to arrive earlier, however, they recognised that some passengers did not change their behaviour. Notably, each TDM had a different approach to notifying passengers to arrive early. At the workshop, different services from the sample timetables were selected for early arrival notifications and different justifications were given for their choices. Where as some TDMs only considered the spacing between train departure times and passenger numbers, others considered a broader set of factors such as how the mix of business and leisure travellers varies throughout the day, connections from other transport links, and other external events. It was observed that TDMs could see added value from the simulation model developed in first life-cycle loop and the potential of simulation to support a smoother introduction of the new DAT. The conceptual model from the first loop of the life-cycle was extended to capture this new feature.

4.5. Summary of Engagement Process

The workshops described above gave the modellers the adequate information to develop a conceptual model and in turn develop that into a simulation model. Further, in both life-cycle loops, experimentation with the model led to actions being taken by the relevant stakeholders (Jones et al., 2019). This suggests that the engagement activities described generated the necessary confidence in the model for stakeholders to trust its outputs as valid (Law, 2009) and, in turn, act on those results (Brailsford & Vissers, 2011; Fone et al., 2003; Young et al., 2009).

5. Discussion

In our previous work, we presented a simulation model of EIL's London terminal and explained how it was extended using a second life-cycle loop (Jones et al., 2019). We presented empirical results demonstrating how TDMs could reduce terminal queues using DAT.

The key contribution of our current study is to the understanding of the modelling process and the simulation life-cycle literature by presenting methodological details of how an existing simulation can be extended by performing a second loop of the simulation life-cycle with a new group of stakeholders. Further, the study contributes to the conceptual modelling literature by demonstrating the effective use of HPM as a PSM to support conceptual model development and experimental design.

Below, we highlight important learning from our experience, contrasting the differences between the first and second life-cycle loops as regards the role of modeller, stakeholders, facilitation, and PSMs. We go on to discuss in further depth key findings from this study relating to the modelling process as well as demonstrate how EIL stakeholders were effectively engaged in both life-cycle loops. We also highlight some

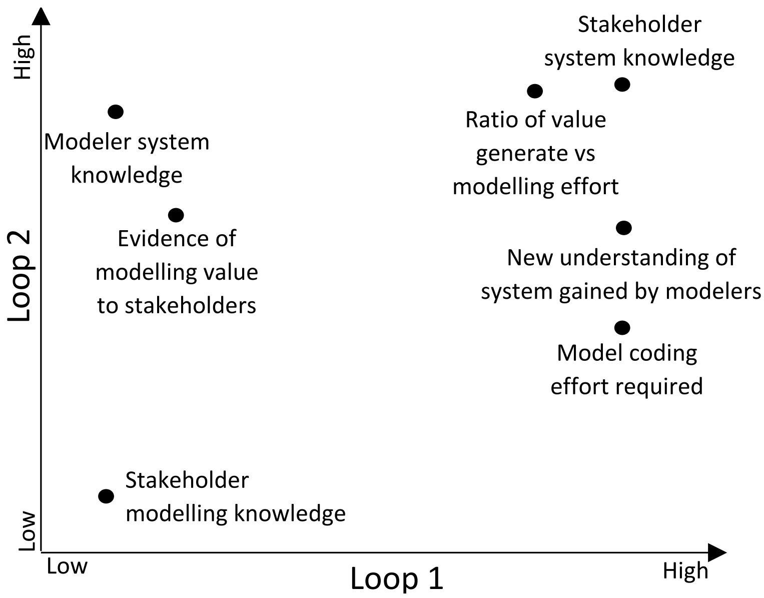

Figure 3. A comparison of key stakeholder attributes and modelling benefits between the two life-cycle loops.

opportunities for future research.

5.1. Comparison of the First and Second Life-cycle Loops

The role of stakeholders and modeller(s) was similar for both loops of the simulation life-cycle (see Tabs. 3 and 4). Yet, there were some notable differences. In both loops, significant effort was required by the modelling team to design, plan, and facilitate the initial workshops for engaging stakeholders in the initial development and subsequent extension of the conceptual model. The level of effort was comparable for both loops. For the 'second loop', however, having already modelled the system in some detail, the modelling team had familiarity with the system. Unlike the individual stakeholders, who mostly had specific expertise in the specific part of the system relevant to them, the modelling team had developed a more holistic perspective of the system. This changed the dynamic of the interaction between modeller and stakeholder in the second loop. Whereas in the first loop the modelling team worked with the system experts (i.e., stakeholders) to develop an appropriate conceptual model, in the second loop the modelling team partially shared the role of system expert when engaging with stakeholders to extend the conceptual model. Figure 3 displays some of the key differences between the two life-cycle loops. Note 'Evidence of modelling value to stakeholders' is greater in loop two, as an existing model could be presented to stakeholders. Further, although both life-cycle loops generated significant value, in our study the 'ratio of value generated vs modelling effort' was also higher in loop two as the effort involved was lower than the first loop and the process provided insight into a high value question and the knowledge and actions generated had immediate high impact.

Developing a simulation model of complex system usually requires a significant investment of time and expertise. Due to the scale and complexity of the model developed for EIL, the original model took many weeks to code. For the second loop, having already built a fully functional simulation model, the primary modeller knew exactly

Table 3. Comparison of the roles of stakeholders and modeller(s) in the first and second life-cycle loops of this study.

	First Loop		Second Loop	
	Stakeholders role	**Modeller(s) role**	**Stakeholders role**	**Modeller(s) role**
Conceptual Modelling	Work collaboratively with the modeller(s) to define the boundaries of the system to be modelled, its component parts, and the relationships between those component parts.	Engage stakeholders and facilitate conceptual model development. Involves organising workshops and activities to capture stakeholders' understanding of the system and to provide a bridge between the real world and computer model to be produced.	As the first loop, work collaboratively with the modeller(s), but, now the objective is to revise the system boundary of the existing model and to identify new component parts or details not included in the first version of the model and to further define the relationships between those new components of the model with existing parts.	Re-engage stakeholders and facilitate extension of the existing conceptual model. Again, this involves organising workshops and activities. Now, having developed a unique, holistic understanding of the system through developing an initial model, the modeller(s) may propose workshop activities more specific to capturing the new requirements of stakeholders.
Model Coding	Backroom activity, stakeholders are not directly involved.	Code the conceptual model into a computer model. Developing a simulation model of a complex system typically requires a significant investment of time and expertise. For this study, the simulation model took several weeks to build due to the scale and complexity of EIL's London terminal.	As the first loop, this remains a backroom activity, stakeholders do not need to be directly involved. However, it is important for the stakeholders to engage and understand why the original model was not suitable for capturing the scenario of interest and why the changes that are made to the model make it suitable.	Edit the existing model code to capture the extended conceptual model. Having already built the first version of the simulation model, the modeller(s) will already know the design and structure of the model. As such, the time and effort involved with modifying the code will (likely) be significantly less than the first loop. For this study, changes to the London simulation model were made in less than a week.
Experimentation	Identify scenarios of interest that can be investigated using simulation. Work with the modeller(s) to understand (as best as possible) the modelling / experimentation approach and what can be learned from it.	Support stakeholders with identifying scenarios to be investigated and devise experiments that can appropriately address scenarios identified by stakeholders. Many scenarios may be identified from the initial conceptual modelling workshops. Additional scenarios can/should be identified by maintaining engagement with stakeholders throughout the simulation life-cycle.	Undertaking a second loop was likely prompted by recognising a particular scenarios of interest that can be investigated using simulation, not captured by the original model. Once the model has been sufficiently extended to capture this, as the first loop, the stakeholders must Work with the modeller(s) to understand (as best as possible) the modelling/experimentation approach and what can be learned from it.	Devise and perform experiments that can appropriately address scenarios identified by stakeholders. Further, present the experimental methodology to stakeholders such that they are satisfied the problem has been investigated robustly and accept experimental findings.
Implementation	Work collaboratively with the modeller(s) to agree feasible actions based on simulation findings.	Present experimental findings in a way that is clear and understandable to a non-technical audience. Propose actions or identify areas where actions should be developed to address identified issues.	Same as the first loop.	Same as the first loop.

Table 4. Comparison of the roles of PSMs and facilitation in the first and second life-cycle loops of this study.

	First Loop		Second Loop	
	PSMs	**Facilitation**	**PSMs**	**Facilitation**
Conceptual Modelling	A vital activity for engaging stakeholders. Structured brainstorming (e.g., using HPM) helps formulate a shared conceptual model by defining the scope and boundaries of the simulation study, dependencies among different parts of the system, and exploring options to improve the system.	Facilitation skills are essential to create stakeholder buy-in, enable effective group model building, and help stakeholders to reach agreement regarding the boundaries and component parts of the conceptual model.	Again, a vital activity for engaging stakeholders (possibly a new group). Here, presentation of the conceptual model developed in the first loop and use of more situation specific brainstorming activities may be helpful to extend the conceptual model and capture additional features.	Similar to the first loop. Here, Facilitation skills are essential to create stakeholder buy-in for the existing model, enable effective group model building, and help stakeholders to reach agreement on the revised boundaries and component parts of the conceptual model. Demonstration of the value added by the simulation in the first loop can be especially helpful to encourage stakeholder buy-in.
Model Coding	PSMs will directly inform the conceptual model. PSM findings may also directly or indirectly influence how to structure and design the computer model.	Model coding is largely a backroom activity, which stakeholders will not directly be involved in. However, the modeller(s) should facilitate ongoing stakeholder engagement and transparency, to create further buy-in, by providing an explanation, pitched at a level stakeholders can understand, of how the conceptual model will be converted into simulation model. This should include explanation of the basics of the chosen paradigm(s).	PSMs in the second loop help the modeller(s) to understand how to extend the existing conceptual model. Changes to the model code must reflect the revised conceptual model. The extent of the coding required will depend on what extensions will be added. Assuming the modeller(s) had collaborated closely with stakeholders during the first loop, this is likely to be less than building the initial model.	Again, model coding is largely a backroom activity, which stakeholders will not directly be involved in, but, again the modellers should ensure ongoing engagement. It is important that the stakeholders have an understanding of what has been changed/added to the model as a result of the second loop and why this will impact the simulation results produced.
Experimentation	Experimentation should focus around areas identified as being important to stakeholders. Many of these will likely arise during PSM activities and conceptual model development. Some may be explicitly requested by stakeholders. Others may be discussed only briefly during PSM activities, but should still be recorded by the modeller(s) and examined later.	Facilitation should encourage stakeholders to share suggestions for potential scenarios for experimentation. Facilitators must educate stakeholders in what is possible with simulation so as to encourage useful suggestions. Facilitators must also relay results back to stakeholders in language that they can understand.	Experimentation should focus around relevant changes made by stakeholders to the original conceptual model and understand their implications.	Facilitation is needed to draw out from stakeholders what they expect the implications of any newly added features to the model will be. Further, the modeller(s) must work stakeholders so they understand how and why the experiments being conducted are best suited to exploring this and present results back to them in language that they can understand.
Implementation	If the above steps have been followed, actions proposed will likely relate back to the process model developed and ideas captured in earlier PSM activities.	At this stage of the lifecycle, facilitation is required to engage stakeholders with simulation findings and work collaboratively to propose actions that can make a positive impact.	Results of earlier activities involving PSMs can be referred to by the modeller(s) to explain to stakeholders how points they had raised have been addressed.	As in the first loop, facilitation is required to engage stakeholders with simulation findings and work collaboratively to propose actions that can make a positive impact.

the design and structure of the model. Although significant changes to the model code were required, total time and effort involved was much less than in the first loop. All modifications were made in less than a week.

PSMs and facilitation played important roles in both loops of the life-cycle, but again there were some notable differences. Initially, HPM, the PSM of choice for the current study, was used primarily to map the system. In the second loop, group discussion and activities designed to extend the conceptual model were much more focused. The HPM models developed in the first loop could be shown to the second group of stakeholder to explain why the existing model had been developed in the manner it was. This helped not only to bridge the gap between the real system and the computer model, but also clarified to stakeholders where their proposed extensions fit within the wider system model. Similarly, facilitation was equally important in both life-cycle loops, particularly in the development of a conceptual model, but serving in different ways. In the first life-cycle loop, the role of facilitators was mainly to extract from stakeholders their understanding of the system and devise a model that could capture this. In the second loop, the facilitators had to be more focused on convincing a new group of stakeholders that the existing model, which they did not help develop, was appropriate for investigating the issues and concerns specific to them.

Throughout the both loops, the simulation study was pitched to stakeholders as an ongoing process with their involvement key to ensuring actionable findings were generated. Emphasis was placed on the notion that developing a model is primarily a means for exploring a problem systematically and an opportunity for learning, as opposed to a tool for precise forecasting (Epstein, 2008). Facilitators explained that a simulation model produces new insights, which can, in turn, help inform design choices and operational decisions prior to implementation (Robinson, 2004) by testing proposals in a risk-free environment. It was acknowledged by the modelling team that building a simulation requires time and expertise (Robinson, 2004) and is an iterative process (Balci, 1994; Robinson, 2013; Willemain, 1995). They also pointed out that any model, including simulation, has limitations that must be recognised and that the quality of model outputs are dependent on having reliable input data. This transparency throughout the process promoted validation as an integral part of the simulation development life-cycle, rather than a task undertaken after the model has been built (Law, 2009). Clarifying where and why assumptions were made and, in turn, their impact, was key to ensuring stakeholders judged the model as valid for investigating the system of interest. Ensuring this understanding among stakeholders is a primary reason for engaging them via workshops.

The existing literature observes that a member of the modelling team may need to explicitly make stakeholders aware of the learning that has been achieved (Nisbett & Wilson, 1977; Robinson, 2004; Rouwette et al., 2009), which may, in turn, help them propose actions. In the context of DES modelling, Monks, Robinson, and Kotiadis (2016) and Gogi, Tako, and Robinson (2016) explored how insight and learning generated from involvement in simulation studies impacts stakeholder behaviour. Thompson, Howick, and Belton (2016) investigate a similar concept in an SD context. Behavioural changes resulting from learning, a common theme in the growing Behavioural OR literature (Franco & Hämäläinen, 2016), were evident in our study with new insights generated leading to changes in priorities and specific actions. During stakeholder feedback in the first life-cycle loop, the importance of processes identified in the lowest layer of the HPM (Fig. 2) were ranked and specific actions proposed in relation to each process. Stakeholders subsequently adjusted their priorities and adopted a number of recommended actions, thus successfully completing the first life-cycle loop and showing that they considered the model valid. While feeding back to TDMs in the second life-cycle loop, the modeller explained how increased congestion may arise when early arrival notifications and check-in opening times are not coordinated. TDMs agreed that this may be a key factor in causing long queues in the station, indicating that they also considered the findings of the simulation study valid. Furthermore, extensive scenario testing beyond that specifically requested by TDMs (in the initial workshop) demonstrated to them that the problem had been investigated thoroughly and enhanced their confidence in the model's validity. The TDMs' implementation of specific actions, based on results produced by the simulation model (e.g., requesting the DAT development team include additional functionality proposed by the modeller) underlines the models validity and successful completion of the second life-cycle loop. The study had the additional benefit of making stakeholders aware of simulation as a tool for addressing future problems.

5.2. The Modelling Process and Stakeholder Engagement

The framework presented in this study differs from other frameworks for engaging stakeholders in simulation studies, notably PartiSim (Tako & Kotiadis, 2015). Firstly, here we used HPM rather than SSM (an arguably simpler and quicker method) as a problem structuring technique to engage stakeholders. A key difference is that whereas PartiSim presents a framework to engage stakeholders to produce a model, the framework we present encourages ongoing engagement with stakeholders by promoting modelling to become an integral part of an organisation's planning processes. Partisim (or parts of it) could be embedded within each loop, however, more research is needed to establish this. Similar challenges were faced throughout both life-cycle loops in ensuring stakeholders' willingness to act upon simulation findings to those identified by other authors (Brailsford & Vissers, 2011; Fone et al., 2003; Young et al., 2009): 1) developing buy-in; 2) engaging stakeholders throughout the modelling process; and completing the 'loop' by 3) validating the model. In this study, closely involving stakeholders in the model development process was key to enabling discussion and the emergence of a shared understanding of the system and how it was captured within the model (Eden & Ackermann, 2006). Equally important, it gave stakeholders a sense of responsibility for the simulation study and its success. The HPM model developed helped define the system's boundaries and relationships among its component parts. In the second life-cycle loop, the HPM models produced by the first group of stakeholders were shown to the second group for their comment. This helped ensure transparency in the modelling process between modeller and stakeholders, something identified as one of the key challenges for the future of PSMs (Checkland, 2006; Eden & Ackermann, 2006; Rouwette et al., 2009; Westcombe et al., 2006). HPM is a simple process to understand and engage with and proved to be a very suitable methodology for this study. Although it worked well here, there may be other situations where HPM has limitations (e.g., when stakeholders really struggle to articulate processes or explain how the system of interest works and can be improved). There is clear opportunity for future studies to experiment with using HPM and other PSMs as part of the conceptual modelling to compare the advantages and disadvantages of each.

Figure 4 illustrates stakeholders' views of the model at the end of the first/beginning of the second life-cycle loop. Those stakeholders involved in the first loop could see how the model captured the topics discussed in the initial workshop. When presented with the model in the second loop workshop, the new group of stakeholders could

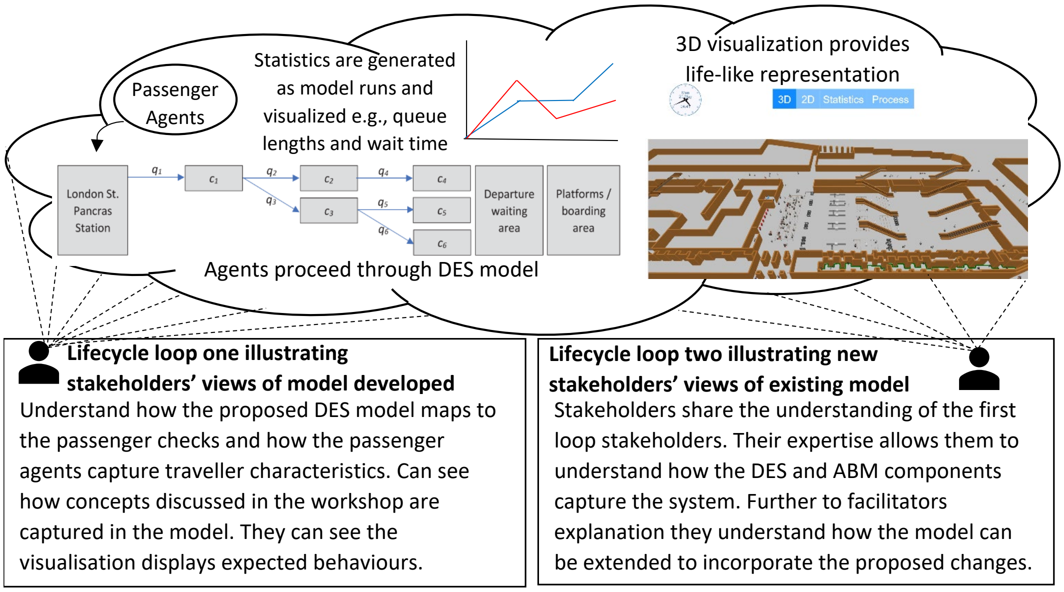

Figure 4. A highly simplified illustration of the EIL London terminal hybrid simulation model structure and stakeholder views at the end of the first life-cycle loop / beginning of the second life-cycle loop.

understand how the proposed changes could help with the question of interest.

A key finding that emerged when introducing the simulation model to workshop participants in the second loop was that using a hybrid approach was useful for both communicating the model's design to stakeholders and getting their buy-in (Jahangirian et al., 2015). The model was designed such that ABM components captured agent (passenger) characteristics and interactions, while DES components captured the processes (security/border controls) the agents went through. Jones, Kotiadis, and O'Hanley (2020) identified that stakeholders were able to engage with models developed parsimoniously (Vandekerckhove, Matzke, & Wagenmakers, 2015) when they were experts in the sub-system being modelled, whereas when stakeholders had less expertise in the system, a highly descriptive modelling approach (Edmonds & Moss, 2005) was easier for them to engage with and found to promote validity of the model. EIL stakeholders in this study had high levels of system expertise. Study participants could see from the model that as the profile of passengers changed, interaction time with checks and permissible routes through the system also changed. Although this could be captured using a purely DES approach (Brailsford (2014) notes many hybrid ABM and DES models could be purely DES), presenting a model which captured passengers as autonomous agents, via an ABM approach, more closely reflected the reality stakeholders were familiar with, thus making it easier for them to engage with. Jahangirian et al. (2015) note that adopting a hybrid approach can help reduce the "*communication gap*" between simulation practitioners and stakeholders by facilitating the development of models that are easily recognisable to non experts as representations of the system of interest.

It is commonly acknowledged that simulation offers a high impact means of visualising and communicating ideas which can aid stakeholders to reach consensus when testing a range of theories (Robinson, 2004). Our experience reinforces the observation that designing hybrid models in a way that aids understanding of the resulting simulation tool can further encourage stakeholder engagement. Additionally, the sophisticated visualisation capabilities within AnyLogic (2019) helped to easily demonstrate the model and the benefits it brings to an audience with no prior experience of simulation. In the second loop, for example, providing stakeholders with successful cases of how the model provided benefits to EIL during the first loop further convinced workshop participants of its potential value.

5.3. Limitations and Future Research

Our study demonstrates that it is possible to engage a new group of stakeholders for the purpose of extending an existing simulation model when stakeholders have expertise in the system that the model captures and the model is designed such that stakeholders can understand the abstraction (Jones et al., 2020). If presenting a less obviously representative model of a system to a group of stakeholders with less expertise in that system, modellers may not find stakeholders so willing to accept the model's validity. Additional studies are needed to confirm this.

In our example, the additional expertise of the second group of stakeholders increased the model's value. The existing literature provides little evidence of model extension via the input of additional stakeholders as in our study and perhaps this shows that EIL's case is rare. It has been noted that models are both "frame and picture" (Matos, Houston, Blum, & Carreira, 2001), capturing not only what the modellers and stakeholders can see, but also their way of seeing it. Any model is conceptualised as a response to a particular need and the resultant model being suitable for addressing that need, but not necessarily appropriate for exploring others, even if related to the same system. Often new problems require a new model. EIL's case is rare in that there emerged an appropriate application to which the model could be extended (i.e., DAT). It is maybe equally rare then that the appropriate expertise to extend a model's value can found in a new group of stakeholders (as opposed to the original group). Future research should seek to identify opportunities where new groups of stakeholders are able to add value to existing simulation models.

Hybrid simulation continues to grow as an area of reseach interest (Brailsford et al., 2018). This study is one of very few to discuss engaging stakeholders in the development process of a hybrid model and, to the best of our knowledge, the only study to discuss extending a hybrid model via a second life-cycle loop. The model in this study combines DES and ABM. The framework presented takes inspiration from frameworks such as Kotiadis and Mingers (2006) and Tako and Kotiadis (2015), which consider DES modelling. These frameworks and the one we propose also reflect on best practice from the SD literature (Andersen & Richardson, 1997; Peck, 1998; Richardson & Andersen, 1995), however, further research is required to understand if the methodology we propose is suitable for other forms of hybrid modelling. Future studies should experiment with more techniques for engaging stakeholders in hybrid modelling (besides HPM) and investigate other methods for conducting additional life-cycle loops.

Of course, this study is limited in that it presents just one example of first and second loop workshops, each lasting a relatively short amount of time (two hours). However, this is the reality most modellers have to deal with. At EIL, arranging a time to bring a group of key stakeholders together, each of whom has a demanding job within the organisation, was by itself a significant logistical challenge. Accordingly, there is significant interest within the modelling community to understand how to maximise the value of limited opportunities to bring key stakeholders together. Our study contributes to this literature by developing understanding of best practice for the delivery of stakeholder facilitated workshops. Further studies should consider and improve upon our methodology.

6. Conclusion

Our study contributes to the simulation life-cycle literature by demonstrating how an existing simulation can be extended by iterating a second time through the simulation life-cycle with input from a new group of stakeholders. For the current study, this second iteration helped to interrogate the potential benefits EIL's new dynamic arrival tool (DAT) for managing early customer arrival notifications and make recommendations for how to improve the use of DAT through better coordination with check-in opening times. This study further contributes to the conceptual modelling literature by demonstrating how HPM can be used in problem structuring to support conceptual model development and experimental design.

Monks et al. (2009) note that one of the main benefits of simulation is the learning that is generated through the process of model development. Based on our experience, further iterations of the simulation life-cycle, while carefully maintaining stakeholder engagement throughout, provided additional learning opportunities and incrementally improved EIL's understanding of the system and, hence, improve its performance. Due to the time, expertise, and expense of modelling complex systems (Robinson, 2004), iteratively extending a model in this way should enable other organisations to maximise their return on investment from undertaking a simulation study.

References

Ackermann, F. (1996, jan). Participants' perceptions on the role of facilitators using Group Decision Support Systems. *Group Decision and Negotiation*, *5*(1), 93–112. Retrieved from `http://link.springer.com/10.1007/BF02404178`

Ackermann, F. (2012, 6). Problem structuring methods 'in the Dock': Arguing the case for Soft OR. *European Journal of Operational Research*, *219*(3), 652–658. Retrieved from `http://linkinghub.elsevier.com/retrieve/pii/S0377221711010010`

Andersen, D. F., & Richardson, G. P. (1997). Scripts for group model building. *System Dynamics Review*, *13*(2), 107–129. Retrieved from `https://onlinelibrary.wiley.com/doi/abs/10.1002/%28SICI%291099-1727%28199722%2913%3A2%3C107%3A%3AAID-SDR120%3E3.0.CO%3B2-7`

AnyLogic. (2019). *AnyLogic: Simulation Modeling Software Tools & Solutions for Business.* Retrieved from `https://www.anylogic.com` (Online: accessed 12th June 2019)

Arons, H. d. S., & Boer, C. A. (2001, jul). Storage and retrieval of discrete-event simulation models. *Simulation Practice and Theory*, *8*(8), 555–576. Retrieved from `https://linkinghub.elsevier.com/retrieve/pii/S0928486901000362`

Bakar, N. A. A., Fauzan, A. I. A., Majid, M. A., Allegra, M., & Fakhreldin, M. (2018, nov). The simulation models for human pedestrian movement of a departure process in an airport. In *2018 international conference on innovation and intelligence for informatics, computing, and technologies, 3ict 2018.* Institute of Electrical and Electronics Engineers Inc.

Balci, O. (1994). Validation, verification, and testing techniques throughout the life cycle of a simulation study. *Annals of Operations Research*, *53*(1), 121–173. Retrieved from `http://link.springer.com/10.1007/BF02136828`

Balci, O. (2012). A life cycle for modeling and simulation. *SIMULATION*, *88*(7), 870–883. Retrieved from `http://journals.sagepub.com/doi/10.1177/0037549712438469`

Balci, O., Arthur, J. D., & Nance, R. E. (2008, dec). Accomplishing reuse with a simulation conceptual model. In *2008 winter simulation conference* (pp. 959–965). IEEE. Retrieved from `https://ieeexplore.ieee.org/document/4736162/`

Balci, O., & Ormsby, W. F. (2007, aug). Conceptual modelling for designing large-scale simulations. *Journal of Simulation*, *1*(3), 175–186. Retrieved from `https://www.tandfonline.com/doi/full/10.1057/palgrave.jos.4250023`

Banks, J., Carson, I., Nelson, B. L., & Nicol, D. M. (2010). *Discrete-event system simulation* (5th ed., International version ed ed.). Upper Saddle River, New Jersey, US, Pearson Education.

Bell, D., Mustafee, N., De Cesare, S., Lycett, M., & Taylor, S. (2006). A web services component discovery and deployment architecture for simulation model reuse. *European Simulation Interoperability Workshop 2006*. Retrieved from `http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.113.777`

Brailsford, S. (2014). Modeling Human Behaviour - An (ID)entity Crisis? In *Proceedings of the winter simulation conference, edited by a. tolk, s. y. diallo, i. o. ryzhov, l. yilmaz, s. buckley, and j. a. miller* (pp. 1539–1548). Piscataway, New Jersey: IEEE. Retrieved from `http://dl.acm.org/citation.cfm?id=2694013.2694045`

Brailsford, S. (2015). Hybrid simulation in healthcare: New concepts and new tools. In *Proceedings of the winter simulation conference, edited by l. yilmaz, w k v. chan, i moon, t. m k. roeder, c. macal, and m d. rossetti* (pp. 1645–1653). Piscataway, New Jersey: IEEE.

Brailsford, S., Eldabi, T., Kunc, M., Mustafee, N., & Osorio, A. F. (2018, nov). Hybrid simulation modelling in operational research: A state-of-the-art review. *European Journal of Operational Research*, *278*(3), 721–737. Retrieved from `https://doi.org/10.1016/j.ejor.2018.10.025`

Brailsford, S., & Vissers, J. (2011). OR in healthcare: A European perspective. *European Journal of Operational Research*, *212*(2), 223–234. Retrieved from `http://dx.doi.org/10.1016/j.ejor.2010.10.026`

Brown, N., & Powers, S. (2000). Simulation in a box (a generic reusable maintenance model). In *2000 winter simulation conference proceedings (cat. no.00ch37165)* (Vol. 1, pp. 1050–1056). IEEE. Retrieved from `http://ieeexplore.ieee.org/document/899910/`

Checkland, P. (2000). Soft systems methodology: a thirty year retrospective. *Systems Research and Behavioral Science*, *17*(S1), S11–S58.

Checkland, P. (2006, jul). Reply to Eden and Ackermann: Any future for problem structuring methods? *Journal of the Operational Research Society*, *57*(7), 769–771. Retrieved from `https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602111`

Davis, J., & Hall, J. (2003, jun). A software-supported process for assembling evidence and handling uncertainty in decision-making. *Decision Support Systems*, *35*(3), 415–433. Retrieved from `https://linkinghub.elsevier.com/retrieve/pii/S0167923602001173`

Davis, J., MacDonald, A., & Marashi, E. (2007, dec). Integrated performance measurement to support strategic decision making in engineering organisations. In *2007 ieee international conference on industrial engineering and engineering management* (pp. 1762–1766). IEEE. Retrieved from `http://ieeexplore.ieee.org/document/4419495/`

Davis, J., MacDonald, A., & White, L. (2010, jun). Problem-structuring methods and project management: an example of stakeholder involvement using Hierarchical Process Modelling methodology. *Journal of the Operational Research Society*, *61*(6), 893–904. Retrieved from `https://www.tandfonline.com/doi/full/10.1057/jors.2010.12`

Eden, C., & Ackermann, F. (2006, jul). Where next for problem structuring methods. *Journal of the Operational Research Society*, *57*(7), 766–768. Retrieved from `https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602090`

Eden, C., & Sims, D. (1979). On the nature of problems in consulting practice. *Omega*, *7*(2), 119–127. Retrieved from `http://link.springer.com/10.1007/978-94-007-0753-5_3314`

Edmonds, B., & Moss, S. (2005). *Multi-Agent and Multi-Agent-Based Simulation* (Vol. 3415; P. Davidsson, B. Logan, & K. Takadama, Eds.). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved from http://link.springer.com/10.1007/b106991

Eldabi, T., Paul, R. J., & Young, T. (2007, feb). Simulation modelling in healthcare: reviewing legacies and investigating futures. *Journal of the Operational Research Society*, *58*(2), 262–270. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602222

Epstein, J. M. (2008). Why Model? *Journal of Artificial Societies and Social Simulation*, *11*(4), 12. Retrieved from https://www.jasss.org/11/4/12.html

Félix, M., & Reis, V. (2016, dec). A micro-simulation model for assessing the performance of check-in in airports. In *Ieee conference on intelligent transportation systems, proceedings, itsc* (pp. 253–258). Institute of Electrical and Electronics Engineers Inc.

Fletcher, A., Halsall, D., Huxham, S., & Worthington, D. (2007, dec). The DH Accident and Emergency Department model: a national generic model used locally. *Journal of the Operational Research Society*, *58*(12), 1554–1562. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602344

Fone, D., Hollinghurst, S., Temple, M., Round, A., Lester, N., Weightman, A., ... Palmer, S. (2003, dec). Systematic review of the use and value of computer simulation modelling in population health and health care delivery. *Journal of Public Health*, *25*(4), 325–335. Retrieved from https://academic.oup.com/jpubhealth/article-lookup/doi/10.1093/pubmed/fdg075

Franco, L. A., & Hämäläinen, R. P. (2016). Behavioural operational research: Returning to the roots of the or profession. *European Journal of Operational Research*, *249*(3), 791-795. Retrieved from https://www.sciencedirect.com/science/article/pii/S0377221715009601

Franco, L. A., & Montibeller, G. (2010, sep). Facilitated modelling in operational research. *European Journal of Operational Research*, *205*(3), 489–500. Retrieved from http://dx.doi.org/10.1016/j.ejor.2009.09.030

Gogi, A., Tako, A. A., & Robinson, S. (2016). An experimental investigation into the role of simulation models in generating insights. *European Journal of Operational Research*, *249*(3), 931–944.

Gunal, M., & Pidd, M. (2005). Simulation Modelling for Performance Measurement in Healthcare. In *Proceedings of the winter simulation conference, edited by m.e. kuhl, n.m. steiger, f.b. armstrong, and j.a. joines* (pp. 2663–2668). Piscataway, New Jersey: IEEE. Retrieved from http://ieeexplore.ieee.org/document/1574567/

Gunal, M., & Pidd, M. (2006, dec). Understanding Accident and Emergency Department Performance using Simulation. In *Proceedings of the 2006 winter simulation conference* (pp. 446–452). IEEE. Retrieved from http://ieeexplore.ieee.org/document/4117638/

Hall, J., Blockley, D., & Davis, J. (1998, oct). Uncertain inference using interval probability theory. *International Journal of Approximate Reasoning*, *19*(3-4), 247–264. Retrieved from https://linkinghub.elsevier.com/retrieve/pii/S0888613X98100105

Hoover, S. V., & Perry, R. F. (1989). *Simulation: A problem-solving approach.* Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc.

Hurrion, R. D. (1976). *The design, use and required facilities of an interactive visual computer simulation language to explore production planning problems.* (Unpublished doctoral dissertation). University of London.

Jackson, M. C. (1999, jan). Towards coherent pluralism in management science. *Journal of the Operational Research Society*, *50*(1), 12–22. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2600661

Jahangirian, M., Borsci, S., Shah, S. G. S., & Taylor, S. J. E. (2015, jun). Causal factors of low stakeholder engagement: a survey of expert opinions in the context of healthcare simulation projects. *SIMULATION*, *91*(6), 511–526. Retrieved from

http://journals.sagepub.com/doi/10.1177/0037549715583150
Jones, W., Kotiadis, K., & O'Hanley, J. (2019, dec). Engaging Stakeholders To Extend The Lifecycle Of Hybrid Simulation Models. In *2019 winter simulation conference (wsc)* (pp. 1304–1315). IEEE. Retrieved from https://ieeexplore.ieee.org/document/9004744/
Jones, W., Kotiadis, K., & O'Hanley, J. (2020, mar). Developing a Hybrid Simulation Model using both Parsimonious and Highly Descriptive Approaches: A Case Study from the Transport Industry. In *Proceedings of sw20 the or society simulation workshop.* The OR Society. Retrieved from https://www.theorsociety.com/what-we-do/events-conferences/simulation-workshop/
Jones, W., Sooriyabandara, M., Yearworth, M., Doufexi, A., & Wilson, R. E. (2016, jul). Planning For 5G: A Problem Structuring Approach for Survival in the Telecoms Industry. *Systems Engineering*, *19*(4), 301–321. Retrieved from https://dl.acm.org/doi/abs/10.1002/sys.21354
Jun, J. B., Jacobson, S. H., & Swisher, J. R. (1999, feb). Application of discrete-event simulation in health care clinics: A survey. *Journal of the Operational Research Society*, *50*(2), 109–123. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2600669
Kaylani, A., Mollaghasemi, M., Cope, D., Fayez, S., Rabadi, G., & Steele, M. (2008, oct). A generic environment for modelling future launch operations—GEM-FLO: a success story in generic modelling. *Journal of the Operational Research Society*, *59*(10), 1312–1320. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602478
Kotiadis, K., & Mingers, J. (2006, jul). Combining PSMs with hard OR methods: the philosophical and practical challenges. *Journal of the Operational Research Society*, *57*(7), 856–867. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602147
Kotiadis, K., Tako, A. A., & Vasilakis, C. (2014). A participative and facilitative conceptual modelling framework for discrete event simulation studies in healthcare. *Journal of the Operational Research Society*, *65*(2), 197–213.
Kreutzer, W. (1986). *System Simulation Programming Styles and Languages.* Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc.
Law, A. (2007). *Simulation modeling and analysis.* Boston, London: McGraw-Hill.
Law, A. (2009). How to build valid and credible simulation models. In *Proceedings of the winter simulation conference, edited by m. d. rossetti, r. r. hill, b. johansson, a. dunkin and r. g. ingalls* (pp. 24–33). Piscataway, New Jersey: IEEE. Retrieved from http://ieeexplore.ieee.org/document/5429312/
Lowery, J., Hakes, B., Lilegdon, W., Keller, L., Mabrouk, K., & McGuire, F. (1994). Barriers to implementing simulation in health care. In *Proceedings of the winter simulation conference, edited by j.d. tew, s. manivannan, d.a. sadowski, and a.f. seila* (pp. 868–875). Piscataway, New Jersey: IEEE. Retrieved from http://ieeexplore.ieee.org/document/717447/
Majid, M., Fakhreldin, M., & Zamli, K. (2016). An Enhanced Simulation Model for Complex Human Pedestrian Movement System using Hybrid Discrete Event and Agent Based Simulation. *International Information Institute (Tokyo). Information*, *19*(9B), 4213–4218. Retrieved from http://search.proquest.com/docview/1860272743/
Malak, R., & Paredis, C. (2004). Foundations of Validating Reusable Behavioral Models in Engineering Design Problems. In *Proceedings of the 2004 winter simulation conference, 2004.* (Vol. 1, pp. 412–420). IEEE. Retrieved from http://ieeexplore.ieee.org/document/1371344/
Marashi, E., & Davis, J. (2007, oct). A Systems-Based Approach for Supporting Discourse in Decision Making. *Computer-Aided Civil and Infrastructure Engineering*, *22*(7), 511–526. Retrieved from http://doi.wiley.com/10.1111/j.1467-8667.2007.00507.x

Marashi, E., Davis, J., & Hall, J. (2008, jun). Combination Methods and Conflict Handling in Evidential Theories. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, *16*(03), 337–369. Retrieved from http://www.worldscientific.com/doi/abs/10.1142/S0218488508005315

Matos, J. F., Houston, S., Blum, W., & Carreira, S. P. (2001). *Modelling and mathematics education: Ictma 9-applications in science and technology*. Elsevier.

Midgley, G. (1997). *Mixing Methods: Developing Systemic Intervention*. University of Hull, Centre for Systems Studies. Retrieved from https://books.google.co.uk/books?id=uyfRMgEACAAJ

Mingers, J. (2001a, sep). Combining IS Research Methods: Towards a Pluralist Methodology. *Information Systems Research*, *12*(3), 240–259. Retrieved from http://link.springer.com/10.1007/s00415-007-0569-9 http://pubsonline.informs.org/doi/abs/10.1287/isre.12.3.240.9709

Mingers, J. (2001b, September). Multimethodology: Mixing and matching methods. In J. Mingers & J. Rosenhead (Eds.), *Rational analysis for a problematic world revisited* (Vol. 1, pp. 289–310). Chichester: John Wiley and Sons Ltd. Retrieved from https://kar.kent.ac.uk/3900/

Mingers, J. (2011, dec). Soft OR comes of age—but not everywhere! *Omega*, *39*(6), 729–741. Retrieved from https://linkinghub.elsevier.com/retrieve/pii/S0305048311000089

Mingers, J., & Rosenhead, J. (2001, September). *Rational analysis for a problematic world revisited* (Vol. 1). Chichester: John Wiley and Sons Ltd. Retrieved from https://kar.kent.ac.uk/3902/

Mingers, J., & Rosenhead, J. (2004, feb). Problem structuring methods in action. *European Journal of Operational Research*, *152*(3), 530–554. Retrieved from https://linkinghub.elsevier.com/retrieve/pii/S0377221703000560

Monks, T., Robinson, S., & Kotiadis, K. (2009, dec). Model reuse versus model development: Effects on credibility and learning. In *Proceedings of the 2009 winter simulation conference (wsc)* (Vol. 2010, pp. 767–778). IEEE. Retrieved from http://ieeexplore.ieee.org/document/5429691/

Monks, T., Robinson, S., & Kotiadis, K. (2016). Can involving clients in simulation studies help them solve their future problems? a transfer of learning experiment. *European Journal of Operational Research*, *249*(3), 919–930.

Munro, I., & Mingers, J. (2002, apr). The use of multimethodology in practice—results of a survey of practitioners. *Journal of the Operational Research Society*, *53*(4), 369–378. Retrieved from http://kar.kent.ac.uk/3908/ https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2601331

Mustafee, N., Brailsford, S., Djanatliev, A., Eldabi, T., Kunc, M., & Tolk, A. (2017). Purpose and Benefits of Hybrid Simulation: Contributing to the Convergence of Its Definition. In *Proceedings of winter simulation conference, edited by w.k.v. chan, a. d'ambrogio, g. zacharewicz, n. mustafee, g. wainer, and e. page* (p. 1-15). Piscataway, New Jersey: IEEE. Retrieved from http://dl.acm.org/citation.cfm?id=3242181.3242315

Nance, R. E. (1994, dec). The Conical Methodology and the evolution of simulation model development. *Annals of Operations Research*, *53*(1), 1–45. Retrieved from http://dx.doi.org/10.1007/BF02136825 http://link.springer.com/10.1007/BF02136825

Nisbett, R. E., & Wilson, T. D. (1977, may). Telling more than we can know: Verbal reports on mental processes. *Psychological Review*, *84*(3), 231–259. Retrieved from http://doi.apa.org/getdoi.cfm?doi=10.1037/0033-295X.84.3.231

Paul, R., & Taylor, S. (2002). What use is model reuse: is there a crook at the end of the rainbow? In *Proceedings of the winter simulation conference* (Vol. 1, pp. 648–652). IEEE. Retrieved from http://ieeexplore.ieee.org/document/1172943/

Peck, S. (1998, jul). Group Model Building: Facilitating Team Learning Using System Dynamics. *Journal of the Operational Research Society*, *49*(7), 766–767. Retrieved from

https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2600567
Pidd, M. (1988). *Computer Simulation in Management Science* (2nd ed.). New York, NY, USA: John Wiley & Sons, Inc.
Pidd, M. (1992). Guidelines for the design of data driven generic simulators for specific domains. *SIMULATION*, *59*(4), 237-243. Retrieved from https://doi.org/10.1177/003754979205900403
Pidd, M. (2004). Complementarity in systems modelling. *Systems modelling: Theory and practice*, *1*, 20.
Pidd, M., & Carvalho, A. (2006, dec). Simulation software: not the same yesterday, today or forever. *Journal of Simulation*, *1*(1), 7–20. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jos.4250004
Pierce, N. G., & Drevna, M. J. (1992). Development of generic simulation models to evaluate wafer fabrication cluster tools. In *Proceedings of the 24th conference on winter simulation - wsc '92* (pp. 874–878). New York, New York, USA: ACM Press. Retrieved from http://portal.acm.org/citation.cfm?doid=167293.167757
Richardson, G. P., & Andersen, D. F. (1995). Teamwork in group model building. *System Dynamics Review*, *11*(2), 113–137. Retrieved from http://doi.wiley.com/10.1002/sdr.4260110203
Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, *4*(2), 155–169. Retrieved from https://www.jstor.org/stable/4531523
Robinson, S. (2004). *Simulation: The practice of model development and use.* Chichester: John Wiley & Sons.
Robinson, S. (2013). Conceptual modeling for simulation. In *Proceedings of the winter simulation conference, edited by r. pasupathy, s.-h. kim, a. tolk, r. hill, and m. e. kuhl* (pp. 377–388). Piscataway, New Jersey: IEEE. Retrieved from http://ieeexplore.ieee.org/document/6721435/
Robinson, S., Worthington, C., Burgess, N., & Radnor, Z. J. (2014, apr). Facilitated modelling with discrete-event simulation: Reality or myth? *European Journal of Operational Research*, *234*(1), 231–240. Retrieved from http://dx.doi.org/10.1016/j.ejor.2012.12.024
Rouwette, E. A. J. A., Vennix, J. A. M., & Felling, A. J. A. (2009, nov). On Evaluating the Performance of Problem Structuring Methods: An Attempt at Formulating a Conceptual Model. *Group Decision and Negotiation*, *18*(6), 567–587. Retrieved from http://link.springer.com/10.1007/s10726-007-9100-z
Sargent, R. (2001). Some approaches and paradigms for verifying and validating simulation models. In *Proceeding of the winter simulation conference, edited by b. a. peters, j. s. smith, d. j. medeiros, and m. w. rohrer* (pp. 106–114). Piscataway, New Jersey: IEEE. Retrieved from http://ieeexplore.ieee.org/document/977251/
Siebers, P. O., Macal, C. M., Garnett, J., Buxton, D., & Pidd, M. (2010, sep). Discrete-event simulation is dead, long live agent-based simulation! *Journal of Simulation*, *4*(3), 204–210. Retrieved from https://www.tandfonline.com/doi/full/10.1057/jos.2010.14
Sinreich, D., & Marmor, Y. (2004). A Simple and Intuitve Simulation Tool for Analyzing the Performance of Emergency Departments. In *Proceedings of the 2004 winter simulation conference, 2004.* (Vol. 2, pp. 908–916). IEEE. Retrieved from http://ieeexplore.ieee.org/document/1371561/
Spiegel, M., Reynolds, P., & Brogan, D. (2005). A Case Study of Model Context for Simulation Composability and Reusability. In *Proceedings of the winter simulation conference, 2005.* (Vol. 2005, pp. 437–444). IEEE. Retrieved from http://ieeexplore.ieee.org/document/1574279/
Tako, A. A., & Kotiadis, K. (2015). PartiSim: A multi-methodology framework to support facilitated simulation modelling in healthcare. *European Journal of Operational Research*, *244*(2), 555–564. Retrieved from http://dx.doi.org/10.1016/j.ejor.2015.01.046

Thompson, J. P., Howick, S., & Belton, V. (2016). Critical learning incidents in system dynamics modelling engagements. *European Journal of Operational Research*, *249*(3), 945-958. Retrieved from https://www.sciencedirect.com/science/article/pii/S0377221715008905

Vandekerckhove, J., Matzke, D., & Wagenmakers, E.-J. (2015). *Model Comparison and the Principle of Parsimony* (Vol. 1; J. R. Busemeyer, Z. Wang, J. T. Townsend, & A. Eidels, Eds.). Oxford University Press. Retrieved from http://oxfordhandbooks.com/view/10.1093/oxfordhb/9780199957996.001.0001/oxfordhb-9780199957996-e-14

Westcombe, M., Alberto Franco, L., & Shaw, D. (2006, jul). Where next for PSMs—A grassroots revolution? *Journal of the Operational Research Society*, *57*(7), 776–778. Retrieved from https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602161

White, L., & Tacket, A. (1997). Critiquing multimethodology as metamethodology: Working towards pragmatic pluralism. *Multimethodology: The Theory and Practice of Combining Management Science Methodologies*, 379–405.

Willemain, T. R. (1995, dec). Model Formulation: What Experts Think About and When. *Operations Research*, *43*(6), 916–932. Retrieved from http://pubsonline.informs.org/doi/abs/10.1287/opre.43.6.916

Wilson, J. C. T. (1981, sep). Implementation of Computer Simulation Projects in Health Care. *Journal of the Operational Research Society*, *32*(9), 825–832. Retrieved from https://www.tandfonline.com/doi/full/10.1057/jors.1981.161

Yearworth, M., Singer, J. W., Adcock, R., Hybertson, D., Singer, M., Chroust, G., & Kijima, K. J. (2015). Systems Engineering in a Context of Systemic Cooperation (SCOOPs): Development and Implications. *Procedia Computer Science*, *44*, 214–223. Retrieved from http://www.sciencedirect.com/science/article/pii/S1877050915002847

Yearworth, M., & White, L. (2014, 9). The non-codified use of problem structuring methods and the need for a generic constitutive definition. *European Journal of Operational Research*, *237*(3), 932–945. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0377221714001301

Young, T., Eatock, J., Jahangirian, M., Naseer, A., & Lilford, R. (2009). Three Critical Challenges for Modeling and Simulation in Healthcare. In *Proceedings of the winter simulation conference, edited by m. d. rossetti, r. r. hill, b. johansson, a. dunkin and r. g. ingalls* (pp. 1823–1830). Piscataway, New Jersey: IEEE. Retrieved from http://dl.acm.org/citation.cfm?id=1995456.1995709