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Highlight

- Trust plays an important role in model acceptability and results implementation.
- Facets of trust interact between the stakeholder, the modeller and the model.
- These interactions occur dynamically throughout the lifecycle of an M&S study.
- The Trust Model allows reflection on relevant factors which influence trust in a model throughout the M&S study lifecycle.

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Abstract:
The purpose of a modelling and simulation (M&S) study for real-world operations management applications is to support decision-making and inform potential action, therefore investigating the aspects of the modelling process which influence trust is important. Previous work has considered the question of trust through the lens of model validation. However, whilst a simulation model may be technically well executed, stakeholders' trust in the results may also depend upon intangible factors such as interpersonal relationships. Existing literature has also focused on the credibility of the simulation practitioner, however the credibility attribute belongs to the stakeholder, and it ignores the trust aspects that may exist between the stakeholders and the model itself. In this paper, we argue that different facets of trust emerge throughout the stages of a simulation study, and both influence, and are influenced by, the interaction between the model, the modeller and the stakeholders of the study. We present a synthesis of existing literature and extend it by proposing a formative model of trust which presents a conceptualisation of this tripartite relationship. Our contribution is the identification of the different facets of trust in the lifecycle of a modelling and simulation study. We argue that these interacting facets converge via the three-way relationship between modeller, model and stakeholders toward epistemic trust in the knowledge generated by the simulation study and ultimately model acceptability and implementation. To the best of our knowledge, ours is the first study that focuses solely on the question of trust in an M&S study.

Keywords— Decision Processes, OR Practice, Trust, Facilitated Modelling, Participatory Modelling.

1. Introduction

Modelling and simulation (M&S) is a thriving area of applied research and practice with wide application in many domains, however in real-world operations management problems within complex sociotechnical systems, the question of trust in the knowledge produced by M&S is rarely considered. The purpose of M&S is to provide insight and understanding into the physical processes of a system. Potential changes to the system can first be simulated to predict their impact on system performance (Fishwick, 1995). Assuming the results of the study are trusted, the knowledge gained may be of great value toward suggesting improvements in the system under investigation (Banks et al., 2001). While the potential for action is implicit in the purpose of a study, without real-world implementation of the results, it is difficult to determine the impact of an individual study, or of the methods more generally in a given domain. Across different sectors there is considerable variation in the implementation of the results of simulation studies, usually defined as concrete changes to the system under investigation, resulting from the recommendations from findings (Monks et al., 2016; Ranyard et al., 2015). For example, results from simulation of manufacturing assembly lines are routinely used for operational decision-making (Mebrahtu & Ladbrook, 2008; Negahban & Smith, 2014). A review of supply chain simulation research (Oliveira, Lima & Montevechi, 2016) found that 28% of papers reported implementation of results based on real-world applications, a figure that the authors considered to be low. Meanwhile, evidence from healthcare has for decades reported very low levels of implementation (e.g. Brailsford et al., 2009; England & Roberts,1978; Fone et al., 2003; Jahangirian et al., 2015; Jun, Jacobson & Swisher, 1999; Katsaliaki & Mustafee, 2011), for example, Mohiuddin et al. (2017) reported in their review that only 14% of results were implemented. This issue also crosses methodological boundaries, for example, Macal (2016) stated that very few published agent-based M&S (ABS) applications have made significant policy impacts or are used regularly to support decision-making. The use of mixed methodologies has been proposed as a potential solution to low levels of implementation (Sachdeva et al., 2007), however a recent review of hybrid (mixed method) simulation modelling across all domains found that only 2% of papers described evidence of real-world implementation (Brailsford et al., 2018). Although this may be an outcome of the relatively more complex approach of combining methods and the challenges associated with verification and validation of such models, a decade earlier, Taylor et al. (2009) observed that evidence of real-world engagement and benefit as a result of simulation studies was markedly low across multiple domains.

While implementation of results is not the only criterion for determining the success of an M&S study (e.g. Gogi et al., 2015), Royston (2013) argued the case for OR as a whole to focus on implementation of results of studies. Similarly, Ranyard et al. (2014) focussed on the scope of OR practice within the real-world needs of organisations. Translating research into real-world results is a concern in all sciences, however Royston asserted that for OR this is a particularly serious issue given that improvement is the goal of the discipline. While the aim of a simulation study is to provide insight and understanding toward informing potential action (Jahangirian et al., 2017; Robinson & Pidd, 1998), the decision to implement changes based on the results of the study belongs to the stakeholder. For this reason, focusing on the aspects of the modelling process which influence *trust* is imperative, and the motivation of our paper is to gain an in-depth understanding of what is meant by the term ‘trust’ in an applied M&S study, and how modellers might influence facets of stakeholder trust toward more successful outcomes. The contribution of our paper is a conceptual model which can be used by modellers engaged in real-world M&S studies applied to management problems within complex socio-technical systems, to pay attention to aspects of trust which arise throughout the lifecycle of an M&S study. These are studies which, in general, require a comprehensive contextual understanding of the system and problem under investigation, and engagement with stakeholders to define, develop and validate solutions.

In the following section we articulate the motivation for our work, then review the *trust* literature in terms of the relationship between models, modellers (simulation practitioners) and stakeholders of the study. In the subsequent sections 3, 4, and 5, we examine the consequences of these relationships and their interactions during aspects of a simulation study. Section 6 is the discussion section. It captures our conceptualisation of the three-way, interdependent relationship between the modeller, stakeholder and the simulation model over time, and presents it as the Trust Model. Section 7 outlines future work.

2. Review

2.1. Trust in M&S Studies

The process of conducting a simulation study is considered to be as important as its technical aspects (Robinson, 2002), as OR is a collaborative discipline, and modellers engage with stakeholders in the system, even if indirectly, to define and develop solutions to problems (Monks et al., 2014). For example, five critical success factors for M&S studies were derived from the simulation literature by Jahangirian et al. (2017). Four of the five of these factors were related to stakeholders, including communication with stakeholders, involvement of stakeholders, and responsiveness to their needs. As trust relationships develop gradually, trust is seen as the outcome of a process (Blomqvist, 1997), hence we argue that throughout the course of an M&S study, decision-makers may use knowledge and information beyond that provided by the results of the study to determine the potential for action.

Typically, an M&S study progresses through a number of stages before trust in the outcome of the study can be established, and the results can be accepted. Figure 1 illustrates the stages of a typical M&S study and the feedback between the stages (Brooks & Robinson, 2000; Sargent 2004). The study starts with a real-world problem or consideration for a future system. A conceptual model is then developed and validated, followed by model coding. In the verification stage the computer model is checked to ensure that it is a good representation of the conceptual model and is implemented correctly. Experimental scenarios are then developed and verified. Finally, and subsequent to the process of ensuring operational validation, the results of the simulation may be implemented. With reference to the stages described above, Casti (1997) and Johnson (2000) have considered the question of trust through the lens of model validation. Casti (1997) presents six axes along which to evaluate the scientific validity of a model; these could arguably be mapped to the dotted lines in Figure 1. These are *operational validity* (whether the model provides answers for which it is built), *empirical validity* (whether the model is in agreement with observed data), *theoretical* and *consistency-based validity* (checks to ensure that the model has no contradictions with established theories or logical inconsistencies), *faith-based validity* (whether domain experts agree with the results produced by the model), and *test-based validation* (whether the model can be tested in the real world). Johnson (2000) proposed an extension of Casti's work by enumerating eight additional criteria which seek to induce trust in models of sociotechnical systems. These additional criteria could be grouped under scenario verification, operational validation, and informing practice, and include affording communication, scenario exploration, the objectivity of the modeller, and the perceived risks of the outcomes of the simulation. While these more policyoriented additional criteria go some way to pointing us in the direction of trust, Johnson stops short of presenting a coherent model. Casti's and Johnson's work lay the basis for an academic discourse on the trust aspects of a computer model, however their discussions primarily centre on the modelling artefact (the computer model), computer simulation of the model, and the resultant data generated through experimentation, such that the existence of a computer model is a precursor to answering the questions on trust. While model validation and verification are clearly important, this perspective assumes that the decision-maker is able to enact rational decisions, supported by the results of the M&S study (Hulshof et al., 2012). However, decisions contain an element of risk and judgement. While a simulation model may be technically well executed, a decision-makers' trust in the results may depend upon intangible factors such as interpersonal relationships. For example, in their critical review of management literature, Nikolova and Devinney (2012) argued that many organisational decisions are primarily made intuitively based on factors such as domain expertise and the decision-makers' position of power.

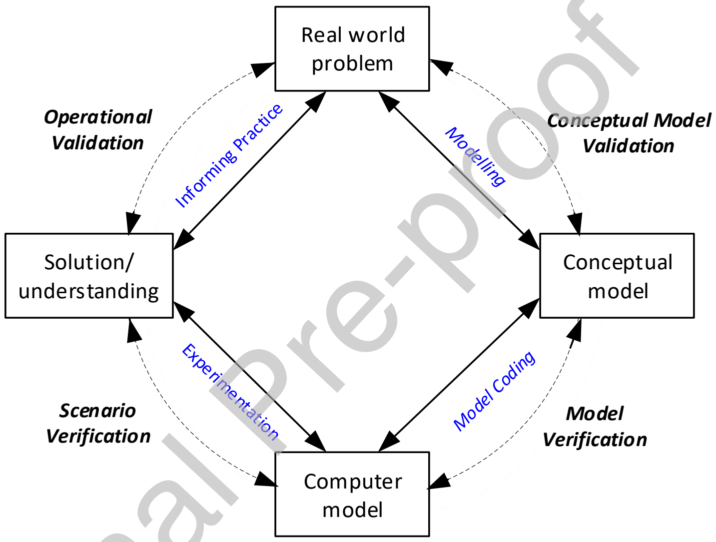

Figure 1: Stages of an M&S study showing validation and verification; adapted from Brooks and Robinson (2000) and Sargent (2004).

Perceptions of a specific situation or a specific object, which may be a model, a person or an organisation, are a precursor to trust (Ebert, 2009). These perceptions are affected by context, and will affect both the need for trust and the evaluation of trustworthiness (Mayer et al., 1995). These perceptions are also dynamic, as dyadic trust evolves within a relationship as parties interact over time (Blomqvist, 1997; Welch, 2006).

The notion of trust in the relationship between OR practitioner, the model and stakeholders has been the subject of limited work in the OR field. A search in IAOR (https://iaorifors.com/) using the term 'trust' returned 234 abstracts, the majority in management and information systems (IS) disciplines. INFORMS (https://pubsonline.informs.org/) returned 76 papers with the word 'trust' in the title; the majority were also in IS and management. Through a review of the titles, four papers were retained from the IFORS search, and three from INFORMS. Each of these has contributed toward an understanding of dyadic sources of trust, but none are specific to OR applications. There is a sparsity of literature that is focussed on the empirical study of the relationship between OR practitioner and client. Notable exceptions are Ormerod (2008, 2014, 2017a, 2017b) who has called for more informative case studies to be published with a clear articulation of the sort of data that is needed, Eden (1982, 1989) and Franco (Franco 2006, 2013; Franco & Rouwette, 2011; Franco et al., 2016) addressed similar issues. Our review into the trustworthiness of models developed for simulation studies has been limited by the dearth of existing work. In the field of management, a considerable amount of research has examined trust over the last two decades, focussing on interpersonal, team and organisational levels of trust, with or without a communication channel or artefact as a medium (Blomqvist, 1997; Ebert, 2009; Fulmer & Gelfand, 2012; Mayer et al., 1995; Schoorman et al., 2007; Welsh, 2006). In IS, work has focussed on technology acceptance and adoption, alongside the importance of trust in the provider (Oksuz et al., 2016; Söllner et al., 2010, 2012, 2016a, 2016b; Wang & Benbasat, 2005; Wang et al., 2015). Also beyond OR, the nature of trust in the relationship between a consultant and client is the subject of a wider literature more generally associated with management consultancy, e.g. see Faust (2012, pp.149-152) and Nikolova and Devinney (2012, pp.398-403). More widely, Ebert (2009) synthesised 800 highly-ranked articles on trust, aggregating definitions, drivers and consequences of trust across disciplines - the majority were in human resource management (HRM), marketing, strategy and psychology – reaching a consensus of defining concepts and a general trust model for management research. Similarly, Fulmer & Gelfand (2012) selected highly-ranked business school journals in organisational behaviour, HRM, strategy, entrepreneurship and international business to categorise trust drivers and consequences at multiple organisational levels. Castaldo et al. (2010) categorised definitions and key dimensions of trust in business relationships, and Blomqvist (1997) explored the perspectives of psychology, philosophy, economics, contract law and market research to define trust for business research. Each of these has informed our review. We start by defining 'trust' as used in this paper.

2.2. Defining trust and the role of risk

Many concepts have been used interchangeably in the literature to define aspects of trust, subsequently unpacked by scholars who have attempted to reposition these terms within a consistent definition of trust. Examples include: cooperation, confidence, predictability (Mayer et al., 1995); and competence, credibility, confidence, reliance, faith (Blomqvist, 1997; Ebert, 2009).
'Confidence' has been variously defined in relation to trust, for example: (i) Confidence is a certain expectation that something will happen, with no consideration of the possibility of failure, while trust involves the conscious consideration of alternatives (Blomqvist, 1997); (ii) Mayer et al. (1995) contrasted the two terms as per Luhmann (2000), whereby trust recognises and assumes risk, while confidence accepts the risk; (iii) Trust suggests certainty of feeling based on inconclusive evidence, while confidence implies stronger cognitive grounds for certainty, and the content of experience, thus performance (Ebert, 2009).
Specific to data modelling studies, Kolkman et al. (2016) conducted a qualitative analysis to identify the criteria for acceptance of a sample of models used for informing policy. 'Acceptability' was defined in terms of the model being 'used routinely as part of a user's occupation'. Mayer et al. (1995) differentiated between 'trust' and 'engaging in trusting action'. There is no risk taken in the 'willingness to be vulnerable' (that is, to trust), but risk is inherent in its behavioural manifestation. In other words, acceptability of models as defined by Kolkman et al. (2016) implies a confidence in the model, or the modeller, or both, where trust is a precursor to confidence and to assuming risk, and action is an outcome of confidence. Definitions of trust in the literature vary, capturing different elements of trust. Blomqvist (1997) offered the simple definition "an actor's expectation of the other party's competence and goodwill" (p. 283), while Ebert (2009) referred to "a generalised expectancy held by an individual that the word of another...can be relied on". These are consistent with other

highly cited definitions of trust (Castaldo et al., 2010), however they fail to capture the risk-taking which is inherent in a trusting situation (e.g. Mollering, 2006). Mayer et al. (1995) proposed the definition of trust that we have used in this paper, as the "*willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor…*" (p. 712).

This definition encompasses positive expectations of trustworthiness, referring to expectations or perceptions about the trustee's (modeller's) competence and motivations, and the trustor's (stakeholder's) willingness to take a risk. The use of the term 'vulnerable' does not imply weakness or defencelessness. Rather, it describes a willingness or intention to depend on the model results with a feeling of relative security, even though risks are possible. Mayer et al. (1995) proposed that the level of trust is compared to the level of perceived risk in a given situation. If the level of trust exceeds the threshold of perceived risk, then the decision-maker will engage in action. Trust will increase the likelihood of action, however whether or not a specific risk is taken will be influenced by both the amount of trust and the perception of risk inherent in the behaviour (Mayer et al., 1995; Schoorman et al., 2007). The criteria outlined by Johnson (2000) explicitly addressed risk. For example, where the simulation is used to make life-critical decisions or to allocate large amounts of resources, significantly more trust may be required in the results compared with simulations of physical systems, particularly where some decision-makers do not like the outcome (Johnson, 2000). The relationship between trust, risk and action may not be as simple as Mayer et al. (1995) positioned it, however it forms a helpful conceptualisation. For example, a more participatory approach to diverging and converging on a solution can help to reduce the possibility of stakeholders believing that their preferences and objectives were not taken into account, enhancing confidence in the outcome (Franco & Montibeller, 2010).

2.3. Individual and contextual factors of stakeholder trust

Risk-taking is given as an explicit component of trust by many scholars in management (Mayer et al., 1995; Sitken & Pablo, 1992), IS (Li et al., 2008; Oksuz et al, 2016) and other disciplines (Blomqvist, 1997; Ebert, 2009). However, while trust will lead to risk-taking, the form of risk-taking is dependent upon the context and the risks involved, including domain familiarity, organisational control systems and social norms (Sitken & Pablo, 1992). A personal disposition or willingness to trust has also been identified as a significant factor (Mayer et al., 2015; Wang et al., 2015), as well as affect and emotion (Fulmer & Gelfand, 2012; Schoorman et al., 2007), cultural differences (Blomqvist, 1997), and the balance of power in the relationship (Fulmer & Gelfand, 2012; McEvily et al., 2017; Nikolova & Devinney, 2012; Schoorman et al., 2007). Communication processes between the trustor and the trustee play a key role in the development of dyadic trust. This can include engaging in non-task related communication, sharing information, being accessible, being positive, and transparency (Fulmer & Gelfand, 2012). Kolkman et al. (2016) found that the reputation of the modeller and participation in development affect model acceptability, alongside organisational conditions including responsibility for acting on the results, and the existence of advocates within the organisation. Some of these factors have been investigated individually or in specific domains in the simulation literature toward improving the successful implementation of such studies, with broad agreement on the underlying constructs (e.g. Brailsford et al., 2013; Tako & Robinson, 2015; Steins & Persson, 2015). For example, in healthcare interpersonal factors include senior management support and a local champion (Brailsford et al., 2013), and organisational criteria include the timing of the study to support critical decisions, and cost/benefit ratios (Steins & Persson, 2015). Many of these criteria can be influenced by the practitioner, emphasising that the usefulness of a model to policymaking or decision-making cannot be isolated from the context in which it is used, and that unless a modelling study is aligned with the perceived reality of organisational decision-making, it is unlikely to be accepted. While this seems obvious, the implications for M&S practitioners are clear. Our focus turns now to antecedents of trust, those conditions which lead to interpersonal trust.

2.4. Antecedents of interpersonal trust

Trust antecedents have been collated repeatedly in the literature. For example, Ebert (2009), Fulmer & Gelfand (2012), Mayer et al. (2005) and Welsh (2006) have examined the trust literature to determine the most commonly characterised conditions of trustworthiness. Benevolence, ability and integrity appear in the literature most often (Ebert, 2009; Fulmer & Gelfand, 2012; Mayer et al., 2005; Söllner et al., 2016a; Wang & Benbasat, 2005; Welsh, 2006). *Benevolence* is the extent to which a trustee is believed to want to do good to the trustor. It is associated with terms such as loyalty (Mayer et al., 2005), rapport and cooperation (Fulmer & Gelfand, 2012), and honesty (Blomqvist, 1997). Ebert (2009) clustered the key variables cooperation, benefit, collaboration, commitment, reciprocity and loyalty, which she labelled as 'future intention'. This conforms with the definition of trust proposed by Gambetta (2000) in which benevolence is central: an assessment that a particular, beneficial action will be performed, and that the trusted actor is unlikely to behave in a way that is damaging. *Integrity* is the perception that the trusted person adheres to a set of acceptable principles, beliefs and values, and is associated with terms such as fairness and consistency (Mayer et al., 2005), reliability and ethical conduct (Fulmer & Gelfand, 2012), trustworthiness and confidence (Ebert, 2009). *Ability* describes the context-specific competencies and skills needed to perform a future action. It is associated with the terms competence and expertise (Fulmer & Gelfand, 2012; Mayer et al., 1995; Welsh, 2006). Gabarro (1978) drew attention to the context-specific nature of the construct, identifying functional/specific competence, interpersonal competence, business sense, and judgment as bases for trust. Similarly, Ormerod (2008) outlined a set of competencies required by both the client organisation as well as the practitioner in OR studies, such as the ability of each to manage the process, and to articulate and understand contextual factors. He also emphasised that participation is key to eliciting understanding, and generating commitment.

Other antecedents have been identified less commonly in the literature, and include dependability, reliability, past interactions, availability, discretion, openness and motives (Castaldo et al., 2010; Fulmer & Gelfand, 2012; Mayer et al., 1995). Blomqvist (1997) synthesised the commonly used terms into a parsimonious, two-dimensional conceptualisation of trustworthiness, *goodwill* and *competence*. This includes ability, while the more abstract dimensions which imply moral responsibility and good intentions, are absorbed into the dimension *goodwill*. For all constructs, participatory practice can be viewed as a tool for communicating these features, however where participatory practices engage collaborative teams, team-level trust must be distinguished from interpersonal trust. Team-level trust is a relatively new research area, and research has begun to examine additional antecedents and outcomes of trust at this level, such as conflict management strategies, leadership abilities, communication behaviours, and transparent and unambiguous goals and knowledge sharing (Dirks, 2000; Fulmer & Gelfand, 2012). This aligns with the 'social learning model' or participatory view of the client-consultant relationship, in contrast to the expert mode, where the consultant delivers solutions uni-directionally, and little learning occurs (Nikolava & Devinney, 2012). Participatory consulting describes a form of mutual helping and reciprocity, and power relations are balanced. Similarly, in OR, the expert mode is contrasted with facilitated modelling, where OR models are co-created with stakeholders in facilitated mode (Franco &

Montibeller, 2010). However in practice, most real-world research benefits from some form of bi-directional participatory practice (Ormerod, 2012).

2.5. Trusting a model

The above factors capture important elements of dyadic trust, but there are further antecedents between stakeholders and the simulation model itself. Robinson and Pidd (1998) identified trustworthiness as an important attribute in two dimensions pertaining to the delivery and assessment of the success of a simulation study, namely, confidence in the model and credibility of the provider. Credibility is the quality of being believable; this can focus on a person or an artefact (Wang & Benbasat, 2005), although is generally seen as an attribute belonging to the decision-maker (Robinson, 2002). Sargent (2015) defined credibility as being concerned with developing the confidence needed by users and potential users to use the model, and in the knowledge derived from the model, assuming it is sufficiently accurate for its purpose. As the first stage of the life-cycle of modelling, Balci and Nance (1985) argued that problem formulation greatly affects the credibility and acceptability of model results. This is what Schön (1983) called 'problem setting', a process which defies technical rigor, but embraces uncertainty, uniqueness and value conflict, both in formulating the problem and validating it. In the case of insufficient problem definition, the problem solution becomes irrelevant, as it is failing to address the actual problem.

Clearly, a model needs to be established as structurally and operationally valid before it can be trusted, both by stakeholders, and by the modeller themselves (e.g. Balci, 1989, 2012; Onggo, 2016). Using a comprehensive life cycle of simulation model, Balci (1989) emphasised that sufficient effort must be devoted to every process of the life cycle of a simulation study to assess accuracy toward ensuring the credibility of simulation results. Focusing on validation, Oral and Ketani (1993) advanced a bridge between scientific solutions and real-world practice through four facets: managerial situation, conceptual model, formal model, and decision, corresponding with the lifecycle model in Figure 1. Visualising these elements as facets, rather than a cycle, allows a shifting focus on different features of an OR study, where 'modelling' and 'simulation' may be of varying importance, and other methods or priorities may require specific emphasis. While underlining the interdependence between validations of each of these facets, this practical and inclusive conceptualisation also positions the process of validation as dependent on the nature and specific objectives of the practical OR problem being considered, rather than applying a universal validation methodology. This supports rigorous application within pragmatic practice, a balance which Schön (1983) insisted is required if we are to address the reality of organisational problems which start, and progress, from the assumption that action is built into the inquiry.

In IS literature, trust has been shown to be a major factor in technology acceptance research. Antecedents of trust between the artefact and the decision-maker have been investigated empirically (e.g. Li et al., 2008; Wang et al., 2015). In an M&S study, a computer model is a technical artefact, generally developed using a simulation package. Alongside model validation, a range of perceptual factors can be influenced by the practitioner to enhance model credibility and influence the confidence that decision makers can have in an M&S study. Conceptually, Wang and Benbasat (2005) and Söllner et al. (2012) argued that trust in a person and trust in technology are fundamentally similar, citing empirical evidence which indicates that there are no significant differences between components of trust in humans and those in technological artefacts. Artefacts mediate trust relationships between humans but also have a direct relationship, for example, providing recommendations (Söllner et al., 2016a, 2016b). In this case, Komiak and Benbasat (2006) proposed that as with interpersonal trust, the level of trust is compared to the level of perceived risk. Other trust frameworks have been applied in the IS literature, for example Li et al. (2008) adapted the Theory of Planned Behaviour (Ajzen, 1991) to measure trusting beliefs, trusting attitudes, and social norms. These underline the effects of social influence, reputation and organisational factors in building initial trust in technology, and capture risk in the outcome: intention to act. However, trust develops over time (Blomqvist, 1997) and Wang et al. (2015) argued that familiarity resulting from the accumulation of trust-relevant knowledge is an important antecedent of trust between stakeholders and the artefact. More generally, and again comparable to interpersonal trust, for trust in technology, the counterpart to competence is functionality, to benevolence is helpfulness, and to integrity is reliability (McKnight et al., 2011). These describe the degree to which the technology functions as promised, provides adequate and effective results, and operates predictably (Oksuz et al, 2016). A model for measuring trust in artefacts developed by Söllner et al. (2010, 2012) included similar dimensions, those of competence, accuracy, reliability, functionality, consistency, understandability and predictability. These factors also accord with those found by Kolkman et al. (2016) in their empirical analysis of model acceptability. Acceptability was associated with the degree to which the model is perceived to be valid, the quality of the underlying data, the transparency and tractability of the model in terms of its complexity and its underlying assumptions, the efficiency of the modelling process, the flexibility of the model to answer new questions, model usability, compatibility with existing systems, and consistency of results with decision-makers' expectations.

While some of these factors focus on 'initial trust' (Li et al., 2008; Söllner et al., 2010, 2012) whereby the existence of the artefact or model is a pre-requisite for determining the level of trust, others capture how trust dimensions change as the relationships, attitudes and beliefs between the artefact, the practitioner, and stakeholders mature throughout the project lifecycle (Kolkman et al., 2016). Franco (2013) argued that models can act like 'boundary objects' (Star and Griesemer, 1989), tangible artefacts around which modellers and stakeholders can interact to explore the possibilities for action. Dodgson et al. (2007) make early use of the concept of boundary object in the context of M&S studies. However, despite the relevance of the idea of the boundary object acting to support the building of trust this was not considered by either Dodgson et al. (2007) or Franco (2013). Furthermore, trust did not appear as a concept in Star and Griesemer's work (Star & Griesemer, 1989) and we therefore regard this as an area of further research.

Models can support negotiations and reflect incremental changes over time in group members toward common agreement and new knowledge about the problem situation being addressed. This is understood to enhance confidence in the analysis (Franco & Montibeller, 2010); researchers agree that the development of trust is a dynamic process, as trust progresses gradually during an interaction and needs to be maintained over time (Tang et al., 2015, 2018; Welch, 2006). Furthermore, the process of trust-building is seen as self-enforcing, whereby trust creates trust, and distrust creates distrust (Blomqvist, 1997). Viewing trust as a dynamic process has important implications for M&S studies, and is a process that needs to be managed.

2.6. Trust and the time dimension

The time dimension is central to the factors involved in trust. For example, Schoorman et al. (2007) argued that judgements of ability and integrity are formed quickly, while judgements of benevolence take more time, shifting as the relationship between the parties develops. Previous definitions of trust focus on its strong temporal component (Gambetta 2000; Luhmann 2000). The relative importance of trust changes over time, as parties gain experience and confidence in each other, such that faith becomes trust, and trust becomes confidence (Blomqvist, 1997). Lave and Wenger (1991) placed strong emphasis on learning through interaction with others in their theory of situated learning; empirical evidence supports this, for example trust transfer has been shown to be dynamic, with expectations about future behaviour updating through repeated interactions (Delgado-Marquez et al., 2010).

Interpersonal trust has been defined in the context of social learning theory (e.g. Rotter, 1980). Lave and Wenger (1991) defined learning as social participation, which leads to shared knowledge and understanding of the world. This accords with Bandura's (1977) view of social learning, where reality is perceived through interaction, feedback and reciprocity between the environment and individual cognition. A very early theory of social learning (Miller & Dollard, 1941) suggested that individuals observe the behaviour of others, transform it into cognitive representations and execute the behaviour if it is associated with benefits or incentives. Although learning does not necessarily result in a change of behaviour (Muro & Jeffrey, 2008), this theory highlights the role of mental representations in knowledge creation. More recent theories of situated learning and cognition emphasise the generation of knowledge. Muro and Jeffrey (2008) adopt a social constructivist point of view and stress the creation of shared knowledge and development of a common social reality. Participatory practice is central to social learning processes, as a bidirectional learning process is largely missing from expert modes of practice. Additionally, managing group processes in transdisciplinary research has led researchers to extend the application of individual social learning to investigate how groups learn through interaction and collaboration (e.g. Schauppenlehner-Kloyber & Penker, 2015).

The concept of learning from models has received relatively little attention in the literature. Hodges (1991) explored various ways that a simulation model, even of low accuracy, can support learning and insight, while Gogi, Tako & Robinson (2016) evidenced empirically that simulation generates insights. Through experimental research, Monks et al. (2014) found that learning occurs both during model development and during experimentation. Where time is limited, this suggests a learning trade-off, however Monks et al. (2016) reported that transfer of learning occurs best where there is sufficient time for involvement in both stages. Van Ittersum and Sterk (2015) described the potential contribution of computer models to social learning, the convergence of stakeholder perspectives and potential solutions to a problem situation. They argued that results of computer models may be implemented given the merging of specific circumstances, including the social learning process that contains the values and aspirations of the modeller, fitting the model to the context, and interpreting the results in relation to other knowledge sources such as expertise and experience of stakeholders. This underlines how different elements become important at different phases of a study. Furthermore, positioning the argument within social learning emphasises how changes in understanding are occurring through social interactions and processes between actors. Similarly, Eden and Ackermann (2001), Franco and Montibeller (2010) and Franco and Rouwette (2011) reinforced the importance of social processes of delivering, exploring, negotiating and analysing data and model results, and agreeing the directions of action, with involvement acting as an effective incentive for supporting outcomes. With an emphasis on knowledge creation and the social construction of decision-making, Franco (2013) argued that models should be viewed in terms of their possibilities for action, rather than as static tools providing absolute solutions. His argument focused on the role of the model as a cognitive representation in enabling interaction processes, and the new knowledge which is dynamically created. Velez-Castiblanco et al. (2016) described this as an evolving process, resulting from the aggregation of communications exchanged over time, both task and non-task focussed. As the model acts as a shared representation, the process of learning is also shared, with the goal of increasing the group's commitment to implement change, as insight converges over time (Franco & Montibeller, 2010).

2.7. A three way conceptualisation of trust for modelling and simulation

Alongside the creation of actionable insights is the creation of trust, as the willingness to engage in action requires trust as a precursor. The definition of trust provided in Section 2.2 allows for individual and contextual factors such as domain and problem knowledge, internal control systems to manage risk (Schoorman et al., 2012), and the OR project's terms and management structure, which may provide some reassurance that remaining risks can be managed (Ormerod, 2008). Furthermore, as several scholars have argued that trust relationships with artefacts (models) are comparable to interpersonal trust relationships (e.g. Söllner et al., 2012), existing definitions and dimensions of trust have been extended to encompass technical artefacts. The combined effect can be seen as a three-way interaction between the model, the modeller and the stakeholders. The aggregated outcome of a given interaction is a certain level of trust. Given the context of an M&S study, when stakeholder trust (the willingness to take a risk) is higher than the perceived risk, the resultant level of trust may act as a precursor to confidence in the model and is likely to enhance the possibility that its results will be used to inform practice. By viewing trust development as a temporal process, modellers are enabled to systematically increase their perceived trustworthiness by both communicating their own relevant skills and intentions, and the ability of the model to address the problem situation throughout the M&S study lifecycle. Further, as a deepening understanding of the problem situation, contextual factors and stakeholders' evolving perceptions occur, the modeller may become aware of indicators signalling that appropriate shifts in the process need to be managed to ensure credibility throughout the project lifecycle. We propose that viewing an M&S study through the lens of trust can increase confidence in the model and its results, and support the potential for action. We conceptualise this as interacting facets of trust between the model, the modeller and stakeholders (Figure 2).

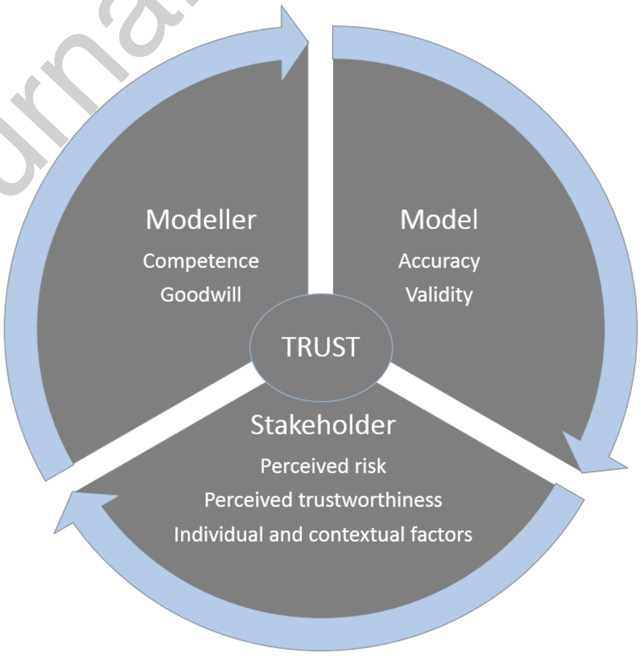

Figure 2: Three-way trust relationships

For the stakeholder, the perceived risk (Section 2.2), the perceived trustworthiness of the model and modeller (Sections 2.4 and 2.5) and individual and contextual factors (Sections 2.3) are relevant. For the modeller, their ability to convey their competence and goodwill, amongst other trust antecedents (Section 2.4), and for the model, its accuracy/validity and other contextually relevant elements such as functionality and transparency (Section 2.5) can influence trust. We consider these to be factors which can change over time. In the following sections we attempt to disentangle these facets. We argue that different facets of trust emerge throughout the stages of a simulation study, and both influence and are influenced by this three-way interaction. We explore this tripartite interaction by focussing on some of the factors that influence the trust relationship between the practitioner and stakeholders (Section 3), between the modeller and the model (Section 4), and between stakeholders and the model (Section 5). We conclude by proposing a formative model of trust which conceptualises these relationships dynamically, and their contribution toward confidence in, and acceptance of M&S studies for informing real-world improvement.

3 Facets of trust between modellers and the stakeholders

This section focuses on the facet of interpersonal trust between the modellers and stakeholders of an M&S study. Our previous discussion has shown that two aspects of this relationship are important – (i) the perceived trust that stakeholders have in the modeller, influenced by the degree to which the modeller is able to communicate his or her relevant, project-related competencies and goodwill; and (ii) the degree to which stakeholders are able to communicate the relevant problem situation and context, and modellers are able to understand what is involved and what is expected of them. These two factors are inter-related, and while this interaction is occurring throughout the study lifecycle, arguably this facet has the greatest influence in the early phases of a study, prior to the development of a formal model. For this reason, this facet is explored during the problem formulation and conceptual modelling stages, where the focus is on shared communication and understanding but it must be emphasised that this relationship will continue to evolve throughout the study lifecycle.

3.1. Problem formulation

Problem formulation is the first stage of an M&S study, and greatly influences the acceptability and credibility of model results. In a complex social system, this is necessarily a participative process. A participative approach does not necessarily involve formal qualitative methods, problem-structuring methods (PSMs), or facilitated modelling. It is an approach to research which incorporates local knowledge into research and planning, and collaborative activities in an iterative, flexible design (Cornwall & Jewkes, 1995). Balci and Nance (1985) and Balci (2012) outlined procedures for problem formulation, verification of the problem and a set of indicators for measuring errors of problem formulation. These emphasise both the importance of adequately formulating a problem, and of appropriate stakeholder engagement. The pragmatic advantages of simulation modelling come with epistemic costs, albeit in a context-sensitive way, in particular where uncertainties in the system make it more difficult to build reliable simulations. Models do not objectively capture reality, only the modeller's subjective interpretation of reality, hence the epistemological justification for inferences made about the real-world system is often considered to be the researchers' trust in the relevant similarities of the model to the real world and the knowledge, assumptions and theories built into the model (Giere, 2009; Parker, 2009; Padilla, Tolk, & Diallo, 2013; Winsberg, 2009a, 2009b). However whilst the modeller must achieve a good understanding of the problem and its context (Edwards et al., 2004), it is equally important that stakeholders perceive that the modeller has achieved a good understanding. This is an important antecedent of trust, as discussed in Section 2.3. This is the start of the process of trust-building, and establishes both the motives of the researcher and the purpose and context of the simulation study. The need to engage stakeholders and domain experts is established in social simulation studies (Jahangirian et al., 2015), however the importance of engaging the most relevant, key stakeholders is rarely emphasised. This partly addresses the need to capture multiple perspectives and interests through direct involvement, but also enables consideration of those stakeholders who may need to be managed with respect to outcomes (Ackerman, 2012; Balci, 2012). The degree of participation required is likely to vary through the study cycle, however studies reporting higher client involvement are more likely to report implementation of recommendations (de Gooyert et al., 2017; Kotiadis et al., 2014; Kotiadis & Tako, 2016, 2018; Robinson et al, 2012; Tako & Kotiadis, 2015).

3.2. Conceptual modelling

Participative approaches are common in the conceptual modelling phase of an M&S study, and, as discussed in Section 2.4, form a bidirectional learning process of communication and understanding. Conceptual modelling is a key part of a simulation study, defining the structure and nature of the problem of interest as understood by the modeller. Robinson (2006, 2013), Tako et al. (2010), and Onggo (2016) underlined the importance of conceptual modelling as a process and tool that can assist in communication and trust-building with stakeholders. The aim is to model an abstraction of the system, rather than a system description, which can result in unnecessarily complex models which are harder to validate and can be less acceptable to clients (Ahmed & Robinson, 2007; Roca et al., 2015).

Knowledge about the real world and problem situation is acquired from stakeholders as domain experts (Kotiadis & Robinson, 2008), and consideration of competencies should include the expertise and knowledge of stakeholders. Once developed, the conceptual model is communicated back to the stakeholders. This participatory process is particularly important where problems are 'messy', the organisation is politically charged and/or stakeholders have conflicting interests. Integrating PSMs into the conceptual modelling stage of a study can assist with structuring the problem, validating the model and supporting credibility and transparency of the study process (Elsawah et al., 2015; Holm, Dahl, & Barra, 2012; Kotiadis, Tako & Vasilakis, 2014; Pessôa et al., 2015). PSMs can be effectively used to determine the study objectives by providing methodologically-informed approaches to engagement (Ackermann, 2012), for example Soft Systems Methodology (Checkland, 1995). A modeller may require a potentially large set of relevant competencies, and expertise in PSMs enhances its efficacy (Keys, 2006). Strengthening group capabilities and managing expectations and perceptions supports achieving study aims, while collective behaviour can be seen as an emergent property which may need managing, as a range of dynamics can occur in groups (White et al., 2016). These processes determine how members relate to and engage with one another, as well as the nature and trajectory of the group and what it achieves (an in-depth critical appraisal of the theory and research of group behaviour can be found in Forsyth, 2018).

Additionally, combining constructivist methods with formal computer modelling involves working across paradigms, which can present difficulties for the researcher, although Kotiadis and Mingers (2006) and Mingers and Brocklesby (1997) argued that it can be achieved with reflective practice. Whether or not formal PSMs are required to achieve early study objectives, reflective practice and documentation is essential, particularly where quantitative techniques are to be applied in a social context (Mingers & Rosenhead, 2004; Yearworth & White, 2014). Maintaining awareness of individual impacts and inter-relationships acknowledges how contextual factors can influence and inform trust as knowledge is created during the study, as discussed in Section 2.3. More broadly, Keys (1998) described OR interventions as a complex relationship between the social and technical, and between theory and practice. He argued that OR is neither theoretical nor technological in character, as stakeholders are necessarily integrated into different stages of the modelling process. While technical skills and a theoretical basis for method choice, application and validation are important, stakeholders determine the degree of credibility the conceptual model has as a representation of the problem of interest, but also the perceived trust in the simulation practitioner to understand and deliver, where technical expertise is only one component. From this pragmatic, practice-based perspective, mixing methods, even trivially, is necessary even in the most straightforward sociotechnical simulation intervention.

3.3. Method selection

OR studies often touch on the importance of stakeholders, but few describe how stakeholders are involved. De Gooyert et al. (2017) found that published studies which explicitly describe the process of involving clients are also more likely to describe implementation of recommendations, and more likely to use qualitative methods. The use of qualitative approaches can support an M&S study at various stages (Mustafee et al., 2015; 2018; Powell & Mustafee, 2014; 2017). These might include combining simulation with, for example, site visits, meetings, workshops, questionnaires, cognitive mapping or soft systems modelling, depending upon the situation and the outputs required (Ormerod, 2008). According to Balaban (2015), M&S should embrace expansion of methods, such that hybrid or mixed-methods modelling, triangulation and replication are guiding principles of simulation research. Where theoretical and empirical uncertainties exist, Arnold (2010) proposed the use of triangulation to gain a more comprehensive view of the problem. This can increase the validity and credibility of simulation models, by combining qualitative and quantitative methods at each stage of a simulation study, for example checking stakeholder insights against other data sources for convergent information. Where stakeholder opinions conflict with other data, further analysis may be required. This approach was extended by Burton and Obel (2011), who recommended combining computational modelling with other methods such as ethnographies, surveys and observational methods for the purpose of gaining new knowledge and exploring boundaries, limitations and ideas. The strengths of different approaches can offset the limitations of others, and enhance trust by keeping the specific purpose of the modelling approach central, avoiding the temptation of creating overly complicated models in an attempt to fully capture a problem situation. Burton and Obel (2011) used a range of empirical case studies combining computational modelling with a complementary approach, to illustrate how in a complex world, no one study can answer a question definitively or address a question completely. For the modeller, this means critically examining whether and how their research has or will generate information or knowledge, and communicating this convincingly to stakeholders. Increased stakeholder engagement increases opportunities for these activities throughout the study lifecycle.

While the simplest method needed to address a problem is advocated, the usefulness of a model can only be determined with respect to its purpose and each question asked of it (Gilbert & Ahrweiler, 2009). Andersson, Törnberg, and Törnberg (2014) argued that many quantitative approaches fail to do this, and that combining M&S approaches often combines the weaknesses rather than the strengths of constituent approaches. They argued that formal M&S approaches are unable to access many of the problems that societal systems present us with, instead selectively addressing partial problems. In a complicated organisation with complex dynamics which are constantly renegotiating and challenging the ability of the system to settle, the system resists decomposability, and therefore formal, controlled investigation. It has been found that qualitative approaches used within an M&S study can improve model transparency, ease of use and acceptability; support discussion and debate; and assist participants to increase their knowledge of their own systems toward intervention and change (Lehaney & Paul, 1994; 1996; Lehaney et al., 1999). However, this approach has limitations, in particular the increased time and resources required of both the modeller and the stakeholder organisation. Additionally, Lehaney et al (1999) pointed out the difficulty of sustaining stakeholder interest over a lengthy study. The choice of methods needs to be justified and appropriate, for example Ormerod (2008) advocated 'judicious mixing and matching' (p1439), adapting methods as required in an iterative, flexible and intuitive approach. This enables context-specific adaption and sensitivity to the demands upon the organisation, while also providing the opportunity to build trust during the study process and to gather the data required to address the problem sufficiently.

4. Facets of trust between modellers and the model

Accurate problem formulation and conceptualisation, and attention to interpersonal relationships and appropriate methods, requires consideration during the lifecycle of an M&S study. However, a modeller must also trust in their own skills, ability and motivations to create a simulation model that is sufficiently accurate and valid for the purpose required of it. These competencies and their outcomes are integrated into the building and validation of the model. These are discussed in terms of validation and verification, and standards of practice.

4.1. Validation and verification

Validation and verification occur throughout the study lifecycle, and form an essential criterion for stakeholder trust, as outlined by a number of simulation scholars over the decades (Balci, 1989, 2012; Barlas, 1996; Oren, 1981; Sargent, 2004, 2015) and discussed in Section 2.5. However Padilla et al. (2013) emphasised that while trust in models can be created through sound practices of methodology and validity, models can be subjective because there is neither a perfect nor accurate representation of a system. The complexity of simulation modelling extends our cognitive capabilities, but according to Tolk et al. (2013), published studies frequently conflate the truthfulness of a model, and model usefulness. They called for independent verification and validation of simulations and their results, a challenging and time-consuming activity which they argued is vital in a scientific discipline which operates according to principles of scientific philosophy. Oral and Ketani (1993) advocated a more pragmatic and context-dependent approach to model validation, allowing shifting emphasis on different facets of a study and the chosen method or methods. Validating the *truthfulness*, or deductive ability, of a simulation reflects its static and dynamic correspondence with reality, while the *usefulness*, or the inductive portion, of a simulation is its statistical predictive ability. However, the truthfulness of simulation as a scientific method can be difficult to determine in complex systems or where there is a lack of data (Tolk et al., 2013). Some authors consider that simulation modelling is a link between theory and empirical reality (Winsberg, 2003); the underlying theories built into a model are important for determining the epistemic value of the results. This is particularly true of agent-based models of social simulations. Arnold (2010) argued that the reliability of such models rests on (a) the strength of the background theory and underlying knowledge; (b) well approved techniques of simulation modelling and validation; and (c) successful empirical tests. The less one of these three can be relied upon, the more important the other two factors become, depending upon the model's purpose.

Winsberg (2009a,b) and Giere (2009) have argued that the focus on epistemological features of simulation modelling should be on how researchers justify their own beliefs that the target system can learn something from the model. This necessitates a reflective approach to both methodological and theoretical considerations. As an abductive process, simulation modelling often infers a hypothesised cause for a known effect, hence while the explanation or prediction may be correct, the model may be wrong. Lorenz (2009) called this an abductive fallacy. Barlas (1996) argued that design-oriented models such as SD models, as a 'theory' about the real system, must explain how the behaviour is generated through white-box validation. The internal structure should adequately represent those aspects of the system which are relevant to the problem situation, the "right output behaviour for the right reasons." A model is refuted if a critic can show that a relationship in the model conflicts with an established "real relationship", even if the output behaviour of the model matches the observed system behaviour (Barlas, 1996). As the aim of the model is to generate insight and understanding, the modeller must plan and design the model with that goal in mind, for example by specifying the right problem and selecting the right stakeholders. Diallo et al. (2016) argued that stakeholders can appreciate intelligent simplifications inherent in M&S methods where it is clear that the explanatory payoff can be large, however both stakeholders and modellers must also qualitatively believe that the internal structure of the model matches the system under investigation. How this is achieved and the specific, relevant tests of validity and quality used are dependent upon the OR problem, specific purpose of the model, and the method used (Barlas, 1996; Oral & Kettani, 1993).

4.2. Documentation, reproducibility and replicability

Documentation supports the success of a study as the life-cycle is followed in an organised and structured manner, according to the phases and processes of the study. Sargent (2005; 2015) outlined a recommended procedure for documentation, including specifics on tests, evaluations, data and results, conceptual model validity, assumptions, model verification and operational validity. Documentation allows models to be kept updated, and supports multiple use and re-use of the model (Ahmed and Robinson, 2013); there is a strong argument for standardising model description and documentation to allow models to be more readily adapted for reuse by other researchers (Uhrmacher et al., 2016). Challenges to this include data governance issues and revalidation and verification, however simulation studies are time consuming, and enabling models to be more reusable can shorten the process significantly. Detailed documentation also allows reproducibility and replicability in published research, which is important for credibility and scientific transparency (Monks et al., 2019; Rahmandad & Sterman, 2012). The more costly and risky the decision, the more important these factors become.

Replication of an M&S study involves a new implementation of an existing conceptual model that may differ in some way, for example in the platform or language, but are sufficiently similar so that experiments conducted on each generate results that cross-validate (Tolk et al., 2013). Reproducibility refers to the ability to reproduce simulation models associated with published work. This has emerged as a critical issue due to what has been seen as laxity in documented reporting of simulation activities in published research (e.g. Milkowski et al., 2018), with the purpose of increasing the credibility of simulation models in the wider simulation community (Monks et al., 2019; Taylor et al., 2015, 2018; Tolk et al., 2013). However, the issue is contingent, as M&S is considered to be both an art and a science. The art of problem formulation and conceptualisation is dependent on the skills of the modeller, the context and problem situation and the objectives of the model. For example, Eldabi (in Taylor et al., 2018) argued that while the science of simulation is reproducible, the art of simulation is neither reproducible, nor relevant to the question of reproducibility. More broadly, there is evidence that contextual factors are associated with reproducibility in experimental scientific research; attempting a replication in a different time or place or with a different sample can alter the results (van Bavel et al., 2016). Nonetheless, post-problem formulation, reporting sources of qualitative and quantitative data and definitions and logic behind variables alongside other relevant information (Rahmandad & Sterman, 2012) enables reproducibility and communication between researchers. These are issues for consideration as modellers assure themselves, project stakeholders, and the simulation community that their models and results are trustworthy, by adhering to high standards of practice and reporting. Modellers as researchers are part of a community of researchers, and share the responsibility for the rigorous execution and progress of good research.

5. Facets of trust between stakeholders and the model

A modeller must satisfy themselves that the model is sufficiently accurate and valid for its purpose, however specific attention must also be paid to aspects of the relationship between the model and the stakeholder, as the insight and understanding gained from the model and its results ultimately hope to inform practice. Without trust in the model, there will be little confidence to take action. This facet involves (i) communicating the accuracy and validity of the model; and (ii) stakeholders' perceptions of the usefulness of the model and the knowledge gained from it. These are discussed in terms of model credibility, while facilitated modelling is evaluated as one example of a methodology which considers aspects of both of these factors, and provides further insights into the concept of trust in M&S.

5.1. Model credibility

As discussed in section 2.5, credibility refers to believability (Blomqvist, 1997). It is a perceptual construct which belongs to the stakeholder, and is a belief that a person or object is capable of performing what it claims it can do. Luhman (2000) relates credibility to confidence, where one action is chosen in preference to others. The empirical study by Kolkman et al. (2016) examined criteria for model acceptance, an outcome of confidence. The quality of the model in terms of model validity was found to be the most observed criterion for model acceptance by stakeholders. While simulation models cannot be described as absolutely accurate, Balci (1985; 1989) outlined three types of errors associated with trust in a model. Type 1 errors are committed when sufficiently accurate results are rejected, and indicate insufficient trust in the model, the modeller or both. Type 2 errors involve accepting study results when they are not sufficiently accurate. This is a risk taken by the stakeholder when contextual, individual and perceptual factors are accounted for. The level of trust exceeds the level of risk, but nonetheless, risk remains when taking trusting action. Type 3 errors correspond to solving the wrong problem. In this case, the problem was insufficiently specified, and the conceptual model and formal model did not fully contain the problem. Thus, type 3 errors would negate trust from the start. While stakeholders can disagree on what the 'right' problem is, this is a failure of communication (Diallo et al., 2019). Type 2 errors also need to be considered alongside the purpose of the model and level of accuracy required, while avoiding Types 1 and 3 errors.

Factors other than actual and perceived validity influence trust in a model. These include model transparency/tractability, timing of the simulation modelling process, communication, documentation, and flexibility of the model toward providing solutions (Kolkman et al., 2016; Steins & Persson, 2015). For example, Dewson (2006) reported that lack of documentation resulted in lack of stakeholder confidence in the accuracy of model outputs. Clear and appropriate documentation also allows modellers to draw conclusions and communicate the contextual conditions under which the model was able to inform real-world implementation. As discussed in Sections 2.4 and 3, a key element for increasing trust in simulation models and enhancing contextual understanding is participation of stakeholders, a direct criterion for model acceptance (Brailsford et al., 2013; Freebairn et al., 2018; Jahangirian et al., 2015; Tako & Robinson, 2015). While this enables reflection on the quality of communication, organisational culture and interpersonal relationships, involving stakeholders in model development also indirectly addresses other criteria related to model quality such as ease of use, cost-benefits and fit with work tasks. For example, Brailsford et al. (2013) found that usability, interpersonal support, having a credible advocate and local champion, appropriate training and ongoing support, and sustained engagement enhanced take-up of a simulation modelling tool within an organisation.

One criterion identified for effective modelling and stakeholder acceptance is the need to develop the simplest model possible (Brailsford et al., 2013; Robinson, 2006; Tako, Tsioptsias & Robinson, 2020). Simple models increase transparency and tractability, the ability of expert stakeholders to review the logic of the model and its underlying assumptions, and improve understanding of a problem. This is also context dependent however, as Kolkman et al. (2016) noted that for decision-makers, model simplifications can result in scepticism. Similarly, in system dynamics (SD) applications, Winch (1993) pointed to literature indicating that sufficiently detailed models are required if benefit is to be obtained from the method, as confidence in the model results requires each stakeholder to be assured that their viewpoint is captured within the macro-level model. Acknowledging that detailed models are complex, can be difficult to understand, and lack transparency, Lyneis (1999) also argued that stakeholders are more likely to trust the results of detailed models. He asserted that allowing stakeholders to 'grow slowly' with the concepts and develop a solid understanding of the SD model mitigates these problems. Group model building, or facilitated modelling, is integral to SD studies, with increasing empirical evidence for improved communication, learning, consensus, commitment, behavioural change, and implementation supporting the approach (Rouwette, Vennix & Mullekom, 2002; Scott et al., 2016). While less common in other M&S method studies, Monks et al. (2015b) suggested that a collaborative forum as part of a discrete-event simulation (DES) study might increase the integration of different forms of knowledge and enhance the likelihood of implementation. Elsawah et al. (2015) used a similar approach in an agent-based M&S study, and concluded that the iterative methodology enabled transparency and supported the progression from qualitative to quantitative models, supporting social learning and engagement. In this study, the researchers viewed trust as an enabler, but it is arguable that through the process of social learning, trust is also a self-enforcing outcome: trust creates trust and distrust creates distrust (Blomqvist, 1997). Through facilitated DES modelling, this concept is further explored.

5.2. Facilitated modelling and social learning

While stakeholders are usually involved in the conceptual modelling phase of an M&S study to a greater or lesser extent, an alternative approach to building models by an expert modeller whereby a problem-situation is described, a model built and a solution delivered, is that of facilitated modelling. In this instance, the whole study is conducted with stakeholders, with a plurality of objectives and opinions, and the model acts as a focus for discussion and shared understanding (Franco, 2013). A set of benefits of this approach outlined by Franco & Montibellar (2010) comprised the socially constructed nature of problems and their unavoidable subjectivity; satisficing solutions as an outcome; and increased stakeholder commitment to implementation through enhanced confidence in both the approach and recommendations. However, this constructivist view of knowledge creation does not limit the approach to models as transition objects. One advantage to facilitated modelling is that it can also be applied to 'Hard-OR' methods studies, and can be used to manage and analyse group data, validate the model throughout its development and use, and to cultivate trust. The process can enhance perceptions of model quality, and deepen stakeholders' understanding and ownership of the problem and its context, as well as providing implicit feedback (Franco & Montibeller, 2010; Hämäläinen et al, 2013; Kolkman et al., 2016; Kotiadis, 2007; Onggo, 2016; Pessôa et al., 2015).

Several researchers have used facilitated modelling to support computer modelling methods at the operational level, and have discussed the advantages to these approaches. Although the concept of trust is not overtly addressed, several elements of our working trust model are explicit in the programme objectives, such as changing beliefs over time through stakeholder engagement, addressing context, and focusing on implementation and improvement from the beginning. *SimLean,* the integration of lean principles with DES, is a rapid-improvement approach to facilitated modelling in healthcare (Burgess et al., 2011; Robinson et al., 2012; Worthington et al., 2011)[1]. A clear complementarity between lean and DES was demonstrated empirically in healthcare using interviews, both with a focus on improvement (Robinson et al., 2012). *SimLean* has the further advantage of being a rapid model building process, alleviating the problem of stakeholders losing interest as DES studies can be time-consuming (Jahangirian et al., 2010; Robinson et al., 2012). This is domain and context appropriate, as maintaining stakeholder engagement is critical, and healthcare priorities and roles can shift rapidly (Brailsford et al., 2009). Additionally, once trust has been established, the methodology supports progression to full-scale DES modelling. This is an example of a methodology which successfully adapted to integrate trust-building through acknowledging contextual enablers and barriers, enhancing education through communication, changing attitudes and beliefs, enhancing confidence in the results, and focussing on implementation and improvement from the start in a given domain. In this case, success was evaluated in terms of generating understanding and implementation of results, i.e. engaging in trusting action (Robinson et al., 2014).

A second approach is the *PartiSim* multi-methodology framework (Kotiadis et al., 2013, 2014; Kotiadis & Tako, 2016, 2018; Tako et al., 2010; Tako & Kotiadis, 2015), which supports facilitated DES studies across six stages, combining Soft Systems Methodology (SSM) with DES. Previous studies have used SSM in the conceptual modelling stage (Holm & Dahl, 2011; Kotiadis, 2007; Kotiadis et al., 2014; Lehaney & Paul, 1994, 1996); the novelty and potential benefits of this methodology lie in the last five stages. As with *SimLean,* the approach is aimed at implementation and improvement, acknowledging domain-specific contextual factors. Other applications of facilitated modelling combined with DES have been described (e.g. den Hengst et al., 2007; Proudlove et al., 2017), however the comprehensive and reflective evaluation and reporting of PartiSim's development specify aspects that are applicable to our conceptualisation of trust. For example, the authors have suggested that there is a process of learning and changing beliefs throughout the study lifecycle (Tako & Kotiadis, 2015), central to our conceptualisation which acknowledges that trust changes over time. They reported that efforts to gain the group's confidence in the model gradually resulted in enhanced confidence in both the modelling team and the model, resulting in consensus about action to be taken: trust led to confidence to engage in action. As learning occurs continually throughout the M&S study lifecycle, stakeholders' beliefs and attitudes will be constantly in flux, as described by our three-way conceptualisation.

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[1] The Warwick SimLean project was inspired and initiated by Professor Ruth Davies. We wish to acknowledge her contribution to the early stages of this project.

While we focus on the issue of trust, implementation is an explicit component of the above methodologies, and is provided as the measure of success. Ultimately bridging the gap between confidence in results and action is a decision belonging to the stakeholder, however these studies show that once trust has been established, behavioural control can be increased by removing barriers and providing the required resources to act, enabling the final transition from 'confidence' to action. It has been argued elsewhere that OR should engage with implementation science toward creating an evidence base about how to effectively conduct OR interventions and to provide evidence and evaluation of impact (Monks, 2015a). While interventions in complex systems can be difficult, and often require support which is outside the remit of the modeller, it is important to understand how stakeholders make sense of an M&S study process, and how the results are used to assist decision making.

There can be disadvantages to facilitated modelling, for example where the modeller is inexperienced. Other disadvantages include the additional time required compared with 'expert mode', and the difficulty converging on agreement (den Hengst et al., 2007). Den Hengst et al suggested that part use of expert simulation mode, and the use of reusable model blocks could reduce the time required. Facilitated modelling is one approach for stakeholders to gain trust in a model and its results, and provides a close ability to monitor and adjust behaviour as required, as participants in the modelling process. However, there are many mechanisms to gaining trust. In very large models, accreditation processes may be involved (e.g. US Department of Homeland Security, 2006; Elele, 2009), and models (or model blocks) that are already validated can be used for developing larger simulations. In this case, the client may be reusing sub-systems in which they had no original input. Pragmatically, some problems may benefit from increased use of participation or facilitation, but as discussed in Section 3.3, examining the underlying rationale for these approaches may enable a determination of how and where they can contribute to the success of a study, and which aspects of trust they are influencing.

6. Discussion

The trust literature, in particular in management, IS and in the area of facilitated modelling has provided us with a theoretical basis for understanding how viewing M&S practice through the lens of trust can focus our attention on those areas of practice which enhance trust and confidence, and therefore increase the likelihood of informing real-world practice. With many M&S studies, the challenge of meeting the requirements for trust needs more than technological rigor. Limited literature in the field of OR has focussed on the empirical study of the relationship between OR practitioner and client, though Ormerod (2008, 2014, 2017a, 2017b) developed the conceptual tools we need for studying the relationship, and issued a clarion call for more informative case studies to be published with a clear articulation of the sort of data that is needed. While Ormerod's work has mostly been directed towards the study of participatory practice, we make here a similar plea that more informative case studies are necessary to make progress with the study of simulation practice. Evaluating the success or otherwise of a modelling study may require sufficient descriptive narrative of the research process to enable conclusions to be made regarding the conditions under which the model was successful. Recent case studies in facilitated DES modelling have demonstrated the value of this approach for researchers who are interested in the relationship between trust and outcomes, and the factors that influence these in practice (Kotiadis et al., 2014; Kotiadis & Tako, 2016; 2018; Robinson et al., 2012; Tako & Kotiadis, 2015). Despite the assumptions, ambiguities and subjective nature of M&S methodologies, a reflective understanding of its limitations and how it is being used can increase the level of trust and confidence. Many researchers have argued that simulations have sources which are evaluated and revised independently of the theory and data, which are built into the model throughout the study life-cycle, including the skills, competence, experience, values and motivations of the modeller (Winsberg, 2003; Barberousse, Franceschelli & Imbert, 2009; Grune-Yanoff & Weirich, 2010; Roush, 2017).

Ormerod (2014) proposed that technical studies could learn from non-technical studies, which pay more attention to the human, contingent and contextual aspects of the OR research process by describing some of the key motivating factors of a study which affect the choice of issues to be addressed, the technical and non-technical approaches and the final outcome. His emphasis was in enabling a more reflective, critical approach to an OR case study; focussing on conceptual frameworks, individual impacts, and key factors and inter-relationships acknowledges how contextual factors can influence and inform trust in the knowledge gained by the study. Many researchers have argued that the human and social challenges facing simulation practitioners are as important as the technical and intellectual ones, such that models become more value-laden, contingent and situated, rather than simply promoting rational decision-making (Brocklesby 2016; Hämäläinen et al., 2013).

Confidence in the results of a model depends on the type of decision-making activity being supported. While efficiency and effectiveness decisions may be validated with historical data, problem-solving modelling may support only the decision-makers' representation of the real-world, although Luoma (2016) emphasised that in many cases this is adequate for the purpose. Although real-world implementation is a key factor in gauging the success of a simulation study, it is not the only factor. According to Robinson and Pidd (1998), success is not a singular outcome and can vary during the M&S project lifecycle. A benefit could be a better understanding of the system of interest and identification of the opportunities for improvement. Regardless of the objective of the simulation study, the position we offer is that the issue of *trust* needs to be understood from the very beginning.

In healthcare, where the real-world benefit of M&S studies remains an open question, researchers have pointed to contextual cultural, financial, political and regulatory factors that affect the uptake of M&S studies (Pitt et al., 2016; Tako & Robinson, 2015). According to Flyvbjerg (1998), rationality and knowledge define reality, but are defined by power. The provision of new, valid information will not necessarily change practice, particularly where entrenched power forms part of the organisational context (Franco, 2006). One answer may be laying open the relationship between rationality and power with participative practice. This can engage stakeholders at different levels of organisational hierarchy, account for contextual and individual factors, enable conscious awareness of both interpersonal and team-level antecedents to trust, and support attempts to manage these relationships throughout the study lifecycle. Management decisions are often a mix of intuitive and deliberative decision-making types (Salas et al., 2010), and the degree to which results generated through simulation are integrated with previous knowledge to inform action is dependent upon a number of factors which can influence trust in the different forms of knowledge (Faust, 2012).

We therefore propose a trust model for M&S (Figure 3) which captures our conceptualisation of the three-way, interdependent relationship between the modeller (or team of modellers), stakeholder (or team of stakeholders) and the simulation model over time. The facets are seen to inter-relate throughout the stages of an M&S study, as per Figure 1. Our position is that the process of building trust starts at the very beginning of the study, and dynamically evolves throughout the phases of the study. Where the results are required to inform practice, confidence in the results is a precursor to 'trusting action' (shown by the link from the three-way trust relationship to the 'informing practice' stage of an M&S study). We argue that trust aspects of each dynamic facet of this model - between modellers and stakeholders, between modellers and the model, and between stakeholders and the model - requires attention and consideration toward actively managing the evolving trust relationships. When the outcome is trust, as perceived by stakeholders, there is a higher chance of confidence in the model results, where the risks are acknowledged and accepted (Mayer et al., 1995; Schoorman et al., 2007). This is not intended to be a prescriptive model, but to focus modellers' attention on those relevant aspects that may be influenced to realise maximum benefit from M&S approaches to real-world improvement.

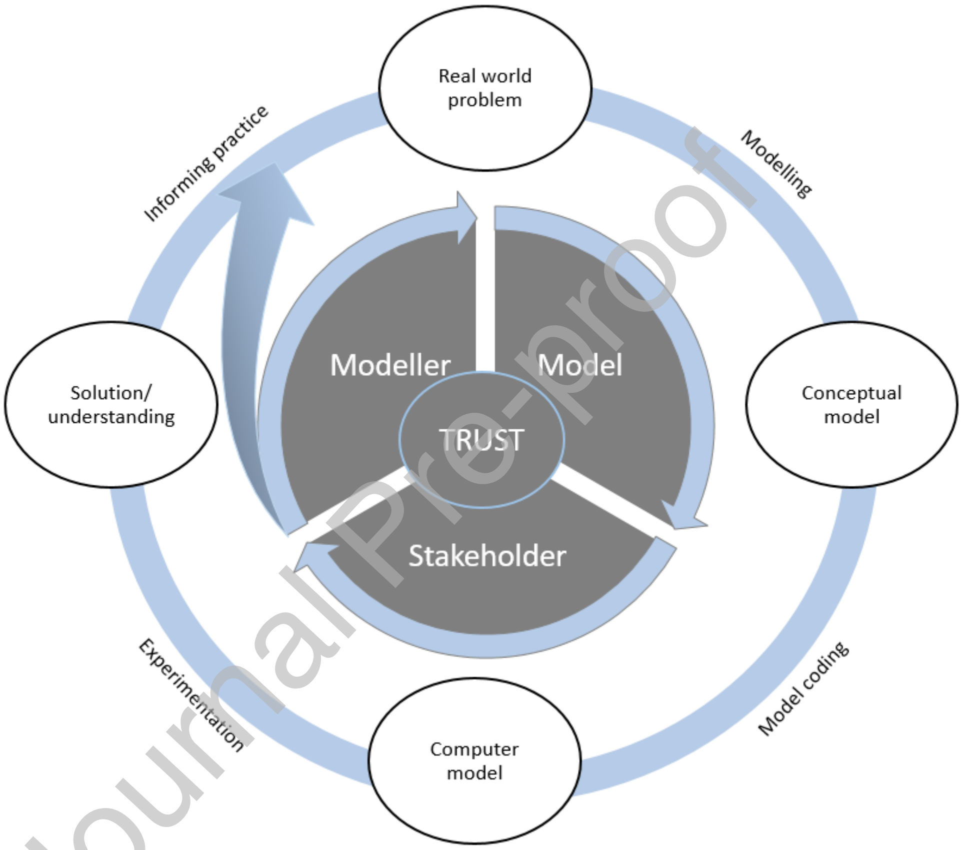

Figure 3: The Trust Model for M&S

Our key recommendation toward effective M&S studies where the aim is to generate actionable insights is that the concept of *trust* is considered from:

(A) The stakeholder-modeller facet: (i) stakeholders' perceived trust in the modeller's relevant range of competencies and skills, their motivations and responsibilities, their understanding of the problem situation and the context, and their methodological choices; perceptions of their leadership, facilitatory, communication and conflict-management styles; (ii) The actual technical, interpersonal, judgement and domain-relevant competencies and abilities of the modeller and their ability to communicate these, their skills and experience in facilitation, their ability to draw out and understand appropriate problem and context-specific information, to manage relationships over time, to communicate effectively and appropriately.

(B) The modeller-model facet: (i) A modeller's own trust gained through the application of best practices, their certainty that the model is valid, credible and sufficiently accurate for its purpose, with consideration and application of relevant validation techniques across the model lifecycle, appropriate to the methods and aim of the study; (ii) that the study is managed such that the timing is appropriate for supporting critical problems, that key relevant decision-makers are involved and managed throughout the process as relationships evolve, and that the process is appropriately documented, including consideration of contextual aspects where appropriate and relevant to study outcomes.

(C) The stakeholder-model facet: (i) Stakeholders' perceptions of the accuracy and validity of the model, its usefulness, its transparency, understandability, functionality and usability, the timing of its delivery, its flexibility in providing solutions and their confidence that the level of detail in the model is appropriate to their situation and context; (ii) Consideration that these factors evolve and change over time alongside learning, and are influenced by the level of engagement with the model build process throughout the lifecycle, from problem formulation through to making a decision, by contextual and social influences; and by the use of the model during this process to support and facilitate discussion and knowledge creation, and/or to provide solutions.

6. Conclusion and future work

6.1. Future work

Our proposed conceptualisation opens the question of trust in simulation studies to further exploration. A significant area is the measurement of trust. Some areas have been investigated in terms of implementation of results and evaluated using researcher documentation, such as facilitated DES studies (Tako & Kotiadis, 2015), though not explicitly with regard to trust. Research on group-model building in qualitative SD has evaluated shifting power relations, reducing cognitive bias, enhancing ownership over a problem situation and supporting consensus and commitment, which are all aspects of trust. For example, Rouwette et al. (2016) used longitudinal questionnaires and semi structured interviews to measure open communication, changes in insight, and quality of conclusions. This enabled reflection on questions such as how to best reconcile conflict in facilitation, and how knowledge about facilitatory processes might be used to improve available methods to support decision-making. Research in facilitated modelling has had comparable aims, for example investigating dynamic decision development (Franco & Rouwette, 2011) and dynamic knowledge creation (Franco, 2013). Similar approaches could be used in M&S studies to measure trust outcomes.

The question of how to measure trust remains open, however our model provides a basis for a measurement instrument of trust in M&S studies. Schoorman et al. (2007) outlined the development, validation and implementation of a short, four-item measure which attempted to capture the degree to which a trustor is willing to be vulnerable to a trustee, which was implemented in several management settings. The scale, and variations of it, measures a trustor's willingness to be vulnerable, and longer measures, in particular, had high validity. It would be of significant interest to determine the validity of these measures, or adaptations of them, in M&S studies.

Empirical work in IS has measured dimensions of trust between stakeholders and artefacts and as our previous discussions have shown, some of these may be applicable to simulation studies, though further investigation is required to determine whether these concepts of trust apply to simulation. There is little research which seeks to understand how stakeholders perceive and trust simulation models. Those which have been done look at initial trust, though longitudinal measures would provide additional insight, for example, which factors are important for sustaining trust. For example, Kolkman et al. (2016) and Brailsford et al. (2013) have investigated aspects of trust in a model as a static concept. Diallo et al. (2016) highlighted the epistemological challenge of codifying natural language, for example from interviews or other qualitative data, which is also subject to change, contradiction and evolution. How this is performed is as much an art as a science, but for researchers, the implications and process of this would benefit from investigation. Kotiadis et al. (2018) addressed the ontological challenge of converting the worldviews of multiple, divergent stakeholders into potential solutions, which they supported with a feasibility measure. Questions remain for investigation, such as how learning takes place during facilitation, the effects of learning on acceptance of models, the effects of affect and emotion, and how different facilitatory approaches might affect scenario selection (Kotiadis et al., 2018). Additionally, specific aspects of simulation models which are known to influence trust could be evaluated, for example, the early development of visual interfaces for simulation packages focused on end-user engagement (e.g. Hurrion, 1991); other aspects of model transparency could be investigated.

Methodological questions are also open to investigation. For example, there are questions regarding the degree to which mixed-method approaches might influence trust or components of it, and how (Powell & Mustafee, 2017; Brailsford et al., 2018). One potential advantage to combining simulation with qualitative methods is that the research design can be viewed top-down, formalising ‘stakeholder engagement’ within a research method. Poor stakeholder engagement has been linked with low levels of implementation of results (e.g. Jahangarian et al., 2010; 2015; Brailsford et al., 2013) but levels of engagement are rarely reported. It may be of interest to examine published studies that report evidence of real-world benefit to identify factors which point to facets of trust toward the successful outcome. Published studies rarely report contextual factors applicable to interpersonal trust, such as leadership, reputation, organisational culture and reciprocity. Inductive examination of these factors in simulation studies may yield important information to inform future conduct in similar domains.

7. Conclusion

We have conceptualised trust in M&S studies as a holistic construct that captures features of the model, the modeller, and the stakeholder, and perceptions of the stakeholder which influence trust. The definition of trust we have used in this paper, as proposed by Mayer et al. (1995), describes the willingness of a trustor (a stakeholder) to be vulnerable to a trustee (the modeller and the model), as a precursor to engaging in trusting action. The stakeholder must trust the modeller, and the model, and the insights derived from the model, to develop the confidence needed to take action. A range of factors influence trust, which we have conceptualised as a three-way relationship between the model, the modeller, and the stakeholders. This relationship evolves through the different stages of an M&S study (Figure 1). It is dynamic in the sense that the relative significance of the three facets (model-modeller, model-stakeholder and stakeholder-modeller) assume importance based on the specific stage of the study. For example, the facet of trust between the modellers and the stakeholders is perhaps the most important in the problem formulation (section 3.1) and the conceptual modelling (section 3.2) phases of the study. This facet is also important for studies that involve clients in the problem formulation stage (section 3.3). As the M&S study progress from conceptual modelling to model coding, the trust associated with modeller and model becomes very important. The modeller must ensure the validity of the model (section 4.1) and that it is documented and the results reproducible (section 4.2). This also positively contributes to stakeholder-model trust since a validated, verified and well documented model provides the stakeholders with the confidence to use the results of the model to implement policies, which could be mapped to the solution understanding phase of an M&S study. In this context, we have discussed model credibility (section 5.1) and facilitated learning (section 5.2).

For the stakeholder, the level of perceived risk, the perceived trustworthiness of the model and modeller, and individual and contextual factors, are relevant. For the modeller, their ability to convey their competence and goodwill, amongst other trust antecedents, and for the model, its accuracy/validity and other contextually relevant elements such as functionality and transparency, can influence trust. We consider these to be factors which can develop over time, enabling modellers to systematically increase their perceived trustworthiness across the study lifecycle by communicating their relevant skills and intentions, and the ability of the model to address the problem situation. Further, as the modeller's understanding of the problem situation, contextual factors and the stakeholders deepens, the modeller may become aware of indicators signalling that appropriate shifts in the process need to be managed to maintain credibility throughout the study lifecycle. Additionally, trust is seen as dynamic and self-enforcing: trust creates trust and distrust creates distrust (Blomqvist, 1997), creating a reinforcing feedback loop. Viewing M&S studies through this lens enables researchers to focus on those aspects of the study which influence trust, and are relevant and appropriate for the specific objectives of the study. This becomes increasingly important as more complex problems are tackled, and technology enables more complex methods. As technology evolves and we become increasingly reliant on it, the interaction between technology, actors and the environment alongside social uncertainty and complexity, results in a continuous shift in the application of methods for generating new knowledge and new conceptualisations of the sociomateriality of OR practice (Burger, White & Yearworth, 2019). However, in practice, advanced methods, increased availability and quality of data, and new challenges to solve are not necessarily asking for more and more complex solutions. As an applied discipline focusing on real-world problems, OR distinguishes itself as a discipline in which people work with technology to gain insight and understanding. Viewing an M&S study process as a vehicle for social learning opens up opportunities for knowledge production, a deeper reflection and integration of organisational needs and a clearer focus on the interface between science and practice. This requires a shift from expert practice towards a shared learning culture, where methods, role understandings, competences, interpersonal relationships and contextual factors are all directly relevant to the outcomes of the study. Our trust model provides the basis for a measurement instrument of trust in M&S studies by integrating each of these criteria.

Brocklesby (2016) reflected that simulation modelling can never be entirely objective, and that the modeller has an ethical imperative to take an appropriate degree of responsibility for its outcomes. We argue that the three-way relationship between the modeller, model and stakeholders converge toward epistemic trust in the knowledge generated by the simulation study and ultimately model acceptability. Bridging the divide between the factors needed to drive model trust, credibility and acceptance requires reflective and critical practice, and a focused awareness that stakeholders, as the trustor, ultimately determine the potential for action.

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