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IDENTIFICATION OF THE MAIN METHODS USED IN SIMULATION PROJECTS

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ABSTRACT

Discrete event simulation is a tool to support decision-making that has been increasingly used to study complex systems. Several simulation research methods are found in the literature, each one has its own characteristics, to guide analysts during the development of simulation projects. In view of this, the current work identified the main research methods used in simulation projects. For this, a literature review was carried out on some of the major discrete event simulation books and papers from the proceedings of the Winter Simulation Conference, which is considered the main international conference on simulation. From the analysis performed in this study, it was possible to identify the most comprehensive methods, as well as the simplest ones. The common activities among them were presented and those that are important to conduct a simulation project were also discussed.

1 INTRODUCTION

The discrete event simulation is considered a powerful tool to support decision-making, if it is used correctly (Ingalls 2013). According to Pereira et al. (2014), over time this tool has being increasingly employed. Siebers et al. (2010) claim that discrete event simulation was the most applied tool in Operations Research.

According to Rutberg et al. (2015), discrete event simulation is a computational modeling tool that replicates complex systems, allowing the study of interventions without compromising the real world with the implementation of changes that one cannot know the likely effects. To Lu and Olofsson (2014) and Liu and Findlay (2014), discrete event simulation is a technique that studies the behavior of variables that change their status in a discrete time, within a system.

Sturrock (2014) points that to develop a simulation project it is necessary much more than just building a computational model. It requires skills that go beyond just knowing a particular simulation tool. Balci (1989) claims that the challenge is to do it right.

It is observed, from the papers published in different journals and conferences, that there are several methods being used to develop simulation projects both in the in the educational and business environments. Several simulation research methods are found in the literature. Each one with its own characteristics aims to assist simulation analysts to better conduct projects by providing them a logical sequence of steps to be followed.

Thus, this work aims to identify the main methods used to conduct simulation projects, considering the proceedings of the Winter Simulation Conference (WSC) and some of the main books on simulation. As a specific aim, we intend to highlight the commonalities among these methods, through the conduction of a literature review.

This paper is divided into five sections. The first section was already presented and introduced the topic of study. The second section brings the theoretical framework of discrete event simulation. The third presents the research methods most employed in the conduction of simulation projects. Then, the next section discusses and analyzes these methods. Finally, the fifth section reflects the conclusions of this work.

2 RESEARCH DEVELOPMENT

To conduct this work, a literature review was carried out on some of the main discrete event simulation books published by recognized authors of the field, such as: Banks (1998), Law (2000) and Brooks and Robinson (2000).

The research also focused on analyzing some papers published in the proceedings of the Winter Simulation Conference, between the period of 2005 and 2015. This conference presents the latest advances in modeling and simulation and is held every year since 1968, with simulation practitioners, suppliers of simulators and researchers as the primary audience.

Following, the main research methods in Modeling and Simulation, found through this study, will be presented.

- Mitroff et al. (1974) (Figure 1);
- Banks et al. (1998) (Figure 2);
- Brooks and Robinson (2000) (Figure 3);
- Carson II (2005);
- Law (2006) (Figure 4);
- Montevechi et al. (2010) (Figure 5);
- Sargent (2010) (Figure 6);
- Balci (2011) (Figure 7).

3 SIMULATION RESEARCH METHODS

The first method described in the literature is the oldest known method according to the evidences. The method of Mitroff et al. (1974) (Figure 1) is divided into four phases: the first phase is the "Contextualization", followed by "Modeling", then "Solution by the model", and finally the "Implementation".

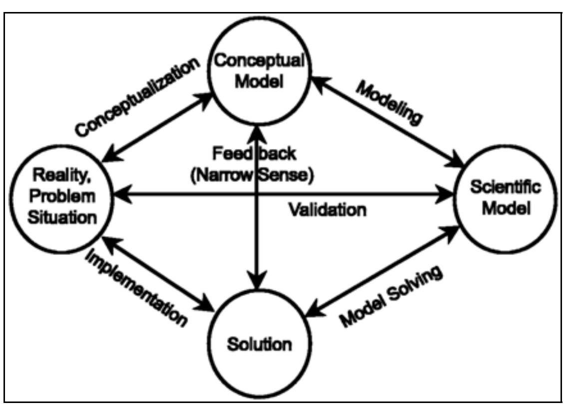

Figure 1: Research structure in simulation. (Source: Adapted from Mitroff et al. (1974).)

In the first phase, the conceptual model is created based on the reality, problem or situation being studied. Then, this model is transformed into the computer model, which must be validated. From this validated computer model, experiments are performed so that the analysts can come up with possible solutions. It should be noted that, if necessary, there may have feedback from the conceptual model and the cycle may continue from this modified conceptual model. At the end of the method, the solutions obtained from the simulation can be implemented in the real world.

The second method was proposed by Banks et al. (1998) (Figure 2) and published in his book "Handbook of simulation: Principles, Methodology, Advances, Applications, and Practice".

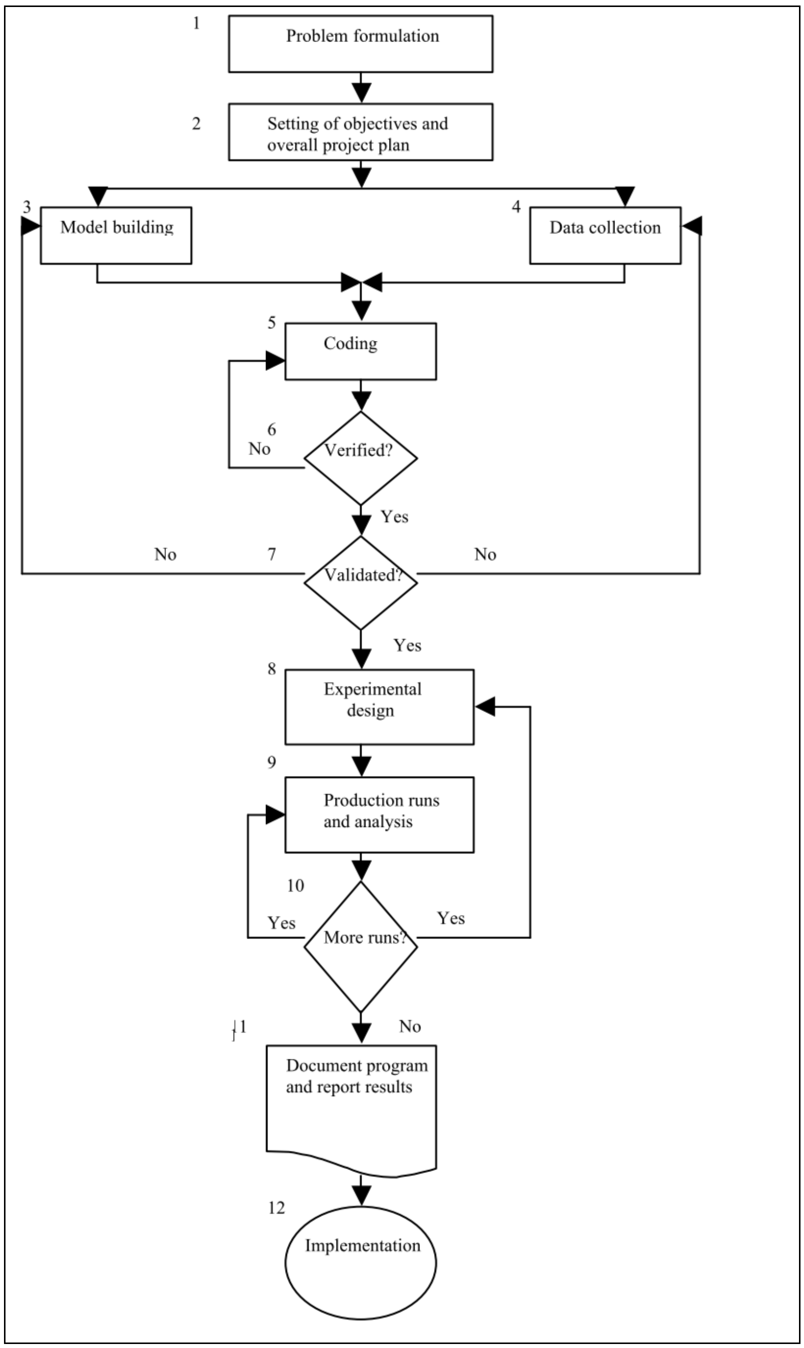

Figure 2: Phases of a simulation study. (Source: Banks et al. (1998).)

The method starts with problem formulation. Then, the objectives and the project plan are defined. At this point, the simulation analyst can build the conceptual model and, simultaneously, collect the necessary data for simulation. When these two activities are completed, the fifth activity of the method refers to build up the computer model, that is, the conceptual model must be translated into the computer model.

The sixth activity is the model verification. If the computer model is rejected by the verification, then we should return to the third and fourth activities. On the other hand, if the computer model is verified, we can proceed to the next activity, namely the validation. Likewise, if the computer model is rejected by the validation, we must return again to the third and fourth activities. Otherwise, we can move to the following eight activity, in which the experimental designs are made and the analysts define scenarios to be simulated and changes to be implemented in the current state model, among other changes that they wish to analyze based on the computer model.

Following, in the ninth activity, replicas are produced and the analysis are performed. If the execution of more replicas is required, then we return to the ninth activity. Or else, we follow to the activity number 11, in which the data obtained from the simulation is documented. Finally, to conclude the method, implementations are done in the real system under study.

The third method analyzed was proposed by Brooks and Robinson (2000) (Figure 3) and published in the book "Simulation Studies: Key Stages and Processes".

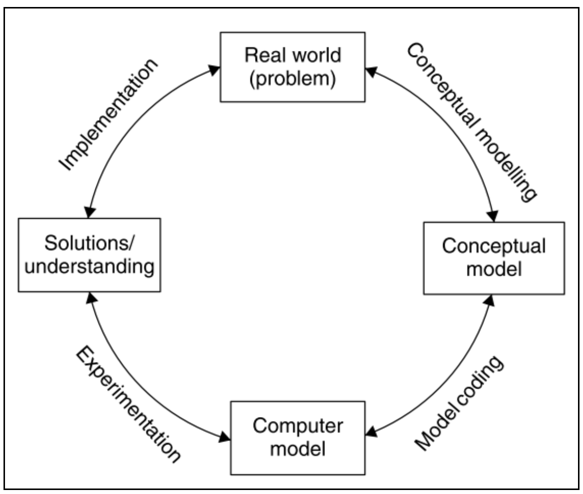

Figure 3: Key Stages and Processes. (Source: Brooks and Robinson (2000).)

This method starts with the problem in the real world and executing the conceptual modeling. From this modelling, the conceptual model is built. Then, the model is transferred to the computer model and the required data to feed the model is collected. Next, experiments are performed. And, finally, the results are interpreted and some solutions are proposed to be implemented in the real world.

The fourth method was established by Carson II (2005) and his study was published in the Winter Simulation Conference. The author did not develop a figure encompassing the simulation development steps, however he presented a phase sequence for conducting a simulation project. Initially, the project is initiated by the problem formulation and the definition of objectives, characterizing the scope and limitations of the work and the level of detail. Then we must develop the overall project plan, in which deadlines, and verification, validation, trials and analysis procedures will be defined. From this, we prepare and document the conceptual model. The next step is to develop the computer model and to collect the data to feed this model. When these steps are completed, the computer model should be verified and then validated. Finally, experiments and analysis can be conducted and the simulation results are reported to the clients.

The fifth studied method is from Law (2006) (Figure 4), which was published in the proceedings of the Winter Simulation Conference. This method is divided into seven activities. The first activity refers to the problem formulation. Next, data is collected and a conceptual model encompassing the simulation goals should be developed. In the third activity, the conceptual model validation is performed. If the model is not validated, one must return to the two previous activities. Otherwise, from a validated model, we can start the fourth activity in which the computer model is constructed. Thereafter, the computer model must validated. If it is not possible to validate the model, we must return to the first and second activities. In case the model is validated, we move to the sixth activity. In this activity, the experiments are designed, conducted and analyzed. Finally, the simulation results are presented and documented.

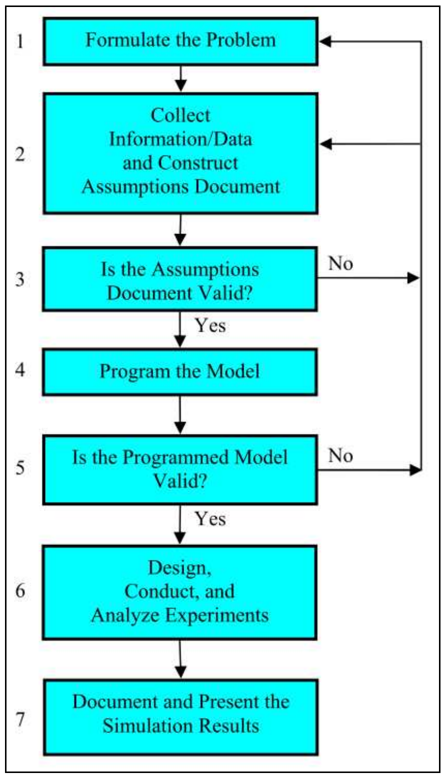

Figure 4: A seven-step approach to perform a successful simulation study. (Source: Adapted from Law (2006).)

The sixth method analyzed in this research was the work of Montevechi et al. (2010) (Figure 5), presented in the proceedings of the Winter Simulation Conference. The authors divide this method in three phases: conception, implementation and analysis.

In the conception phase, we should set the system goals, build the conceptual model, and perform its validation and its documentation, in case it was validated. If the model is not validated, we must rebuild the model. Once the model is validated, one should obtain and model the required data to feed the computer model.

In the implementation phase, we must build the computer model, which must be verified and then validated. If the model cannot be verified, we need to rework on the model building activity until it can be verified. As soon as the model is validated, we can move to the last phase of the method, called analysis.

In this last phase, we must define the experimental design, run experiments, perform statistical analyzes on simulated data and from there, propose the conclusions and recommendations on the system.

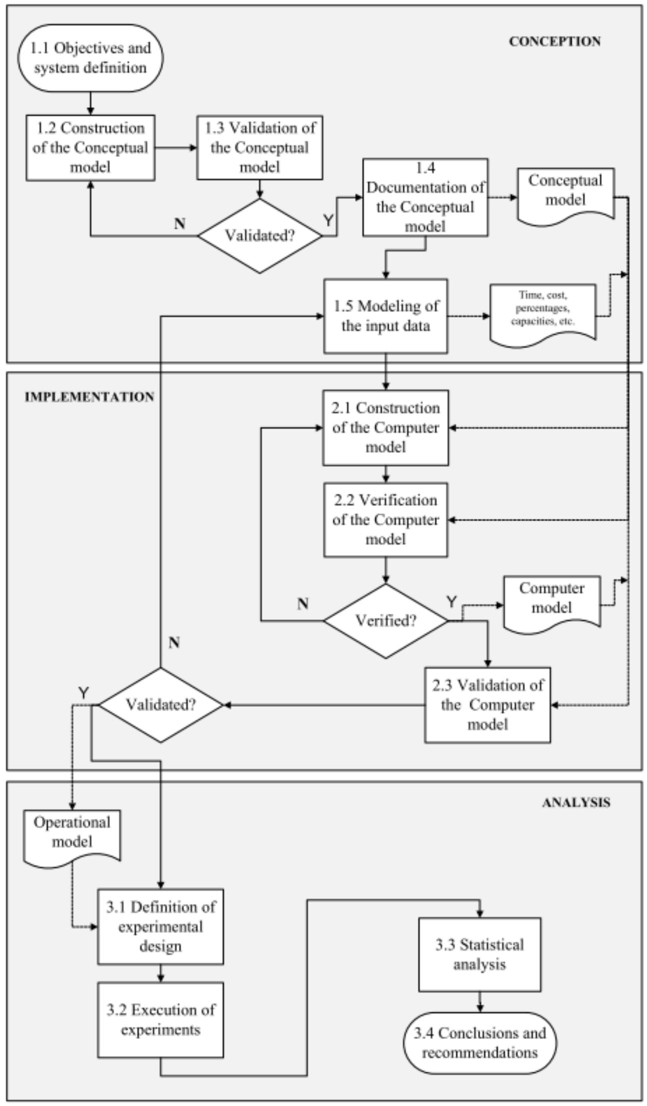

Figure 5: Research structure in simulation. (Source: Montevechi et al. (2010).)

The seventh method was proposed by Sargent (2010) (Figure 6) and is divided into three phases. Between each phase, some activities must be carried out, which may alter the flow of the method. The study begins with the problem identification within the system. Then, the conceptual model is developed to represent the simulated process. As this model must be validated, the analysts must return to the system, analyze the necessary data and perform its validation. When the conceptual model is validated, we can build the computer model. For this, the analysts must obtain the necessary lead times and validate them, so that they can feed the computer model. Once this is performed, the analysts implement the computational model considering the validated data. However, the computer model must be also verified. In this case, the analyst may need to return to the conceptual model, which in turn may return to the studied system so that the model can be verified. After verifying the computer model, the analysts are responsible for its operational validation. In this case, the analyst can refer to the actual system information. Finally, they should run the experiments, closing the cycle established by Sargent (2010). Note that there is an activity in the center of the method, specifying that in all phases the analysts must use validated data.

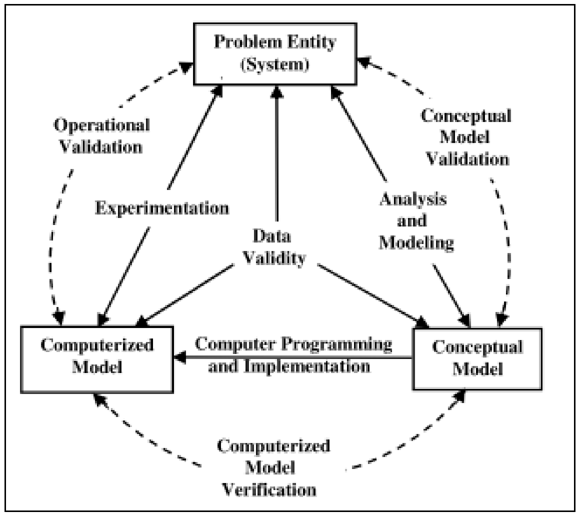

Figure 6: Research structure in simulation. (Source: Sargent (2010).)

Finally, the eighth and last method analyzed in this paper was proposed by Balci (2011) (Figure 7) and presented in the Winter Simulation Conference.

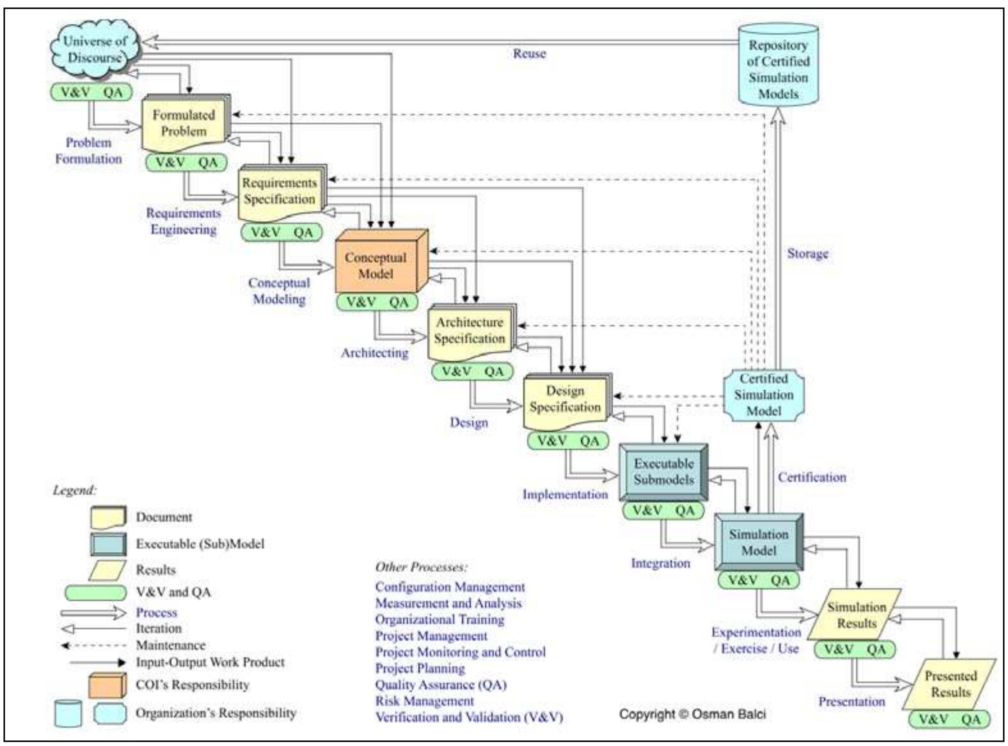

Figure 7: Life cycle of a simulation project. (Source: Balci (2011).)

The method begins with the problem formulation in a real system (Universe of Discourse), followed by the requirements specification and, thus, the conceptual model construction. The author proposes that an architectural specification is carried out, which consists in defining the resources that will be used to develop the simulation model. Then, design specifications are made based on the architectural definition.

Thereafter, sub-models, namely pilot models, are executed, followed by the model execution. At this point, we should conduct the computer model certification (validation). For this, we use the sub-models and the resultant documentation must be stored. Upon the certification completion, the simulation is conducted and its results are presented to the clients.

At all stages the author proposes the enforcement of two processes: verification and validation (V&V) of each step and also the quality assurance (QA). These processes are critical for the execution of the next steps. That is, if the analysts do not perform these processes, one cannot move forward on the project.

4 DISCUSSION AND ANALYSIS OF THE METHODS

From the literature review in the proceedings of the Winter Simulation Conference, the largest international congress on the simulation field, between the period of 2005 and 2015, and also in some consecrated books on the area, there were identified eight research methods in simulation. Following, we will present the main characteristics of these methods, their strengths and the commonalities among them.

The methods of Mitroff et al. (1974), Brooks and Robinson (2000), Sargent (2010), and Balci (2011) show the existence of a real world that one wants to simulate. This is the first feature that analysts must be familiar with before starting to develop the simulation project.

The methods of Mitroff et al. (1974), Banks et al. (1998), Carson II (2005), Law (2006), Montevechi et al. (2010), Sargent (2010), and Balci (2011) present as a first step of a simulation project the problem formulation. Or as Mitroff et al. (1974) show in their method, the conceptualization, in which we define the simulation goals and the project plan.

Balci (2011) proposes the specification of requirements. After this formulation or system conceptualization, Mitroff et al. (1974), Banks et al. (1998), Brooks and Robinson (2000), Carson II (2005), Law (2006), Montevechi et al. (2010), Sargent (2010), and Balci (2011) state that the next activity to be done is to build a conceptual model that represents, in a structured way, the system being simulated, and as a result, the analysts have on hands a conceptual model of the real system.

In the methods of Law (2006), Montevechi et al. (2010), Sargent (2010), and Balci (2011), it is proposed the validation of the conceptual model to ensure that it faithfully represents the real system.

Balci (2011) declares that design and architectural specifications must be defined to establishe the resources and ways of analyzing, verifying, and validating the simulation data.

Carson II (2005) and Montevechi et al. (2010) discuss that data should be documented, before moving forward on the project.

According to Banks et al. (1998), Carson II (2005), Law (2006), and Montevechi et al. (2010), the next activity for conducting the project is the collection of necessary data to feed the computer model and the modeling of these data.

Up to this point of the simulation development, Montevechi et al. (2010) classify the aforementioned activities as part of a set, called conception.

Balci (2011) states that computer sub-models must be created. However, according to Mitroff et al. (1974), Banks et al. (1998), Brooks and Robinson (2005), Carson II (2005), Law (2006), Montevechi et al. (2010), Sargent (2010), and Balci (2011), one can build the simulation model or the computer model using a simulator software from all other previous activities.

Banks et al. (1998), Carson II (2005), Montevechi et al. (2010), Sargent (2010), and Balci (2011) propose the verification of the computer model before proceeding to the next activity. The verification consists in checking that the computer model is correctly programmed. If the model is rejected by the verification process, the authors suggest that simulation analysts should return to the model building activity, to correct possible mistakes and, then, verify the model.

Mitroff et al. (1974), Banks et al. (1998), Carson II (2005), Law (2006), Montevechi et al. (2010), Sargent (2010), and Balci (2011) propose the validation of the computer, once it is verified. Balci (2011) calls this process as certification. The validation or certification is to ensure that the computer model faithfully represents the conceptual model. Sargent (2012) presents some of the computer model validation methods that can be used by analysts.

According to Montevechi et al. (2010), at the end of these activities, the set of activities called implementation is concluded.

Banks et al. (1998), Brooks and Robinson (2000), Carson II (2005), Law (2006), Montevechi et al. (2010), Sargent (2010) and Balci (2011) argue that at this point of the project and having the computer model, the experiments must be designed, executed and analyzed. When this activity is concluded, the analysts get the simulation data to be examined.

The data analysis or interpretation is proposed by Brooks and Robinson (2000), Carson II (2005) and Montevechi et al. (2010). This analysis is very important in simulation, once it is from there that the data obtained from the simulation are interpreted and transformed into recommendations for the project customers. Banks et al. (1998), Law (2006) and Balci (2011) mention that the data should be documented.

Mitroff et al. (1974), Brooks and Robinson (2000), Law (2006), and Montevechi et al. (2010) propose that from the simulation data, one must draw the conclusions, recommendations and suggestions for the simulation clients. It is worth noting that in this activity a series of improvements should be proposed, which will be evaluated by the customers and can be implemented or not. Carson II (2005), Law (2006), and Balci (2011) propose a presentation of the results to the clients of the simulation.

Finally, Mitroff et al. (1974), Banks et al. (1998), and Brooks and Robinson (2000) propose a final activity, which is the implementation of the suggestions obtained from the simulation into the real system. At the end of these activities, according to Montevechi et al. (2010), the last set of activities, called analysis, is concluded.

In order to make a comparison among all methods discussed in this work, the information was compiled in Table 1, which shows the main activities that must be performed in a simulation project, according to these methods. These activities were grouped into three sets: conception, implementation and analysis. From the analysis of each method, there were identified 21 major activities within modeling and simulation methods for the development of a simulation project.

These methods could be developed thanks to the method proposed by Mitroff et al. (1974), one of the first methods found in the literature to guide the execution of simulation projects. It was possible to identify common activities among all methods. There are: the activity number 5, called "Building the conceptual model", and number 12, called "Building the computer model."

As seen in Table 1, Montevechi et al. (2010) is the only author that divides the simulation project activities in three phases: conception, implementation and analysis. This division can assist the execution of projects, as it structures the project activities.

The methods that have a greater number of activities to be performed are those proposed by: Montevechi et al. (2010) and Balci (2011). Among all 21 activities found in all methods, these authors propose that 14 of them must be performed. Second in the ranking of methods that encompass more activities are the methods developed by Carson II (2005) and Law (2006). The methods that have a smaller number of activities to be performed are proposed by Mitroff et al. (1974) and Brooks and Robinson (2000), and they consider that only 7 activities are to be executed in a simulation project.

Another important point identified by this study was that not all methods propose the execution of data collection. This activity is responsible for feeding the computer model and without the data, there is no system representation. Some methods also do not mention the computer model verification and validation. These activities define whether the computer model effectively represents the reality and, hence, they are extremely important for the development of projects.

Finally, we observed differences in each of the methods studied, once some are simpler and others are more detailed. However, all methods aim to support analysts in the conduction of simulation projects.

It is also worth noting that the work presented here aimed to discuss the methods for conducting simulation projects presented in the literature. These methods have been increasingly enhanced in order to assist teachers, students and researchers in improving the development of simulation projects. Thus, this paper contributed to the explanation here conducted, highlighting that the simulation method must be used throughout all stages of the design of a simulation project.

Table 1 – Comparison of the methods.

#	**Activities**	**Mitroff et al. (1974)**	**Banks et al. (1998)**	**Brooks and Robinson (2000)**	**Carson II (2005)**	**Law (2006)**	**Montevechi et al. (2010)**	**Sargent (2010)**	**Balci (2011)**
1	Big phase called "**conception**"						×		
2	Real system definition	×		×				×	×
3	Problem formulation	×	×		×	×	×	×	×
4	Requirements specification								×
5	Building the conceptual model	×	×	×	×	×	×	×	×
6	Conceptual model validation					×	×	×	×
7	Architectures and design specifications								×
8	Data documentation				×		×		
9	Collection and modeling of input data		×		×	×	×		×
10	Big phase called "**implementation**"						×		
11	Building computer sub models								×
12	Building the computer model	×	×	×	×	×	×	×	×
13	Computer model verification		×		×		×	×	×
14	Computer model validation	×	×		×	×	×	×	×
15	Big phase called "**analysis**"						×		
16	Design, conduct and analysis of experiments		×	×	×	×	×	×	×
17	Data analysis or interpretation			×	×		×		
18	Data documentation to date		×			×			×
19	Conclusions and recommendations	×		×		×	×		
20	Presentation of results				×	×			×
21	Implementation	×	×	×					

5 CONCLUSIONS

This paper analyzed some work presented in the Winter Simulation Conference, the largest international congress on the simulation field, and also some main books of the area. From this study, eight methods were identified to guide the development of simulation projects.

Considering these eight methods, there were identified and described all activities of each of the methods, and thus it was showed how the authors propose to develop a simulation project. Then, the results were analyzed.

The identified methods were proposed by: Mitroff et al. (1974), Banks et al. (1998), Brooks and Robinson (2000), Carson II (2005), Law (2006), Montevechi et al. (2010), Sargent (2010), and Balci (2011). Through this analysis, 21 major activities were identified.

However, each method considers a specified number of activities. The methods that have a greater number of activities were proposed by Montevechi et al. (2010) and Balci (2011) and mention 14 activities among all 21 activities found in all methods.

From the analysis performed in this study, it was possible to identify the most detailed methods, and the simplest ones. The common activities among the methods were also presented, as well as the important activities to conduct a simulation project. Finally, we identified that Montevechi et al. (2010) divides its method into three major phases: conception, implementation and analysis.

It is concluded from this work that teachers, students and researchers of the subject, can use the comparison here undertaken to base their decision on the simulation method that best fits their simulation goals, noting that the method intends to guide the simulation analysts on how to develop each step that makes up a simulation project.

As future work, it is suggested the analysis of specific simulation journals in order to identify other methods and compare them to the methods presented here.

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