Specification, simulation and optimization of a production line for the company FrontWave

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Abstract

FrontWave, a company in the field of natural stone, has developed an innovative product, the Stork® (a composite of stone and cork). And therefore, a production line was devised. This need for industrialization is a requirement to be able to market the product with credibility. Frontwave wanted Stork to be a substitute of the natural stone bringing very differentiating properties, such as the increase of specific resistance and thermal and acoustic insulation. The work carried out consists of the study of the necessary resources for the development of a production line with capacity to produce the Stork®, according to the specifications of the product. For this purpose, discrete event-based simulation techniques were used to obtain results from the operation of complex systems such as a production line. It was also important to simulate several scenarios to ensure optimization. Through the software Simul8, it was possible to develop a simulation model of the productive process. This model allowed not only to define the necessary resources, but also to analyze the bottlenecks in the line. The results obtained allow us to conclude that to reach the productive capacity desired by the company, three collaborators must be associated with the line and a kiln capacity that allows the placement of 10 plates of material simultaneously. It was also possible to conclude that an increase in production of around 20% can be achieved without increasing the number of employees, which can reach 35% if four employees are allocated.

Keywords: Stork®, Simul8, stone industry, production line management, discrete event simulation

1. Introduction

In the period from 2008 to 2013, the construction industry felt a strong impact because of the crisis that hit the whole of Europe. Depression was felt not only in conventional construction, but also in the consumption of innovative materials and products often used in new types of construction (FEPICOP, 2013).

According to the Euroconstruct (2016), the crisis has put a brake on the role that construction was to play for the European economy. Only in 2013 did we see some growth, and the situation is expected to continue until 2018. It is important to mention that the crisis has strongly affected small and medium-sized enterprises in Portugal. Many were forced to shut down. Of those who survived, they were forced to innovate their construction techniques or models.

FrontWave is a pioneer company in the design, development and implementation of natural stone production products and technologies and related / complementary materials (Instituto Superior Técnico, 2016). FW sought to innovate to recover the construction sector. After a few years of research, the Stork® was born. The Stork® product was created with the aim of improving an existing product, gaining a foothold in the markets of flooring, facades, benches, tables and for design. When compared, the Stork® stands out for its improvements in mechanical strength, impact and greater flexibility. These features also allow for greater durability (FrontWave, 2016).

The company's goal is to develop a production line associated with a proprietary product, the Stork®.

Considering that the project focuses on the development of a production line with a certain productive capacity, a series of conditions are divided into two types: i) first, related to the resources needed to produce the desired annual quantities; ii) secondly, related to the analysis of viable alternatives, that will allow to reach an optimization of this same production. To achieve the proposed goal, it is necessary to create a simulation model.

2. Theory of Constraints

2.1. Simulation

In industries with complex processes there is a need to find methods to eliminate the most common problems: Bottleneck and waiting times. These problems lead to cost increases for firms (Zahraee, 2016). Another important aspect is that companies feel the need to remain competitive, leading to an increase in productivity, efficiency and production quality. That is, the high yield and high resource utilization rate (Jahangirian *et al.*, 2010).

To deal with problems and variations in integrated production systems, Tsai (2002) defends the use of computer simulation. This can be very useful for analyzing, designing and scheduling production systems. It also allows the use of simulators instead of complex mathematical models. The use of this type of simulation can be applied to a small area of the factory or to the totality. This feature allows engineers to predict what will happen in the real world. This means that engineers will have a better understanding of how the layout they designed will behave when applied (Smith, 2005).

According to Evans (1991), computer simulation consists only of a function that transforms the inputs into outputs. The operational parameters and their variables are described as the inputs of the system and their performances the results of the simulation.

2.2. Classification of simulation models

In engineering a model is the representation of a system with the purpose of studying it. This can be grouped into the following types (Banks *et al.*, 2005):

- Static or dynamic - the first one occurs at a certain point in time. Meanwhile in the second, the system changes over time;
- Deterministic or stochastic - the first does not contain random variables while in the second there is at least one;

- Discrete or continuous - in the first case, the variables change only in one specific interval of time; on the other, the state changes continuously over time.

2.3. Simulation of discrete events vs Simulation of dynamic systems

In the field of operational research, it is very common to use simulation as a computer modeling tool, with the aim of understanding and experimenting with a real system (Pidd, 1998). According to Robinson (2005), the most commonly used simulation types are discrete event simulation (DES) and dynamic systems simulation (DSS), and it should be noted that both simulations have evolved in parallel with the evolution of computers.

DES is an operational tool, designed to optimize system performance at a detailed level, and it is used to model queuing systems where stochastic variability is important. DSS is a more strategic tool, used at a more general level, to better understand the general behavior of the system and may even be essentially a deterministic approach (Brailsford et al., 2010).

Considering the definitions presented above and the table 1 below, the best solution is to use the discrete event simulation, since the system to be simulated has a small amount of resources, the data that is to be obtained is quantitative and is necessary resorting to probabilistic distributions.

2.3. Simul8

For the execution of the simulations we will use the simulation program Simul8. Simul8 is a computer program for resolving SED. This simulation feature was created by Mark Elder, a professor at the University of Strathclyde. However, due to the success of this program at university level, it began to be commercialized faster as a professional tool in simulation projects (Chwif and Medina, 2006; Shalliker and Ricketts, 2014; Simul8 Corporation, 2017).

3. Case Study

In this work, we intend to develop and optimize a production line for Stork®. To do this, it is necessary to acquire a specific knowledge of the materials used. It is also important to understand the entire production process. After researching the previous topics, it is necessary to develop a research in the stone area: to understand the type of machines used and which can be adopted for this project. The research developed will be essential for the collection of essential data for the simulation model

Table 1 - Comparison between DES and DSS

Aspects to compare	DES	DSS
Nature of problems modeled	Tactics/Operational	Strategic
Duration of siimulation	Slow	Fast
Flexibility	Flexible	Inflexible
Representation in the system	Analytical vision	Holistic vision
Complexity	Complex systems	General systems
Number of entities	Few	Many
Outputs	Quantitative	Qualitative
Variability	High	Low
Objective	Optimization and comparison	Formulation of policies

3.1. Stork's production process

Before explaining the production process, it is essential to understand what the Stork product is. This product consists in a sandwich compound. In the case of Stork, the sandwich is formed by stone, resin, fiber and cork. As can be seen in the following image 1.

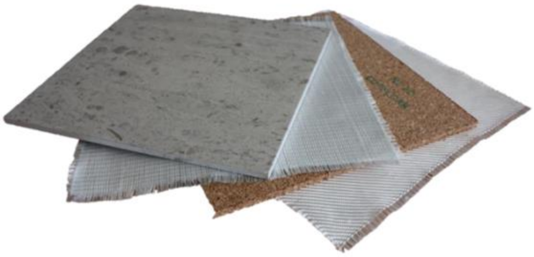

Image 1 – Stork's constituent layers (Ribeiro, 2016)

As far as the production process is concerned, it is very simple, based on the combination of all the previously discussed components. The sequence of steps that allow the production of the Stork product are: Drying the stone, building the agglomerate, applying pressure and heating so that the stone can be cured.

3.2. Description of the company objectives

Through the case study, we intend to be able to base decisions regarding the Stork® production line with a minimum production capacity of 5,000 m2 / year.

The development of this project will focus on the optimization and simulation of the small line. It is intended to answer the questions essential to the development and implementation of the line, not only in terms of the initial conditions, but also its optimization.

Once the first line results are achieved, it will be possible to design the mid-dimension line. The conclusions drawn from this second analysis will be important for the research and development of the equipment needed for production.

4. Development of the case study

According to Pidd (1998), for the development of a simulation it is necessary to resort to a computer, which leads him to affirm that the steps of development of a simulation are identical to those associated to the resolution of other problems. During the development of this simulation model it would follow a sequence of steps developed by Banks et al. (2005). The sequence of panels can be seen in image 2.

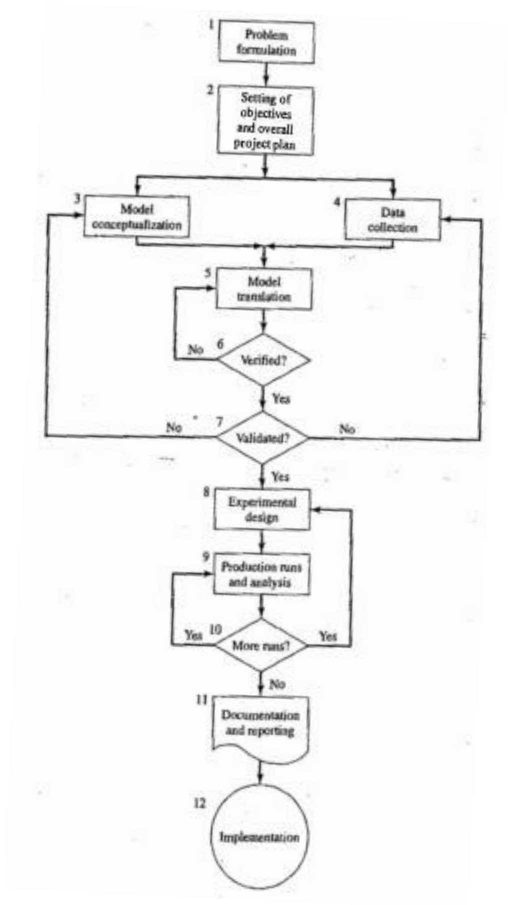

Image 2 – Banks' Diagram

4.1. Formulation of the problem

The problem consists in the development of a simulation model associated with the Stork production process. A process that has been presented previously. After delineating the production process, it was defined that should be use stones with twice the thickness and replicate the process on both sides of the stone. With this option, it was necessary to add to the production process a new stage which is known as cutting. It is important to note that all transfers between stages of the line will be carried out by a collaborator with the support of a crane. Employees will still be needed during the rolling activity. It is concluded that the simulation begins, from the entry of the stone into the system as MP, and ends when the product is packed and is ready to deliver to the final customer.

4.2. Definition of objectives and the overall project plan

In this simulation will be illustrated a factory with the production capacities stipulated by the company. For a real-world plant implementation to be possible, it is necessary to consider some conclusions to be drawn from the simulation. These conclusions that will need to be removed are: the initial conditions for the small line and the evaluation of possible bottlenecks, so that in the future extrapolations can be made for lines with higher productive capacity.

4.3. Conceptualization of the pilot model

In the conceptualization of the pilot model we intend to identify the important entities in the development of the model and present the respective Life Cycle Diagrams (DCV) and the Activity Cycle Diagrams (DCA). The construction of these diagrams is fundamental for creating the model in a suitable software.

In the conceptualization of the pilot line it was decided not to make the simulation for the entire process, concentrating only the concern in the part associated to the productive process since the stone arrives as MP until the cutting.

The relevant entities for the model are: Oven, Support Table 1 and 2, Collaborator, Press, Lamination Table 1 and 2, Cutting Table. All presented are permanent, and there is still the stone that is the temporary entity.

Once the entities were defined it was possible to create the CVD and then the DCA. These diagrams will then be important when constructing the model in Simul8.

4.4. Collection and analysis of relevant data

Data was collected at two distinct locations. The first one was at the FW warehouse and the second in a neighboring company, Marmores Galrão. Pilot tests were conducted at FW warehouses to evaluate the required travel times between product development stages. The remaining data - production times - were collected in a partner company of FW.

In addition to the production times, it was necessary to define some more data: operating hours, raw material quantity entering the system, productive capacities of the resources and respective quantities and finally the final product values that the company intends to achieve.

4.5. Development of the pilot model in Simul8

After the definition of all the DCV, the DCA and the data collection essential to the study of the simulation model, it was already possible to construct it. For its development, first was necessary to insert all the activities and queues of wait in Simul8 and then define the parameters associated to each one. It was also necessary to put some fictitious activities to ensure that the requirements of the company were fulfilled. These activities appeared whenever it was necessary to group the quantities of stone, before the beginning of the next activity. There was also the need to enter initial quantities in some waiting queues to ensure that there were initial quantities in activities that required it.

With the model created there is always the need to perform the verification and validation of the simulation model. This is one of the most important steps for developing it. Although a simplified model of the real model is used, the results obtained are close to the real ones. It is also important to ensure that the simplification of the model allows maintaining the actual situation of the company and not another.

The purpose of verification and validation is to ensure that the conditions previously addressed are met. The verification is performed in order to analyze if there are no implementation errors, while the validation ensures that the model presents the necessary rigor to imitate reality.

Once we had the model verified and validated, it was then studied the existence or not of warm up and simulation time. During the construction of the model, it was taken care of adding initial quantities to the queues that could cause the postponement of the stable start of the model, there is no need to define warm up time. The simulation time was defined as eleven months, which corresponds to one year of work.

The number of runs that would be required to determine the desired solution was also defined. The number of runs is defined by analyzing the performance indicators that are needed to be characterized throughout the analysis. After the analysis, it is concluded that the number of runs is forty-one.

4.6. Analysis and discussion of results

During the analysis of the results, were analyzed two essential points for this project. The first was the definition of the initial conditions of the production line and second, the optimization of the process both at the level of production and resources.

During the verification and validation of the model, initial conditions were used as the starting point. These conditions were: three employees, five spaces in the oven and one press. From the analysis of this scenario it is concluded that the presented conditions were the minimum ones to be able to reach the objective proposed by the company.

After reaching this first objective, five new scenarios were conceived with the objective of optimizing line production, since it was no longer possible to reduce the number of resources. In the table shows the different scenarios and their values taken from Simul8, which will be important for scenario analysis.

Table 2 – Control indicators

Control indicators	scenario 0	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
Number of spaces in the kiln	5	6	6	7	7	8
Number of worke-people	3	3	4	3	4	4
Quantity of raw material per year	1100	1320	1320	1540	1540	1760
Quantity of work items starting in systems	15	18	18	21	21	24
Number of work items left in the system	15	37	27	52	63	293
Employee utilization rate (%)	18,31	21,69	16,38	22,31	18,9	19,62
Average amount of final product	2199,83	2598,25	2625,5	2669,25	3002,75	2966
Average system time (days)	7	11	8	29	12	33

After the presentation of Table X with the data referring to the various scenarios created, develop to the three analyzes:

- Analysis 1: Comparison of Scenario 1 with Scenario 2 and Scenario 3 with Scenario 4, with the objective of realizing the extent to which it is advantageous to allocate the worker, and then compared with the initial model (Scenario 0).
- Analysis 2: Comparison that allows the evaluation of production rates per MP input.
- Analysis 3: Make a brief history about the evolution of bottlenecks in the system.

4.6.1 Analysis 1

In the first analysis, when comparing the different sets of scenarios, it can be concluded that the use of three collaborators is advantageous until the production reaches six plates per day. In case you want to produce seven or more, you will need at least four more collaborators. It is essential to note that from eight daily plates is a big unknown, because the bottleneck ceased to be the number of employees, but began to be the press.

With the analysis of the five scenarios complete, we can then make a brief comparison with the simulation model developed initially. In this way, when scenario 0 and 1 are compared, it can be concluded that it is more advantageous for the company to use 1, because without increasing the fixed costs of production associated to the hiring of a new employee, we can increase production annually by about 18%

If the company intends to increase production, it is necessary to increase one employee, the scenario that best describes the situation is 4. In this case and considering only the data already analyzed, an increase of more than 15% in productive capacity it may be advantageous for the company to be hired if the company believes that it can be an asset not only in the direct activities of the line, but also in indirect processes (storage, packaging, preparation of raw materials, among other activities).

4.6.2. Analysis 2

During this analysis a small comparative table of line yield will be developed. The six scenarios were run, and the essential data for the study were grouped in Table 16.

By analyzing the yield of the line in the various scenarios, you can organize the results into two distinct groups: the first for the values that run 99% and a second where the values below 87%.

Table 3 - Data to support analysis 2

	Cenário 0	Cenário 1	Cenário 2	Cenário 3	Cenário 4	Cenário 5
Quantity of raw material per year	1100	1320	1320	1540	1540	1760
Quantity of work items starting in systems	15	18	18	21	21	24
Number of work items left in the system	15	37	27	52	63	293
Variation of products in the manufacturing process	0	19	9	31	42	269
Average number of plates produced per year*	1100	1299	1313	1335	1501	1483
Line yield	99,99	98,42	99,45	86,66	97,49	84,26

* As each plate gives to produce two plates of stork and as at this point what is meant to take into account is the number of plates produced, half of the total value produced

As for the first group, scenarios 0, 1, 2 and 4 are found. When the scenario 0 and 1 is compared, it is concluded that the line in an initial phase is undersized. This situation occurs because it is possible to increase its capacity, by increasing the space in the kiln, affecting its yield by only 1,5%.

If the company intends to recover the lost income from the transition from 1 to 2, it is possible to increase the resources of the line in a collaborator, it has scenario 3. But this increase in income is not advantageous because it requires an increase in fixed costs of the company.

If the company considers an increase in production due to the increase in the demand for the product to be important, the transition to scenario 5 is advantageous. Even if it loses in comparison to the initial model of the line 2.5% of the yield. It is also important to mention that there is a need to invest in another employee so that the desired production values can be achieved. The transition to scenario 4 brings about a productive increase of about 35%, which means that productive costs also should increase. It is important to mention that this situation only happens if the company transitions directly from scenario 0 to scenario 4. If the company prefers to do an intermediate step that consists only of the productive increase, scenario 2, the productive variation is only 15%.

Although all this study is only around the number of employees, it must be considered that the production capacity of the furnace is the factor that will delimit the production, so it is essential that the company obtains a furnace that has a capacity above of two values studied, for example with capacity for 10 sheets per batch.

4.6.3. Analysis 3

In this third analysis, we try to understand what is the manufacturing evolution that the company needs to perform in order to increase production. For this it is important to study the evolution of bottlenecks of the system with increasing production.

The first bottleneck in production is the productive capacity of the kiln, since this was first idealized so that it was always working at maximum capacity. That is if the expected production figures were five plates the capacity of the kiln was five plates.

After analyzing the scenarios 1 and 2, it can be concluded that for the elimination of this bottleneck, the ideal would be to develop a kiln that would allow a productive capacity of ten plates per day if the company needed to increase in a large scale the production. This increment would give the company the possibility to work in two shifts, since having ten spaces in the oven, it would be possible to dry ten stones at a time that would allow feeding the shifts of the day, since the post-cure process would be done in the same with five stones at a time.

Since the issue of the kiln was solved, the evolution of the scenarios put another bottleneck that would have to be solved. We are talking about the number of employees needed. If the company wanted to produce seven plates a day with only three employees, it would not have shown in scenario 3. If the company intends to increase production of the line, it will be necessary to invest in another employee, so that this feature is no longer a bottleneck. At least up to the production of 8 plates day by shifts.

The last bottleneck with which this investigation came across was the issue of the press, in which we came across a bottleneck from the production of eight day-by-day plates. This bottleneck is very much due to the need for the same resource to be executed in two distinct steps in the process. To solve this issue, it would be relevant for the company to consider the possibility of acquiring a new press, since this acquisition would not only bring a monetary investment as well as the need to allocate more space to the productive area.

In short, there are three bottlenecks in this study: the furnace's productive capacity, the number of employees and the press. The first is undoubtedly the simplest to solve, since it would only be necessary when buying the oven if we considered the number of shelves, which, according to the analysis, would be ten ideally. Regarding the second, can be a situation analyzed after the beginning of production, that is, it is only feasible for the company to hire another employee, if the number of orders justifies it. The third and last bottleneck that came with this study is the most critical case, because the company would have to decide at the beginning of the assembling of the line, whether it is advantageous or not to leave a space reserved for the need to increase a press and a discharge table.

5. Conclusion

With the development of this project it was possible to respond to the two objectives presented by the company. The first objective consisted in the definition of the initial conditions and the second was the optimization of the line.

It is concluded that the ideal initial conditions are: to ensure that the capacity of the furnace is higher than the productive capacity of the line, that it would be possible to work with three employees until a production of six-per-day plates. If we want to produce more, we will need to increase the number of employees. But it is still important to note that if the company intends to produce more than seven plates per day, it is essential to rethink the line pressing system.

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