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FaMoSim: a facilitated discrete event simulation framework to support online studies

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Abstract

Paper aims: To propose a framework to support online simulation studies considering facilitated modeling and concepts of modern industry context, such as agility and flexibility.

Originality: Since the frameworks in the literature deal with simulation projects focused on healthcare and face-to-face meetings, the present work innovates by offering an agile and flexible guide for simulation projects in production systems, which also supports online interventions.

Research method: Action Research method was used to develop the framework. After its development, the FaMoSim (Facilitated Modeling Simulation) framework was applied in a real case to evaluate its applicability.

Main findings: In the application of FaMoSim, we achieved the framework's objectives: carrying out a faster (up to 3 months) and more 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.

Implications for theory and practice: Considering some challenges that prevent the expansion of DES studies, the framework assists in expanding DES studies in environments where it is not widely used. The framework supports online interventions, making it an interesting tool that can be used mainly in times of social distancing.

Keywords

Facilitated modeling. Industry 4.0. Framework. Online intervention.

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1. Introduction

In recent years, computer simulation has been highlighted as an essential tool for decision-making (Mourtzis, 2020). In this case, we highlight applications in several areas, such as hospital decisions, military operations, logistics, and mainly manufacturing processes (Gabriel et al., 2022). Moreover, considering the context of modern industry, simulation plays an essential role since it allows for more efficient decisions and combines low investments and high flexibility (Santos et al., 2022).

Despite being widely spread by researchers and practitioners, it is noted that simulation still represents a fertile field of research (Mourtzis, 2020). Moreover, a new era of decision-making is observed, marked by increasingly efficient processes and decisions based on emerging technologies, allowing the development of increasingly agile and flexible simulation models (Rodič, 2017; Santos et al., 2022). However, we noted that many companies and managers still fail to take advantage of the benefits of the simulation (Skoogh et al., 2012; Teerasoponpong & Sopadang, 2021; Oliveira et al., 2022).

Santos et al. (2021) report that approaches that connect and integrate models with physical systems have been gaining space, such as the so-called "Symbiotic simulation", "Data-driven simulation", "Near/ Real-time simulation", and "Digital Twins", among others. These approaches have become possible due to the increased availability of data and the adoption of promising technologies by the production processes. Thus, by connecting the models to the processes through sensors and intelligent systems, we have modeling projects that are increasingly agile and flexible and aligned to the requirements of decision makers (Rodič, 2017).

However, although the approaches mentioned above are promising, especially considering the context of Industry 4.0, there are still challenges to be overcome. These challenges are found mainly in industrial environments with low/medium degree of development, where significant investments and process structure changes are impossible (Moeuf et al., 2018; Santos et al., 2022; Choi & Kang, 2018; Goodall et al., 2019).

Considering contexts where DES is not widely used, such as (i) where there are financial constraints to invest in the data collection of large samples and to hire qualified people for data analysis (Teerasoponpong & Sopadang, 2021; Saez et al., 2018); (ii) where the number of data is small or operational data is not available (Omri et al., 2020; Ivers et al., 2016; Byrne et al., 2013); (iii) where there is a lack of experts with skills and knowledge to take advantage of DES and develop complex models that represent the characteristics and behaviors of physical systems (Teerasoponpong & Sopadang, 2021; Mittal et al., 2018); (iv) where simulation time is restricted, and it is required agility in the process (Barlas & Heavey, 2016).

In this context, regardless of the degree of development and investments in production systems, it is observed that an essential characteristic for simulation projects refers to the adoption of increasingly flexible and agile models, considering the concepts of Industry 4.0 (Rodič, 2017; Vieira et al., 2018; Santos et al., 2021). In this case, we highlight the Facilitated Modeling as a mechanism that simplifies the steps involved in simulation projects (Robinson et al., 2014).

The facilitated simulation is based on developing 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 independent of a large volume of data (Proudlove et al., 2017; Tako & Kotiadis, 2015; Franco & 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, there is research potential for applying facilitated modeling combined with DES (facilitated DES) in contexts where DES is not widely used, as previously reported. We also see that facilitated DES is aligned with the main concepts of Industry 4.0, striving for flexibility and agility in a simulation application. Thus, facilitated DES represents a different approach for application in industry, which is also aligned with modern industry concepts.

In exploratory research of the literature in recent years, we observed several works that used facilitated DES, with emphasis on decision-making in the healthcare area, such as Robinson et al. (2014), Tako & Kotiadis (2015, 2018), Proudlove et al. (2017) and Tako et al. (2019, 2021). Oliveira et al. (2022) compared the challenges of applying DES in industrial contexts with the facilitated DES frameworks presented in the literature. The authors concluded that creating a facilitated DES framework for application in different contexts other than hospitals is necessary. None of the analyzed frameworks considered all the challenges related to the use of simulation, as presented above. Moreover, applying the analyzed frameworks without modification is unfeasible since they were created focused on the healthcare area. In addition, the authors say that the frameworks have not considered online communication resources. According to Standaert et al. (2022), virtual meetings will only intensify in the coming years, and for Oliveira et al. (2022), new ways of conducting facilitated DES online would innovate DES applications. Thus, the literature lacks more applications for expanding this technique to other areas (Kotiadis & Tako, 2021; Tako et al., 2019, Kotiadis & Tako, 2018; Robinson et al., 2014).

Therefore, we highlight research opportunities involving the proposition of methods and steps focused on facilitated modeling and simulation in production systems (goods and services). Then, this work aims to propose a framework containing the main steps to be carried out in an online facilitated DES study. Finally, to assess the applicability of the proposed framework, it was applied to a real object of study.

This article contributes to the literature by providing an online facilitated DES framework, which considers the challenges related to simulation use and guides an online facilitated DES without visits to the study site. This framework was applied in an industrial context, providing theoretical contributions to the literature by discussing the online application of facilitated DES and practical contributions to the company under study, assisting managers in decision-making. In this new era of decision-making based on emerging technologies (Rodič, 2017; Santos et al., 2022), providing an online application of facilitated DES contributes to the literature that seeks to use emerging technologies in simulation.

The rest of the paper is as follows: section 2 gives the theoretical background, while the proposed approach is described in Section 3. Section 4 is dedicated to applying the proposed framework to an actual study object. Finally, Section 5 concerns the conclusions and future directions.

2. Theoretical background

The adoption of simulation models to support decisions is commonly used due to this approach's flexibility and financial benefits (Pereira et al., 2015). In this case, Banks et al. (2010) reveal that simulation is one of the main Operational Research techniques. It is based on computer models built from observing the behavior of the physical system. 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 Discrete Event Simulation (DES) (Scheidegger et al., 2018).

Considering simulation-based decisions in production processes, we highlight decisions related to production planning, routing, scheduling, resource planning, inventory management, and layout planning, among others (Scheidegger et al., 2018; Mourtzis, 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). Furthermore, the adoption of simulation integrated with other decision support techniques has been widely disseminated, with emphasis on the integration of simulation models with forecasting techniques, optimization algorithms, Artificial Intelligence (AI) models, Virtual Reality, and Augmented Reality interfaces, among others (Amaral et al., 2021; Mourtzis, 2020; Santos et al., 2022). These decision support techniques allow the development of increasingly agile and flexible simulation models (Rodič, 2017; Santos et al., 2022).

Industry 4.0, the fourth industrial revolution, has substantially changed simulation-based decision-making (Santos et al., 2022). In this case, developing new communication and connection technologies and processes automation has enabled greater integration between physical and virtual environments. It has become a friendly tool focused on daily decision support (Rodič, 2017; Ferreira et al., 2020). However, although the approaches mentioned above are promising, not all companies have access to these technologies. This happens especially in industrial environments with low/medium degree of development, where significant investments and process structure changes are impossible (Moeuf et al., 2018; Santos et al., 2022; Goodall et al., 2019; Choi & Kang, 2018).

Considering contexts where DES is not widely used, such as (i) where there are financial constraints to invest in the data collection of large samples and to hire qualified people for data analysis (Teerasoponpong & Sopadang, 2021; Saez et al., 2018); (ii) where the number of data is small or operational data is not available (Omri et al., 2020; Ivers et al., 2016; Byrne et al., 2013); (iii) where there is a lack of experts with skills and knowledge to take advantage of DES and develop complex models that represent the characteristics and behaviors of physical systems (Teerasoponpong & Sopadang, 2021; Mittal et al., 2018); (iv) where simulation time is restricted, and it is required agility in the process (Barlas & Heavey, 2016).

Thereby, joining the concepts of Industry 4.0 regarding agile and flexible simulation models and the challenges in using DES, several authors present the use of facilitated modeling together with DES to overcome the challenges exposed above. Considering the limitations regarding the availability and collection of data for the model building phase, Robinson (2001) and Robinson et al. (2014) claim that the lack of accurate data did not characterize an obstacle for DES models. In this sense, DES was employed in the facilitated mode.

Facilitated DES aims to develop understanding and learning of the real system by generating discussions about the problem using a simple and faster model that may be discarded at the end of the intervention (Robinson et al., 2014). This gives flexibility and agility to simulation projects. According to Robinson et al. (2014), the model is not judged by its accuracy but by promoting a debate and understanding of the problem.

Tako et al. (2020) state that a simple model focuses on key elements of the system. In this way, unnecessary efforts are avoided, where studies are shorter, more transparent, and more efficient. Advantages include better understanding, faster analysis and modification (flexibility), and runtime that results in better implementation of the results suggested by the simulation. The authors explore the learning achieved from simulation models focusing on the level of model detail (complex vs. simple models). In conclusion, the results show that the differences in learning from using the two models were not significant. They found that simple model users had a better understanding of the problem, providing some initial empirical evidence that simple models may be useful in supporting clients to understand their problems and make decisions.

Robinson et al. (2014) state that 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 an understanding of the problem and, consequently, supporting decision-making. Tako et al. (2019) also highlight the growing popularization of facilitated simulation in recent years, appearing among several works in the literature.

Furthermore, among the main characteristics of this approach, we highlight: (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 & Montibeller, 2010; Robinson et al., 2014; Proudlove et al., 2017; Kotiadis & Tako 2018; Harper et al., 2021). Thus, several authors recognize that DES has a great potential to be used in the facilitated mode, and more work should be done on this subject (Robinson et al., 2012, 2014; Tako & Kotiadis, 2015; Proudlove et al. 2017; Kotiadis & Tako, 2018; Tako et al., 2020; Harper et al., 2021).

Table 1 shows the alignment among challenges in using DES, some facilitated simulation characteristics, and the simulation requirements in Industry 4.0. Although Industry 4.0 involves technological systems and developments, we note that some requirements are related to adopting fast and flexible solutions that may or not require high investments and structural changes. In this case, we note that the Facilitated DES can be a good alternative to make up this kind of solution since it is based on systems modeling in a faster and simplified way compared with traditional simulation approaches.

Table 1. Challenges in using DES, Facilitated simulation's characteristics and simulation in Industry 4.0.

Challenges in using DES		Facilitated simulation characteristics	Requirements considering the use of simulation in the modern decision-making context
Financial constraints (Teerasoponpong & Sopadang, 2021; Saez et al., 2018)	Financial constraints on investing in equipment for automatic data collection, experts with knowledge in DES, or consultancies.	Focus on practical decisions, but not optimal ones (Franco & Montibeller, 2010; Robinson et al., 2014).	Periodic and continuous use of simulation to base decision making (Rodič, 2017; Santos et al., 2022).
Data gap (Omri et al., 2020; Ivers et al., 2016; Byrne et al., 2013)	Little or no data is available on the processes.	Simplified data collection (Robinson et al., 2012; Robinson et al., 2014; Proudlove et al., 2017).	The modeling phase might not require extended mapping and data collection times (Santos et al., 2022).
Lack of experts (Teerasoponpong & Sopadang, 2021; Mittal et al., 2018)	Lack of experts in DES and in developing computer models.	Active participation of stakeholders and decision-makers in a simpler modeling process (Robinson, 2001; Franco & Montibeller, 2010; Kotiadis & Tako, 2018; Harper et al., 2021).	Modeling from user-friendly interfaces that do not require the help of specialists throughout the entire project but in specific phases (Rodič, 2017).
Restricted time (Barlas & Heavey, 2016)	Little time is available to engage in a simulation project.	Fast and flexible modeling (Robinson et al., 2014).	Faster and more flexible modeling (Vieira et al., 2018).

Moreover, we cannot ignore the COVID-19 pandemic that directly affected face-to-face contact between people. In this context, adaptations in routine activities were necessary and virtual alternatives were used for communication. According to Standaert et al. (2022), virtual meetings will intensify in the coming years, and for Oliveira et al. (2022), new ways of conducting facilitated DES online would innovate DES applications. Therefore, considering the challenges encountered in applying DES and virtual media for communication, online facilitated DES presents great potential for spreading DES studies.

3. Proposed framework

Considering the critical analysis of the facilitated DES frameworks presented in Oliveira et al. (2022), no framework has considered all challenges in using DES nor the virtual communication resources. Meanwhile, the social distancing caused by COVID -19 pandemic should not be ignored. Moreover, applying the analyzed frameworks without modification is unfeasible since they were created focused on the healthcare area. Hence, the authors concluded that it is necessary to develop a facilitated DES framework for application in different contexts other than hospitals. New ways of conducting facilitated DES online would innovate DES applications (Oliveira et al., 2022).

Therefore, this paper aims to fill the gaps found in the literature by proposing an online facilitated DES framework. The framework can be carried out in situations with challenges in using DES, such as industrial processes. Figure 1 shows The FaMoSim (Facilitated Modeling Simulation) framework. We used the Action Research (AR) method to develop the framework. This method was also used to develop and apply the SimLean Facilitate (Robinson et al., 2014) and PartiSim (Tako & Kotiadis, 2015) facilitated DES frameworks.

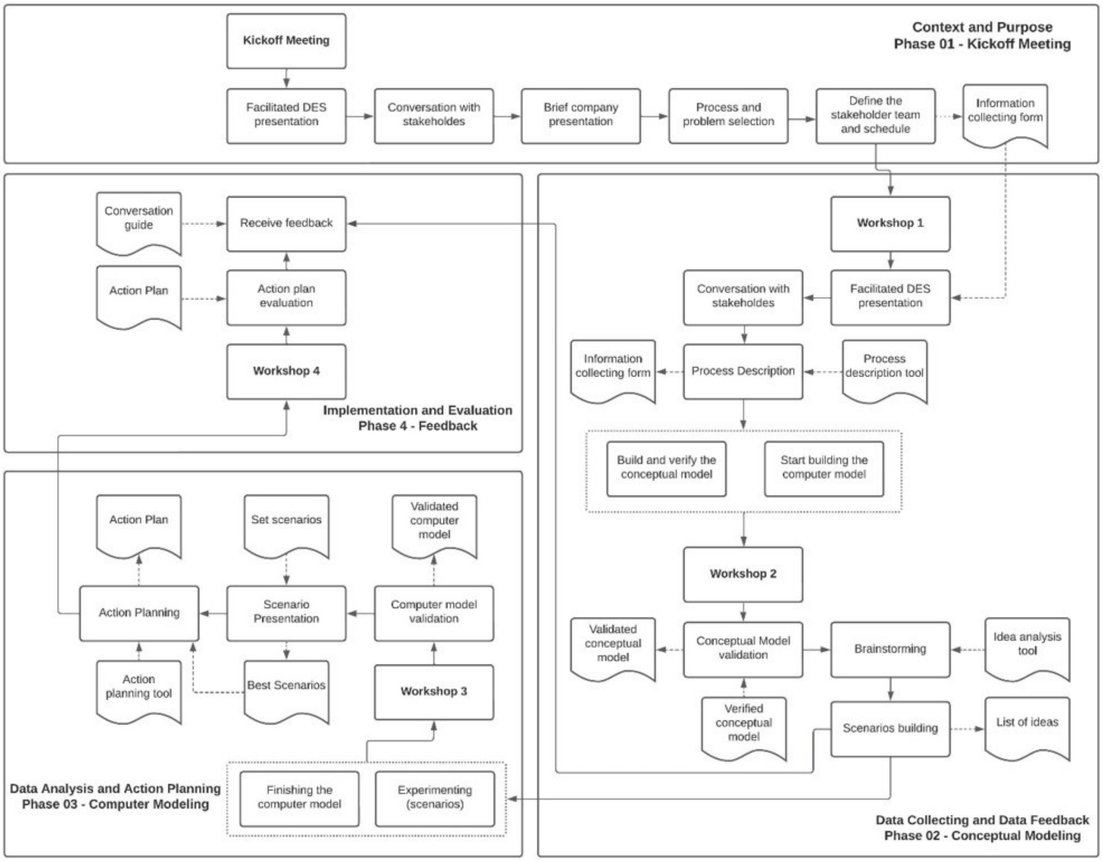

Figure 1. FaMoSim framework. Source: the authors.

According to Coghlan et al. (2014), AR is a research approach based on a collaborative problem-solving relationship between the researcher and the client. It aims to generate knowledge (research) and solve a problem (action). A characteristic of AR is the active involvement of the researcher in the investigation (McKay & Marshall, 2001). AR is a suitable method to develop the framework, not only because it was used in the literature (Robinson et al., 2014; Tako & Kotiadis, 2015) but also because: (i) provides support for the interaction between researcher and client (company), necessary in the analysis of the results. The client feedback is essential for the framework improvement; (ii) generates knowledge for literature since the proposed framework, after being applied, represents a structure that may be carried out in other projects to expand the DES studies; (iii) assists in problem-solving.

Coughlan & Coghlan (2002) report that the AR cycle is divided into three phases. The first phase aims to understand the purpose of the situation. The second one comprises six steps: data collection, data feedback, data analysis, action planning, implementation, and evaluation. The last phase is a monitoring meta-step. Therefore, the FaMoSim framework was designed following the AR cycle proposed by Coughlan & Coghlan (2002).

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. 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. We know that stakeholder availability may affect the lead time of the process. However, we recommend at most three months. We project the meeting to be about 60 minutes each (Tako & Kotiadis, 2012).

Then, the difference between traditional DES and the new approach is that simulation is performed in a 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.

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: Adaptad 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. The DES model must have low complexity and focus on the system's key elements. 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. Context and purpose - Phase 01 kickoff meeting

According to Coughlan & Coghlan (2002), two questions must be answered at this stage: "What is the reason for the research?" and "What is the reason for the action?". Regarding the reason for the research, the development of a new framework fills gaps in the literature, as shown in item 2, such as (i) presenting alternatives for using DES where the implementation in the traditional form is not suitable (Teerasoponpong & Sopadang, 2021; Mittal et al., 2018; Ivers et al., 2016) (ii) use of facilitated DES in sectors different from healthcare (Oliveira et al., 2022; Tako et al., 2019; Robinson et al., 2014); (iii) ways to carry out more flexible and agile simulation studies (Vieira et al., 2018); (iv) seek alternatives in applying DES, such as conducting online studies without an in-person visit to the real process (Oliveira et al., 2022).

Regarding the reason for the action, Scheidegger et al. (2018) highlight that DES is a widely used technique in the literature with positive project results. However, there are possibilities for studies in contexts where it faces challenges when implemented (Table 1). Therefore, the work aims to unite DES with facilitated modeling (facilitated DES) to carry out the study in contexts that present the challenges in Table 1 or studies that need to be performed faster and more flexibly. The concepts of Industry 4.0 (agility and flexibility) reinforce the use of facilitated DES in industry. At the Kickoff Meeting, the problem the company wants to solve will be discussed, or the process that needs improvements.

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. It is required to schedule some dates for the next meeting and workshops at this meeting.

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. Data collecting and data feedback - Phase 02 conceptual modeling

Two workshops are required in the second phase. In the first workshop, data about the study is collected. Therefore, the defined process is detailed by the stakeholders, helping the modeling team build the conceptual model. In workshop 2, data feedback will take place. The modeling team will provide feedback to the stakeholders by presenting the conceptual model built from the data collection performed in workshop 1. This means that the stakeholders will validate the verified conceptual model.

In this stage, the team can brainstorm possible improvements that may be applied in the real system, or that should be tried 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 not use computer modeling. Phase 02 comprises the steps of data collection and feedback presented in the AR cycle.

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 facilitator fills out a form with the process description when he/she analyzes the recording.

We developed a tool to support the process description based on Robinson et al. (2014) study. 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 estimating 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 and 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 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, stakeholders must understand the process, the problem to be solved, and the conceptual model. The facilitator will analyze the statements during the meeting to check their understanding.

In the second part of the workshop, a virtual brainstorming session with the stakeholders is set up to develop ideas to improve the system and test them in the simulation 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. For this, an idea analysis tool is used. 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 following activity is scenario building, where the stakeholders should suggest scenarios that do not require complex adaptations in the computer model. A list of ideas is built containing the scenarios that will be tested in the computer model. 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 finishes the computer model for further validation in workshop 3. The stakeholders may be triggered between the workshops to provide estimated data for the model input (experimenting).

3.3. Data analysis and action planning - Phase 03 computer modeling

In Phase 03, data analysis and action planning are carried out. 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. The modeling team must evaluate the necessity of fast, simple, and less data collection. Model verification and validation are carried out using the face-to-face technique. The results obtained with the model should be interpreted as indicative rather than predictive. Finally, at the end of workshop 3, the stakeholders should assess if the results are easy to understand and well structured.

3.3.1. Workshop 3

Workshop 3 aims to (i) conduct face-to-face computer model validation and (ii) establish 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, and the model validation is performed.

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 planning 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, we suggest a contact within the company to follow up on the changes. Thus, if the intervention ends at this point, the modeling team should ask the stakeholders how the experience was for them, as presented in the activity "receive feedback" in workshop 4.

3.4. Implementation and evaluation - Phase 04 feedback

Finally, the last phase is feedback. Implementation and evaluation are performed in this step. The stakeholders will implement the proposed activities in the action plan, and there will be a discussion about the results. The discussion of the results will be about solving the problem and about the framework, aiming at its improvement.

Unlike the facilitated DES frameworks in the literature (Robinson et al., 2014; Tako & 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 & Tako, 2018; Robinson et al., 2014; Franco & 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, 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 and 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, we suggest completing the second objective of the feedback phase.

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 to understand how simple DES models can efficiently improve the process. 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, we suggest that the researchers contact the stakeholders by the last deadline to update the results.

The AR monitoring meta-step occurs throughout the facilitated DES project. Each of the stages of AR methodology is monitored by researchers. The monitoring is carried out through the emails sent to the stakeholders after each workshop containing the results and questions about their perception of the process. In addition, the stakeholders' understanding is monitored during the project execution. The researchers ask the stakeholders if they understand the process, if they have any questions and if they agree with what is being done.

It is essential to highlight that considering all steps described above, the proposed approach is in line with some important Industry 4.0 era concepts. 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, we also have a simpler modeling framework that does not require a complex data collection structure nor a specialist team involving long training times. Therefore, we note that the proposed framework can be used in contexts where DES is not commonly used.

Finally, the proposed framework offers support for researchers who wish to conduct online facilitated DES, giving some recommendations for successful hybrid meetings, mainly related to the number of members in the project team and the durations of meetings. The literature points out that in face-to-face meetings, the duration of the meeting can be extended by up to 3 hours (Robinson et al., 2014). This duration is difficult in online meetings because members are likelier to be easily distracted (Oeppen et al., 2020). Thus, the framework divides the activities in each workshop, ensuring that the meeting does not exceed the stipulated time, causing damage to the results. The number of project team members is another relevant concern in online meetings. The literature points out that too many participants (more than five) can negatively affect the effectiveness of the meeting (Standaert et al., 2022; Itzchakov & Grau, 2022). The duration time and the number of participants are concerns that the frameworks reported in the literature do not present (Oliveira et al., 2022).

4. Discussion: the FaMoSim framework

This section provides our observations of using the FaMoSim framework in a large company. It is a company in the auto parts business and has several complex processes where data collection could be a hindrance due to the high volume of parts produced. Thus, only critical data were requested to build the simulation model, which did not depend on a significant investment for data collection.

4.1. FaMoSim in a real process

During the study, all contact with the stakeholder was done virtually (email or cell phone). Before each meeting, an email was sent to the stakeholders containing the agenda and a brief explanation about it. The study was applied for three months, with four 60-minute meetings that were recorded. The stakeholders decided not to perform the action plan together with the modeling team because the changes in the process would not be simple, and it would be necessary to contact other areas.

The kickoff meeting happened between the facilitator and the key stakeholder. Some doubts were answered during the initial presentation, causing the presentation and the conversation simultaneously. After answering all the questions, the facilitator led the meeting to the second part, asking the stakeholder about the process that needed improvements. Since the main stakeholder already knew how traditional DES works and how it helps decision-making, he indicated the process to be studied.

Four more people were asked to participate in choosing the other stakeholders. The new stakeholders must assist in data collection and estimation for the model. Since the company has dynamic daily activities, we found it difficult to establish a schedule, and the meetings had to be set up one by one. Meetings must be held in a short time, and the researchers must be responsible for maintaining the engagement.

In workshop 1, the modeling team was complete (facilitator and modeler), unlike the stakeholder team (only two process engineers), due to unforeseen events in the company. Unfortunately, it is a problem that may happen in any intervention, and it has occurred in the study of facilitated DES in the healthcare sector (Tako & Kotiadis, 2015). Although the team was not complete, the engineers described the process, and it was not a problem since they are experts. Moreover, the company had the layout of the process.

In the first meeting, there was little participation from the modeler. The facilitator conducted the dynamic using the process description tool (something previously structured). Therefore, we conclude that the presence of the modeler/modeling expert is not required, as long as the facilitator has some modeling experience.

Workshop 1 started 15 minutes late because the company's employees were engaged in other activities. Therefore, the facilitator did not formally introduce DES to focus on the second objective of the workshop. The facilitator only recalled about facilitated DES and explained the study's purpose. This was an acceptable alternative since the stakeholders already knew about the DES. In addition, the presentation used in the kickoff meeting was sent to the manager to present to the other participants. Finally, the participants had no doubts during the meeting.

The facilitator used the process description tool to guide the questions about the study. With the description provided by the stakeholders in workshop 1, it was possible to create the conceptual model. The meeting was recorded, which facilitated further analysis.

In the meeting, the team decided to use real data in the simulation. Therefore, the facilitator sent messages to the process engineering to discuss the data. In the conceptual modeling stage, the facilitator used the software Cawemo. Although IDEF-SIM (Montevechi et al., 2010) is focused on simulation, we choose to use the BPMN technique. Proudlove et al. (2017) claim that the BPMN technique provides a natural entry point for stakeholders in DES study, especially those with less knowledge. Dani et al. (2019) reinforce this idea by stating that BPMN is a notation widely used in the industry and easy to understand.

In workshop 2, the conceptual model was validated by stakeholders, requiring a few modifications. Analyzing the conceptual model, the stakeholders could not think of any immediate improvement to the process. They did not have ideas because the process had already been studied and improved in other opportunities. This way, a deeper analysis was necessary to understand and improve the process. In the end, the stakeholders defined that the DES model should show the impact of each machine on the bottleneck. The center often stops due to a lack of parts.

The idea analysis tool was used to check if what was requested for experimentation would be possible. Therefore, the meeting ended with scenarios the company would like to test. The researchers modeled the scenarios after workshop 2 and presented them in workshop 3.

After workshop 2, more data was requested from stakeholders, such as machine downtime, stock capacity, and distance that parts traveled in the process. There was also an unscheduled 40-minute meeting with the industrial engineer to clarify some information. In the model, we decided to represent only one family of parts, then it was not necessary to input the setup time. The production rates of each machine were used, and the exponential distribution was adopted, as pointed out by Banks (1998). According to historical data, we use the average downtime for each machine. Finally, average data were used for the other model data (distance traveled, stock capacity, etc.).

The results provided by the DES model were compared to the real system data. It was possible to conclude which machines most impact the bottleneck. We also modeled and ran scenarios increasing the capacity of the stocks and changing them in the layout. The stakeholders were aware and agreed on all scenarios defined.

Workshop 3 had to be adapted because stakeholders chose not to develop the action plan with the modeling team. However, a meeting was held at the company with several stakeholders, including from different company areas, to plan the actions. The action planning activity was removed from the workshop, and the activity of receiving feedback, present in workshop 4, was inserted.

Therefore, workshop 3 started with the computer model validation. The model was presented to stakeholders, and it was executed. The results were presented, and stakeholders were surprised because, according to them, the model represented the real system. The surprise was due to the context of the application. That is, obtaining a model that represents the real system through online meetings, a few data collected, and a fast simulation project was possible.

The scenarios were also presented, and several discussions were raised between the team. The discussions took up the entire meeting time, and another 20 minutes for the feedback were necessary. We present some participants' perceptions about the model results.

> Process Engineer (stakeholder A): *the model showed some things we didn't know. Changing the F machine tools every 1000 parts does not impact the bottleneck station. However, the most important thing was that the model showed us data and numbers. It turned what we know into numbers. We see where we have to attack/act. The model was presenting our reality. Everything you showed is not a lie, it reflected what was happening.*

> Supervisor (key stakeholder 1): *this work will be used to show and justify to management that specific changes require a high investment.*

> Industrial Engineer (key stakeholder 2): [the model] *turned our feeling into something real.*

Through the visual analysis of the participants and their voices, it was noticed that they were very excited about the technique and how the simulation could generate results that justify investments in the production line. They argued that the company should know simulation and people should be able to use it because the gains are remarkable. Regarding feedback on the intervention, stakeholders reported the following:

> Key Stakeholder 2: *Since it was an online application, I first confess that I doubted it a little because I thought that maybe you* [facilitator] *would have difficulty* [in understanding] *not knowing our process. But I think the process and the meetings we had were very productive. Our communication was very smooth. I was surprised when the results were very similar to the real thing. I was a little surprised because I thought maybe it would be more complicated to achieve it.*

> Key stakeholder 1: *I also agree with what was said. When talking about something at a distance, there is this question, "will it work?" However, what the work achieved was enough for me, and I thought it was a very cool way it was carried out. I agree that you can work with such a (simple) model and be very efficient with the results. Our next step here is to look for what we can improve to increase the machines' efficiency or think of another way to improve the process.*

> Stakeholder A: *the proposal to do it online worked. It surprised me to have been carried out that way and given the result we saw.*

All stakeholders agreed that the model represents the real system, it generated a greater understanding of the process and will assist in decision-making. Moreover, we asked them if they would indicate the framework application in another company. All of them had a positive impression of the study:

> Key Stakeholder 2: *I would indicate in the same company, inclusive. We have another line here.*

> [Laughter]

> Key Stakeholder 1: *We are willing to do a second project, mapping another process. I liked what was done.*

We concluded that the framework and study achieved their objective from these feedbacks. We got a greater process understanding and worked in a simpler model, which helped decision-making. Conducting the work online also proved quite efficient, yielding good results. Furthermore, the results showed that online facilitated DES could be successfully applied in industrial environments.

Considering Oliveira et al. (2022), the authors compared the facilitated DES frameworks presented in the literature and the characteristics of contexts where DES is not widely used. The authors concluded that no framework addressed all the challenges in using DES. Therefore, Table 3 presents the FaMoSim framework together with these frameworks.

Table 3. Comparison among facilitated DES frameworks.

Frameworks	Challenges in using DES			
	Financial constraints	Data gap	Lack of experts	Restricted time
SimLean Facilitate	+	+	-	+
PartiSim	-	-	+	-
The structure presented in Robinson (2001)	+	+	-	+
The structure presented in Proudlove et al. (2017)	-	-	-	-
FaMoSim	+	+	+	+

Source: Adaptad from Oliveira et al. (2022).

Analyzing Table 3, we can conclude that FaMoSim succeeded in developing simple models and used a few data to build the computer model ("+" sign in financial constraints). The FaMoSim also used existing data from the company. A visit to the study site was unnecessary for detailed data collection ("+" sign for data gap). The approach is detailed and explains how online facilitated interventions should take place. This is an important issue as it assists other researchers in replicating the approach. Furthermore, developing a simple computer model does not require experts to build it ("+" sign for lack of experts). Finally, The FaMoSim could also be implemented in a short period ("+" sign for restricted time).

4.2. Observations of using FaMoSim

Considering the application of FaMoSim, we highlight some issues:

- Meeting dates were set one by one.

We noted that holding meetings every week was not suitable for the following reasons: (i) stakeholders needed a certain time to collect the required data; (ii) it was necessary to combine the agenda of all involved in the project; (iii) There were some unforeseen events during the project activities, such as unplanned meetings and production line stops. Therefore, some meetings had to be rescheduled/postponed. Thus, scheduling previous dates for the workshops may be difficult in this industrial environment.

- Real data was adopted.

Although facilitated DES applications consider estimated data by the stakeholders, real data was used in this study. It happened because the company already had historical data, and the employees could collect others quickly. This characteristic may be more common in large companies with structures and resources for data collection.

Another issue is that we did not consider statistical analyses even using real data. The computer model was inputted by the average and production rates were converted into exponential distributions (Banks, 1998).

- Project Lead Time

Stakeholder participation was active, especially in the last workshop, which featured many discussions. Providing a discussion time among the team about the process significantly strengthened their intention to seek improvements. In other words, after the study, the stakeholders were very excited and confident about improving the production line. Although they already knew about their problems, this study was necessary to better understand their problem and justify the process's investments.

Considering the modeling team, we concluded that only the facilitator's presence was enough in the meetings. The modeler was contacted to assist in creating post-workshop models and participated in only one meeting. However, we highlight that the facilitator also knew DES.

- Face-to-face validation

The face-to-face model validation was considered successful for the project team. This is an interesting result since, in just one meeting (workshop 1), practically 100% of the process could be represented. In other words, a few changes were made to the conceptual model after it was presented to stakeholders, and the computer model did not need to be changed. According to the stakeholders, it surprised them, mainly because the entire study was conducted remotely.

- Online application

An online facilitated DES application is not addressed in the literature. Therefore, FaMoSim presents this contribution to conducting online facilitated DES studies in industrial environments. The result obtained was quite significant since it was possible to succeed in its application. Considering a simple computer model (few data and less details), it was possible to provide the stakeholders with a greater understanding of the process and assist them in identifying potential improvements.

- Combination of workshops 3 and 4

Since it was impossible to create the action plan during workshop 3, the feedback part (from workshop 4) was included at this meeting. This approach did not impact the results obtained in the study. This decision was considered plausible since (i) any change in the production line would imply significant financial investments; (ii) the line has already been studied. Therefore, simple and easy-to-apply changes have not been found; (iii) any change in the process should be justified, being necessary to contact other company areas.

5. 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, facilitated simulation is a valuable tool. 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. We applied the proposed framework in a real case to assess its applicability. Considering the active participation of the stakeholders, they engaged well in the project, interacting with the facilitators and each other during the workshops. It was suitable to develop an online study, generating significant results for the company and the literature. The simulation model was built fast, with less data and less details. It provided the stakeholders with a greater understanding of the process and assisted decision-making. Therefore the objectives of FaMoSim were achieved.

As future directions, we suggest applying the framework to other companies of different sizes (e.g., small and medium enterprises) to compare the results, providing more analytical discussions for the literature. We recommend analysis of (i) data use (estimated vs. real data); (ii) action plan development; (iii) the implementation and follow-up of improvements in the real system. Furthermore, we encourage more studies considering different processes, such as services.

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