Dimensioning of operations in a chemical warehouse - Development and application of a discrete simulation model

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Abstract

The elements of logistics and supply chain have always been fundamental for the production, storage and movement of goods and products. However, it is only recently that these elements have been recognized as vital pieces in the economic environment. The proper functioning of supply chains has been increasing as a determining factor for the success of the entities that compose it, such as warehouses/distribution centers, which consequently have seen their responsibility increase.

With the resurgence of interest in L-Fucose (a rare monosaccharide with limited natural availability), compared to the previous 30 years and the consequent (exponential) growth of the market, the company 73100 saw the opportunity, being its area of business, to manufacture the monosaccharide. The scope of the work to be developed consists in the analysis and dimensioning of the logistical operations of an industrial area, in order to obtain reduced costs from a good management of inventory and resources related to a Biotechnology company, 73100, and which operates in a continuous process of supply of raw material (MP) and shipment of final products (PF). This work also intends to manage human and material resources, stock management and identify possible bottlenecks due to the traffic present in the complex. The results allow us to conclude that there is a big difference in the storage of raw material in comparison to what was previously calculated with the proposed input rates, significantly reducing the maximum amount of raw material storage, as well as a previously unrecorded balance of the Sodium Hydroxide raw material, ending its scarcity for production. It was also possible to verify an increase in the final product obtained due to a continuous production over time.

Keywords: Logistics Management, Supply Chain Management, Event-Based Discrete Simulation

1. Introduction

Setenta e Três Mil e Cem, Lda (“73100”) is a Portuguese start-up founded in 2006 to carry out R&D (research and development) projects, mainly in the area of Biotechnology, related to microbial fermentation of high added value products from renewable raw material, essentially for applications in the Biomedical, Pharmaceutical, Cosmetic and Food industries. The objective of this project is to analyze and dimension the logistic operations of an industrial area in order to obtain an improvement in efficiency and effectiveness from a better management of inventory and resources.

2. Case Study

2.1. Problem Definition

The company is headquartered in Lisbon and has a manufacturing unit in the parish of Igrejinha in Alentejo, municipality of Arraiolos, in the premises of "Antiga Fábrica do Tomate" with an area dedicated to the reception and delivery of products with utilities, with a total area of approximately 1820 m^2 in which activities related to the production and commercialization of monosaccharides are obtained from an innovative industrial process. The present work focuses its analysis on the complex presented in figure 1.

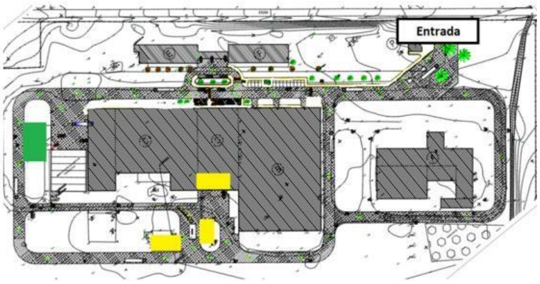

Figure 1 - Complex layout

The issues to be studied in this industrial complex, range from the control of bottlenecks caused by the arrival of raw materials in its own vehicles, to the dimensioning of resources and security stock, so that there is no stockout or excess of warehouse capacity. This implies that the timing of each operation within the industrial unit is necessary, respect for the circulation policies in the warehouse and that the flow of matter is always continuous, that is, all material that is received and transformed is then shipped at a constant ratio. As the company's production is only driven by demand for the product, we also want to study how demand peaks will influence the company's logistics.
The process will be subdivided into storage of raw materials, production and packaging and storage of final products as shown in the flowchart in Figure 2.

Figure 2 - Flowchart of the main processes

2.2. Description of the warehouse and main flows

Regarding the issues that may arise with the arrival of raw materials in its own vehicles, in addition to the traffic itself and the limitation of the routes provided, the company is considering subsequently manufacturing products for third parties, where the handling of raw materials of a dangerous nature is necessary, resulting in the priority of circulation of the truck cistern that transports it. Therefore, several alternatives for this transport will have to be studied, taking into account the time of operations and the traffic in the complex from vehicle entry to raw material unloading. Regarding the routes that the vehicles can take, in the figure 3, they are delimited with red and green lines. The red lines represent the paths that have a mandatory direction and the green ones that allow circulation in both directions.

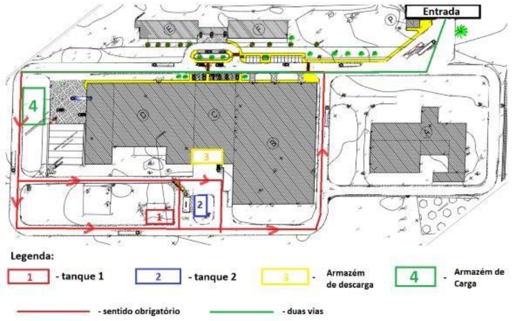

Figure 3 – Possible Flows in the industrial unit

There are 2 phases of handling goods: supply and dispatch. The supply operation starts with the existence of an order from the customers which, consequently, is transformed into a raw material order. The PM arrives at a port by sea, in a flexitank or in containers (liquid and solid respectively), and is then transported by its own vehicles in partnership with a 3PL-Third Party Logistics (outsourcing of logistics processes) that takes charge of all AC shipping. It should be noted that all these operations take a certain amount of time to reach the factory. When they arrive at the factory, the vehicles that transport them will be subject, upon entering the industrial unit, to a verification of documents by the security guard. Then, they are sent to the weighbridge where they will be weighted under the supervision of the security guard so that there is control of the good entering the factory. Subsequently, these will be sent to each respective discharge zone by order of the operator, with the liquid raw material going to the tanks and the solids going directly to the unloading warehouse. In this way, the glucose and sodium hydroxide are discharged in tank 1 and in tank 2 respectively, while the remaining reagents (solids) go to the discharge warehouse. It should be noted that in the case of liquid reagents, only one operator and one worker are needed to help unload the raw materials while in solid chemical reagents there is no maximum number of workers to unload the truck. Then, the solid raw material is transported to the separation zone and is stored on shelves according to the weights and its description.
In the case of the dispatch phase, the vehicle is also subject to document verification by the security guard and to weighting control. It is then forwarded to the loading area where it will take a certain time to be loaded by workers who will pick up the final product from the shelves in the refrigeration area, and the shelves in the ambient area, in which case it can be operated by both workers and operators using forklifts in the ambient area of the cargo warehouse. After loading, it will be sent back to the weighbridge so that the weighting is supervised by security and carried out after getting the documentation verified.

As long as the industrial complex is in operation, it is also restricted to one vehicle per unloading or loading zone.
In relation to material dispensing, the transport of raw materials in solid state is all done on pallets. They will be sealed in drum bags of 25 or 50 kg or in bottles of 1, 5 or 10 kg while being transported on pallets (max 1000 kg) and then being stored on shelves.

3. Literature Review

3.1. Logistics management

The logistical thinking, despite not knowing where it really started, it is possible to find already documented, in the mid-1900s, evidence of logistics in the theme of agricultural economy as reviewed in the document Kent and Flint (1997). However, it was in World War II when there was an evolution in various functions such as product transport, inventory, storage and spatial distribution due to the need for countries to gain advantages over each other. Later, logistics began to be taught as an area (1960) focusing on total system performance rather than individual performance as before. In 1970, with the growing importance of customers, logistics began to focus more on them, the customer becoming the main focus of companies, and only later, when concepts such as GCA, environmental logistics and reverse logistics began to appear, Logistics was considered a critical component of the companies' strategy (S. Globerson 2014). Despite its military origins, logistics is currently present in all supply chains and is even defined by the Council of Logistics Management (CLM) as "Logistics or Logistics Management as the part of the Supply Chain that is responsible for planning, implement and control the efficient and effective direct and reverse flow and storage operations of goods, services and related information between the point of origin and the point of consumption in order to meet the requirements/needs of customers. Michael Porter, in 1985, with the article The Value Chain – The Value Chain (Porter, 1985), Logistics appears having as its primary activities the supply management (inbound logistics) and the management of customer distribution (outbound logistics) how seen n figure 4.

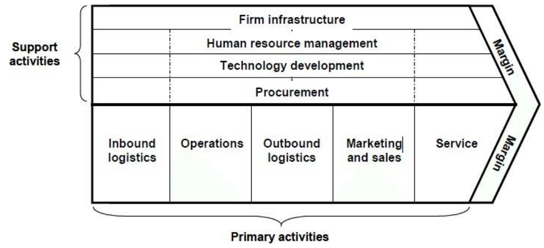

Figure 4 - The value chain (Porter 1985)

3.2. Warehouse management

Warehouse management is actively linked to the GCA. In demand-driven supply chains, warehouses work only for the storage of goods or, eventually, for the operation of more activities, but both for the purpose of supplying external customers. In supply-dominated CAs, warehouses are renamed stores and are intended to hold the stocks needed to feed internal activities such as production.
Warehouses are therefore an integral part of the CA infrastructure (Richards 2011).
Managing warehouse trade-offs is critical for the manager. The main trade-offs which are "Low costs", "High Service level" and "reduced inventory" are shown in Figure 5.

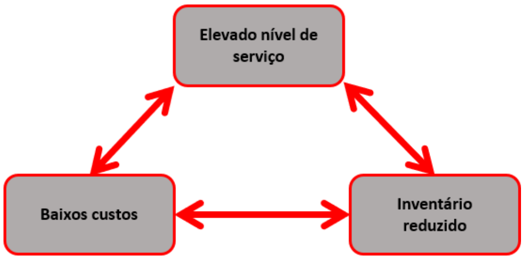

Figure 5 - Trade-offs in warehouse management (adapted from Richards (2011)

Warehouse managers must also recognize and balance other tradeoffs within the warehouse, examples of which are the following according to Richards (2011):

- increased productivity versus reduced labor costs;
- storage density versus faster pallet extraction;
- manual versus automated processes;
- increased choice versus accuracy rates;
- stock-holding costs versus out-of-stock costs.

Time is a non-accumulative resource that, once lost, cannot be directly recovered (Emmett 2005). Thus, process improvements and increased productivity come from the better use of time. In warehouse operations, it is critical that all the times required to perform activities are measured. The way different types of work are performed has a direct impact on the time used.

3.3. Shipping-Related Activities

These activities are a reflection of the goods receiving area. In order to do this, according to Emmett (2005) the following must be done :

- Make sure that space is available for any packaging according to the type of shipment.
- Analyze if the goods have loading areas.
- Check the order documentation and record each item on the delivery note.
- Check the goods for condition and perform quality control.
- Report discrepancies and inferior condition / quality.
- Establish the correct loading area; make sure it is safe and suitable for the operation.
- Make sure the vehicle is secure before loading it.
- Load the vehicle.
- Position the security seal with the driver present.
- Obtain the driver's signature.
- Record the departure of the vehicle and note the number corresponding to the label.

3.4. Flow Organization

After observing each activity in the warehouse, it is possible to usefully consider how to ensure that the operation occurs in an efficient and effective manner in conjunction with other activities. Thus, according to Emmett (2005), it is necessary to ensure these important principles for flow:

- Check the correct product handling group data and transfer speed principles.
- Check stock holding levels.
- Minimize travel distances to save time and resources.
- Check the trade-off between manual labor and mechanical handling.
- Assess the impact of operational requirements and paperwork / automated real-time information systems.
- \- Check the necessary trade-off between speed of access and use of available space by evaluating labor and equipment requirements, costs and key performance indicators (KPI's).
- \- When planning and simulating a 'new' warehouse layout, allow for proper stock/security control and regulatory compliance.

3.5. Inventory Management

Inventory management aims to manage the flow of products in a supply chain in order to achieve the required level of service at an acceptable cost. "Movement" and "Product Flow" are key concepts in inventory management (and also throughout the supply chain) because of the added cost of having inventory sitting idle. That said, Stuart Emmett gives the following reasons for keeping inventory in storage:

To decouple supply from demand. Because warehouses lie between supply and demand, one can find various types of inventory:

- raw materials for production
- semi-finished goods
- finished articles

As safety / security:

- to protect against supplier uncertainty
- to fulfill an unscheduled order physically supplied, by the warehouse.

In anticipation of demand:

- promotional or seasonal increases
- price discounts for bulk supply.

To provide service to customers (internal and external):

- finished goods stock cycles
- availability of safety stock for unforeseen demand (figure 6)

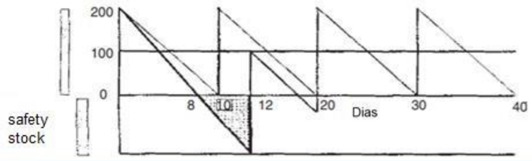

Figure 6 - Example of the existence of safety stock (Adapted from Emmett 2005)

You also need to take into account demand variation and the bullwip effect (refers to increasing swings in inventory in response to variations in consumer demand as you move up the supply chain. Fluctuating prices and lack of production of raw materials in pharmaceuticals intensifies this phenomenon (Simchi-Levi and Kaminsky, 2004).

3.6. Storage of Chemicals

Although chemicals contribute much to our society, they also pose serious threats to human health and the environment when handled improperly. Although companies sometimes appear to be reducing their amount of stock, the storage of goods (whether finished goods, semi-finished goods, or raw materials) remains an important step in the supply chain. Chemicals stock usually appears as either pipeline or warehouse stock. Pipeline stock includes products in maritime containers, such as gas tank transports, chemical tank transports, and mineral oil transports, while road transports include liquid bulk chemicals or even goods packed with chemicals. Warehouses can be found at GCA to store chemicals while they are not in transit to another

destination or prior to processing. Because many chemicals are hazardous to the environment or people, the effects of a poorly managed chemical storage facility can extend far beyond the boundaries of the warehouse itself, as has been seen in several disasters over the years.
Proper and sustainable management corresponding to the storage of chemicals must include measures to eliminate or reduce handling risks. This can be done from a good layout of the facilities and good handling of the equipment.

4. Case study analysis

To carry out this work and analyze the operations that involve the industrial complex, a simulation model will be built.

4.1. Problem Formulation

Through simulation, we intend to analyze the system of internal operations of the plant, from the arrival of raw materials to the shipment of the final product.
Given the large number of types of raw materials arriving at the plant, it was decided to group them into three different groups according to the way they are handled and the procedures to which they are subjected. In table 1, it is possible to see how a standard lot is composed (ratios).

Table 1 - Groups of raw materials used and its ratios

	Glucose	Sodium Hidroxide	*Solids*
Value	770448,98	92463,12	158490,31
Percentage (%)	75,4305	9,0526	15,51

4.2. Identifying the main entities

The diagrams are composed of shared entities and, for their construction, it was necessary to make an identification of the entities that have an impact on the warehouse performance. In this way, the entities that condition the operation in the system were identified:
Permanent, they remain in the system during the simulation:

- Tank 1
- Tank 2
- Loading warehouse
- Unloading warehouse

Temporary, they enter and leave the system during the simulation. They arise from an order:

- Unloading truck,
- Waste collection truck,
- Cistern truck 1
- Cistern truck 2
- Raw Material (Glucose, Sodium Hydroxide and solids (Drumbags and flasks)).

Since the entities mentioned are relevant to the operation of the system under study, it is expected that they are among the bottlenecks to be identified by the simulation model.
With the ratios already presented previously (table 1) follows the calculation of the Raw Material needed from each of the groups.

$$Group\ Required\ raw\ material\ (kg) = Total\ required\ raw\ material\ (kg) * Group\ production\ ratio\ (\%) \quad (1)$$

In order to assist in the creation of the simulation model, a life cycle diagram was created for each of the entities described above. The LCD describes the sequence of active and passive states through which entities pass (Oliveira 2014).
An activities cycle diagram will also be created which consists of the combination of all the life cycle diagrams of each of the system's entities (Robinson et al. 2010), diagrammatically representing the dynamic behavior of a system. The ACD describes the process of each entity through the succession of active states and passive states as well as the interactions between the different entities that make up the system (Oliveira 2014).

4.3. Duration of the activities considered

Because the products chosen for the development of the simulation model present a low turnover, it implies that the reception of their raw materials in the factory does not occur with the desired frequency to collect sufficient data for each of the activities.
Thus, several months would be necessary to collect the necessary data to be used in the construction of the simulation model to make it as close to reality as possible. However, it was decided to apply the triangular distribution to some activities in order to circumvent the uncertainty associated with their durations to overcome the difficulties.
This time will be used in the simulation software according to its type of statistical distribution. In this way, it will be possible to

make an approximation to the reality of the operations in the plant and this will be translated into results close to reality.
The application of the triangular distribution is a continuous distribution with a fixed minimum and maximum value (extremes) and a value most likely to occur (mode). The application of the triangular distribution is frequent in work done in the field of simulation (Okagbue et al. 2014).

4.4. Building the Model in SIMLU8

In this subchapter the construction process of the simulation model in SIMUL8 will be described, as well as the explanation regarding the data entered in the software. Based on the life cycle diagrams of the entities and the activity cycle diagram of the system, the simulation model was built from scratch.
The simulation model developed as part of the master's thesis is illustrated in figure 32. In order to simplify the various parts of the model, it was divided into 3 different sections:

- A - Process that the vehicles perform from their entry into the plant to their exit;
- B - Unloading and manufacturing process;
- C - Process of loading and shipping the Final Product;

Since the simulation model created is extensive, only the most relevant and/or complex activities are present in the document.

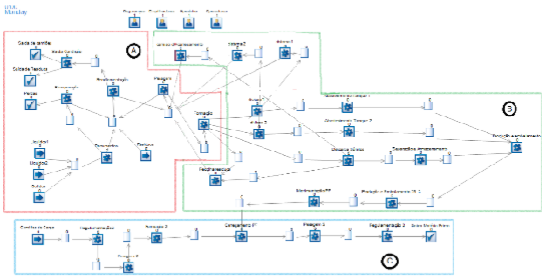

Figure 7 - Simulation model developed in Simul8

4.5. Model verification and validation

Verification and Validation of the simulation model is a necessary step in the development of a simulation model. Although the model created is a simplification of the real model, it is also possible to obtain results that are consistent and close to reality. That said, it is necessary to verify and validate the developed model. One of the main objectives of model verification is to ensure that there are no errors in the implementation of the model so that it presents the necessary rigor to be as close as possible to reality. A simulation was then performed for 5 years of the plant.
The verification and validation of the model was carried out in 3 phases:

- **Raw materials and other vehicles entering the system:** In order to verify that the raw materials and other vehicles enter the system correctly, it was necessary to analyze the results of the queues that receive the work items from the respective start points.
- **Applying Labels and manipulating them.** The correct functioning of the labels is determinant for the success of the model developed, since its bad implementation can lead to misleading results
- **Simulation Model Validation (bottlenecks).** After verifying the model and confirming the successful implementation of the various processes, it is necessary to proceed to its validation. As the work developed is about a start up company, which still has no data to be compared, it will only be possible to verify if there is any bottleneck throughout the model.

5. Experiences and Discussion of Results

In this section the results obtained after performing some analysis on the simulation model are presented. The use of sensitivity analysis in this section is an interesting tool in that it is possible to change the inputs of the model, in order to see its effect on the output of the system. Also entered in this section is the stabilization of the system, defining the warm up time, the simulation time and the number of times the model is run (number of runs) to be considered.

Inputs to be corrected

As mentioned before, one of the main reasons for the constraints is due to the shortage of Sodium Hydroxide raw material. Analyzing the Sodium Hydroxide stock chart, it is possible to verify during most of the time there is not enough raw material for production (figure 8).

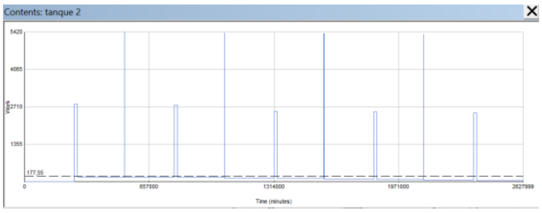

Figure 8 - Sodium hydroxide stock amount available

Although no limits on stock storage capacity were shown for the plant, the numbers shown for glucose and solids are excessive as can be seen in figure 9 and 10. This wait for production, also affected the amount of finish products.

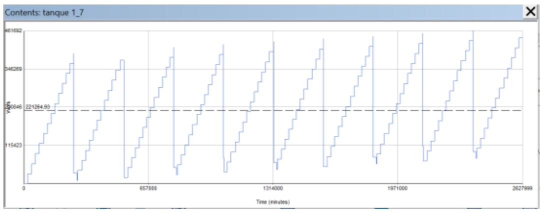

Figure 9 - Amount of Glucose stock available over time

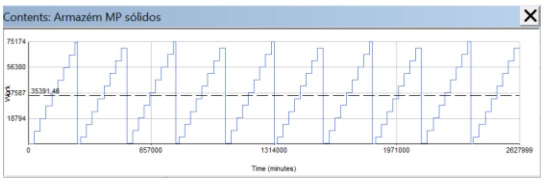

Figure 10 - Amount of Solids stock available over time

5.1. Analysis of the raw material input rate variation

Because it was not possible to change the production part due to the maximum capacities predefined by the company and the machines, changes were made to the input rates of the raw materials. Previously, the data thought by the company were the ones presented in table 2. That said, new data will be tried in order to overcome the constraints.

Table 2 - Previous Raw Material arrival data

Glucose		Sodium Hidroxyde		Solids	
System input time (minutes)	Quantity (units)	System input time (minutes)	Quantity (units)	System input time (minutes)	Quantity (units)
20215	29633	262800	46232	32850	9907

In order to calculate the new data to do the analysis, the consumption ratio given by the company was used. It should be noted that the data presented in table 3 does not correspond to an optimal solution and only serves as a path for an improvement of the results to be obtained. That said, we will proceed to the results analysis according to table 3.

Table 3 - New Data from Raw Material Arrivals

Glucose		Sodium Hidroxyde		Solids	
System input time (minutes)	Quantity (units)	System input time (minutes)	System input time (minutes)	Quantity (units)	Quantidade (unidades)
57524	29632,65308	113688	7200	86139	9905,644375

Warm up

The warm up period is necessary because at the beginning of the simulation, as the model is not stabilized, there is some inconsistency in the results. That said, the warm up is the time interval in which the software does not account for the results, so that the model becomes stable before the results are analyzed.

The big reason for the system needing warm up is the difference in time intervals between the arrival of the raw materials. Thus, in order to choose the optimal warm up time, the activity after production and packaging was analyzed, as it is here that the system begins to produce and consequently use resources. Having said this, the system does not start producing until approximately 3 months being this the warm up period settled.

Simulation Time

In order to determine the simulation time, the same procedure was performed as for the warm up. A run was executed, but now with the previously defined warm up time. To register its evolution, the simulation time was varied to verify the moment where the system begins to stabilize, that is, that the performance indicators stabilize. Having said this, it was verified that the system starts to stabilize at 5 years, being this the time defined for the simulation.

Number of runs to consider in the experiment

In order to test a solution, it is necessary to conduct an experiment with several runs, using a series of pseudo-random and independent numbers, with the goal of ensuring results with narrower confidence intervals. Using SIMUL8's tool, Trial Calculator, it was possible to arrive at a recommended number of runs. Since the system presents a great variability a confidence interval of 5% was introduced.

The reading of the results allows us to conclude that the average dwell time in the system is the performance measure that has the most variability given the high number of recommended runs. Being 31 the highest number of recommended runs, it is concluded what the most adequate number of runs for the model should be.

Results of the new input rate variation of raw materials

In order to verify the maximum stored capacity of each raw material, the graphs showing the quantity of raw material over time are presented (figures 11, 12 and 13). These graphs show a greater coherence of results, verifying that the new input rates register a remarkable improvement in the model, being this the chosen solution.

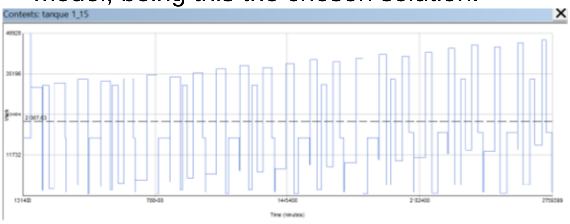

Figure 11 - New Glucose stock amount available over time

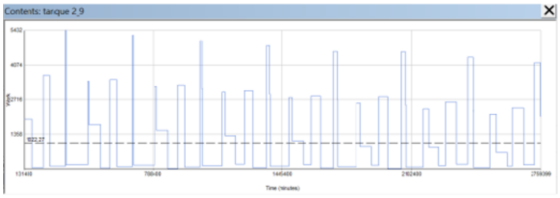

Figure 12 - New Sodium Hydroxide stock amount available over time

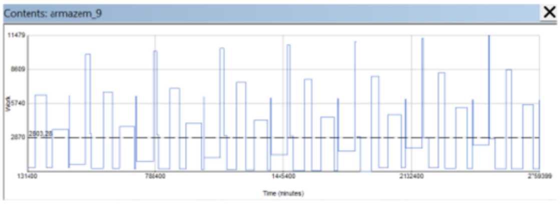

Figure 13 - New Solids stock amount available over time

It is also possible to verify that, in relation to the quantity of final product obtained, there was a considerable improvement, thus producing 882 drumbags of 25kg (figure 14), an improvement of approximately 11.1% compared to the 794 drumbags produced previously.

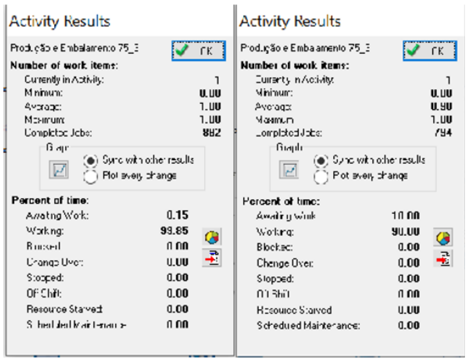

Figure 14 - New production results vs Old production results

6. Conclusions

With the resurgence of interest in L-Fucose (a rare monosaccharide with limited natural availability) compared to the previous 30 years, and the consequent (exponential) growth of the market, the company 73100 saw the opportunity, being its area, to manufacture the monosaccharide. The main difficulty in the L-fucose market is that it is only produced on a small scale, in the order of tens of grams to a few kilos. To date, there are no viable production processes to meet the large-scale demand resulting from future applications in the food and pharmaceutical markets due to the difficulty of obtaining L-fucose. In order for the production of the monosaccharide to be feasible, it is necessary to have cost reduction and efficiency increases in all operations that involve it. That said, it was necessary to explain the concepts involved in the manufacture of monosaccharides and to refer to the data relevant to the problem. Next, a literature review was performed regarding the concepts and definitions relevant to the correct analysis of the problem, namely Logistics Management, Warehouse Management and Simulation. In order to understand why simulation methods were chosen for the development of this study, several points of view were analyzed according to several authors who promote the use of simulation techniques, specifically discrete event-based simulation.
Next, the system referring to the case study was presented, the industrial complex where all the manufacturing processes will be done where all the issues to be studied are mentioned, as well as how to obtain data for the study. Discrete event simulation, using the SIMUL8 software, was also identified as a tool capable of assisting the analysis of this study. Because the factory under study belongs to a start up company, some difficulties arose during the development phase. The lack of comparison data and the creation of a model without the activities in operation in the factory was an obstacle that accompanied the

development of the document. However, the decomposition of the simulation model into several parts allowed to help both the construction and the verification, analyzing the processes in order to avoid the complexity of analyzing a system of this size as a whole.

The simulation model developed allowed to predict the various bottlenecks that may exist when the plant starts its production, to test the resource utilization rates. and finally to analyze the input rate.

Through the analyses performed it was possible to conclude that the minimum resources chosen by the company 73100 did not prove to be a problem. That said, as the utilization rate of these was very low, it is advisable to plan under the requirement of human resources, with these perhaps only called in their eventual need and not full time.

Regarding the number of workers, it was noted that the minimum necessary so that there would be no queues and that production would be continuous without interruptions would be the use of six workers.

The implementation of an input rate with the minimum possible orders became unfeasible, registering major constraints in terms of stock management and production. Therefore, new raw material input rates were calculated, and a new quantity of product to be input each time from the raw material Sodium Hydroxide. These calculations were based on the production time and quantity of the plant in order to obtain a higher level of balance throughout the system. Concluding the study, it was verified that five would be the indicated number of orders for Sodium Hydroxide, registering a greater number of orders.

The results allow us to conclude a big difference in the storage of raw material, significantly decreasing the maximum amount of raw material storage, as well as a previously unrecorded balance of the Sodium Hydroxide raw material ending its shortage for production. It was also possible to verify an increase in the final product obtained due to continuous production over time.

Although it was possible to draw some interesting conclusions regarding the simulation model developed within this work, some recommendations for future work are suggested. As the results obtained define only an improvement of the system, it is suggested the use of another tool with algebraic calculation and mathematical optimization that can formulate complex optimization problems in order to calculate better results for the raw material input rates in order to optimally stabilize the problem faced. It would also be interesting to use an inconstant raw material input rate (namely another type of distribution) in order to calculate a safety stock limit that would leave the plant always in continuous process.

In the eventual inauguration of the factory and start of production, it would be interesting to study the different activities of the factory again and compare them with the results obtained in this paper. If possible, it would also be interesting to collect new data for analysis.

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