Discrete event simulation and lean production: quantification of waste in a pharmaceutical industry

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Abstract: Nowadays it is imperative that companies seek constant improvements in their operational performance so as not to become obsolete in relation to the new cutting edge trends of smart manufacturing or industry 4.0. In this context, it is noteworthy that manufacturing must occur in the presence of variability and uncertainty, and manufacturing systems must be complex, efficient and lean. Therefore, a conduct aimed at interventions focused on reducing waste in manufacturing and service operations are essential actions. A tool that can help in this purpose is the discrete event simulation (DES). In this context, the objective of this research is to apply DES and quantify the financial waste arising from non-value-adding activities. The object of study was a production line of a pharmaceutical industry and as a research method an approach was used combining modeling and simulation (quantitative) and case study (qualitative) methods. The software chosen was *Flexsim*®, a powerful simulation and process analysis tool that helps professionals in decision making. Finally, the results obtained through this research show the great financial waste in the analyzed assembly line. This impactful result on losses in the operation serves as a warning so that intervention measures are planned and executed to eliminate or mitigate the consequences of this waste.

Keywords: Discrete Event Simulation; Lean Production; Pharmaceutical Industry.

1. Introduction

Every day the world becomes more globalized and digitized, so companies always need to be improving so they do not become obsolete in relation to the new cutting edge trends of Smart Manufacturing or Industry 4.0. In this context, it is worth mentioning that manufacturing must occur in the presence of variability, uncertainty and randomness, and manufacturing systems must be complex to face these challenges (Gershwin, 2018). Therefore, a conduct aimed at interventions focused on reducing waste in manufacturing operations and services are imperative actions that every process manager must implement (Vilela *et al*., 2020). Thus, a tool that can help in this attempt is the Discrete Event Simulation (DES). According to Law *et al*. (2014) computer simulation provides us with most of the resources needed for an assertive analysis of the process. In addition, according to Law *et al*. (2014), process simulation is a tool that can be used to analyze systems through computer modeling, simulating their process with the help of software that can more accurately analyze the details and thus indicating possibilities for improvement in the process before implementing it.

Within the context, the objective of this research is to apply the DES and quantify the financial waste arising from non-value-adding activities. The object of study was a production line of a pharmaceutical industry and as a research method an approach was used combining modeling and simulation methods (quantitative) and case study (qualitative). Choosing a software capable of implementing what you need is fundamental, and for the present study, the software chosen was *Flexsim®*, a powerful simulation and analysis tool that helps professionals in decision making in their projects (Kumar, 2006). The justificative for choosing the object of this study is due to its relevant role in history, being responsible for the research, development, manufacture and distribution of medicines and items aimed at the treatment of diseases of both humans and animals. It is also essential in the discovery of new drugs, as well as in their production in time and scale.

Finally, the results obtained through this research show the large financial waste in the assembly line. This impacting result on the loses in the operation studied serves as a warning for intervention measures to be planned and executed to eliminate or mitigate the consequences of these wastes.

2. Literature Review

2.1. Discrete Events Simulation (DES)

Software process simulation is increasingly being used to address a variety of issues, from strategic software development management to support process improvements and software project management training (Kellner *et al*., 1999).

DES has been widely used for quick decision making, through which it is possible to visualize the operation holistically and thus have the basis to make improvement decisions assertively. Computational simulation therefore seeks the representation of the reality of the system, and with this better alternative can be discovered for a more precise decision (Montevechi *et al*., 2007).

According to Banks *et al*. (2005), there are many advantages provided by simulation, although it also has some disadvantages, such as the difficulty and complexity of modeling large flows of materials and products. For Law (2009), DES is an alternative to direct experimentation in the actual operation, thus avoiding various costs due to tests that cause the interruption of the flow of activities of the real system. For the construction of a simulation model, it is of paramount importance to create a conceptual model before (Chwif and Medina, 2006). According to Brooks and Robinson (2001), the conceptual model is the one that describes what will be built, which does not depend on which simulation tool will be used.

A conceptual modeling technique called IDEF-SIM, presented by Leal *et al.*, (2008), uses logical forms in an organized and sequenced way for modeling, therefore, it helps in the construction of a computational simulation in a more systematic and accurate way. The latter technique was used in the present study to construct the conceptual model.

According to Harrell, Ghosh and Bowden (2004), simulation is the imitation of a real system modeled on a computer for later carrying out experiments to evaluate and improve its performance. For Banks *et al*. (2005), discrete event simulation is the creation and observation of a history of a real system to generate inferences regarding it.

Leal *et al*. (2008) defines the simulation as the representation of a procedure in a shorter time than it would take in the real scenario and at a lower cost, favoring the prediction of the behavior of the system so that corrective actions can be taken in order to reduce costs.

According to Bloomfield *et al*. (2012), the fact that discrete-event simulation simulates the behavior of systems without it physically existing, drastically reduces the cost of developing this system. The advantage of this operation is that the computer simulation software seeks to repeat the same behavior that the real process would have under the same conditions. The computer simulation model is used, particularly, as a tool to obtain answers to sentences such as: "what happens if..." (Chwif and Medina, 2006).

Modeling and Simulation helps visualize, evaluate, implement, modify and improve complex production processes using computer animations within a reasonable time and investment. (Sandanayake *et al.*, 2008; Sandanayake and Oduoza, 2009).

Ryan and Heavey (2006) point out that simulation is one of the most used research techniques, mainly due to its versatility, flexibility and analytical power.

Banks *et al*. (2005) state that simulation has become one of the most popular techniques for analyzing complex problems. Currently, with the evolution of studies in the area, discrete-event simulation has been increasingly used and the benefits obtained have generated impacts on the most different systems (Miranda *et al*., 2010).

According to Hillier and Lieberman (2001), simulation is an extremely versatile technique and can be used to investigate virtually any type of stochastic system. This versatility has made simulation the most used operational research technique for studies dealing with stochastic systems. Still, according to these authors, due to the enormous diversity of its application, it is practically impossible to enumerate all the areas in which the simulation seeing is being used.

Taking the proceedings of the Winter Simulation Conference (WSC) as a reference, Banks *et al*. (2005) and Hillier and Lieberman (2001) present some particularly important categories of simulation applications. Among the main categories, the following stand out: design and operations in manufacturing, project management and civil construction, logistics, supply chain and distribution networks, inventory system management, transport and traffic modeling, risk analysis, medical applications, military applications and applications in the most diverse areas of services, such as: government services, banks, hotels, restaurants, educational institutions, among others.

According to Banks *et al*. (2005), there are numerous advantages provided by simulation, although it also has some disadvantages. Pinho (2008) and Torga (2007) state that, when compared to mathematical models, the advantages provided by the simulation of discrete events are enormous. Mainly, with regard to its easy-to-understand conceptualization and the possibility of virtual comparison, bringing greater contributions to the object under study.

According to Law (2009), simulation is an alternative to direct experimentation in the real system, thus avoiding the costs due to real experimentation and the interruption of the flow of activities in the real system. Chwif and Medina (2006) emphasize that, due to the great complexity of manufacturing models, due to their dynamic and random nature, a simulation model allows to reproduce in a computer the same behavior that the system would have submitted to the same boundary conditions.

According to Reeb and Leavengood (2003), the simulation should be used when it is not possible to carry out an experiment with the real system, when other models would not work, when it is necessary to analyze how the systems operate in a certain period of time or when it is desired to compare alternative projects.

According to Greasley (2003), simulation animation can be used to communicate to directors, customers and employees the “before” and “after” of implementing a new project, showing how the changes will affect the process in practice. The same authors also state that the simulation animation can be used to train employees in the face of a new system operation and allow them to create an overview of the benefits of the change, from the view of the running model.

2.2. Suggested steps for DES: design, implementation and analysis

Some authors present a sequence of steps, contradicting the false idea that simulation consists of the computational programming of a model. It is known that simulation involves much more than the simple construction of a program, which is just one activity, among the numerous activities of a simulation study. A framework proposed by Montevechi *et al*. (2010), guides on the design, implementation and analysis stages for DES project.

In the “design stage”, the simulation analyst must clearly understand the system to be simulated and its objectives, by discussing the problem with the experts. At this stage, conceptual modeling must be carried out, which can be performed using various techniques.

It is extremely important in this design stage to correctly and carefully obtain the input data, as they are an important basis for the model and the validation of the computational model may depend on how they will be considered.

Conceptual modeling corresponds to the "design stage" of the DES project, as the authors Chwif and Medina (2006) also show, but they state in their work that the conceptual model creation stage is the most important aspect of a simulation study, although many books and many analysts skip this step.

In his work, Sargent (2004) seeks to explain the difference between the conceptual model and the computational model. According to this author, the conceptual model is the mathematical, logical or verbal representation of the problem, and the computer model is the conceptual model implemented in a computer.

For Balci (2003), the conceptual model can be used as a tool to control the requirements of the modelling and simulation process, to evaluate simulation concepts, effectiveness and errors, as a basis for the modelling and simulation project, in addition to helping in the process of verification and validation of the computational model. For Hernandez-Matias *et al*. (2008), there is no single conceptual modelling method that can completely model a complex manufacturing system. As a result of the limitations of these techniques, different integrated modelling methods have been developed.

In his work Robinson (2013) says that one of the most difficult issues in modelling is to determine the content of the simulation model. The modeller's job is to understand the real system, which is the subject of the simulation study, and transform this into an appropriate simulation model. The model chosen can vary from a very simple to a much more complex one. Indeed, there are an infinite number of models that could be selected within this range, each with slightly different content. The question is: which models should they choose to represent the reality of a given context?

Chwif *et al.* (2006) propose a technique to reduce the complexity of a simulation model to discrete events already in the "design stage". The importance of the conceptual model, who belongs at "design stage", is also highlighted in the work of Zhou *et al.,* (2006). In this work, the authors propose that automation can help improve the results of the use of conceptual models in simulation.

In the context of conceptual model, according to the Federal Information Processing Standards Publications, during the 1970s, the US Air Force's Program for Integrated Computer Aided Manufacturing (ICAM) sought to increase manufacturing productivity through the systematic application of computer technology. ICAM identified the need for better analysis and communication techniques for people involved in manufacturing productivity improvement programs. As a result, ICAM developed a series of techniques known as IDEF (Integrated Definition Methods). These techniques were defined as follows:

-IDEF0: used to produce a working model. A functional model is a structured representation of functions, activities or processes, within a modelled system or defined area;

-IDEF1: used to produce an information model. An information model represents the structure and semantics of information within a modelled system or defined area;

-IDEF2: used to produce a dynamic model. A dynamic model represents the time-varying behavior of the characteristics of a modelled system or defined area;

-IDEF3: according to Ryan and Heavey (2006), the technique allows the capture and representation with graphic elements, both for the transition of states in a discrete event system, and for the representation of the activities associated with each transition state. Tseng *et al*. (1999) made some simplifications and adaptations in IDEF3, aiming at its use, in the specific case of service operations. These modifications highlighted the issue of client-process interaction.

In the "implementation stage", you must initially define which commercial software will be used. Thus, an important point in a simulation study (but not fundamental) is the correct choice of simulation software. For Chwif and Medina (2006), it is not fundamental because the most important point is the "humanware", or the analyst who is carrying out the study.

However, it cannot be denied that the selection of software and hardware mainly influences the total time of a simulation study.

Finally, it is worth mentioning, over the years, there was a great evolution of the graphical interfaces of the operating systems of the PCs, favouring the simulation softwares to become much easier to operate, due to the construction of the models having become more graphical and less textual.

Still in the "implementation stage" model verification and validation is very important, because according to Chwif and Medina (2006), there is a concern with the confusion generated between the terms validation and verification.

The term validation is related to the conceptual model (there is another type of validation called operational validation, but when it refers only to validation, it is referring to conceptual validation). In this case, the objective of validating the model is the same as answering the following question: "is the correct model being developed?", or even "will the considerations made, the level of detail, the scope of the model, represent adequately the system to be simulated"?

According to Chwif and Medina (2006), one can see the distinction of the term "validation" associated with the conceptual model. For the same authors, checking, in a more simplistic sense, means removing bugs from the model. Validation is related to what will be modeled and verification is related to how the model is being implemented. In the view of Kleijnen (1995), verification aims at a perfect computer program, in such a way that the programming code used does not contain errors. Validation, however, cannot be used to result in perfect models, because, by definition, perfect models would be the real systems themselves. A model must be good enough, which depends on the objectives of the model.

Finally, In the "stage of analysis", the DES Project it is validated, and can now be called an operational model, as it is prepared to receive several experiments.

In the work proposed by Montevechi *et al*. (2010), this step is carried out through a design of experiments, which are tests conducted in a planned way, in which the factors are changed in order to assess their impact on a given response. . The experiment can be defined as a test, in which proposed changes are applied to input variables of a process, in order to observe and identify changes in output variables.

Therefore, having completed the verification and validation steps, the simulation model becomes operational, becoming a powerful source of statistical experiments used in the process of analysing the behaviour of the system. In this way, different simulation experiments are carried out with the created model, experiments generated from the questions "what if..." (Chwif and Medina, 2006).

The same authors also warn that, as the simulation inputs are random processes, the outputs will also be random, so it is not recommended to draw conclusions with a single simulation replica. When defining each scenario, the professional in the simulation area must keep in mind, which input variables should be modified and which output variables will be analysed.

In addition, according to Chwif and Medina (2006), the results analysis process is generally less expensive than the modelling, computational model construction, verification and validation processes, since it is the model that works to generate results.

2.3. Lean Production

In this context, lean thinking focuses on the idea of added value and consists of the use of best practices, tools and techniques, with the aim of reducing waste and maximizing the flow and efficiency of the production system to achieve final customer satisfaction with as little waste as possible. Therefore, lean manufacturing is a manufacturing philosophy that increases overall system productivity and, consequently, reduces the time between customer order and product delivery, eliminating mapped sources of waste (Rother and Shook, 1998).

Finally, it is essential to highlight that one of the elementary concepts of Lean Production is the continuous improvement of a value stream or process (Kaizen). The latter is considered one of the most effective Japanese production methods since this philosophy arose with the focus of improving processes through the continuous reduction of waste. In addition, according to Rother and Shook (1998), there are two levels of Kaizen:

- ✓ Flow Kaizen: which focuses on value flow, directed to management; and
- ✓ Kaizen process: focusing on individual processes, directed to work teams and team leaders.

The following are the seven main wastes that must be reduced and eliminated throughout the operation: transportation, inventory, movement, waiting, over processing, overproduction and defect. It is important to point out, finally, that the present study will focus on the waste of waiting, which causes an idleness that will be quantified through the Financial Analysis available in the *Flexsim®* software dashboard.

2.4. Lean Thinking

In the post-war period, Japan did not have the necessary resources for high investments. From there, Taiichi Ohno, as vice president of Toyota, structured a new management standard capable of rebuilding Toyota: the Toyota Production System (TPS).

According to Ghinato (1996), TPS has been more recently referred to as "lean production system" or "lean manufacturing". It is a system used by thousands of companies that aim to eliminate waste and improve productivity, using machines and management techniques, producing more efficiently and with fewer resources.

The main idea of lean manufacturing is to produce what is needed, when it is needed and in the quantity required (Ohno, 1997). Use the least amount of equipment and labor to produce without defects in the shortest possible time, eliminating all waste through efforts applied in all departments of the company (Shinohara, 1998).

Liker and Meier (2007) propose the 4Ps as a way to explain the principles of lean manufacturing: (i) philosophy: the basis of thought, where leaders see the company as a vehicle to add value to customers, society, the community and its employees; (ii) process: when you follow the right process, you get the right result, through instruction and experience; (iii) people & partners: the development of people and partners is essential as a way of adding value to the organization; and a good alternative is challenging your employees and partners to grow; (iv) problem solving: the solution to the root of problems must be continually sought, this leads to organizational learning.

2.5. Kaizen

Kaizen is based on the elimination of waste through the use of common sense, on the use of cheap solutions that are based on the motivation and creativity of employees to improve the practice of their work processes, with a focus on the search for continuous improvement. As Rother and Shook (1998) emphasizes, Toyota is a great reference for the concepts of world-class best practices in the use of the kaizen tool, as it efficiently conducts all its processes, eliminating any productive loss and transforming them in values.

Werkema (1995) came to the conclusion that kaizen is a tool of Japanese origin that has the meaning of continuous improvement, claiming to be a methodology to quickly achieve necessary improvements, which consists of the organized application of common sense and creative thinking to improve a process or a value stream. Generally, this tool is used after carrying out a Value Stream Mapping and is then conducted by a team composed of individuals with different roles in the company.

Rother and Shook (1998) classify kaizen as two distinct points, which are distributed in:

- ✓ Flow or system kaizen: which aims to focus on the flow of value, directed towards management; and
- ✓ Process Kaizen: focuses on individual processes, directed at work groups and leaders.

On the other hand, Martins and Laugeni (2005) point out the following points:

- ✓ Project Kaizen: Focuses on developing new concepts for new products;
- ✓ Planning Kaizen: aims to develop a production, finance or marketing planning system; and
- ✓ Production Kaizen: aims to develop actions that eliminate waste on the factory floor and offer improvements in work safety and comfort.

2.6. Aggregation of value

When performing temporal analyses of a quantitative nature about the aggregation of value to the final product within the product flow, three different types of activities inserted in the productive environment are identified. Being them:

- ✓ Value Adding Activities (VA): These are activities that add value directly to the final product or in process;
- ✓ Non-value-adding, but necessary (NAN) activities: Includes activities that do not directly add value to the product or service, but are essential for the company to function, and there is no possibility of eliminating the activity; and
- ✓ Non-Value-Adding and Unnecessary Activities (NAD): Refers to activities that do not directly add value to the final product and are wasteful. Therefore, they represent possibilities of cuts and elimination.

For Rother and Shook (1998), process mapping is a tool that provides a complete visual illustration of the entire environment and production chain, including value-adding and non-value-adding activities.

2.7. Value Stream Mapping

Value Stream Mapping or VSM, according to Rother and Shook (1998) and Azevedo (2011), is a methodology to see the entire flow of information and material, allowing organizations to visualize and identify their sources of waste or activities that do not add value, being able to direct their actions towards the search for the best performance of the flow.

In addition to mapping the transformation of raw materials into final products, in physical terms, it is necessary to survey the flow of information generated in this process, its evolution, its connections in generating value, from suppliers to customers (Vinodh *et al*., 2010).

As stated by Rother and Shook (1998), the VSM tool enables the connection of all processes that make up the production flow, from the supplier to the final consumer, identifying all the steps in order to apply lean thinking techniques. According to the same authors, the mapping of the value stream must follow the following steps:

- ✓ Product family selection: select a product family composed of a group of products that undergo similar processing steps;
- ✓ Current and future state design: drawing the current state and future state, which is done from information collected on the shop floor; and
- ✓ Work and implementation plan: prepare an implementation plan that describes how you want to get to the future state.

As seen, the main objective of lean production is to make materials flow through the processes, without interruptions and waste, adding value in order to meet customer expectations. This means considering processes in a broad sense and not just as individual processes, seeking improvements in the whole and not just in isolated parts. For this, the VSM is used as a tool to demonstrate the flow of processes.

The execution of the VSM starts by choosing a family of products. From this, the flow of production must be followed from the supplier of the raw material to the customer, detailing the map of the current state, its flows of materials and information (ROTHER and SHOOK, 1998). The analysis of the current map is then carried out, which must consider the seven losses.

Thus, the value stream mapping helps to understand the current state, how the process is, in order to reach the future state, which is where you want to go, guided by actions (implementation plan), visually showing three flows: of materials, products and information, identifying opportunities for improvement (Chen and Meng, 2010).

According to Rother and Shook (1998), the objective of mapping the future state is, through evidence, to eliminate the sources of waste through the implementation of a "future" value stream that can become a reality in a short period. The aim is to build a flow between processes where it is possible to get as close as possible to producing only in the customer's need, that is, continuous or pulled flow.

According to the same authors, the future state VSM is built from the current state VSM, considering key issues of lean manufacturing concepts:

- ✓ Produce according to takt time;
- ✓ Develop continuous flow, when possible;
- ✓ Using supermarkets to control production;
- ✓ Try to send the client's schedule for only one production process; and
- ✓ Level the mix and production volume.

The current state map is not something immutable, and when reaching the intended future state, a new map must be prepared, aiming at the continuous improvement of the process (Rother and Shook, 1998).

3. Proposed Method

The present research is classified as of an applied nature because it aims at a practical study in the search for the solution of a problem of the object of study presented. The latter problem was related to the quantification of the idleness of the operators of the manufacturing line. Research was also considered as a systematic investigation (Appolinário, 2004). According to Gil (2010), there are three classifications for research: exploratory, explanatory and descriptive. The main objective of exploratory research is to familiarize the researcher with the problem, increasing their knowledge in the study; explanatory research already addresses experiences, where there is the involvement of speculative assumptions, that is, it consists of the creation and explanation of a certain theory about a process, phenomenon and/or fact.

The present research is explanatory, because it makes an identification between variables, analyzing facts, making the description, classification and interpretation, with the objective of bringing the real situation and not the search for cause-and-effect relationships.

Regarding the approach used in this research (Figure 1), quantitative and qualitative data were used, therefore, a combined approach was applied. Quantitative research is characterized by the quantification of what you want to study, according to (Diehl, 2004) and aims to obtain results in which they avoid distortions, allowing a safety margin for the research.

Qualitative research, on the other hand, has as fundamental the understanding, description and experiences of society as a whole, it evaluates what is documented or traits that resemble experiences and integrations (Flick, 2009).

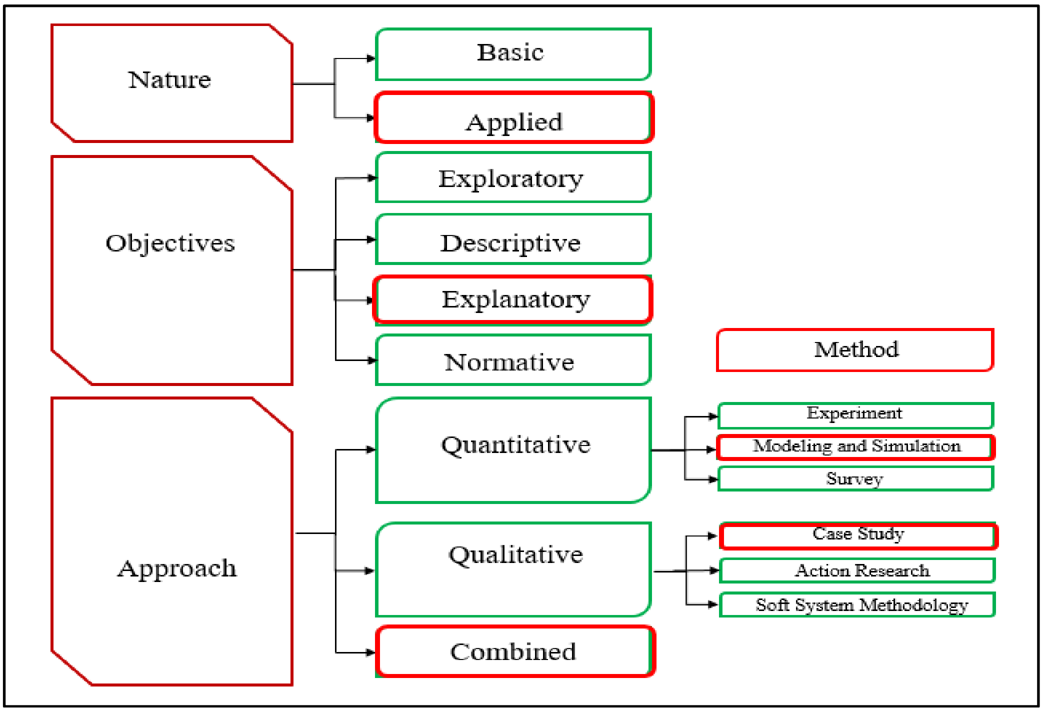

Figure 1 - classification of scientific research in production engineering. source: adapted from Turrioni and Mello (2012)
Source: The authors (2022)

Therefore, within the aforementioned combined approach, the two methods used in the research were: modeling and simulation and case study. In conducting the modeling and simulation method, the steps suggested by the authors Montevechi *et al*. (2007) were fully performed.

4. Application

4.1 Study Object

The production line of a pharmaceutical industry was chosen for the development of the simulation project, as justified in the introduction of the work. This industry works 24 hours a day, has approximately 1500 employees and its workday is divided into 3 shifts. The company has several production lines. In the present study, the sterile product line was selected due to its high demand and importance.

4.2 Conceptualization

As shown in Figure 2, the production process was mapped using the IDEF-SIM technique, proposed by Leal *et al*. (2008).

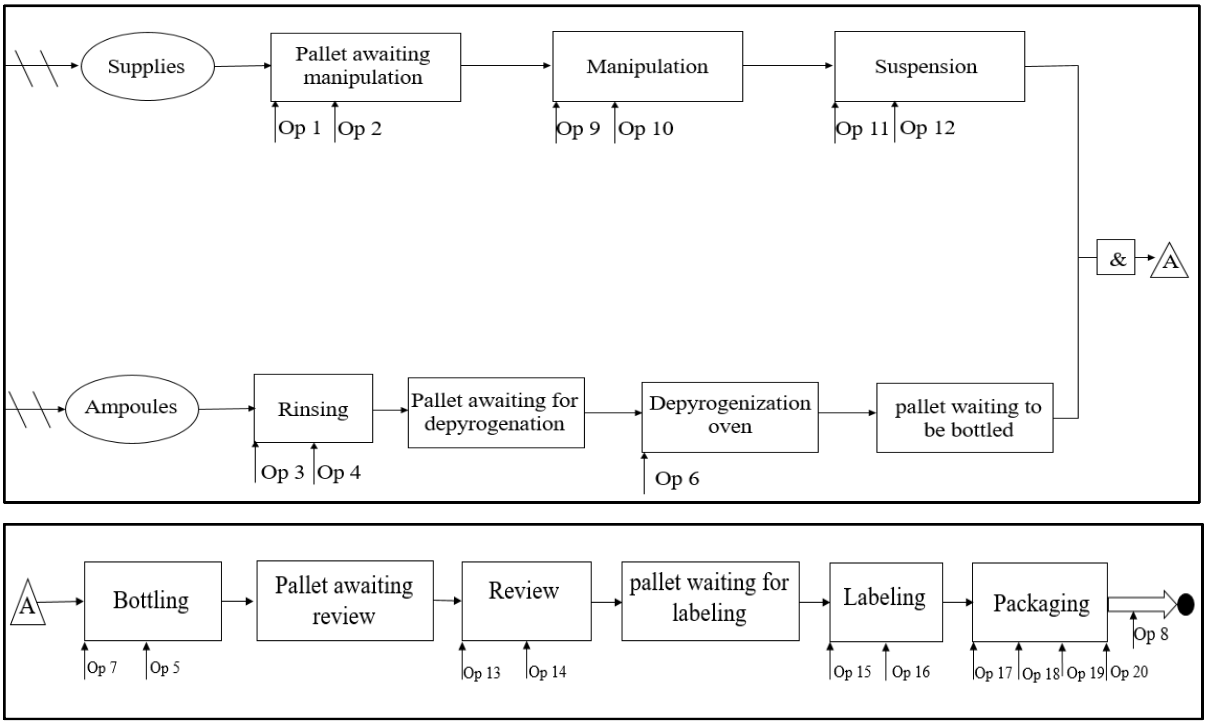

Figure 2 – IDEF-SIM
Source: The authors (2022)

Figure 2 represents the entire process under study. At the beginning of the process, the ampoules arrive at the sector and are placed in stainless steel trays to be washed and dried; then they are placed on carts to enter the ovens for the dry heat sterilization process, and then enter the clean area (environments isolated from other facilities and which controls the number of particles in the environment) where manipulation takes place and is All the raw materials of the product are mixed in their respective measures. The combination of the manipulated product and the ampoules takes place in the filling machines, after that, they are placed again inside the stainless steel trays, where they follow on pallets to wait for the review.

Then they are placed in the particle review machine, later on the same line in the crack review machine, and then reallocated on pallets to go to labeling, where the label is placed and its appropriate markings, and at the end they are allocated again on pallets. Finally, they go to the manual packaging, where the labels are reviewed and placed in boxes for the final consumer.

4.3 Computational modeling

As shown in Figure 3, *Flexsim®* software was used to build the discrete event simulation project.

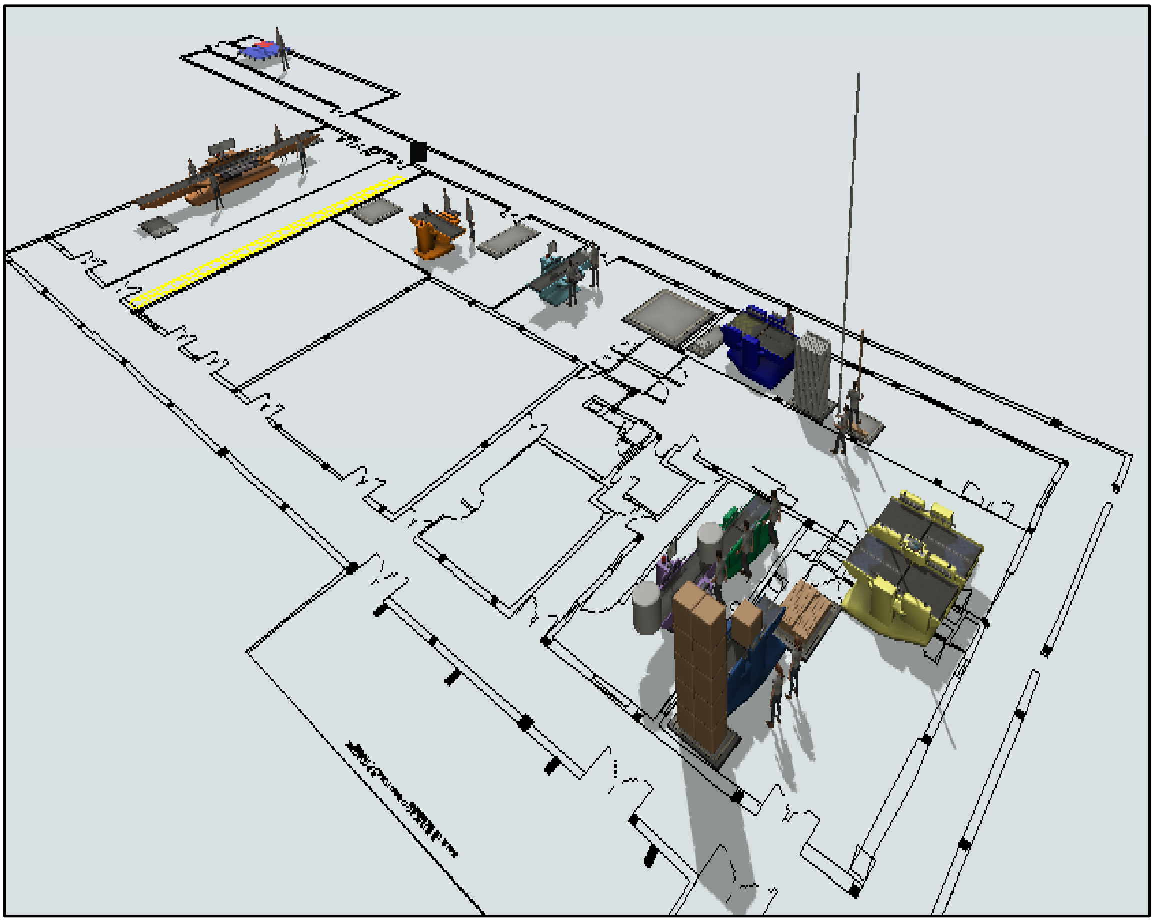

Figure 3 - Process configuration in *Flexsim®*
Source: The authors (2022)

According to Trevisan and Sampaio (2017) it is a relatively new software compared to its competitors and has great growth in Brazil and is also considered a great tool for process analysis. In the study in question, as it is a deterministic computational simulation, only one replica was executed, and the total simulation time was 8 hours and 20 minutes (one work shift). It is worth mentioning that the warm-up time configured was 120 minutes. The 1h lunch period was defined as a "break" through the *Flexsim®* timetable function. Table 1 shows the times of the processes (duration of activities) used in the computer simulation.

Table 1 – Times used in the Computer Simulation

Process	Time (minutes)
Manipulation	100
Suspension	100
Rinsing	85
Depyrogenization Oven	200
Bottling	0,0045
Review	0,005
Labeling	0,0036
Packing	0,4

Source: The authors (2022

It is essential to highlight that the processing times of the "filling", "review" and "labeling" stages shown in Table 1 are for processes carried out by "state-of-the-art" automatic equipment, and these equipments can perform operations with a low turnaround time.

5. Results

5.1 Results from the simulation model

The analysis of the model was carried out according to the data regarding the use of operators, obtained through the *Flexsim®* software dashboard, as shown in Table 2, and were classified into AV activity (adds value), NAN (does not add value, but is necessary) and NAW (does not add value, and is waste) according to the premises presented by the authors Rother and Shook (1998).

Table 2 – AV x NAN x NAW percentages

Operator	AV (%)	NAN (%)	NAW (%)
1	0	16,58	83,42
2	0	16,88	83,12
3	84,25	15,75	0
4	84,25	15,75	0
5	0	35,35	64,65
6	0	24,32	75,68
7	4,74	15,75	79,51
8	0	23,6	76,38
9	83,64	15,76	0,6
10	83,64	15,76	0,6
11	83,64	15,76	0,6
12	83,64	15,76	0,6
13	5,26	15,76	78,98
14	5,26	15,76	78,98
15	3,79	15,76	80,46
16	3,79	15,76	80,46
17	31,75	15,76	52,49
18	0	40,68	59,33
19	31,75	15,76	52,49
20	31,75	15,76	52,49

Source: The authors (2022)

Some operators showed reduced use, which reflects financially on the company, considering that it is a waste of the labor resource. The main causes that can be pointed out are the waiting time to start the process and the movements to transport the products between one stage and another.

Op1	$30.11	Op1	$5.97
Op2	$30.00	Op2	$6.08
Op3	$0.00	Op3	$5.69
Op4	$0.00	Op4	$5.69
Op5	$23.34	Op5	$12.57
Op6	$32.79	Op6	$10.11
Op7	$34.44	Op7	$6.82
Op8	$27.57	Op8	$8.30
Op9	$0.26	Op9	$6.82
Op10	$0.26	Op10	$6.82
Op11	$0.26	Op11	$6.82
Op12	$0.26	Op12	$6.82
Op13	$28.51	Op13	$5.69
Op15	$29.05	Op14	$5.69
Op14	$28.51	Op15	$5.69
Op16	$29.05	Op16	$5.69
Op17	$18.95	Op17	$5.69
Op18	$21.42	Op18	$14.43
Op19	$18.95	Op19	$5.69
Op20	$18.95	Op20	$5.69

Figure 4 – Financial Analysis Result
Source: The authors (2022)

As shown in Figure 4, the Financial Analysis tool of the *Flexsim®* software was used to quantify the cost of NAN and NAW of the activities of the first shift of each operator. It is important to note that this tool used the information in Table 2 and Table 3.

Table 3 – Monthly Cost per Operator

Calculation basis	Value(R$)	Operators
Gross salary 1	R$ 1.249,00	1, 2, 3, 4, 5, 8, 13, 14, 15, 16, 17, 18, 19 e 20
Gross salary 2	R$ 1.500,00	6, 7, 9, 10, 11 e 12

Source: The authors (2022)

Therefore, a daily expense of R$ 515.44 of waste generated by NAN and NAW activities was found, which in one month results in R$ 15,463.20 of financial waste.

6. Conclusions

Through the present research applied to a pharmaceutical industry, it was possible to verify that the established objective was satisfactorily achieved, as the simulation to discrete events was applied assertively and the quantification of financial waste from non-value-adding activities was successfully carried out. The great financial waste on the assembly line was quite evident, reaching a total amount of R$ 15,463.20 per month. This impactful result on the losses in the studied operation serves as a warning for intervention measures to be planned and executed to eliminate or mitigate the consequences of these wastes.

Finally, as a suggestion for future work, considering processing times in their stochastic form would be a way to obtain even greater precision in the results of the Financial Analysis.

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