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Integrating soft systems methodology to aid simulation conceptual modeling

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Abstract

Discrete-event simulation is considered an increasingly common support tool for decision making, especially in manufacturing. Most simulation projects are divided into three distinct phases: conception, implementation, and analysis. Some authors believe the conception phase is the most important, as the simulation study objectives are defined and the project's foundation is laid at this point. Many researchers do not spend the necessary amount of time on this important initial phase. Thus, this article presents an integration method that makes use of soft systems methodology (SSM), a complex problem-solving approach, during the conceptual phase of simulation studies. SSM was used throughout the conceptual modeling phase for a real manufacturing simulation case study. Through the analysis of this study, it can be concluded that the use of SSM to develop the conceptual model enabled identification of the study objectives, thus avoiding errors and reworks. The study's results are presented and the method's application is justified by presenting a valid model capable of analyzing the system's key input variables.

Keywords: discrete-event simulation; soft system methodology; decision support systems; manufacturing; production lines

1. Introduction

Discrete-event simulation (DES) is now ever-increasingly employed as a means of aiding decision making. Through the use of modeling, analysis, and system design, one can characterize the impact of input parameter variations on output parameter performance (Banks et al., 2005; Garza-Reyes et al., 2010; Sargent, 2009).

Law and McComas (1998) state that modeling manufacturing systems for DES has been a practice since the 1960s, since when it has become one of the most popular and powerful tools for analyzing complex manufacturing systems (Banks et al., 2005). One of the main reasons simulation has become so common in industry is its ability to incorporate stochastic, random behavior to inputs, thus making its analyses more robust (Hillier and Lieberman, 2010).

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Most DES projects are divided into three phases: The first phase being conception, in which project objectives are defined (what will be simulated) and the conceptual model is elaborated; the second phase is implementation, in which the conceptual model is translated into a computational model by means of simulation software; and in the final phase—analysis—the computational model is utilized by running scenarios with varying input parameter values and generating output data that aid decision making by identifying more advantageous scenarios.

Throughout simulation projects, analysts, simulation practitioners, managers, and clients gain more understanding of the system (Sargent, 2010). Kotiadis and Robinson (2008) believe that conceptual modeling has gained momentum in recent years, given that practitioners and analysts are indeed interested and dedicated to understanding the processes to be simulated on a more profound basis.

As previously stated, conceptual modeling is frequently considered as the most important phase of the three phases, in which the model objectives and system definitions are established (Robinson, 2008). If information is not correctly defined at the beginning of the project, subsequent phases will certainly present errors and rework, thus wasting time and money.

In order to improve the conceptual model phase, this study uses soft systems methodology (SSM), a technique used to deal with complex situations in which problems are not uniformly identified and not seen from the same perspective by all those involved in the system (Checkland, 1981). Thus, the objective of this study is to integrate SSM methods in the conceptual modeling phase of DES, focusing specifically on what will be simulated and which research questions will be formulated and answered. In order to test the proposed method, a simulation study was carried out in a manufacturing environment.

To attain this objective, the current study is organized in seven sections. Following this introduction, Section 2 presents a literature review of DES and SSM. Section 3 shows the utilized research method. Section 4 presents the study object, followed by application of SSM in the conceptual modeling phase presented in Section 5. Section 6 describes the method's application and the results obtained. Finally, Section 7 offers results and discussions on this study.

2. Literature review

2.1. Discrete-event simulation

Harrel et al. (2004) claim that simulation is defined as the imitation of a dynamic system using a computational model to evaluate and improve system performance. Banks (1998) states that simulation involves the creation of an artificial history of a real system throughout time and the observation of the real system in order to make inferences about the operation's characteristics.

O'Kane et al. (2000) assert that DES has become one of the most popular techniques for analyzing complex problems in productive environments. Banks et al. (2005) states that simulation is one of the most commonly utilized tools to analyze manufacturing systems.

In accordance with Garza-Reyes et al. (2010) and Sargent (2009), DES has been increasingly used to aid decision making through system modeling, design, and analysis with the objective of describing the impact of shifts in input parameter performance.

Furthermore, Shannon (1998) points out the following advantages for using simulation:

- Ability to test layouts and designs without compromising or wasting resources for implementation.
- Ability to explore new stock policies, operational procedures, decision rules, and information flow, without interrupting real system functioning.
- Manipulation of time, which means models can be run for months or years in a question of minutes, enabling rapid analysis of long periods of time or slowing down the model in order to see system dynamics.
- Identification of bottlenecks in information, materials, and/or product flows, enabling the testing of options to improve them.
- Acquisition of valuable knowledge about how the modeled system works and understanding why certain variables are important to performance.

Banks et al. (2005) and Law and Kelton (2000) highlight that in spite of the advantages that simulation presents, there are also some disadvantages: Modeling is expensive and consumes valuable time to be properly developed; moreover, if the model does not provide a suitable representation, its usefulness will be nil; and construction of simulation models requires special training, among other disadvantages.

Dating from the beginning of DES, its purpose has been to aid decision making. According to Siebers (2006), simulation is generally recognized as a valuable decision-making tool for both strategic and tactical planning, both of which are required in project evaluation for manufacturing systems. According to Baines et al. (2004), simulation allows modeled systems to produce better performance forecasts.

2.2. Soft system methodology

Checkland (1981) proposed SSM that aims to solve complex problems in which objectives are difficult to identify or when the problem may be perceived from a distinctly different viewpoint. One of its most attractive points is its ability to structure conversations and debates about complex and poorly defined problems (Checkland, 1999). Furthermore, the methodology is a way of acquiring knowledge from several individuals who represent or make up different system components or subsystems (Kotiadis, 2007; Lehaney and Paul, 1996; Pidd, 2007).

Checkland and Scholes (1999) write that SSM is applicable in a number of complex systems, such as the service, logistical, medical, and manufacturing. Through guiding the dialog between researchers and specialists, and generating diagrams and conceptual models to visualize the problem, the conversation and knowledge extraction process is facilitated.

Checkland and Poulter (2006) state that SSM is described as an organized and flexible process for dealing with problematic situations that demand measures to be taken in order to improve these problematic circumstances. By generating thorough discussion, proposals are generally considered more acceptable by all members and create less tension among involved parties.

Checkland and Scholes (1999) argue that SSM is a singular methodology that possesses a variety of tools to be used to examine messy problematic situations. In accordance with Checkland (2000) and Kotiadis and Robinson (2008), the most well-known tools are the following:

- One, two, three analysis.
- The mnemonic CATWOE (clients, actors, transformation, weltanschauung or world view, owner and environmental constraints).
- Root definitions to outline system participants, purpose, and constraints.
- System performance measures of efficacy, efficiency, and effectiveness to monitor system behavior.
- Purposeful activity model (PAM) to visualize system contingencies.

These system analysis tools help researchers analyze messy problems in which conflicting interests often work or conspire against each other (both culturally and politically). Measures of efficacy, efficiency, and effectiveness are used to gauge the influence of proposed changes.

Lehaney and Paul (1996) assert that the conceptual modeling phase and the process of system discovery are two central aspects of simulation project development. The authors were the first to argue for the use of SSM as a useful tool in the preliminary phases of model development. Moreover, they also claim that the use of SSM improves the confidence that decision makers will have in a study's results, given that the investigation methodology and the way in which the model is defined become clearer, more transparent, and participative.

The methodology depends on a series of steps that uses debates and system definition to enable users to arrive at a consensus about the system's functioning and details. Through the use of SSM's communicative, conversational approach, both practitioners and clients are encouraged to be more participative in modeling, which helps reduce misunderstandings and increase the thoroughness of the simulation. Figure 1 shows the SSM structure, as proposed by Checkland (1999).

SSM is divided into the following four steps:

- Get to know the problem situation, including cultural and political terms.
- Formulate significant activity models of the system.
- Discuss the situation via the models, seeking changes that improve the situation and are also feasible and desirable, and make agreements between conflicting organizational interests that enable action to be taken.
- Finally, action is taken to improve the situation.

3. Research method

The research herein developed relied upon modeling and simulation to achieve its objectives. Modeling and simulation is the process of creating and experimenting in a physical system through the means of a computerized, mathematical model (Chung, 2004). In keeping with Bertrand and Fransoo (2002), this method should be used when the aim is to forecast or anticipate the effect of system alterations, evaluate system performance, or behavior in order to reduce real-life problems.

To represent the process logic in this simulation project, the method proposed by Montevechi et al. (2010) was used. This method is divided into three phases: conception, implementation, and analysis. These steps are presented in Fig. 2.

A DES project starts with the conceptual phase, in which simulation practitioners find out about the system or process to be simulated, delimit the system, and define the study objectives, its scope, and level of model detail (Robinson, 2008). Throughout this phase, the conceptual model, which is

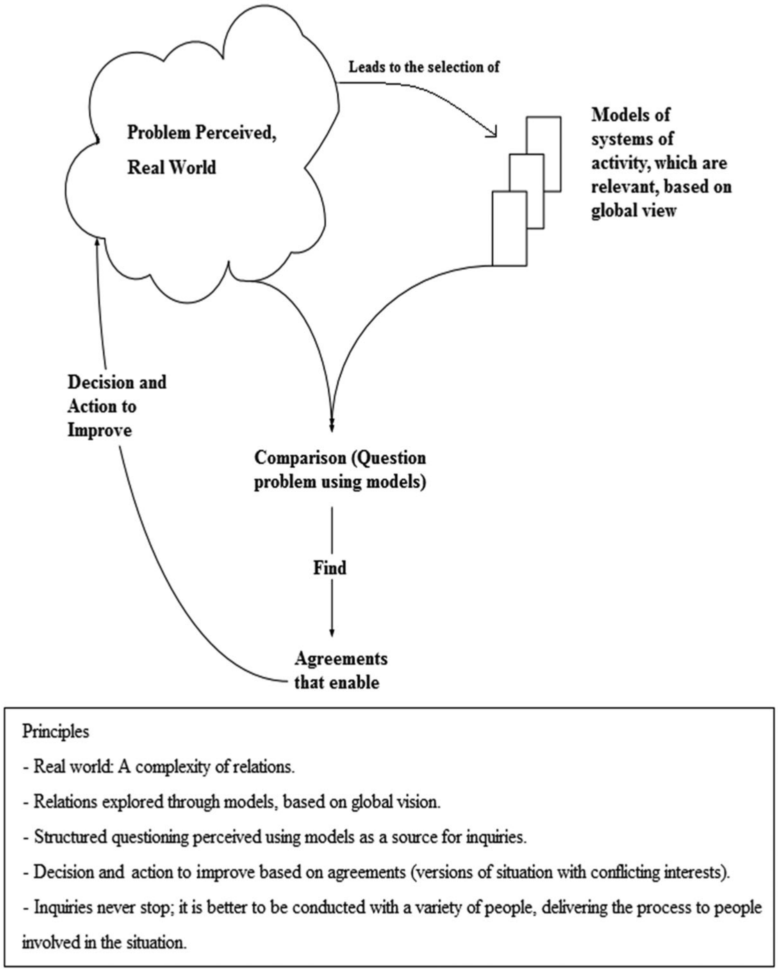

Fig. 1. SSM structure (Checkland, 1999).

an abstraction of reality, is elaborated, through the use of a mapping technique. Banks et al. (2005) assert that model construction is more of an art than a science.

As reported by Law (1991) and Robinson (2008), conceptual modeling is most likely the most difficult part of the simulation model process. In light of this, SSM, identified as a method by which to resolve complex problems (Checkland, 1999), was utilized as a means to arrive at modeling objectives and develop the simulation model.

After defining the study's objectives and constructing the conceptual model, the model must be validated in order to ensure that there are no errors that could disrupt the following stages. Validation may be done directly by specialists, according to Sargent (2009), this type of validation is called face-to-face validation, in which specialists validate and approve the conceptual model via conversation and presentation of the model to system specialists.

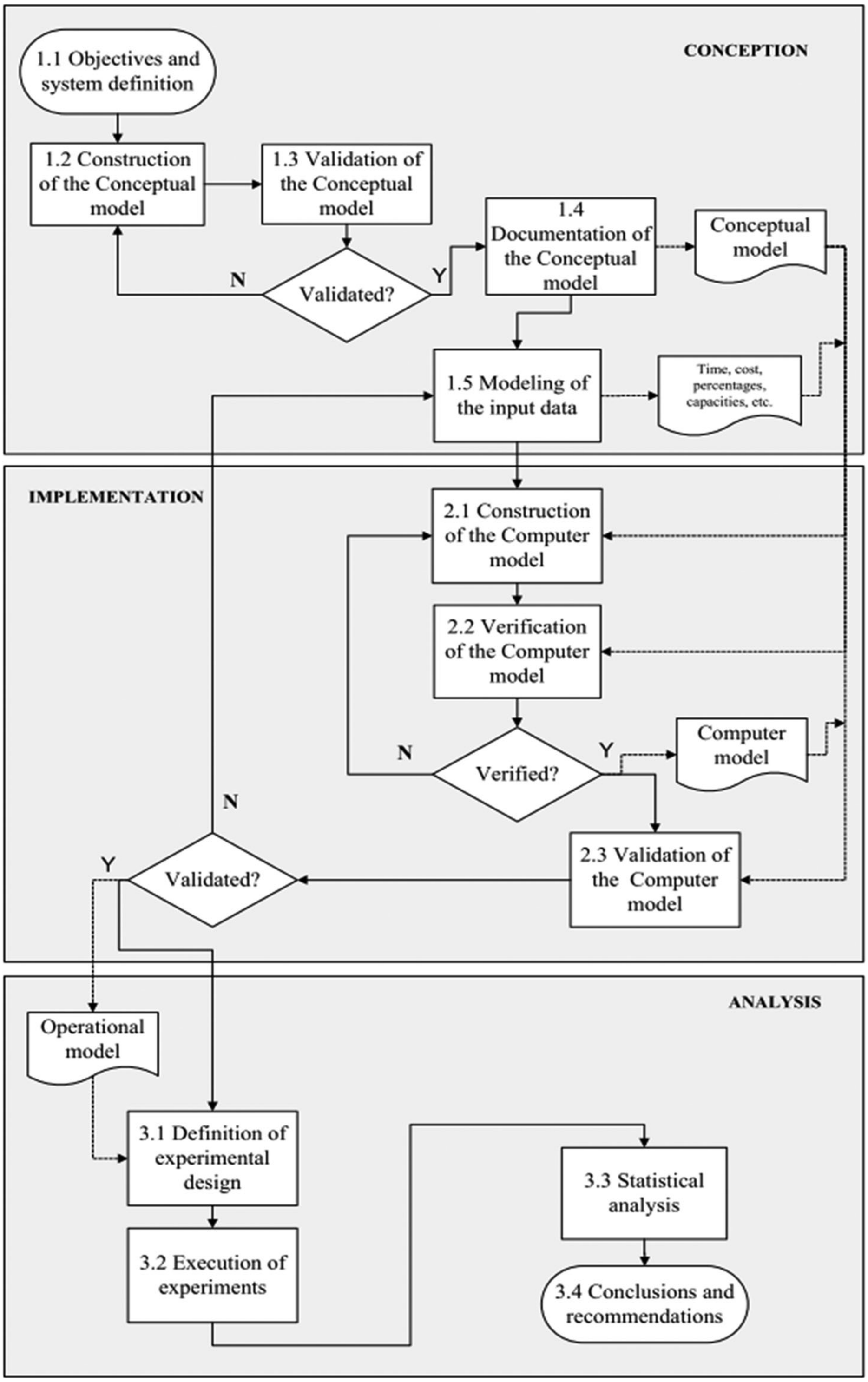

Fig. 2. Phases of project simulation (Montevechi et al., 2010).

Once the model is validated, the next activity is to determine the model's input and output variables, data collection points, and collect the identified data, and then to adjust them according to probability distributions used by the model.

With current, valid data in hand, simulation practitioners advance to the next step proposed by Montevechi et al. (2010): implementation. In this phase, the computational model is constructed based on the logic abstracted and contained in the conceptual model (Sargent, 2010). Analysts use simulation software to construct the model and feed the model with data collected in the previous stages.

The computational model, like the conceptual model, should be verified and validated by the analyst in order to determine its capacity to represent reality. According to Sargent (2010), the steps of verification and validation are important for research, seeing that a model may only be considered valid once it has the necessary precision to achieve the model's objectives.

Upon verification and validation of the computational model, simulation practitioners advance to the last stage of simulation: analysis. In this phase, the experimental design for the project is defined with experiments or scenarios, and analysis is carried out. According to Banks et al. (2005), the replicas and subsequent data analysis are used for estimating measurements of the real system. Then conclusions can be made and recommendations can be suggested for the real system. In the case of alterations, the cycle starts over.

4. Study object

The study object for this article is an international automobile and industrial sector component company that owns and operates a subsidiary in Brazil. The company supplies components to most automotive manufacturers in Brazil, aside from its considerable presence in regional and global markets. The study examined the entire production line of the Brazilian entity's plant, which is composed of a pull-system, a combination of manual and automatic machines, quality inspections carried out by quality inspectors, and productive processes carried out by line operators. Process names and details were omitted due to questions of confidentiality, in accordance with the company's requests.

Upon starting the study, the simulation practitioner noticed the system was quite complex, in which even directors and managers possessed different points of view of the same production line. No single manager could explain all the details of the system, which is a key characteristic of systems deemed as potential applications for SSM (Checkland, 1999). Assessing that SSM is a methodology that can deal with complex problem situations, analysts decided to use this methodology as the system was considered complex and there were many different viewpoints of the system.

The following section presents the combination of SSM tools in the first phase of simulation design: conception.

5. Using SSM to aid conceptual modeling for simulation

The application described herein is motivated mainly by the limitation in the literature on SSM applications in manufacturing simulation, most of the studies that bring together these two concepts have come from the healthcare sector (Kotiadis, 2007; Lehaney et al., 1999).

The above-mentioned authors recommend the use of SSM in simulation projects, which contributes to an application in the area of manufacturing and proposes a methodology that involves SSM in the conceptual phase of simulation.

A simplification of SSM is presented, which involves the principle concepts of the methodology, aiming to be an easily-understandable and readily-employable model. Other SSM models that are components of SSM in the conceptual phase can be found in Kotiadis (2007), Lehaney et al. (1999), Mingers (2000) and Mabin et al. (2006); however, these models are geared toward healthcare applications.

In line with the sequence of steps in Fig. 2, the first step is to define the system to be studied and the objectives of the project, while for SSM, the first step is to know the problem, including its culture and internal politics.

It was clear to the analyst from the beginning that the management team was particularly interested in modeling the line's productive capacity. It was believed that discovering the line's capacity would be an important step in understanding the systems involved. However, there were many doubts lingering about scope and level of project detail.

During the initial deployment of SSM, members of the management team expressed their concerns about the role of their operators, quality inspectors, materials and machine preparers, and inventory personnel, along with quality-control processes and the restrictions under which these productive processes operate. Thus, both the simulation practitioners and management team discussed these points.

Moving forward to the second phase of SSM, simulation practitioners and management team members began to sketch out the system's significant activity models. These activities represented concerns that the production, quality control, and internal logistics managers had expressed during initial system analysis.

During the execution of this study, the simulation practitioner faced great difficulties due to the system's complexity. Thus, a selection of SSM tools was utilized with the objective of aiding analysts. The tools that compose part of the SSM are the following:

- The mnemonic CATWOE (clients, actors, transformation, weltanschauung or world view, owner and environmental constraints).
- Root definitions to outline system participants, purpose, and constraints.
- Purposeful activity model (PAM) to visualize system contingencies.

To avoid any doubts from the simulation practitioners, the first tool utilized by the researchers was the PAM, in which a model was sketched up to exhibit how the global production system was composed of overlapping subsystems (production, internal logistics, and quality). The managers needed a model that served for strategic as well as operational conversations, thus the perspectives of decision making from a top-level approach and factory floor operations were considered and mapped.

A significant activity model enabled the visualization of the entire productive process summarized in the fewest activities, both the researchers and managers could analyze how the activities of the principal system (production system) overlapped with activities of the subsystems (internal logistics and quality). The iterative development process through meetings and interviews facilitated the debate about system definition and assured the managers that the researchers understood the system. The following questions define the PAM model:

- What impact do line operators make on total line production?
- What impact do quality inspectors make on total line production?
- What impact would alteration of intervals between quality-control inspections make on total line production? And on quality control? Can this impact be quantified?
- What impact do material and machine preparers and inventory personnel make on total line production? If materials preparers were eliminated, what would happen?
- How are monitoring and controlling processes carried out?

It is worth mentioning the importance placed on the company's existing knowledge of its processes, both in terms of tacit knowledge—residing in the minds of those involved with the process—and explicit knowledge—expressed through texts, documents, data analysis, and other external storage mechanisms, according to Nonaka (1994). The researchers sought to utilize both types of knowledge throughout the study.

As mentioned, many doubts existed in relation to the objectives that would be simulated in this study, thereby the SSM rules and logic were presented to the managers; and through interviews and meetings, a more detailed organizational analysis was elaborated using a second SSM tool, CATWOE, to create root definition of the system. The use of these tools facilitated the development of the initial phase of the simulation project, the meetings permitted the managers to understand their own system and which points could be improved.

The mnemonic CATWOE was used to identify the main components of the system in question including clients, actors, owners, the transformation process, and worldviews and restraints.

The production manager was identified as the problem owner. The researcher was seen as the would-be problem solver. The production, quality, and logistics managers were identified as the stakeholders, which means all had a direct role in the production line's operations. That is, without the help of each one, the project would face difficulty.

From the preparation of CATWOE, the researchers built a root definition, another SSM tool. The central idea of root definitions is the need to demonstrate the process of transforming an input into an output. Essentially, the process performed to develop root definitions is an instrument that focuses on the perspective of participants in the experimental context.

The definition for the root system of production can be defined as a production system operated by the supervisors, operators, and trainers, and managed by company management that meets the needs of production orders for the effective and efficient transformation of resources to provide shipment with the correct orders at the right time (meeting the needs of end customers), under the constraints of quality standards and the availability of raw materials, time, labor, manpower, and financial resources.

In this study, three models were built with the characteristics to elaborate CATWOE and root definitions for each subsystem. However, only one subsystem is presented in order to illustrate the use of tools in the study of SSM. Table 1 shows a detailed CATWOE for the production subsystem, with the aim of illustrating the use of SSM in this study.

Table 1 presents the CATWOE analysis performed for the production subsystem. The objective of this analysis was to identify the main components, processes, and actors involved in the system,

Table 1
CATWOE—production system

CATWOE analysis
Customer: internal logistics operators
For the production system, the end customers are the internal logistics operators. The principal activities are the expedition of products.
Actors: operators/supervisors/trainers (operational) and production manager (strategic)
Within the control of the production process (production manager) are the operators of each machine, the supervisor of each shift, and materials preparers, who supply the machines components, perform routine testing of quality in semifinished parts and replace the machine operators.
Transformation: needs of the production order—need met
Several mini processing procedures were identified, such as idle machine to a utilized machine, but the main process that takes place on the production line is the processing order requests satisfied, that is, the order of production needs being met.
Weltanschauung: meet the needs of shipping in order to satisfy end customers and generate profits for shareholders
The overview that gives meaning to the process of transformation for shipping demands is satisfying the demand of the expedition in time to meet the needs of end customers by delivering on time, thus generating customer value and profits for shareholders.
Owner: production manager
Considered the starting point. By identifying the owner of the system, the system controlled by the master was identified with ease. Theoretically, the owner is the person who can start and stop the system to the production system, the owner is the production manager.
Environmental constraints: financial resources, manpower, time and raw material
Personnel, equipment, time and other resources that limit the possibilities of production.

as well as their responsibilities. Thereby, both the simulation analysts and the problem owner know which processes and which persons are involved, so that these persons implement the proposed alterations based on the result of the simulation.

The internal logistics operators are the end customers of the actors (operators, supervisors, and materials preparers) of the production system presented in Table 1. The internal logistics operators are those responsible for the expedition of the products, at the end of the production chain. The actors completed diverse activities, of which the end result of the production line would be sent to the end client, also known as the internal logistics operators.

For the definition of the objectives, the analysis permitted the same managers to know the system at a deeper level, and bring up important points that were not being well-crafted, herewith, one can arrive at the questions of this research study.

By using the tools of SSM—PAM, CATWOE, and root definitions—it was possible to facilitate the understanding of the system in question, both for simulation analysts as well as for the clients themselves and owners of the problem. The principal points of the system and the main actors involved in the study can be identified such that alterations that could improve the system's performance could be made.

With the elaboration of the significant activity model, the main points were sketched out through collaborative efforts between the managers and simulation researchers. It is important to note that these models do not represent the actual system, but rather an ideal version of the system operating under optimal conditions. Rather than being a snapshot of the process, it is a blueprint of an ideal process. The SSM approach then proceeded to the third phase.

The third phase of SSM involves structured debate about the system's real situation, and comparison against the ideal system models, seeking changes that improve the situation, bring it closer to the ideal system, and are simultaneously feasible and desirable.

Through the analysis completed in the initial phase of the simulation project the model of significant activities, as presented, was constructed. This model emphasizes the main points of the system being studied, these points were considered difficult to answer. With the other analyses, for example, the CATWOE, through debates and meetings, the team analyzed all of the models and decided which points would be investigated through the simulation. Thus, the objectives for this simulation were defined as follows:

1. What is the line's current productive capacity?
2. What is the impact of the time interval between quality inspections on the line's total productivity?
3. What is the impact of the materials preparers on total productivity?

The fourth and final stage of this SSM application is for those responsible for the system to take a decision that will improve the situation. However, no decision could be taken until the simulation project had been concluded. With the results of the simulation on hand, the analyst, via meetings, conveyed all of the results and analyses to the directors, who had the final word on any alterations to the system.

Based on Fig. 1 in Checkland (1999), the authors developed a figure that presents the joint use of simulation and SSM. Figure 3 presents the phases involving the use of SSM in the initial conceptual phase. These steps may be used in any kind of simulation project with the aim of delimiting the project's scope and objectives.

As shown in Fig. 3, in phase 1 of SSM, the real system is analyzed and researchers know about the system. Here it is proposed that, instead of directly jumping to computational modeling, without knowing what the actual application of simulation will be, researchers should restrict the scope and define main objectives and questions to be answered. To do this, analysts should use SSM tools such as PAM, CATWOE, and root definitions. After such careful detail of the real system was considered, significant activity models should be sketched out in order to identify important activities of system.

Upon the elaboration of activity models, for the third portion of the SSM approach, it is proposed that the situation should be discussed in greater detail, via the ideal system models with the aim of improving the situation. At this moment, the analyst, along with the decision makers, should identify the most important points in the system. These points will normally be those which deserve closer investigation for simulation.

Once these important points are identified, the simulation objectives may be defined, thus enabling him or her to continue with the rest of the project. At this point, a "soft-approach" such as SSM will most likely have been used to its fullest, and will not present much utility going forward with data collection, analysis, or model programming.

In order to conclude this article's procedure, whose last step is to propose points for improvement and decision making, the simulation practitioners concluded all the steps presented in Montevechi

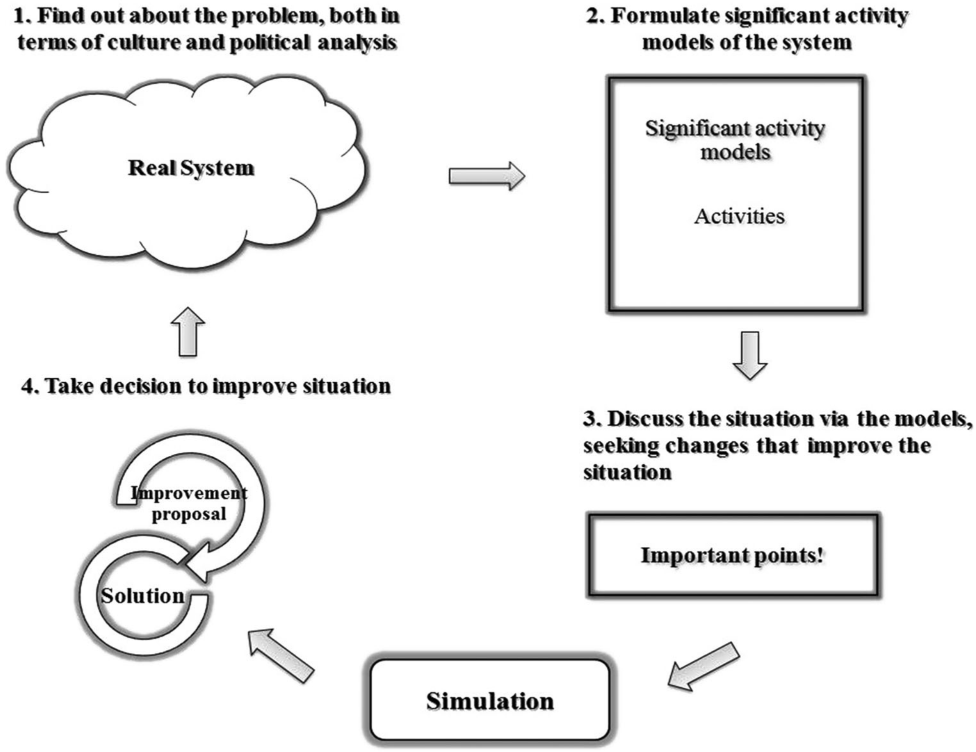

Fig. 3. Phases of SSM in conceptual modeling.

et al. (2010) for the development of simulation projects. SSM and Montevechi et al. (2010) methodologies have many points in common, including development of the simulation, conclusions for research, and aiding decision making. Following this, the development of the simulation methodology is presented, and how each research phase was carried out through project.

6. Application of the methodology

6.1. Conception

Upon the completion of the integration of SSM with the initial phase of simulation, together with the tools of SSM, a model of the significant activities was defined, which understood the essential points, identified in the system, that were the most difficult to answer. With the development of the other analyses, for example, CATWOE, the main objectives for the job can be identified. These three questions are presented in Section 5.

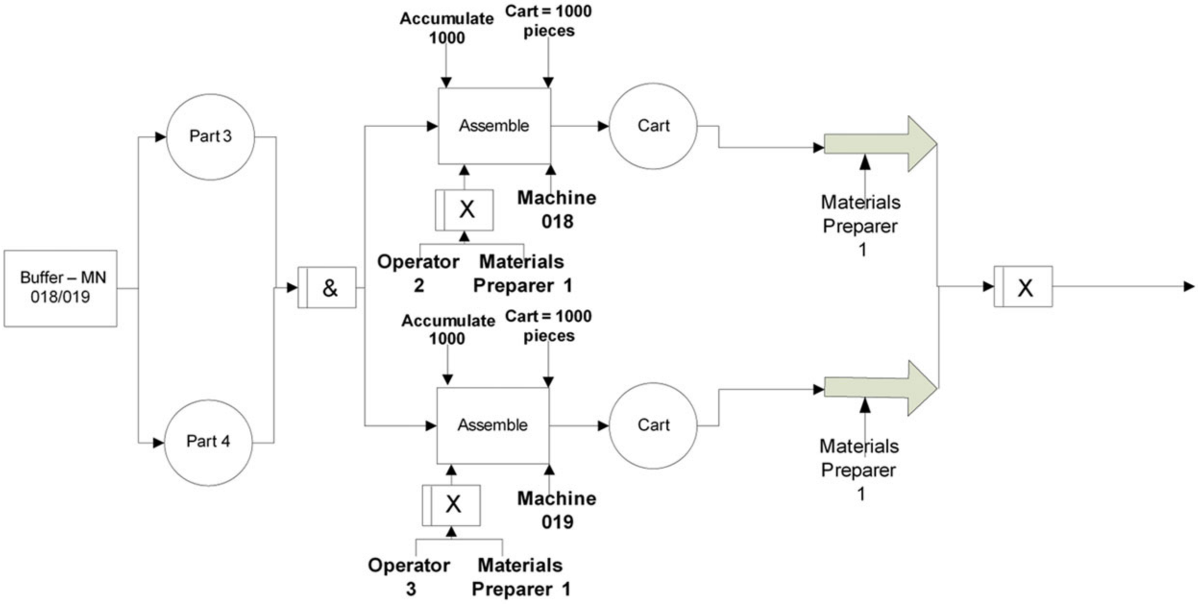

Fig. 4. Portion of the conceptual model developed using IDEF-SIM.

Objectives and system definition

With the use of the integration of SSM in the design phase, presented in Section 5, it was possible to attain the objectives to be achieved. It should be emphasized that the use of the tools of SSM at this stage of the simulation project facilitated the identification of objectives, due to system complexity.

Construction and validation of the conceptual model

The conceptual model was constructed using the technique IDEF-SIM proposed by Montevechi et al. (2010). It aimed at addressing the shortage in the literature by a mapping technique oriented for simulation, the authors have developed an approach for conceptual modeling research specifically for simulation.

In this technique, the authors propose the use of combined elements of the IDEF3, IDEF0, and flowchart. The symbols designed for IDEF-SIM enables direct translation of the conceptual model for computer programming, including symbols of conventional component of many simulation software such as entities, resources, functions, flow controls, logical rules, and identification of transport and handling.

Due to the complexity of the simulated system, only a portion of the developed conceptual model is shown (Fig. 4). It can be noted that the representation of the two entities in stock will be combined (Fig. 4) at an assembly station. An operator or material preparer in conjunction performs this step with a machine. Simulated on the production line, there are two positions for that assembly, each set consisting of a machine and an operator. After accumulating 1000 assemblies, a new entity called cart is added to the system. This new entity is then transported with the aid of the materials preparer, which processes the consecutive activities.

The managers of the case commented that the use of SSM conceptual model made it easy to understand system, especially in the choice of inputs, outputs, and model content. This fact facilitated the process of the validation of the conceptual model.

Once the conceptual model was constructed, managers expressed that they felt little need to have a meeting to formally validate the model, due to their constant participation in dialogues that have used the tools of SSM. However, the researchers suggested that there should be another meeting, so that they could present the finished model. At the meeting, the researchers explained the entire model, from beginning to end, detailing each activity performed, the local entities involved in the implementation of transport, resources involved in the operation, and how these components are related.

After the meeting, the managers were convinced that the conceptual model correctly represented the real system, a fact that allowed for the validation of the conceptual model and starting the modeling stage of the input data. It is worth noting that this type of validation is known in the literature as face to face, for more information see the work of Sargent (2009).

Modeling of input data

This modeling stage is made up of three steps: data collection, data treatment, and inference. In the studied company, production data were collected from the company's own data base, which is linked to the productive cycles at each machine. When a cycle—be it stamping, or cutting or molding—is finished, the time intervals are stored in the data base. Time spent walking between work posts was observed and timed on the factory floor. For the other data collection points, the company had already collected data in spreadsheets and its database.

The data were analyzed using the statistical analysis software *Minitab*® (Minitab, 2013). For each data set, uncommon observations were eliminated, a demonstrative report, along with a histogram and boxplot, were generated to visually represent the samples. Based on these data, the analysts used the software *StatFit*® (StatFit, 2013) to estimate the distributions for each process and identify each distribution's parameters.

6.2. Implementation

Computational model construction

Once the conceptual model was defined and the processing times for each operation were found and adapted for use in the simulation software, the simulation research team moved on to computational model construction. The software *Promodel*® (Promodel, 2013) was used due to its acceptance by both the scientific and professional communities, along with its well-developed animation tools (Banks et al., 2005). Initially, the construction of the model was carried out in a simple fashion, but successive models were honed and improved, as needed. After 14 versions, the model was deemed suitable to simulate the production line's real scenario. A screenshot of the line is shown in Fig. 5.

In Fig. 5, the region shown with the dashed line represents the portion of the conceptual model shown in Fig. 4, detailed in section "Construction and validation of the conceptual model."

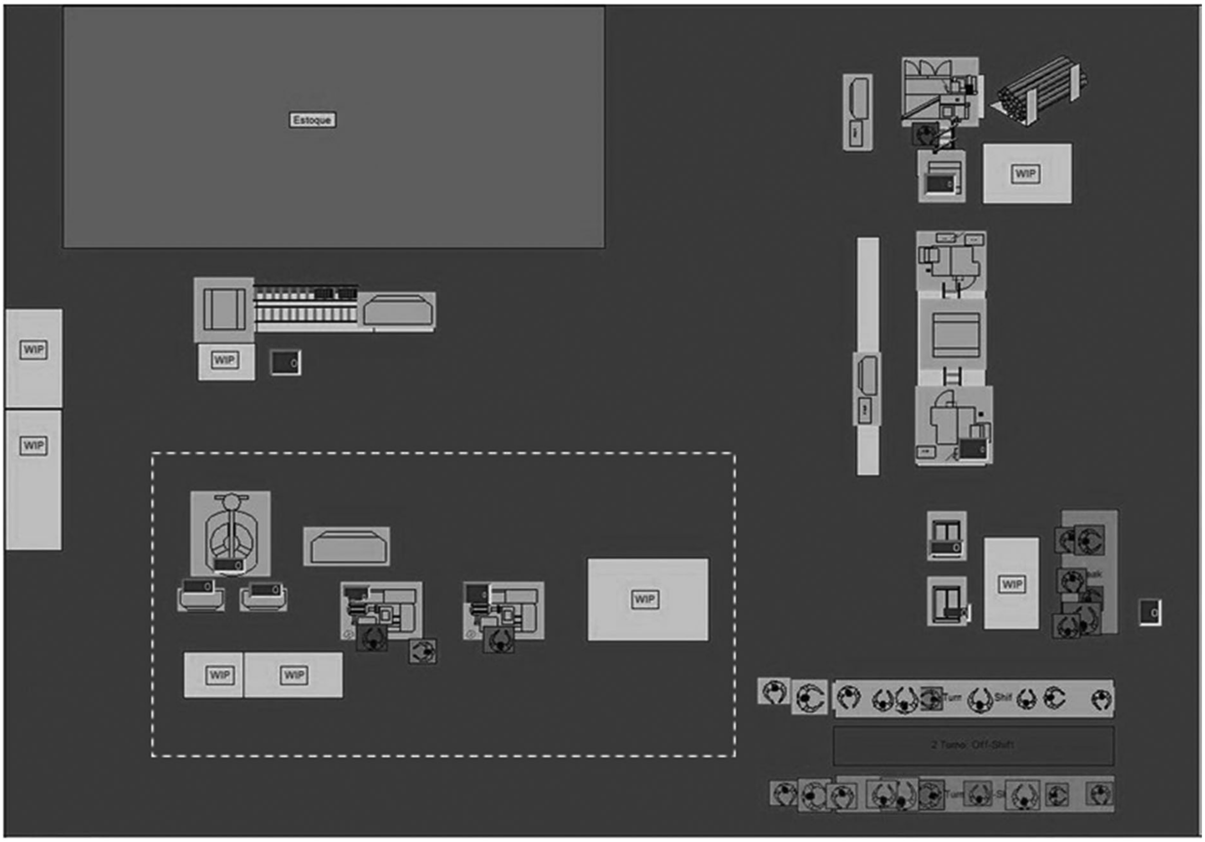

Fig. 5. Screenshot of the computational model.

Verification of the computational model
In accordance with Sargent (2009), verification of a model is defined as assuring that the computational program and its implementation are correct. For this study, verification was done using resources from the simulation software that analyzed the model's logic and programming, this was then compared with the conceptual model.

Validation of the computational model
The validation of the computational model is known to be the determination of the computational model's behavior in terms of precision at representing the real system and achieving project objectives. Thus, if the model is not a sufficient approximation of the system, all conclusions that may come forth are bound to have errors that can then imply erroneous decision making (Sargent, 2009). According to Banks et al. (2005), the validation phase should be carried out for each version of the model until its precision is congruent with the demands of the simulation analysts.

The model was validated statistically using the Mann–Whitney test to compare real production figures from the previous year. Real data of the plant's weekly production were used, chosen randomly over a year of operation, and compared with 30 simulated data. The p-value

Table 2
Mann–Whitney test

	Size of sample	Median
Real data	30	57,148
Simulated data	30	57,348

Mann–Whitney test was equal to 0.1405 (significance level 5%) thus it can be concluded that the simulated model adequately represents the real system and can therefore be considered as valid.

The data in Table 2 show the statistical results of the validation of the computational model, from the Mann–Whitney test.

By the means of the statistical validation, it can be presented that the computational model adequately represents the real system, as well as its complexities. This validation shows that the SSM was able to assist in capturing the main effects of the system.

6.3. Results analysis and discussion

Once the model was verified and validated as being capable of simulating the production line's variability, it was possible to use the model to test and evaluate other scenarios to expand productive capacity for the system.

Chung (2004) warns that due to the fact that simulation results present variations, it is inappropriate to jump to conclusions based on a single replication of a simulation. Thus, to reduce the chances of an erroneous recommendation after experimentation, it is suggested that a number of replications are run in order to perform a more robust analysis from which to take a stance on a situation.

The amount of data in a sample may be understood as the number of replications utilized. An increase in precision (reduction in interval range) can be obtained by increasing the number of replications. Thus, a presample of 10 runs was used to calculate the quantity of replications for this study.

Calculations were carried out, using a confidence level of 95% and an error rate of 1% of the average value of the 10 replications. In doing so, the number of replications for the calculation was inferior to the replications already done. Thus, the number of replications was kept as 10.

For the model under study, as stated before, 10 replications were used per week. A week was selected as sufficient time due to the fact that the company possesses weekly production controls, thus enabling coherent analysis between the simulated and real systems.

Through the realization of the replications, the total productivity for the line, per week, was equal to 57,559 components. This number was an average of the replications. Using the values and a confidence level of 95%, the average confidence interval was determined as 57,520 and 57,597 per week. This case corresponds to the current scenario on the production line, with quality inspections being carried out on an hourly basis with one operator dedicated specifically to the execution of this task, and one for preparing the machines.

As the study's first question, referring to the system's overall productive capacity, had been responded in previous stages of the study, research moved on to the question of the interval between

Table 3
Total produced versus variation in the interval of inspection

	Inspection interval			
	Scenario 1 (30 minutes)	Current scenario (60 minutes)	Scenario 2 (90 minutes)	Scenario 3 (120 minutes)
Throughput	57,345	57,456	57,775	57,828
Throughput	57,402	57,568	57,780	57,836
Throughput	57,078	57,564	57,785	57,832
Throughput	57,024	57,515	57,792	57,825
Throughput	57,348	57,618	57,768	57,834
Throughput	57,294	57,562	57,780	57,842
Throughput	57,024	57,620	57,726	57,778
Throughput	57,412	57,620	57,724	57,790
Throughput	57,348	57,558	57,762	57,834
Throughput	57,075	57,505	57,800	57,830
Median value	57,235	57,559	57,769	57,823
Confidence interval (95%)	(57,118–57,352)	(57,520–57,597)	(57,751–57,788)	(57,808–57,838)

inspection times. In the first scenario, inspections were carried out every 30 minutes of operating time. In the second scenario, this was done every 90 minutes, finally. In the third scenario, after every 120 minutes. The values for these scenarios were compared with the current scenario, in which inspections are carried out every 60 minutes. The results obtained in these four scenarios are presented in Table 3.

The results refer to the 10 replications completed in the model for each scenario, being presented are the value per scenario, the median value, as well as its interval of confidence for a level of confidence of 95%.

Based on these data, and with the help of hypothesis tests, it was possible to prove that there was an increase in production when the last scenario, of 120 minute intervals, was assumed. By using the statistical test ANOVA, it was shown that the average of the data sets for each scenario is different and, sequentially, using the Mann–Whitney test, it was verified that productivity, with inspections every 120 minutes, is greater than all of the other scenarios. Scenario 1 had the lowest production rates.

With these data on hand, the second research question was answered: What is the impact of the time interval of quality inspections on total produced.

It was shown that when there was an increase in time between inspections completed by the quality inspectors on the production line, there was also an increase in the amount produced. The decision to be taken in relation to the quality inspection intervals was left to the responsibility of the management team, which had to take into account not only production figures, but also potential implications of quality control.

The third question of the study, related to the role of the materials preparers' impact on total produced, was still to be answered.

To respond to this question, four other scenarios were created without material's preparer in order to analyze their influence. Their activities were programmed into the logic of the line operators, as is the case when the materials preparers are not available. The constructed scenarios maintained the

Table 4
Total produced without materials preparer versus variation in the interval of inspection

	Inspection interval			
	Scenario 1 (30 minutes)	Current scenario (60 minutes)	Scenario 2 (90 minutes)	Scenario 3 (120 minutes)
Throughput	57,078	57,240	57,780	57,726
Throughput	57,070	57,250	57,672	57,722
Throughput	57,033	57,232	57,668	57,780
Throughput	57,086	57,348	57,726	57,730
Throughput	57,015	57,340	57,510	57,770
Throughput	57,020	57,358	57,672	57,736
Throughput	57,082	57,510	57,785	57,834
Throughput	57,024	57,456	57,725	57,820
Throughput	57,030	57,344	57,678	57,790
Throughput	57,018	57,402	57,506	57,732
Median value	57,046	57,348	57,672	57,764
Confidence interval (95%)	(57,025–57,067)	(57,282–57,414)	(57,603–57,741)	(57,735–57,793)

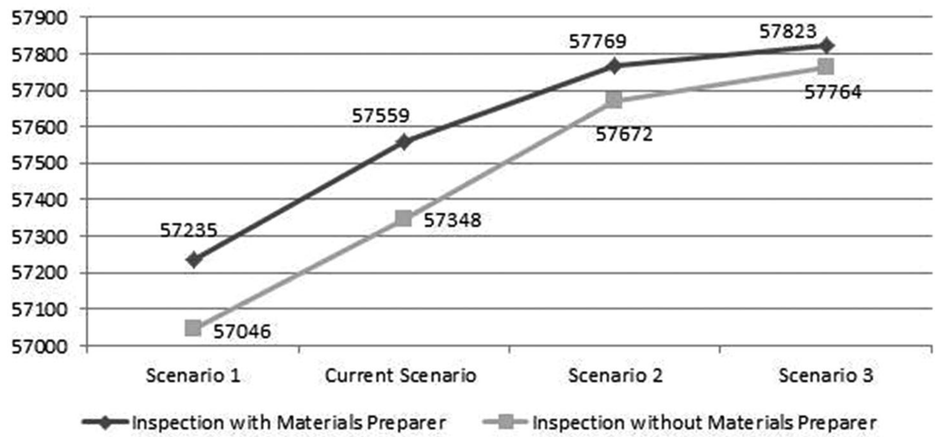

Fig. 6. Total produced per scenario.

same intervals between quality inspections, in order to compare the new scenarios. Results obtained through the realization of the four scenarios are presented in Table 4. Similar tests were carried out to respond to the last research question.

Finally, with the objective of analyzing the impact of removing the material's preparer, the Mann–Whitney test was carried out, comparing production totals with those in which the material's preparer was present with those in which he or she was not. Through the use of this test, it was confirmed that the material's preparer did indeed exercise an influence, as the results presented greater average values than those without.

As an example, Fig. 6 presents the mean value produced in each of the scenarios generated. By analyzing the figure, the behavior of output growth was demonstrated with the increase in inspection time as well as the difference in total production between the scenarios with and without preparer.

7. Conclusions

This study aimed to present the integration of SSM in a simulation project in the area of manufacturing. It was based on the affirmations of Kotiadis (2007) and Lehaney et al. (1999), who state that most literature involving SSM and simulation have come from the healthcare sector. Their recommendation, that studies in other areas be developed, was met through applications of SSM in manufacturing.

Most methodologies in simulation divide projects into three areas: conception, implementation, and analysis. Authors such as Robinson (2008) and Montevechi et al. (2010) believe that the conceptual phase is the most important phase for these projects, as the project objectives are defined and the study's foundation is laid.

The combination of methods here aimed to aid analysts in this important initial phase, based on Montevechi et al. (2010) flowchart, in which the first activity is to define system and project objectives. Another point to be noted is that this methodology enabled both researchers and the managers involved in the project to see activities in which their individually controlled—and sometimes competing—systems overlapped. This helped researchers to delimit the simulation model, while also providing the managers with insight about dynamic points in their productive processes that served as a kind of "gateway" from one process to the next.

An example of this was seen in an area determined for depositing produced and packaged parts. "Actors" of the production system deposited parts there: "Actors" of internal logistics needed to transfer the packages to stock, but this could only be done after "actors" from the quality department performed a randomly selected quality inspection of the produced parts. This created a series of contingencies involving actors of individual systems, who were clients of external systems. The use of simulation in the conceptual modeling phase enabled these objectives to be identified in a suitable way, thus avoiding errors and rework in subsequent stages. This is evidenced by the validated simulation model.

At the end of the project, the necessary analyses were made and taken to the company management team that showed interest in the results. This main confirmation that the integration of SSM and simulation went well, occurred through the confidence that the managers had in the results achieved with the project, by means of the answers presented to the raised questions. This would be one of the main ways to validate the integration proposed in the article. Another fact deserving to be highlighted was that the simulation model was able to capture the complexity of the real system, able to be statistically validated. This validation proves that the simulated model adequately represents the real system.

The analysts proposed many recommendations and suggestions, based on these data, with the objective of improving the processes they had simulated. The final call on these situations was left to managers. It is important to highlight that simulation proved to be a robust decision aiding tool.

Based on the practical experience of the authors, it is common to see many simulation projects without well-defined objectives. Many times, practitioners move ahead even without this important point well-defined. Normally, at some moment, analysts note that the constructed model does not represent reality, so they have to return to initial phase and start the process over.

Thereby, the integration herein aimed to help practitioners resolve this situation, faced by analysts of the simulation, in order to prevent errors and rework. This use of SSM could potentially be applied to any other area where simulation is a practical tool. As a future research possibility, the application of this study is suggested in other areas as a means of evaluating its performance.

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