Systemic Business Process Simulation using Agent-based Simulation and BPMN

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Abstract: The current paradigm of a business process model is that it is a representation of a sequence of tasks that act upon some data input, to produce an output, aiming the production of a new service or product to be delivered from a producer to a customer. Although this is a valid way of thinking, it neglects to consider in enough detail the influence of some phenomenon on inputs, e.g. human behaviour, communication, social interactions, the organisational culture which can have a significant effect on the output delivered by a business process. As the dynamics of these phenomena are non-linear, they can be interpreted as a complex system. This holistic way of thinking about business processes opens the doors to the possibility of combining different simulation methods to model different aspects that influence a process. A BPMN engine and an agent-based simulation (ABS) engine are chosen to serve the basis of our framework. In its conception, we not only consider the technical aspects of the framework but also delve into exploring its management and organizational dimensions, with the intent of facilitating its adoption in enterprises, as a tool to support decision support systems. We analyse how accurate the simulation results can be when using these two tools as well as what considerations need to be considered within organizations.

1 INTRODUCTION

Today rapid technological change is being driven by the information revolution, as we live in environments that are increasingly technology-saturated (Kadar et al., 2015). This saturation makes the question of the relationship between people and technology more explicit than ever, to the extent that this relationship is widely reported and extensively studied in the literature in the domain of socio-technical systems (Bider, n.d.; Gregoriades & Sutcliffe, 2008; Henda et al., 2016; Ibl & Čapek, 2017; Norta et al., 2014; The-Evolution-of-Socio-Technical-Systems-Trist.Pdf, n.d.; Tropmann-Frick & Thalheim, 2015; Vespignani, 2012). Socio-technical systems are an approach to the understanding and design of complex organisations and technologies that recognise the interplay between people and technology (Kloeckner & Birkmeier, 2010).

Despite the realisation of the importance of humans in business processes, as far as we know, there has been little focus on how agent-based simulators(ABS) can be used to enable business process simulation in enterprises. The majority of the studies (Haiyan Zhao & Jian Cao, 2007; Halaška & Šperka, 2018; Liu & Iijima, 2015; Sulis & Di Leva, 2018; Tan et al., 2009) focus on integrating ABS with discrete event simulation(DES), Petri-nets and other workflow engines. This choice can pose some challenges for organizations due to extra investment required to procure software, hire specialized workforce with DES knowledge and time to convert existing business processes to DES models. Although this approach is suitable in some cases, it is less likely to be adopted in organizations because of the time and effort commitments it requires. Our assumption of what constitutes a successful information system implementation is based on the information systems analysis framework depicted by Laudon & Laudon, 2013 that state that there should always be three dimensions to any successful information system.

The first is management, where there should be tasks performed at a management level of the

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organization for the implementation of the system. These include but not limited to reflecting about what knowledge acquisition, retention strategies, training strategies and budget plans are suitable for the project. The second dimension is organization, where they state that there should be a reflection on how issues such as organizations hierarchy, functional specialties, business processes, organizational culture and pollical interest groups impact an information system. Lastly there is the technology dimension, where hardware, software, data management and networking issues should be considered.

We observed that current simulation frameworks involving ABS and BPS, do not take the management and organization dimensions into account, focussing more on technology, and therefore to solve this problem, we ask the following question: "*How to implement a systemic simulation interoperability framework, between an agent-based simulator and a business process engine?*"

2 SOLUTION PROPOSAL

To address the issue, we frame a solution that approaches the problem from a holistic view. Some authors also share the view of a holistic approach to this issue (Wu, 2015), in the sense that holistic modelling plays a vital role in developing socio-technical systems(STS), because of the interplay between social and technical elements within these systems and the resulting emergent behaviour.

The current state of the art in the topic focusses on two main categories. In the first category, we can find solutions that try to conceive a concept equivalency framework between ABM to business process modelling notations or vice-versa. Although there is some success in doing this (Aksyonov & Aksyonova, 2013; Dam et al., 2015; Endert et al., n.d.; Ghlala et al., 2017; Laroque et al., n.d.), they agree that there will be concepts that are merely difficult or even impossible to convert.

The second category consists of integrating ABS with process simulation engines that do not take into account the complexities occurring in enterprises, such as budget limits, training, project deadlines, skillset availability in the workforce. Between these, we find mainly DES, Petri-nets and some other generic process engines.

Instead, in our solution, we propose designing agent-based models and business processes separately and let the software agents drive the business process engine as if they were real users. To address the management and organizational dimensions of our solution, we compared usage trends of business process modelling languages, for the past 16 years worldwide. Although the comparison is not exhaustive of all languages, we focussed on the main ones and collected data using Google Trends.

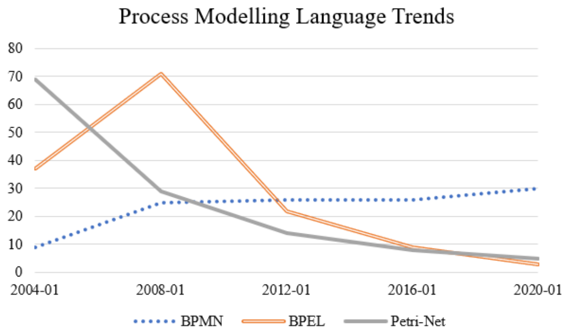

Figure 1: Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term. Source: Google Trends. (2020). Retrieved September 22, 2020, from https://trends.google.com/trends/explore?date=all&q=%2Fm%2F08kq3d,%2Fm%2F01xc3f,%2Fm%2F01gt82

Choosing a highly available modelling language is how we intended to fulfil the management and organizational dimensions of our framework, the assumption being that a highly adopted language requires less investment to implement, less workforce training, less time to convert models, and more skillset reusability encourages collaboration. Given the overall trend of BPMN, we chose it as our business process modelling language.

2.1 The Simulation Process

Our engine of choice, Camunda, continues functioning with the purpose for which it has been designed, and is not aware of the change of process actors, from real humans to software agents.

The same can be said for the software agents and the ABS, which continue working and following the rules defined in its model. Agents send messages to the BPMN engine when specific pre-set criteria are met via REST and are not aware of the purpose of those messages.

This approach is different from the current mapping approaches, in that it avoids any sort of concept equivalency problems altogether because models are not converted, they interact with each other during the simulation runtime.

One of the challenges in conceiving such integration between the two systems is that multiple agent instances will be created during the simulation process, as well as multiple process instances in the BPMN engine. The consequence is that messages may be routed to the wrong process instance if no attention is paid to the way messages are transferred between systems. Therefore, the question is: "*How does a system that has received a message know which request this is the reply for?*"

The solution concept we adopted is demonstrated by Hohpe & Woolf, 2012, where it is suggested that *"the requestor add a Request ID to the request message, have the replier copy the Request ID to the Correlation ID field of the response message so that the requestor can correlate the reply message to the request message."* In our case, the "Agent ID" is used as the identifier of the message.

This separation of concerns also has other advantages, which for instance, opposed to BPMN integration approaches proposed by some authors (Onggo et al., 2017), this one does not suggest any extension artefacts to the BPMN standard. The ability to bypass these difficulties would significantly enhance the process of creating better models because the BPMN standard itself does not need to be modified or extended in any way and no significant investment of time is required to train staff in organisations about features of new extensions, instead, already existing tools are reused.

2.2 Scope of Work

The focus of our research is oriented towards verifying functional aspects of the distributed simulation method being proposed. It intends to understand only aspects deemed fundamental for the operation of such a way of simulating socio-technical systems and ignores testing the broader context of applicability in the industry. A detailed analysis of those aspects is outside of the scope of this work, and hence, they are only briefly outlined here.

3 METHODOLOGY

Our first objective was to determine whether it is possible to perform web requests from an ABS engine to a BPMN engine using the REST protocol. A review was conducted to understand what support is provided within the leading agent-based simulators for performing web requests. Then one engine is chosen based on the effort required to implement models and how easily it can be scaled. The rationale behind this criteria is to find an ABS engine for our work, that has potential to study social systems of a large size, with low investment requirements to develop those models, relative to other engines.

The second objective was to understand if time intervals between events occurring in the ABS are conserved in BPMN. This was mainly an essential step of our research as it has been highlighted several times in the literature (Baker, n.d.; Brodsky, n.d.; Lin & Guo, 2010; Tolk, 2013), that time management is a usual problem to address in distributed simulation engines.

The experimental method was used for this purpose because our primary goal is to determine whether our proposed solution works at a functional level. It means that to determine whether time intervals between events vary between the two engines, we needed to understand how those time intervals change over time between the two engines, and an experiment would give us the control needed to set up those conditions and test our theory. Its been noted in the literature(Dennis & Valacich, 2001) that the objective of experimental research is to enable testing and extending a theory. Also, Williamson & Johanson, 2017 proceed in stating that it is a method that seeks to establish a cause-and-effect relationship between variables, which is the case in our study.

By no means, experimental research is the best or worst method, yet it is the most adequate for some reasons:

- A cause-effect relationship needed to be understood. Specifically, we wanted to understand whether time intervals between events occurring in an ABS are kept constant upon triggering equivalent events in a BPMN engine.
- A specific set of conditions are being studied. We only want to verify that REST API requests can be transmitted between the two systems and that the intervals between two events are respected between the two systems.

3.1 Choosing a Real-life Inspired Business Process

It was important to inspire our experiment in a real business process, as some authors point out (Guala, 2002) there is higher confidence in an experiment if a real component is used. Thus metrics and business process model from a real case study(RCS) had been chosen(Bhat et al., 2014) which is a Lean Six-Sigma(LSS) process improvement study conducted in the Health Information Department (HID) of a Medical College Hospital in India which consisted in using LSS to improve the patient registration process of the hospital.

The RCS concluded that the mother tongue patients and receptionists spoke, had an impact on the process cycle time. This variable was adequate for this experiment because it satisfies the criteria for the case study selection which was that it had to describe the impact of user behaviour in a business process output, in this case, it was communication between patients and receptionists, given that they spoke different languages and how this impacts the number of patients registered per unit of time.

3.2 Modelling Communication between Agents

Communication between actors is a relevant aspect to be modelled in business processes (Gregoriades & Sutcliffe, 2008) and some authors have already studied it (Barange et al., 2014; Elleström, 2019; Frieder et al., n.d.; Kennedy, 2012; March, 2004) within the context of agent-based modelling.

In our RCS all the staff were proficient in the local languages, namely Kannada and Tulu, in addition to English. The study also observed that out of 16 staff working in the department, only two of them knew Malayalam, five knew Konkani, six knew Hindi, one knew Malayalam and Konkani, and the only one knew all three languages in addition to the local language. Thus, six staff with a different combination of language expertise were selected for the study. The cycle time in handling patients, who were proficient in only local languages, only Malayalam, only Konkani and only Hindi was observed for ten patients in each group(Bhat et al., 2014).

The study concluded that cycle time for registering patients, who only spoke Malayalam, Konkani and Hindi was significantly larger than those who knew local languages and therefore, that is the behaviour we model in our ABS, more specifically, which is difficulty in communication between agents as a function of their fluency in certain idioms.

3.3 Modelling the Business Process

Once the behaviour above is configured in the ABS, the business process below is modelled in BPMN.
Due to its versatility and ease of use, we chose Camunda Modeler V4.0.0 to design our model and Camunda BPM 7.12 server as the business process engine for our experiment.
When converting the activity diagram to BPMN, some tasks were omitted as those played no active part in the experiment because they did not send or receive messages from or to agents.

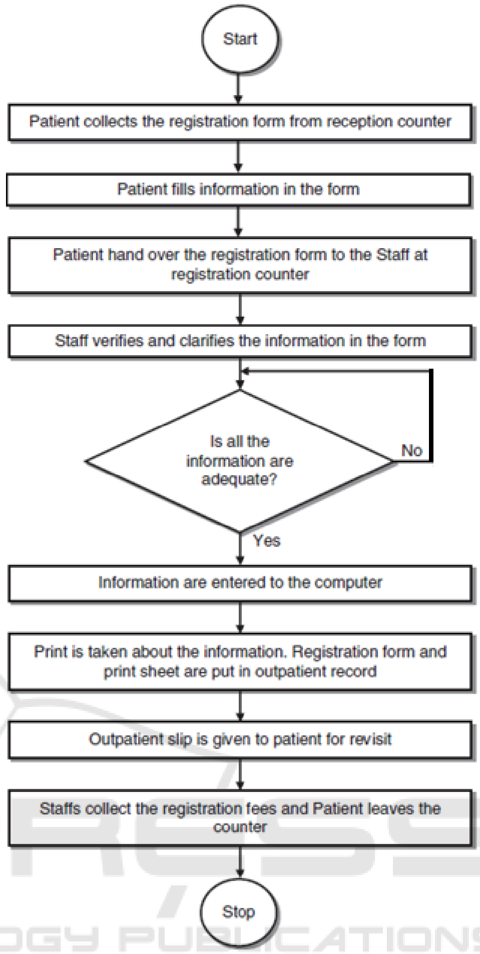

Figure 2: Activity diagram of a chosen business process Source: (Bhat et al., 2014).

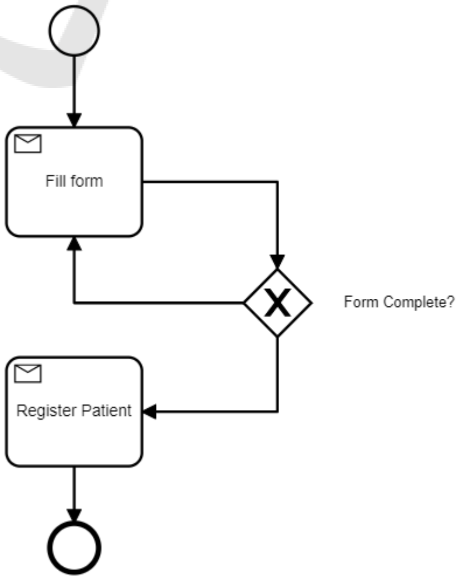

Figure 3: Simplified BPMN model of the RCS.

The ABS engine begins execution, by having agents communicating with each other and invoking the BPMN engine when the PR pair finishes communicating, by sending messages using REST. Cycle time results are collected and stored in a database for posterior analysis.

4 RESULTS

Netlogo had been highlighted by several authors (Abar et al., 2017; Lytinen & Railsback, n.d.; Railsback et al., 2006) as being versatile enough for small and large experiments, as well as presenting a low learning curve. These characteristics were relevant for our choice as we needed to find an engine that is not only robust but also readily available in the industry to facilitate adoption within organisations, and also if further studies are conducted in the future.

Looking at our first objective, we were able to gather data about existing ABM systems concerning the programming languages they use to create their model. Understanding which programming language, they use was fundamental as we assumed that it would be the primary vector by which the ABM could send web requests, the assumption being that if the underlying modelling language supports web requests, then the engine supports them too.

Table 1: Agent-Based Modelling engines vs Programming language they use ('Comparison of Agent-Based Modeling Software', 2020).

Name	Programming Language
AnyLogic	Java
Cougaar	Java
Framsticks	Framscript
JADE	Java
MASON	Java
Netlogo	Netlogo, Python(PyNetlogo)
Repast	Java, .Net, Python

From the short review above, key findings emerge: 100% of the ABM engines support programming languages that can submit web requests or support extensions that allow for external scripting engines to be embedded in the agent-based model, which in turn supports sending web requests.

Besides, we specifically studied the documentation of the ABM of choice, Netlogo 6.1. We found that it does not support any capability to perform web requests natively, although there were some attempts (NetLogo/Web-Extension, 2012/2020) to introduce similar functionality using extensions, however not to send generic web requests. On the other hand, it was also found that one of the extensions supported is the Python scripting engine(Jaxa-Rozen & Kwakkel, 2018) through the PyNetLogo extension. As Python is a generic scripting language, it not only allowed to make web requests via REST protocol but also to establish full integration between the two applications, control message correlation, transformation and logging.

Although the results above confirm that majority of ABM engines support web requests, our method also relies on the BPMN engine supporting a REST API that allows a consumer to start a process.

Table 2: List of major BPMN engines vs support for process invocation through REST.

Engine	Support REST process invocation
ActiveVOS	Y
Activiti	Y
Bizagi BPM Suite	Y
Bonita BPM	Y
Camunda	Y
Flowable	Y
Imixs-Workflow	Y
jBPM	Y
Orchestra	N
Sydle SEED	Undetermined

From this, we can understand that the majority of the BPMN engines do provide support for a REST API that allows invocation of processes, and in our experiment, we used Camunda Server 7.12.

These results together demonstrate the adequacy for implementing our method using the majority of ABM and BPMN engines.

With regards to verifying the accuracy of our simulation results, we had two objectives:

- O1: Determine the correlation between engine type and task execution interval;
- O2: Determine whether the engine type has a significant effect on the task execution interval of different groups of agents.

Regarding O1, the intension was to analyse how event intervals varied between the two engines, considering agent behaviour individually. For this, we collected and compared time deltas between events in each engine. A Pearson Correlation Coefficient was then calculated to understand if event intervals vary significantly between engines. The Pearson correlation analysis was conducted between DeltaABS and DeltaBPMN variables. Cohen's standard was used to evaluate the strength of the relationship, where coefficients between .10 and .29

represent a small effect size, coefficients between .30 and .49 represent a moderate effect size, and coefficients above .50 indicate a large effect size(Cohen, 1988). One of the assumptions made in this work when estimating the Pearson correlation is that a Pearson correlation requires that the relationship between each pair of variables is linear (Conover & Iman, 1981). This assumption is violated if there is curvature among the points on the scatterplot between any pair of variables.

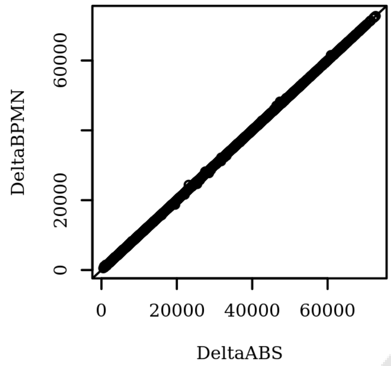

Figure 3: Presents the scatterplot of the correlation. A regression line has been added to assist the interpretation.

The result of the correlation was examined based on an alpha value of 0.05. A significant positive correlation was observed between DeltaABS and DeltaBPMN (r_p = 1.00, p < .001, 95% CI [1.00, 1.00]). The correlation coefficient between DeltaABS and DeltaBPMN was 1.00, indicating a large effect size. This correlation indicates that as DeltaABS increases, DeltaBPMN tends to increase. Table 3 presents the results of the correlation. *Note.* n = 7137.

Table 3: *Pearson Correlation Results Between DeltaABS and DeltaBPMN.*

Combination	r_p	95% CI	p
DeltaABS-DeltaBPMN	1.00	[1.00, 1.00]	< .001

The results of our experiment suggest the correlation coefficient between DeltaABS and DeltaBPMN was 1.00, indicating a large effect size. This correlation indicates that event intervals are kept constant between the ABS and BPMN engines. It confirms our suspicion that the messages flow between systems without significant changes in task execution intervals.

For O2, the intension was to analyse how event intervals varied between the two engines, considering the collective behaviour of agents. This analysis was deemed relevant because it is likely that in real-world agent-based models, the behaviour is modelled for a collection of agents. Many agent-based simulation tools provide support for the concept of "breed" which allows a modeller to create different varieties of agents that behave differently. We segregated our agents by communication difficulty, i.e. each group of agents took a different amount of time to fill in the registration form, and it varied according to time ranges the table below:

Table 4: Agent Group VS Delay Range.

Patient Language	Time Range(ticks)
Hindi	450-550
Konkani	150-250
Malayalam	350-450
Other	0-50

To evaluate point number two, a multivariate analysis of variance (MANOVA) was conducted to assess if mean differences exist on task execution interval for Hindi, Konkani, Malayalam and Others between the different source engines. The MANOVA test is an appropriate statistical analysis when the purpose of the research is to assess if mean differences exist on more than one continuous dependent variable by one or more discrete independent variables (DeCarlo, 1997).

The main effect for source engine was not significant, $F(4, 899) = 0.00$, p = 1.000, $\eta^2 p = 0.00$, suggesting the linear combination of Malayalam, Konkani, Other, and Hindi was similar for each level of source engine. The MANOVA results are presented in Table 5.

Table 5: MANOVA Results for Malayalam, Konkani, Other, and Hindi by source engine.

Variable	Pillai	F	df	Residual df	p	$\eta_p 2$
Source	0.00	0	4	899	1	0

The results indicate that the linear combination of Malayalam, Konkani, Other, and Hindi was similar for each level of source engine, which leads us to conclude that even if the agents were operating in groups, those differences would not be affected during message transmission between systems.

5 CONCLUSIONS

We intended to investigate how could we integrate an ABS engine with a BPMN engine, to perform business process simulations and obtain statistically significant results. The main aim of such integration is to create a mechanism to simulate and study complex phenomena within business processes.

Based on the quantitative analysis of event intervals between the two systems and also based on the event intervals of groups of agents between the two engines, it can be concluded that integrating an ABS engine with a BPMN engine, produces statistically coherent simulation results with respect to time management between the systems.

Despite the success demonstrated, some significant limitations should be highlighted. We could not evaluate how well our findings apply in a real implementation project within an organisation as our experiment has firmly focussed on addressing functional and simulation results significance aspects. It is possible that the practical implementation constrains of our technique outweigh the benefits of using it, so, therefore, it is suggested that further research is undertaken to look into those aspects.

Due to the novelty of the simulation framework proposed, we also encountered difficulties in determining how it compares to other studies in the same field. On the one hand, this can be a significant step forward for a holistic business process simulation paradigm, but on the other, for the time being, it leaves some gaps in knowledge that can only be filled in by further research.

The main achievements, including contributions, may be summarised as follows. First, we created a new way of simulating business processes. The innovation in our method is that it allows for a holistic simulation to happen, where complex phenomena can be made part of the business process simulation. We did consider not only the technical aspects of the solution but also its organizational and management contexts. This, in turn, opens doors to study more complicated problems within enterprises, that are difficult to study analytically, such as the effect of emergence, feedback loops and self-organization on process performance and at a broader sense, it enriches our scientific knowledge base in process optimisation methodologies.

It has been shown that it is possible to use and reuse existing simulation tools to enable this holistic type of simulation. It remains unclear to which degree our framework is related to low implementation costs, for instance, we speculate that our approach requires low investment in purchasing new tools and training staff as tools we propose are readily available in the market. It is suspected that this is an attractive proposition not only for large organisations but also for small to medium businesses that cannot afford expensive software solutions. Finally, we contemplate whether our approach is simple and easy to be adopted in academia or for individual researchers, as a tool to study conservation laws in business processes. All data collected and analysis results were made available online: Duduka, Jacint. (2020) 00xE8/BPABSIF: Business process & Agent-based Interoperability Framework. Retrieved September 22, 2020, from https://github.com/00xE8/BPABSIF.

6 FUTURE WORK

The author identified two categories of work to be proposed based on the experiences collected during the research. The first category is related to problems identified during the work undergone, and the second relates to further areas of research that would expand the scope of the work and enrich the features of our method.

Regarding problems encountered during the experiment, we found that although our results point in the direction that our proposed method can be used to simulate complexity in business processes, the author feels that further investigation should be conducted into some aspects that came to light during the current study:

1. Netlogo and many other agent-based simulation engines are synchronous systems. This means that agents perform actions in sequence without true parallelism, and therefore if the business process being simulated require messages to be sent in parallel, this may create challenges. We are proposing further studies to understand the extent to which this can create issues;
2. Impact of errors in simulation results. It is understood that there is a margin of error in every experiment; however, the author suggests a broader study that looks are factors that can cause Netlogo to behave abruptly and understand how these can influence simulation results. These factors could be hardware, software, resource availability;
3. The implementation of functionality within BPMN to handle incoming and outgoing messages. It has been found that custom scripts embedded in to "receive the message" tasks in BPMN are not invoked when messages arrive but straight after the token arrives in the task. This can influence cycle time results and other problems, and a better way to handle messages in BPMN should be studied;

In terms of improvements to be made to our method, it is proposed that future work consists in exploring other simulation methods that are best suited to stimulate different types of factors that influence a business process. More specifically, system dynamics is a method well suited to study how quantitative variables are impacted by the overall dynamics of the process and thus, variables such as costs and budgets, can be included in the simulation to create an even richer understanding of the overall dynamics of the business process.

In order to better comprehend the suitability of this simulation approach in real-world situations, there is a need to employ it in a project from the design phase, so that aspects as the influence of process designer skills and time to create models can be factored into the effectiveness. These are aspects not covered in this study, as we only focus on understanding the feasibility of building a solution that supports such a simulation approach and whether simulation results are reliable enough compared to real ones. Therefore, a case study employing our approach is another suggestion for future work.

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