

**A FACILITATED DISCRETE EVENT SIMULATION FRAMEWORK TO
SUPPORT ONLINE STUDIES IN INDUSTRY**

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ABSTRACT

This paper aims to propose a framework to carry out simulation projects considering Industry 4.0 and facilitated modeling. The proposed framework presents how to develop a Facilitated Discrete Event Simulation (DES) study in an industrial process. The structure aligns with some important Industry 4.0 era requirements and is based on online interventions. Action Research method was used to develop the framework. Concepts of Industry 4.0, facilitated modeling, and online meetings were adopted in its creation, such as: carrying out a faster (up to 3 months) and flexible online modeling process; creating a simple computer model that does not require a complex data collection structure nor a specialist team; generating a better understanding of the process and assisting the stakeholders in identifying improvements. To the best of our knowledge, the proposed framework is the first in literature that shows how to implement a Facilitated online DES study for industrial environments.

KEYWORDS. Facilitated Simulation. Online intervention. Industry 4.0.

SIM – Simulation

1. Introduction

In recent years, computer simulation has been highlighted as an essential tool to support decision-making [Mourtzis 2020]. Moreover, considering the context of Industry 4.0, simulation plays an important role since it allows for more efficient decisions and combines low investments and high flexibility [Santos et al. 2020].

However, many companies and managers have failed to take advantage of the benefits of the simulation, considering the industry 4.0 era [Skoogh et al. 2012; Teerasoponpong and Sopadang 2021]. In this case, some challenges related to the use of simulation in this new industrial era can be highlighted: (i) high cost related to the time spent in modeling the systems [Barlas and Heavey 2016]; (ii) complexity of models when considering the characteristics and behaviors of physical systems [Robinson et al. 2014]; limitations regarding the availability and collection of data for the model building phase [Saez et al. 2018; Teerasoponpong and Sopadang 2021]; high level of specialization and training of decision makers considering the use of complex models [Banks et al. 2010; Mourtzis 2020]; etc. Considering traditional simulation approaches, the Facilitated Modeling can be highlighted as a mechanism that simplifies the steps involved in simulation projects [Robinson et al., 2014].

The facilitated simulation is based on the development of simplified and agile models, focused on decision-making based on satisfactory and practical solutions. In this case, the modeling process is carried out with the active participation of stakeholders in a simpler modeling process that is independent of a large volume of data [Proudlove et al. 2017; Tako and Kotiadis 2015; Franco and Montibeller 2010]. Robinson et al. (2014) highlight that, although it is a simpler approach than traditional simulation projects, facilitated modeling is not harmed and has great potential in decision support. Therefore, since Industry 4.0 requires tools and techniques to support decisions and, at the same time, requires agility and flexibility in this process, the facilitated simulation stands out as a valuable tool.

In exploratory research of the literature in recent years, several works can be observed that considered the facilitated modeling, with emphasis on decision-making in the services area, such as Robinson et al. (2014), Tako and Kotiadis (2015, 2018), Proudlove et al. (2017) and Tako et al. (2019, 2021). However, production systems characteristics differ from the service sector. Therefore, there are research opportunities involving the proposition of methods and steps focused on facilitated modeling and simulation in industrial processes. Considering this research opportunity, this work aims to propose a framework containing the main steps to be carried out in an online facilitated DES study. Furthermore, all development is based on the context of Industry 4.0 to allow the creation of a framework adapted to the requirements and characteristics of this new industrial age.

The rest of the paper is as follows: section 2 gives the theoretical background, while the proposed approach is described in Section 3. Finally, Section 4 concerns the conclusions and future directions.

2. Theoretical background

The adoption of simulation models to support decisions is commonly used due to the flexibility and financial benefits of this approach [Pereira et al. 2015]. Among its several application areas, manufacturing systems stand out as the main focus of simulation projects, and, considering the types of simulation, the principal is the Discrete Event Simulation (DES) [Scheidegger et al. 2018].

Considering simulation-based decisions in production processes, there are decisions related to production planning, routing, scheduling, resource planning, inventory management, and layout planning, among others [Scheiderer et al. 2018; Mourtzis et al. 2020]. In this case, it is possible to carry out “what-if” experiments and analyze scenarios without impacting physical systems and with low financial effort, allowing for more efficient decisions [Banks et al. 2010].

Despite being a mature research area and well developed by researchers and professionals, simulation had undergone significant changes in the current industrial context [Rodic 2017]. Industry 4.0, a term that refers to the fourth industrial revolution, has brought substantial changes in simulation-based decision-making [Santos et al. 2020]. In this case, the development of new communication and connection technologies and processes automation has enabled greater integration between physical and virtual environments. These make simulation no longer a tool for punctual analysis that involves specialists. It has become a friendly tool focused on daily decision support [Rodic 2017; Ferreira et al. 2020].

Considering the need for more assertive and efficient models demanded by Industry 4.0, several approaches have emerged over time, such as “Online Simulation”, “Near/Real-time simulation”, “symbiotic simulation,” and “simulation-based digital twin” [Santos et al. 2021]. These applications are based on connecting simulation models with physical systems to update them over time according to physical changes. However, despite being promising, Choi and Kang (2018) and Goodall et al. (2019) highlight some difficulties associated with these approaches, such as the necessary technological structure, which may incur high costs and significant changes in the current systems. Moreover, these issues are even more relevant in processes with a low automation level, a common scenario in developing and underdeveloped countries [Tortorella and Fettermann 2017].

Considering the Industry 4.0 decision requirements, Ferreira et al. (2020) emphasize that traditional simulation approaches are still relevant for applications and developments. In traditional modeling, there is a punctual analysis, where the models are built from the observation of systems and data collection, and the decisions are based on experiments and analysis by modelers and decision makers [Banks et al. 2010]. However, Vieira et al. (2018) reveal that the modeling process tends to become increasingly flexible and agile. In this context, the so-called facilitated simulation as a valuable technique in decision-making can be highlighted.

According to Robinson et al. (2014), facilitated simulation has been highlighted as an alternative to traditional approaches regarding the complexity and development time of models. The authors report that the model's focus is not high precision but its usefulness in generating understanding of the problem and, consequently, in supporting decision-making. Tako et al. (2019) also highlight the growing popularization of the facilitated simulation in recent years, appearing among several works in the literature. Furthermore, among the main characteristics of this approach, can be highlighted: (i) participatory approach between modelers and stakeholders; (ii) simplified data collection; (iii) agile modeling; (iv) focus on satisfactory solutions rather than optimal ones (which require more analysis time) [Franco and Montibeller 2010; Robinson et al. 2014; Proudlove et al. 2017; Kotiadis and Tako 2018; Harper et al. 2021].

On the one hand, facilitated simulation provides a more agile and participatory modeling process aiming at efficient decisions [Robinson et al., 2014]. On the other hand, Vieira et al. (2018) reveal the need for modeling methods and techniques focused on agility flexibility considering the Industry 4.0 requirements. Therefore, the applicability of the facilitated simulation considering the modern industrial context can be highlighted. In addition, as shown in Table 1, one can note the alignment between some facilitated simulation characteristics and the simulation requirements in Industry 4.0.

Table 1. Facilitated simulation's characteristics vs. simulation in Industry 4.0.

Facilitated simulation's characteristics	Requirements considering the use of simulation in the Industry 4.0 context
Active participation of stakeholders and decision-makers in a simpler modeling process [Robinson 2001; Franco and Montibeller 2010; Kotiadis and Tako 2018; Harper et al. 2021].	Modeling that does not depend on experts [Rodric 2017].
Simplified data collection [Robinson et al., 2012; Robinson et al. 2014; Proudlove et al. 2017].	Modeling does not rely on lengthy data collections [Santos et al. 2020].
Fast and flexible modeling [Robinson et al. 2014].	Faster and more flexible modeling [Vieira et al. 2018].
Focus on practical decision-making [Franco and Montibeller 2010; Robinson et al. 2014].	Periodic decision-making is based on the simulation results [Rodric 2017; Santos et al. 2020].

3. Proposed framework

The literature shows that facilitated DES frameworks are aimed at service sectors. Therefore, considering the characteristics presented in Table 1, the proposed framework FaMoSim (Facilitated Modeling Simulation) aims to support interventions in facilitated DES in industrial processes. Figure 1 shows The FaMoSim framework. The Action Research method was used to develop the framework. This method was also used to develop and apply the SimLean Facilitate [Robinson et al. 2014] and PartiSim [Tako and Kotiadis 2015] facilitated DES frameworks.

As an innovation for the literature, the framework proposes the conduction of facilitated DES through online intervention, allowing some members to be present virtually while others are face to face. In addition, it is focused on industrial processes. According to some researchers, the hybrid meeting format will be predominant post-era COVID-19 [Hameed et al. 2021; Richter 2020]. Therefore, the possibility to participate virtually in the meetings contributes to the project of DES not being limited geographically, expanding its application in different cities. The stakeholders will be face to face while the researchers will be remote. The company must allow the meeting recording, assisting the researchers in gathering information about the process studied.

FaMoSim framework comprises four phases: Kickoff Meeting; Conceptual Modeling (workshop 1 and 2); Computer Modeling (workshop 3); and Feedback (workshop 4). Each stage presents a specific objective, the activities that should be carried out, the expected results, and the tools used to support the process. Verification and validation are performed in these phases. The stakeholder availability may affect the lead time of the process. However, maximum three months is recommended to complete the simulation project. The meeting was designed to last approximately 60 minutes each [Tako and Kotiadis 2012]. Then, the difference between traditional DES and the new approach in industrial processes is that simulation is performed in an online facilitated environment, where stakeholders can express their preferences, discuss alternatives, and actively participate.

The intervention participants are divided into the modeling and the stakeholder team, composing the project team. The modeling team consists of two researchers (facilitator and modeler). However, the facilitator and modeler may be the same person. The stakeholder team consists of two to four people belonging to the company. Table 2 shows the role played by each member.

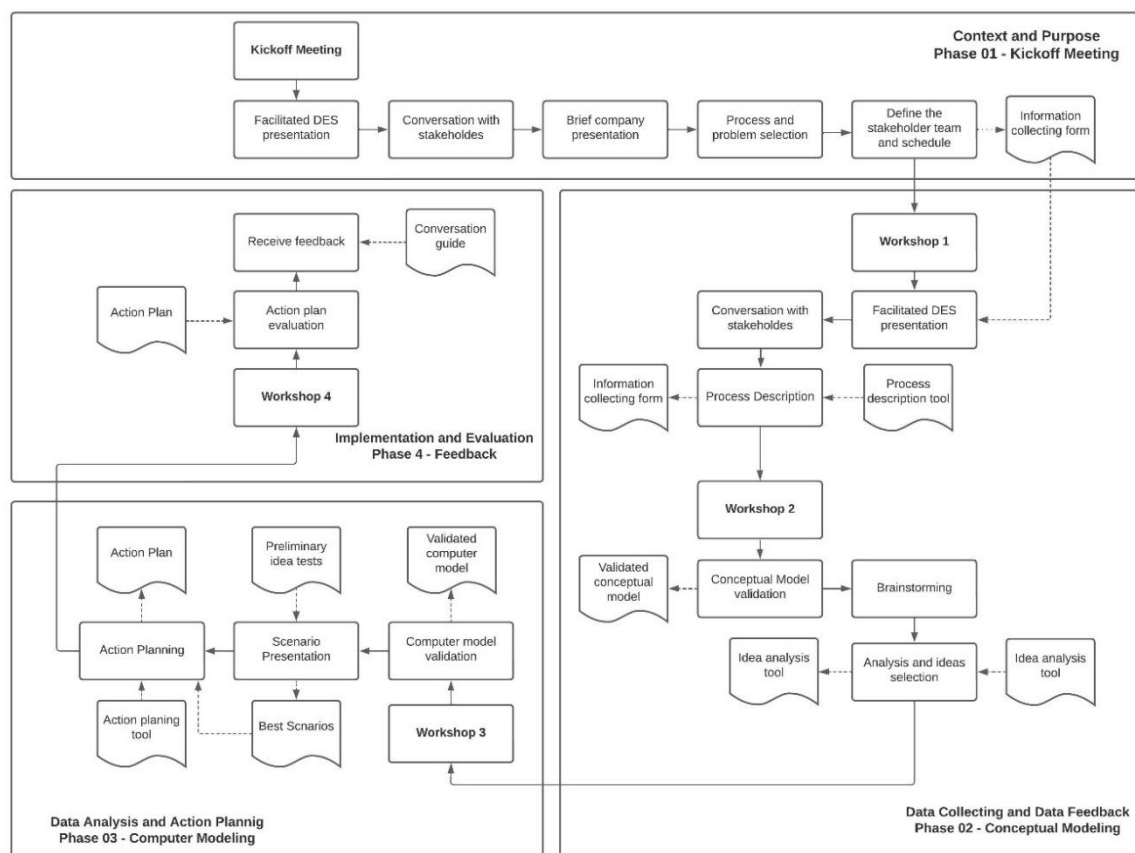


Figure 1. FaMoSim framework
Source: the authors

Table 2 – Project Team Roles

Project Team Roles		Description
Modeling Team	Facilitator	The facilitator leads the meetings, ensuring that the objectives are achieved, and the activities are carried out. He/she manages the group dynamics and promotes interaction among participants. Also, he/she takes notes as a meeting observer.
	Modeler	A DES expert that supports the translation of the conceptual modeling to the computer model. He/she helps in the validation and verification phase. He/she may also assist in observing the situation and making notes.
Stakeholder Team	Key Stakeholder	One or two managers belonging to the company. These people should be enthusiastic about the project. They connect the modeling and the stakeholder team and are also responsible for informing the study in the organization.
	Other stakeholders	Other company employees (one to three) know the system or are experts in the modeled process.

Source: Adapted from Kotiadis et al. (2014)

The focus of the models generated by the framework is to increase the problem understanding and assist the stakeholders in identifying possible improvements in the process. Both

the modeled system and the DES model must have low complexity. The required data are estimated by the process experts [Robinson et al. 2014] or data already collected by the company. The steps of FaMoSim will be detailed in the following sections.

3.1 Phase 01 - Kickoff Meeting

In the kickoff meeting, there must be one or two key stakeholders and at least one member of the modeling team. The meeting has two objectives: (i) clarify to stakeholders what the facilitated DES is, its benefits for the company and how the project will be carried out (framework explanation), and (ii) the stakeholders share with the modeling team the possible process to study and define which people can make up the stakeholder team. At this meeting, it is required to schedule some dates for the next meeting and workshops.

Stakeholders will be notified of the meeting details and agenda via email. Moreover, they will be asked to think of a possible process and problem they would like to study and solve. Preparing the stakeholders in advance will facilitate that the objectives set for the meeting are met.

Regarding the first objective, the facilitator presents the difference between facilitated and traditional DES and the benefits of the technique for the company. The advantages are shorter project time, efficient data collection, and search for satisfactory and feasible solutions (instead of optimal). Moreover, in the presentation, the facilitator explains how the framework works. The stakeholders may ask questions about the presentation during or after the lecture. The researchers also make notes about their impressions related to the voice tone of the stakeholders, whether they were enthusiastic or hesitant, and their participation in the meeting (behavior).

Regarding the second objective, the stakeholders are asked about the process they want to understand and improve. After the prior discussion, stakeholders point out which potential employees comprise the team (experts). The experts will assist in the system description, objectives definition, data collecting, application, and results analysis. Finally, as a result, a form is filled out.

3.2 Phase 02 - Conceptual Modeling

Two workshops are required in the second phase. In the first workshop, the defined process is detailed by the stakeholders, helping the modeling team in conceptual model building. In workshop 2, the verified conceptual model needs to be validated by the stakeholders. In this stage, the team can brainstorm about possible improvements that may be applied in the real system or that should be tried out using the simulation model. Moreover, if the stakeholders prefer, they can draw up an action plan to implement the ideas in the real system and do not use computer modeling.

3.2.1 Workshop 1

Workshop 1 should be attended by the modeling and the stakeholder team. The new participants defined at the kickoff meeting must be present, totaling a maximum of six people. The workshop aims to (i) clarify to the other stakeholders what facilitated DES is and (ii) describe the proposed process. If the team already knows the facilitated DES, the meeting is focused only on the second objective.

After a quick explanation, the stakeholder can ask questions about possible doubts. The next step is a conversation between the company and the researchers to discover which process needs improvements and the problems that should be solved. The meeting is recorded, and the facilitator fills out a form with the process description when he/she analyzes the recording.

Based on Robinson et al. (2014) study, a tool to support the process description was developed. The authors suggest that the process description can present the data and rules needed to build the computer model more quickly. Moreover, they suggest some requirements for rapid simulation modeling, such as entities, activities, queues, conveyors, stocks, and data and distributions.

The stakeholders can estimate the distributions of arrivals and processing. Banks (1998) suggests some distributions, such as exponential, uniform, or triangular. More information about how to estimate distributions can be found in Robinson et al. (2014) and Robinson (2001).

The facilitator is responsible for conducting the meeting and filling out the form (process, problems, model goal, and team). At the end of workshop 1, the process should be mapped and understood by all members.

Kotiadis et al. (2014) assure that preparing preliminary materials for the workshops avoids unnecessary and unproductive time during the meeting. In this way, the modeling team should build and verify the conceptual model before the second workshop. Also, the computer model should be started in parallel, which will be finalized after the conceptual model validation.

3.2.2 Workshop 2

Workshop 2 aims to (i) validate the conceptual model using the face-to-face technique with all teams and (ii) brainstorm ideas for the process improvement. At this stage, the stakeholders can decide whether they prefer to proceed with computer modeling or implement the new ideas in the real system only using the conceptual modeling analysis. Robinson (2008) states that if the conclusion of the conceptual model is suitable for the stakeholders, the project can stop at this point.

In the model validation, the model is expected to represent the system satisfactorily. The facilitator explains all information from the conceptual model to the stakeholders. If any information is incomplete or incorrect, the participants may interrupt the facilitator and correct him.

After performing the first activity, it is expected that the stakeholders understand the process, the problem to be solved, and the conceptual model. The facilitator will analyze the statements during the meeting to check the understanding.

In the second part of the workshop, a virtual brainstorming with the stakeholders is set up to develop ideas to improve the system and test them in the DES model. After brainstorming, the ideas should be classified and prioritized from the simplest to the more complex that can be implemented in the real system. The simple improvements can generate a good impact in the process, but not the optimal one, as expected by the traditional DES. Stakeholders' communication and involvement in this activity can generate more support for ideas to be implemented.

The team makes a list of ideas that may be implemented. To measure the results of this phase, the researchers analyze whether the ideas were simple to implement in the real system and whether they generated positive results in the process under study.

After workshop 2, the modeling team continues the computer model building for further validation in workshop 3. The stakeholders may be triggered between the workshops to provide estimated data for the model input.

3.3 Phase 03 - Computer modeling

The computer modeling phase consists of finishing the computer model, experimenting, and elaborating an action plan for possible improvements according to the scenarios. A simple computer model should be developed quickly, be flexible, require less data than the traditional models, run fast and provide easy results to analyze since its structure is known by all participants [Robinson et al. 2014]. Robinson (2008) affirms that the more a model needs to be changed during (and after) a study, the more flexibility is required. Therefore, the stakeholders should suggest scenarios that do not require complex adaptations in the computer model. The modeling team needs to evaluate the necessity of fast, simple, and less data collection. Finally, at the end of workshop 3, the stakeholders should assess if the results are easy to understand and well structured.

Model verification and validation are carried out using the face-to-face technique. Another step that may be used in validation is to “calibrate” the model [Robinson 2001; Robinson et al. 2014], because the estimated data may be inaccurate and must be adjusted to represent the

system. According to Robinson (2001), calibration refers to changing the estimated data until the model result aligns with stakeholder expectations. Therefore, the results obtained with the model should be interpreted as indicative rather than predictive.

3.3.1 Workshop 3

Workshop 3 aims to (i) conduct face-to-face computer model validation and (ii) set up an action plan. The company may not choose to develop the action plan together with the modeling team. Therefore, if the changes in the real system require more time than expected, the stakeholders may also stop the study at this stage.

The workshop begins with face-to-face validation. Then, the facilitator briefly describes the model logic and runs it. This stage is important because the stakeholders can see how the process works in the simulator. The results are presented, followed by the validation process.

After validation, the modeler presents the scenarios and analyses for discussion. As mentioned before, the results should be indicative and not precise. The team chooses the best indicative results, and the action planning starts. The action plan tool was based on the 5W2H technique and presented what should be done and how to implement the changes, deadlines, and the person responsible for it.

Therefore, after completing the action plan, the modeling team asks a few questions about the stakeholders' opinions about the simulation model and its results. At the end of workshop 3, the results are sent to the stakeholders.

If the stakeholders want to carry out the action plan internally, FaMoSim ends at this point. If possible, a contact within the company to follow up on the changes is encouraged. Thus, if the intervention ends at this point, the modeling team should ask the stakeholders how the experience was for them.

3.4 Phase 04 - Feedback

Finally, the last phase is the feedback. The stakeholders will implement the proposed activities in the action plan, and there will be a discussion about the results.

Unlike the facilitated DES frameworks present in the literature [Robinson et al. 2014; Tako and Kotiadis 2015], FaMoSim features the feedback step at the end. The last phase was inserted because, according to the literature, the participation of the key stakeholders during the simulation project is an important factor in the application of the proposed improvements [Kotiadis and Tako 2018; Robinson et al. 2014; Franco and Montibeller 2010).

Since simple changes should be prioritized, it is believed that some of them can be implemented, and their results can be seen within a few weeks. These contribute not only to the company but also to the literature, which lacks simulation applications.

3.4.1 Workshop 4

Workshop 4 presents two objectives: (i) information exchange, being a time dedicated to following up on the action plan, gathering information about what changes were made and the results obtained; and (ii) receiving feedback from the stakeholders about how this experience was for them. The stakeholders can relate their experiences, their perceptions when participating in the project, whether they would apply the framework again in the company or indicate it to other organizations, and reflect on the gains. If the stakeholders decide to stop the study at the conceptual modeling (workshop 2) or computer modeling (workshop 3) stage, the second objective of the feedback phase should be completed.

The first activity in workshop 4 is to evaluate the status of each action ("completed" or "in progress"). The gains already measured in the system are discussed. All stakeholders are expected to be clear about the deadlines and activities that must be carried out to finish the project and achieve results. To measure the results, the researchers ask if the plan is clear to everyone and observe the participants' behavior.

At the end of the analysis of all activities, the feedback begins. A guiding tool has been developed, where stakeholders can describe their experience of a facilitated simulation project, the relevance of the results, and if the model helps in decision-making. Since the meeting will be recorded, the recording will be available to the researchers for further analysis.

At the end of the study, the research expects the participants understand how simple DES models can be efficient in process improvement. The modeling team also observes the behavior of the stakeholders for the final analyses. Workshop 4 is finished, and the researchers' participation ends. Finally, an email will be sent to the stakeholders with the results generated in this step. Since some activities may still be implemented, the researchers should contact the stakeholders by the last deadline to update the results.

Finally, it is essential to highlight that considering all steps described above, the proposed approach is in line with some important Industry 4.0 era requirements. The framework allows a faster (up to 3 months) and flexible modeling process based on online interventions and can be adapted according to the characteristics of each application. Furthermore, this simpler modeling framework does not require a complex data collection structure nor a specialist team involving long training times. Therefore, the proposed framework can contribute to the simulation project's requirements considering the Industry 4.0 era, as highlighted in section 2.

4. Conclusion and future directions

This paper presented the FaMoSim framework, the result of an investigation that considered the challenges of simulation projects in modern industry. Since Industry 4.0 requires agility and flexibility to support decisions, the facilitated simulation is a valuable tool. Oriented for industrial processes, the FaMoSim framework comprises four phases: Kickoff Meeting; Conceptual Modeling (workshop 1 and 2); Computer Modeling (workshop 3); and Feedback (workshop 4). It is performed in an online facilitated environment, where stakeholders can express their preferences, discuss alternatives, and actively participate in the facilitated DES project. The framework uses concepts of Industry 4.0, facilitated modeling, and online meetings, such as: a faster (up to 3 months) and flexible online modeling process; a simple computer model that does not require a complex data collection structure nor a specialist team; a better understanding of the process and assisting the stakeholders in identifying improvements.

As future directions, it is suggested applying the framework to different sizes of companies (e.g., small, medium, and large enterprises) to assess its applicability in these contexts. Recommended analysis are: (i) data use (estimated vs. real data); (ii) action plan development; (iii) the implementation and follow-up of improvements in the real system.

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