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# PANEL - TOWARDS CONCEPTUAL MODELING FOR HYBRID SIMULATION: SETTING THE SCENE

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## ABSTRACT

A recent review paper of hybrid simulation modelling has identified that conceptual modelling is one of the least developed stages in the modelling lifecycle. Admittedly, it is generally accepted that the same applies to conceptual modelling for single-method simulation. However, in the case of building a hybrid simulation we risk creating even more complex models. Furthermore, it doesn't help that that there are no standard modelling approaches shared by the different modelling methods (DES, SD, ABS) to enable a common hybrid conceptual model. This panel paper discusses the state of art of conceptual modelling for hybrid simulation and further developments needed to support the design of hybrid simulations. The purpose of this panel is to initiate a discussion about conceptual modelling in HS, with the view to identifying improvements and needs for further research in this area.

## 1 INTRODUCTION

Research in hybrid simulation (HS) has gained momentum, with a number of researchers reporting their efforts in developing hybrid models in various domains including manufacturing, supply chain management, construction and healthcare (Martin and Raffo 2001; Chahal et al. 2009; Viana et al. 2014; Rabelo et al. 2015; Morgan et al. 2017; Brailsford et al. 2019). Hybrid simulation has become a mainstream research field, featuring a separate track at the winter simulation conference for the last five year. Recent Winter Simulation Conferences (WSC 2015, 2016, 2017 and 2018) have also held four panels on this topic, discussing the purpose, history, definition and review of HS, respectively. Furthermore, a recent review of the field has identified a sharp rise in interest in hybrid simulation over the last decade (Brailsford et al. 2019).

HS is about combining two or more simulation methods (mainly Discrete Event Simulation, System Dynamics and Agent Based Simulation) and/or mixing other non-simulation methods and modelling techniques from disciplines such as Operations Research, Systems Engineering and Computer Science with simulation (Powell and Mustafee 2014; Powell and Mustafee 2016). Researchers argue that HS provides a better insight of the system as it allows modelers to represent different parts of the problem from different dimensions (Zulkepli and Eldabi 2015). This is particularly useful in modelling modern problems and systems, characterized by a high degree of complexity, multiple stakeholders with opposing and subjective viewpoints and a high volume of data and information sources.

Combining different simulation methods or modelling techniques can be quite challenging. For example, the detailed individual analysis provided by DES and a whole system view provided by SD require different conceptual approaches (Brailsford et al. 2008). Lynch and Diallo (2015) identify six types of challenges faced due to differences in modelling paradigms as well as due to using more than one models. While HS has the benefit of representing different aspects of a system at different levels, there is a price to pay as HS introduces modelling complexity due to combining more than one models together. Conceptual modelling, as the process of abstracting a model from a real world system, has the potential to support modellers in developing HS models. It is however noted that conceptual modelling for HS is still at an early stage (Brailsford et al. 2019).

This panel paper considers conceptual modelling in hybrid simulation projects, including the current state of art and further developments needed to support the design of hybrid simulations. Its aim is to initiate a discussion about conceptual modelling in HS, with the view to identifying improvements and needs for further research in this area.

This paper is structured as follows. Section 2 discusses the current state of conceptual modelling in simulation and hybrid simulation and sets the motivation for this panel. Next, Section 3 presents the panel set up, followed by the panelists' position statements in Section 4. Finally, Section 5, summarizes the main issues identified based on the position statements.

## 2 SIMULATION CONCEPTUAL MODELLING AND HYBRID SIMULATION

Conceptual modelling is one of the most important and least understood stages in the simulation modelling lifecycle. There is not one universally accepted definition of conceptual modelling by researchers in M&S (Robinson et al. 2015). One generic definition found in the literature is that by Robinson (2008, 2013), who defines conceptual modelling as the process of abstracting a model from a real world system, independent of software. A conceptual model typically includes: objectives, inputs, outputs, content, assumptions and simplifications of the model (Robinson 2008). A previous WSC panel on conceptual modelling discusses the need for conceptual modelling in order to achieve the alignment of various viewpoints and possible different methods (Robinson et al. 2015).

A recent review on hybrid simulation research has found that conceptual modeling is one of the least developed and attended to modelling activities by researchers (Brailsford et al. 2019). This is not surprising, given that conceptual modelling is least understood even in single-method simulation (Brailsford et al. 2019). More particularly some observations made in published papers about HS pertaining to or in relation to conceptual modelling are listed below:

- There is no universal definition of conceptual modelling in HS, and in simulation more generally (Brailsford et al. 2019).
- There is limited guidance on how to go about building a hybrid model and when (Zulkepli and Eldabi 2015).
- Current modelling attempts are focused more on overcoming technical challenges at software level with less attention paid at conceptual level. (Zulkepli and Eldabi 2015).

- There are no standardized conceptual modelling processes and methodologies to guide the modeler in designing hybrid simulations (Eldabi et al. 2018; Brailsford et al. 2019).
- Most hybrid simulation models are developed on ad hoc technical basis, focusing primarily on the software connectivity between two or more techniques. (Zulkepli and Eldabi 2015).
- Conceptual models of hybrid simulations are often provided in published papers, 63% of papers reviewed in Brailsford et al. (2019). These generally consist of independently presented conceptual models for the individual sub-models included. No clear explanation about factors such as information exchange or hierarchy in terms of model dominance, are provided.

Brailsford et al. (2019) identify four types of integration in which simulation methods interact, based on the mixed methods design classification in Morgan et al. (2017). They call them types of hybridization and these include the following:

1. Enriching: Models with one dominant method that include minor aspects of other methods;
2. Sequential: Models where the ABS, DES or SD components are executed in a fixed pattern (models linked by a third software);
3. Interaction: Models with ABS, DES or SD components whose execution order is determined dynamically at runtime (normally models run within one software tool that combines more than one methods such as AnyLogic);
4. Integration: Models which are seamlessly combined and inseparable.

Interaction and combination of SD and DES is the most widely used combination of methods so far (Brailsford et al. 2019). There are fewer examples of truly integrated models (the highest level of hybridization in the list above), where it is impossible to tell the elements of one model from the other. The majority of models have connections of sequential or interaction type.

Having identified that there is no recognized methodology for conceptual modelling in HS, Brailsford et al. (2019) suggest that authors should focus less on the individual models and more on the description of the hybridization. They recommend the use of diagrams, especially software-independent graphical notation, unrelated to a specific modelling method, showing all the component modules in the hybrid model, including the module name, its objectives, the modelling method used, the hybridization approach used (enriching, interaction, sequential or integration), and the interconnections between modules (the links and the names of the connecting variables). Furthermore, an edited book on conceptual modelling provides further ideas that can support conceptual modelling for hybrid modelling (Robinson et al 2010).

## 3 PANEL DESCRIPTION

We have created a panel, comprised of the following individuals:

- Antuela Tako (Loughborough University)
- Tillal Eldabi (University of Surrey)
- Paul Fishwick (The University of Texas at Dallas)
- Caroline Krejci (The University of Texas at Arlington)
- Martin Kunc (Southampton University)

Each panel member was asked to respond with a position paper to the following four questions:

1. At what point in the modeling cycle should we decide to build a hybrid model?
2. Is HS conceptual modeling different to that for single method simulations? What should HS conceptual modeling include?
3. Is M&S community fully equipped to design sufficiently good HS conceptual models?

4. What should the M&S community do to further develop conceptual modeling for hybrid simulation?

The questions are meant to facilitate an exploration of the state of play of conceptual modelling in hybrid simulation and the priorities for the field.

# 4 POSITION STATEMENTS

## 4.1 Antuela Tako (Loughborough University)

### 4.1.1 At what point in the modeling cycle should we decide to build a hybrid model?

In my view, the decision to build a hybrid model should be made based on the model aims and characteristics of the system modeled. Hence, this decision falls within the realm of the conceptual modeling stage of the simulation life cycle. The aim should not be to simply build a hybrid model, even though I agree that this is a very exciting area, which has seen a massive increase in interest amongst academics over the last few years. By its nature hybrid modelling comes with added complexity due to the technical requirements posed as a result of combining methods from different paradigms and approaches. Before embarking on building a hybrid model, analysts are reminded to consider whether the added complexity is worthwhile. In other words, does the added benefit of representing different parts of the model through separate methods outweigh the complexity that emerges as a result? Healthcare is a particularly suitable area of application for HS, where systems are inherently complex and interconnected, facing multiple problems that often cannot be captured by using one single method. From my experience of working in this field, this type of setting often justifies the coupling of two or more methods to represent different parts of the system at different levels of abstraction. Indeed the evidence also shows that the majority of hybrid simulation applications in recent literature are in health care (Brailsford et al. 2019).

### 4.1.2 Is HS conceptual modeling different to that for single method simulations? What should HS conceptual modeling include?

Besides the standard activities involved in single-method simulation to decide how the individual sub-parts of the model should be modelled, conceptual modelling for HS is also concerned with identifying the links and interactions between the individual models. The latter is very important in order to design the overarching HS conceptual model. As yet clear guidance is not available to support the modelers on this activity. In addition, a modeler needs to decide which method to use to represent the different parts of the system. Despite the existing research efforts so far, a systematic and rigorous method does not exist to support the modeler in their decision to choose the appropriate modeling method to represent the characteristics of the system. This is an important aspect that should be part of conceptual modeling. So on the whole conceptual modelling for HS should include different layers, one at overall model level and also at each individual sub-model level. It is important to note that a common diagrammatic representation is needed. The overall conceptual model should also include the interactions of individual sub-models.

### 4.1.3 Is the M&S community fully equipped to design sufficiently good HS conceptual models?

A recent review has identified that currently there is no specific conceptual modelling approach or framework available to support hybrid simulation (Eldabi et al. 2018; Brailsford et al. 2019) and I would agree with that. In the section above, I have already identified two aspects of HS conceptual modelling on which there is no clear guidance for the modelers to follow, that is: choosing the right method to represent the different parts of model and identifying the interconnections between the sub-models. On the whole, conceptual modeling for HS is still in its early stages. I believe however that HS is a pretty much brimming field and researchers will continue to enter this exciting field, where we will continue to learn through trial and error and from sharing best practice.

While from the above it may sound that conceptual modelling for HS is in its early stages, I also note that there have been substantial research efforts in the past 15 years, producing findings that serve as a basis in support of HS modelling, such as the selection of simulation methods. For example, a major research project called Research Into Global Healthcare Tool (RIGHT) has carried out an extensive literature search to assess best-practice modelling and simulation methods in a number of application domains (Brailsford et al. 2009). Based on the literature, the project developed a tool that supports the comparison and selection among 28 modelling and simulation methods to assist the selection of appropriate methods for the modeling of specific health services management problems (Jun et al. 2011). On the other hand, research on the comparison of Discrete-event simulation and system dynamics carried out at Warwick University by Antuela Tako and Stewart Robinson has so far culminated with the study by McHaney et al. (2018) where the authors use linguistic analysis to guide the choice between two methods: System Dynamics (SD) and Discrete Event Simulation (DES) to ensure a better fit between the problem and the method chosen. This study shows that the language used by decision makers in problem statements contains linguistic clues related to the type of information desired by problem solvers, that are different for the two methods. They develop a dictionary based on linguistic cues used in the decision makers problem statements which can be used as a tool to decide on which method to use, which can be further extended to include additional methods.

#### 4.1.4 What should the M&S community do to further develop conceptual modeling for hybrid simulation?

As discussed in the paragraphs above, it is clear that the M&S community should continue the existing research efforts, with a particular focus on conceptual modeling for HS. Some key priorities that researchers could consider include the following:

- Develop a widely accepted conceptual modeling framework that guides the process of designing hybrid models.
- Define what a conceptual model for HS should consist of, including identifying what a diagrammatic representation looks like. This could set a standard for researchers in the field and at the same time is useful for sharing and documenting HS conceptual models.
- Use facilitated modelling to reach a common understanding of the different parts of the system by eliciting the view of a group of stakeholders who are knowledgeable of different parts of the real life system (Eldabi et al. 2019). Research in participative and facilitated modelling could prove particularly useful, as it can provide a step by step process to gain a better understanding of complex problems with multiple stakeholders and conflicting objectives, which also describes the types of problems tackled by HS.

The above statements should be considered in light of the fact that single-method conceptual modelling continues to be an art, depending mostly on the individual modelers' skills. For example, in a review of the progress and grand challenges of conceptual modelling in DES research, Robinson (2019) notes that research in this field is still on going. Current research efforts have focused particularly on developing frameworks to guide the conceptual modelling process. Robinson (2019) then identifies three main challenges for conceptual modelling in DES more generally that include: widely accepted definition of conceptual modelling, well-defined and accepted conceptual modelling frameworks and standard representations of conceptual models within the community. It is not surprising to notice that the challenges faced by HS are not that different. In addition, as researchers we also need to get a better understanding of conceptual modeling from other modeling fields to look for examples of best practice. For example SD has a more defined approach to conceptualizing models (Robinson 2019).

## 4.2 Tillal Eldabi (University of Surrey)

### 4.2.1 At what point in the modeling cycle should we decide to build a hybrid model?

There are a number of attempts that have been made in an aim to identifying the need and timing of hybrid modelling. Chahal et al. (2013) remains an important reference for conveying the importance of decision on whether to hybridize or not hybridize, particularly at the earlier stages of modeling. Hybrid Simulation comes with a set of trade-offs that are important to consider before "indulging" in the hybridization process. These trade-offs are based on the well-known project triangle of constraints, i.e. cost, time and scope (or purpose of the model). Logic always favors the alignment of model development towards the purpose of the model. However, in real life, time and cost of development are important constraints and can present real challenges to achieve the ideal purpose of the model. Therefore, the decision of whether to go for a hybrid model, or not, should always be taken during the problem formulation phase. Before even the conceptual phase. This, of course, is a decision that should be set in stone, rather a mere statement of intent. There are two main reasons that the decision should be taken at such an early stage. Firstly, if there is a pressing need to build a hybrid model, it is always cheaper to start from the beginning rather than to decide in later stages, which means most of the initial work is probably going to be wasted. Secondly, it would be easier to decide "not" to go for a hybrid model at the earlier stages of the process. Findings of the review by Brailsford et al. (2019) suggest that the current practice tend to start with single modeling and then resort to a hybrid simulation when such a need arises. This is usually quite costly and leaves less resources for developing an appropriate hybrid model. This will push modelers to make use of the existing models in an ad hoc way, resulting in less than optimum models. Therefore, and to make most use of the potentials of hybrid simulation, it is vital to make the decision of whether to hybridize or not during the problem formulation phase.

### 4.2.2 Is HS conceptual modeling different to that for single method simulations? What should HS conceptual modelling include?

Ideally, a typical HS model is developed by linking two or more single simulation models. Building conceptual models for each of the single models, separately, is expected to be the same whether they are developed as standalone models or within a hybrid simulation model. However, I suggest that there are two added steps when developing a hybrid simulation conceptual model (Zulkepli and Eldabi 2015). Firstly, identifying the potential linking points between the different models. This is currently a major research challenge, as all simulation approaches have their own distinct methods for developing conceptual models. For example, a System Dynamics model is usually made of influence diagrams or stocks and flows of aggregated elements or liquid motions, while a Discrete Event Simulation model utilizes process flows of individual entities. There are currently no conceptual model elements that can capture the links other than arrows from the source of the information to the destination. This is from the visual perspective, where conceptual models are highly depended on their visual representations. Secondly, where it is possible to identify the purpose of each of the nodes and arrows with standalone models, there are no clear visual reorientations of the contents of the links and the conversion/translation of the transferred information between one model to the other. There is no significant need for identifying the contents of the links at the conceptual model, however, there needs to be some indication of how the information is translated from model to the other. This is particularly important for hybridization between different modeling approaches.

### 4.2.3 Is the M&S community fully equipped to design sufficiently good HS conceptual models?

The answer to this question is highly dependent on the definition of conceptual models. For example, the term is of high importance to modelers from Computer Science background, where conceptual modeling is of vital importance during the design stages. As a result we find that Computer Science related disciplines have a number of well-established conceptual modeling methods that are much more advanced when compared to those used for simulation, and the simulation community could benefit from them. This is particularly evident in the case when developing Agent Based Simulation. On the other hand, Operations Research based simulation modellers tend to be more pragmatic when developing conceptual models. The importance of this step is mainly associated with group based or facilitative modeling. System Dynamics for example, tends to utilize the conceptual modeling stage more than others due to its facilitative nature. Discrete Event Simulation, on the other hand, used to give more importance to conceptual modeling when simulation models were developed using raw coding. However, in the last decade or two, and with the advent of visual interactive Discrete Event Simulation tools, conceptual models tended to be developed implicitly using the icons of the simulation packages. It can be concluded that, although each of the different simulation approaches are more or less content with their conceptual modeling practices, there is more research needed to be able to link the different approaches when at the conceptual phase. This is still in its infancy.

#### 4.2.4 What should the M&S community do to further develop conceptual modeling for hybrid simulation?

As discussed earlier, the biggest challenge that faces the simulation community is to develop hybrid conceptual models that clearly links the model together. Currently, it is possible to develop separate conceptual models, however, they cannot be easily linked. The existing modeling tools do not allow for that. Therefore, it is important to develop some linking protocols during the conceptual modeling phase. There is currently no clear method of how this can be achieved, however, a simple table is suggested by Zulkepli and Eldabi (2015) that may provide a way forward for, at the very least, indicate the nature of the exchanged information, sources of information and destination of the information between the models.

### 4.3 Paul Fishwick (The University of Texas at Dallas)

#### 4.3.1 At what point in the modeling cycle should we decide to build a hybrid model?

We need to decide at the very beginning. Most models that we will create in the future are probably going to be hybrid in form—a connected mass, or even agglomeration, of different model types. One can take housing construction and materials as an analogy. To construct a house, we need to pour cement for the foundation, use plastic and metal piping, and then use wood for either the whole house structure or the roof. While one could build a house out of nothing but wood, the house would not be as well-designed for all intended purposes. Movement of fluids would not work well in wood, although this was standard practice 200 years ago in places with ample forests. Returning to modelling, we might use a combination of physics-based (continuous-time) models, discrete-event models, and rule-based models. We may also use a semantic network or concept map to capture the ideas, model elements, and their relations to one another. In this case, we will have chosen to create hybridity by choosing models that are from other disciplines. A "model" might be of knowledge or spatial compositing. Most modeling discrete-event software contains some type of 2D or 3D model of a scenario. The simulation model operates by defining behaviors, activities, and other functions within the spatial model. So, we need to start thinking "outside of the box" with hybrid modelling—hybrid models can involve a diverse set of model types, not all of which are traditionally found in Modelling and Simulation (M&S) culture. A recent sabbatical in Exeter (Fishwick and Mustafee 2019) amplified this observation. During the sabbatical time, we engaged across the UK on modelling within operational research, but also attempted to bridge disciplines such as art, history, and the museum experience.

#### 4.3.2 Is HS conceptual modeling different to that for single method simulations? What should HS conceptual modelling include?

Using a similar philosophy to that expressed in Sec. 4.3.1, conceptual modelling should be expanded to cover basic modelling forms such as natural language and drawing. When we begin to model, if we are to create models at high-levels of abstraction, then we already know the most conceptual of modelling components because we learned them in elementary school: English language (e.g., literature arts) and drawing (e.g., creative arts). This might on the surface seem too basic; however, the most basic of sentences conveys what, as modelling practitioners, we want to capture. This philosophy is central to broadening participation in the modelling enterprise.

#### 4.3.3 Is the M&S community fully equipped to design sufficiently good HS conceptual models?

M&S as a culture is not fully equipped because of our insular nature. Back in the 1960s and 1970s, it became clear that there was a new kid on the block: discrete-event simulation. Societies and conferences were created to focus on this type of simulation. What would the models look like? What would be efficient methods for doing the computation required for simulation? How would we teach this "discrete event thing?" Back then, we needed to be insular and self-contained. Fast forward about 40 years, and I think the need now is to embrace a wider view of modeling that is outside of any single discipline such as industrial engineering, operations research, and computer and information sciences. This builds upon an early outline of conceptual modeling in chapter 3 (Fishwick 1995). In that book, conceptual modelling was about starting with concepts and abstractions regardless of model type ultimately envisioned at the end of the modelling life cycle.

#### 4.3.4 What should the M&S community do to further develop conceptual modeling for hybrid simulation?

We should begin by creating an inventory of modelling beyond the confines of discrete event modelling. To create real hybridity in modeling, we need: 1) multiple models, 2) models at different scales and levels of abstraction, and 3) ways to connect or translate one model to another. In the case of natural language we begin with parts of speech in English. Nouns are going to be agents or objects. Verbs are ways of encoding action in speech and in writing. Why not start at the beginning with languages that transcend the silos of disciplinary thought?

### 4.4 Caroline Krejci (The University of Texas at Arlington)

#### 4.4.1 At what point in the modeling cycle should we decide to build a hybrid model?

Ideally at the very beginning! But I think that in reality it is often challenging to answer the question of whether to build a hybrid model when we are in the first stage of the modeling process. We might have some preconceived ideas about which modeling approaches are likely to be most appropriate, but these ideas should be carefully reviewed before making any firm decisions. As modelers, we all have biases that tend to inform our choice of modeling method(s), and we need to be careful that those biases don't lead us down a suboptimal path. Conceptual modeling is particularly valuable here: it forces the modeler to consciously evaluate high-level modeling decisions – whether to build a hybrid model, what its components should be, and what each component's designated function is – and justify these decisions based on the attributes of the real-world problem.

While I believe that accurate representation of sociotechnical systems (where human social behavior plays a key role) often requires the use of HS, my tendency is to try to get away with using a single modeling method if at all possible. However, inappropriately forcing a complex problem into a single method for my own convenience can yield poor results, including over-simplified assumptions about the real-world system, invalid outputs, and convoluted model development and execution. So the decision about whether to build a hybrid model involves tradeoffs: are the benefits of using multiple methods worth the added difficulty and complexity? Using conceptual modeling to systematically evaluate these tradeoffs early in the modeling process is incredibly useful.

#### 4.4.2 Is HS conceptual modeling different to that for single method simulations? What should HS conceptual modelling include?

HS and single-method conceptual modeling approaches have many things in common and should incorporate the same elements (e.g., inputs, outputs, objectives). However, HS conceptual models must also capture the designation of each modeling component to a required model function (i.e., what software is responsible for what tasks) and clearly define the interactions between the modeling components (i.e., how is data passed between them and the timings).

#### 4.4.3 Is the M&S community fully equipped to design sufficiently good HS conceptual models?

I think that the M&S community might benefit from borrowing from the conceptual modeling tools of other disciplines – for example, systems engineering relies on a suite of conceptual modeling tools that are employed early in a system's life cycle. Requirements hierarchies, functional flow block diagrams, IDEF0 diagrams, and physical architecture models help systems engineers ensure that stakeholder requirements are covered by and traceable to each system function, and that these functions are then covered by and traceable to each physical element of the designed system. Such tools could make the conceptual HS model design process more consistent and systematic.

#### 4.4.4 What should the M&S community do to further develop conceptual modeling for hybrid simulation?

One possibility is to create a widely agreed-upon standard protocol for HS conceptual model definition, and encourage modelers to follow this protocol when they submit papers for publication. Of course, this idea presupposes community-wide acknowledgment that: 1) conceptual modeling is a critical component of the HS modeling process and 2) conceptual modeling standards can be helpful. Individuals and teams could develop and propose protocols to the M&S community, and community members could then provide feedback and/or adopt the most promising protocols for their own work. Because a single governing protocol is unlikely to be appropriate for every conceptual modeling situation, some flexibility would be necessary, as well as willingness to revisit and adapt the protocol design periodically, as modeling requirements/capabilities change over time.

### 4.5 Martin Kunc (Southampton University)

#### 4.5.1 At what point in the modeling cycle should we decide to build a hybrid model?

The need for a hybrid model can be visualized at the beginning of the cycle during the definition of the scope of the model. The definition of the scope of the model usually identifies critical questions, variables and sectors of the model. In this phase, you will realize if you need an agent-based simulation or a system dynamics model for the sectors or certain variables. It is also clear that some questions require more detail than other questions so the need for selecting modelling methodology that can offer the required level of detail.

#### 4.5.2 Is HS conceptual modeling different to that for single method simulations? What should HS conceptual modelling include?

At the initial stage, HS conceptual modelling will be different because there is a need to have a broad overview of all the components of the systems that are being modelled. This overview will involve discussing aspects that do not need to be as specific as required for a single method simulation.

In terms of components of a HS conceptual model, I believe the following are some important elements to include:

- Sector diagrams representing the different parts of the system being modelled
- Variables for each sector
- Modelling approach for each sector
- Linkages between the sectors in terms of variables interconnected.

#### 4.5.3 Is the M&S community fully equipped to design sufficiently good HS conceptual models?

A lot depends on the modeler. HS modelers need to understand "systems thinking" in order to develop a good conceptual model that comprises relevant sectors of the problem as well as the linkages between these sectors.

Some frameworks to assist modelers that I have used are:

1. Causal loop diagrams provide linkages between different variables at an aggregate level. Based on that broad representation, the modeler can pick up variables that require a simulation method suitable for their intrinsic behavior, e.g. stochastic and discrete or continuous and policy-based.
2. Resource mapping (Kunc and Morecroft 2009; Kunc and O'Brien 2017; Barnabe et al. 2019) is a graphical method that consists of selecting the set of resources responsible for the performance of an organization through facilitated workshops. Then, the resources are mapped and interconnected representing a system that underpins the organizational activities. Some resources due to their importance at operational level, e.g. a department serving customers, need more detailed representation, e.g. a discrete event simulation, while other resources reflect the intrinsic behavior of agents so they need an agent based model, and finally resources representing aggregated or undifferentiated entities such as cash will benefit from a system dynamics model.

#### 4.5.4 What should the M&S community do to further develop conceptual modeling for hybrid simulation?

Define standards, such as STRESS (Monks et al. 2019), to document the conceptual model as well as the process of conceptual modelling. In this way, the HS model will become more transparent and open for replication/improvement.

## 5 CONCLUSIONS

This paper considers the state of art of conceptual modeling for hybrid simulation. Five researchers were invited to put their views forward about the current developments and the future needs in this field. Below we summarize the common views expressed by the panelists and some future directions for research.

On the whole, almost all panelists agree that the decision to build hybrid models should be made at the very beginning of the simulation life cycle, either at the problem formulation or conceptual modeling stage to avoid leading to wasted efforts. We acknowledge that using multiple methods increases the complexity of the modelling, however the hybridized model provides a better and optimal model representation of the system, so long as an informed decision is made to justify the choice of a single-method or hybrid model.

We have identified some research challenges that the M&S community should consider to resolve. These include:

- Definition of the interconnections or linking points between the sub-models in a hybrid simulation.
- Creation of a widely agreed standard protocol for HS conceptual modeling that is adhered to within the research community.
- Development of a rigorous and systematic tool to support with the selection of simulation method that is suitable for different types of problems modelled for the sub-models.

In addition, we have furthermore identified a number of weaknesses in our modelling practice that may characterize us as modelers and that we invite researchers to avoid. These include:

- A tendency to start with a single-method and then consider a hybrid approach after we realize that a single method approach yields poor results or a sub-optimal model.
- Modeler bias to use a dominant modelling method that the modeler is more familiar with, which can affect our choices.
- Insular nature of the Modelling and Simulation society.
- Dependence on modeler experience.

In response to the challenges and current weaknesses the panelists make a number of interesting suggestions to modelers, including to:

- Look outside the DES field for best practice examples;
- Borrow tools from other disciplines such engineering, computer science, system dynamics and systems thinking;
- Use natural language to represent our abstraction of systems represented in HS in a move to broaden participation in modelling;
- Use facilitated conceptual modelling to gain an understanding of the real system and to elicit a meaningful and relevant information to inform the model.

It has become clear that all panelists agree that conceptual modeling for HS is in its infancy. The panelists identify a number of challenges and needs for further development in conceptualizing HS. Some divergent suggestions about how to approach conceptual modelling have emerged, inspired by the panelists varied backgrounds and experiences. The M&S community may find these interesting for further consideration in future research.

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