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Design and Planning of Warehouses:

Application to the Case of Sociedade da Água do Luso

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Abstract

The supply chain design and planning is essential for any company, since its competitiveness is closely related with the efficient integration of logistic activities and the fulfilment of the required service levels, at the lowest possible cost. In particular, warehouses are known as an area where significant performance improvements can be achieved.

The problem in study was presented by the company Sociedade da Água do Luso, producer of bottled water. This company aims to redesign one of its current facilities, merging all its production and warehousing activities in this new facility, with the intention of reducing its logistic costs (Project One-Site). This work attempts not only to redesign the existing facility but also to plan its operations, since these decisions are strictly interrelated. A financial analysis and a performance evaluation is also performed in order to evaluate the viability of project *One-Site.*

The present work follows the framework proposed by Gu et al. (2007) for warehouse design and operation problems, comprising three main interrelated areas: design, operation and performance evaluation. The decision process regarding warehouse design and operation planning is made simultaneously, translating their close interrelation. In particular, the sections that compose the warehouse are dimensioned and a proposed layout is presented. It is also performed the equipment selection and it is determined the required workforce. This work is expected to be a useful tool for the decision process for the managers of company Sociedade da Água de Luso.

Keywords: warehouse planning and design, redesign, operation planning, storage.

1. Introduction

The supply chain design and planning is essential for any company, since its competitiveness is closely related with the efficient integration of logistic activities and the fulfilment of the required service levels, at the lowest possible cost.

A supply chain is an integrated manufacturing process, which starts at the raw materials and ends with the delivery of specified final products to customers, through a number of various business entities (suppliers, manufacturers, warehouses, distributors and retailers). Traditionally, this chain is characterized by a forward flow of products and a backward flow of information (Beamon, 1998).

During the optimization process of supply chains, warehouses are known as an area where significant performance improvements can be achieved (Won and Olafsson, 2005).

Warehouses allow companies to buffer the material flow along the supply chain, accommodating variability caused by factors such as product seasonality, and to perform value-added-processing such as kitting and labelling (Gu et al., 2007). Therefore, they are an essential component of any modern supply chain, playing an important role in the success, or failure, of today's businesses (Frazelle, 2002), and being responsible for a significant share of logistic costs. Rouwenhorst et al. (2000) state that the logistic costs associated with a warehouse can be, to a large extent, determined during its design phase. In particular, Sparks (1986) mentions that a centralized storage system allows the achievement of various improvements in operational efficiency.

Warehouse design is a highly complex task, where various trade-offs have to be considered among often-conflicting objectives (Rouwenhorst et al., 2000). Gu et al. (2010) outlines that all warehouse design decisions are tightly coupled and mention the importance of properly evaluate the impact of changing a certain design decision in the operation of the warehouse. These aspects contribute to the fact that, for now, there is not a consensual global systematic procedure for designing warehouses (Rouwenhorst et al., 2000).

Gu et al. (2007) proposes a framework for warehouse design and operation problems, comprising three major interrelated areas: design, operation and performance evaluation. Being the problems related with design and performance evaluation thoroughly analysed by the same authors in a later publication (Gu et al. 2010). Another framework is proposed by Rouwenhorst et al. (2000), which structures the warehouse design and control decision process into three levels: strategic, tactical and operational; depending on the time horizon of each decision.

To the best of our knowledge it was not found any paper regarding the redesign of an existing warehouse, and its specific challenges. Therefore, in this manuscript, the base structure to assess the viability of merging two current facilities of a Portuguese company, in order to reduce its logistic costs, will follow the generic framework proposed by Gu et al. (2007). Note that only the logistic component of the project is being evaluated since, *per se*, since it is sufficiently complex to perform a detailed analysis.

In the present chapter in its presented the introduction to this work, mentioning the most relevant references about warehouse design and planning. In the following chapter the case study is characterized and the main goals for this work are highlighted. In the third chapter the framework followed in this work is presented as well as some assumptions. During the forth chapter the warehouse is designed concerning all its sections. In the fifth chapter the viability of project *One-Site* is evaluated, while in the last chapter the main conclusions are mentioned along with propositions of future work.

2. Case study

As above mentioned, the case study analysed in this manuscript is of a Portuguese company, Sociedade da Água do Luso (SAL), which produces bottled water. This company aims to redesign its current facility in Cruzeiro, merging all its production and warehousing activities in this new facility, with the intention of reducing its logistic costs (project One-Site).

Nowadays, the company has two nearby facilities operating. The Luso facility is responsible for almost 75% of total production (from 3 production lines) being the rest produced in the Cruzeiro's facility that has a total of 6 production lines. Moreover, the Luso facility warehouse is only used as buffer until the pallets are transferred to the main warehouse situated in Cruzeiro, which stores the majority of finished products. It has a capacity for 7202 pallets, and is coupled with 4 provisional tents, with total capacity for 7300 pallets. It is from this facility that all clients orders are fulfilled. In both facilities there is a secondary warehouse, used to store packaging materials. The storage of finished products is also done in a third-party logistics (3PL) service provider called Luís Simões (DLS).

This 3PL helps SAL dealing both with orders that involve a lot of pallet handling and with the seasonality affecting its storage requirements. Since summer sales at SAL are twice as much as winter ones, its storage requirements are much above the average during the months that precede summer. During this period, SAL needs to send pallets to DLS, acting DLS as buffer, in order to be able to meet the high demand during summer. However, these buffer transferences represent a huge cost for SAL, accounting for almost 16% of logistic annual costs.

Consequently, there are four main reasons for which SAL wants to merge its two facilities: (i) extinction of internal transferences Luso-Cruzeiro; (ii) elimination of duplicated operations in both facilities, allowing both the increase of efficiency and the reduction of workforce; (iii) decrease of investment in installations, equipment and land and (iv) reduction of buffer transferences, due to an increase of capacity in the new warehouse of Cruzeiro.

The main goals of SAL are to achieve a 25% logistic costs reduction, while the payback of the related investment should not be greater than 2 years and a half.

The assessment on the One-Site project viability assumes that this new facility should be dimensioned considering a time horizon of 10 years, during which the storage requirements are supposed to grow at an annual rate of 0.5%.

3. Framework and assumptions

The base structure to assess the viability of project One-Site will comprise three major interrelated areas, as proposed by Gu et al. (2007).

i) Warehouse design:

- Overall Structure;
- Warehouse sizing and dimensioning;
- Dock dimensioning;
- Equipment selection;
- Department layout;
- Operation strategy;
- Workforce dimensioning.

ii) Warehouse operation:

- Receiving and Shipping;
- Storage;
- Order picking.

iii) Performance evaluation.

Notice that, in the design problem were included two additional components, dimensioning of both dock and workforce, in order to broaden the scope of analysis.

The decision process regarding warehouse design and operation planning is made simultaneously during this paper, translating their close interrelation.

Further in this paper the project *One-Site* evaluation is performed, considering a financial analysis, a performance evaluation and a sensitivity analyses.

The great majority of data used in the performed analysis was provided by SAL and it refers to the most recent values available, corresponding to the year 2010. Other data, was obtained through measurements in SAL installations, and in some cases it was also necessary to assume some values in order to proceed with the analysis.

Additionally, to the time horizon and annual growth rate of storage requirements, above mentioned, an assumption related with the capacity of the new warehouse in Cruzeiro was discussed with SAL. Therefore, this facility should have capacity to accommodate 80% of the annual peak of storage requirements in the end of the time horizon considered. This percentage tries to balance the trade-off between oversizing the warehouse and transferring a lot of pallets to DLS as buffer, with its related logistic cost.

Note that, during the analysis performed, the inventory policy was assumed to be the same of that of year 2010.

Lastly, it should be highlighted that we look for a redesign of the existing facility in Cruzeiro, leveraging the investment already made both in infrastructures and equipment, which involves restrictions to the design of the facility.

4. Warehouse design

4.1 Overall Structure

Concerning the overall structure of the new warehouse there are two main aspects to consider: (i) logistic infrastructures and (ii) production infrastructures.

Regarding the logistic infrastructures, the main warehouse should be expanded, trying to maintain most of the existing building. Whereas the provisional tents should be removed since they represent a considerable logistic cost (rent and energy cost due to cooling system) and do not present the same safety conditions.

Relatively to the production infrastructures, all production lines will be placed in Cruzeiro's facility. Due to technical restrictions, the 8 production lines output (excluding the ninth one – 1C that produces ice and its products are stored separately) will arrive from two opposite sides of the warehouse, half from the right side and the other half from the left, which will directly influence the layout of the warehouse.

4.2 Warehouse sizing and dimensioning

Sizing and dimensioning a warehouse implies determining the capacities and areas required by its sections. In particular, we will consider 3 sections: finished products storage, packaging materials storage and order pallet handling area.

However, it should be mentioned that the total area available for the construction of the new warehouse in Cruzeiro is 14147m^2 (excluding the area from the current secondary warehouse and the dock area). Moreover, according to the responsible for the logistics' department of SAL, 45% of this area should be reserved for both aisles and the final platform of the production lines. Therefore, the available area for storage equipment is 7781m^2.

4.2.1 Finished products storage

After analysing the occupancy levels of the current warehouses and the number of pallets sent as buffer to DLS, it was possible to conclude that the most critical period of the year is from March to July. It is during these months, that storage requirements exceeded the current maximum capacity (15502 pallets).

In all those months Cruzeiro's warehouse verified occupancy levels well above its maximum capacity, however it was mostly during the last three months that a higher amount of pallets were sent as buffer to DLS. In these critical moments, there were pallets stored both in aisles and in shipping area, which negatively affects the operational efficiency and increases the possibility of occurring accidents.

In 2010, the annual peak occurred in May, whit the storage requirements exceeding the maximum capacity by over 2500 pallets. So, considering the expected growth rate of storage requirements and assuming the same inventory policy, in the end of the time horizon considered for this project, the new annual peak would be equal to 21123 pallets.

As above mentioned, the warehouse will be sized in order to accommodate 80% of the new annual peak of storage requirements. Therefore, the new installed capacity should be equal to 16898 pallets, which corresponds to an increase of 12,6% compared to current total capacity.

Considering the storage rules followed by the warehouses of SAL, which depend on the characteristics of the pallets of products, we will consider that the real capacity of the warehouse will correspond to 95% of the installed capacity. Consequently, the real capacity will be equal to 16053 pallets. When the storage requirements exceed this value we assume that the pallets are sent to buffer in DLS, since we want to avoid the already mentioned negative effects.

Figure 1 presents the expected diary storage requirements of finished products, in the end of the time horizon considered, during the period from March to July. The distribution of pallets between the new warehouse (Project One-Site)

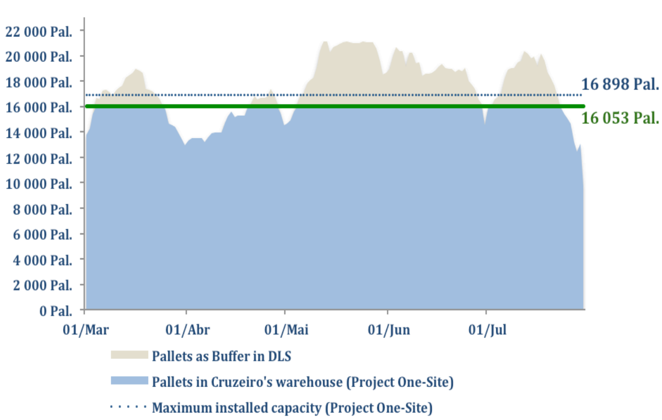

Figure 1 – Expected diary storage requirements.

and DLS is also illustrated in this figure.

This analysis allowed calculating the number of transferences to buffer (each transference corresponds to 30 pallets), and their related cost, for the two scenarios: with One-Site project or without it. Table 1 quotes the values of annual buffer transferences along with the annual buffer cost, regarding the last year of the time horizon considered. A detailed evaluation of this data will be made during the financial analysis.

Table 1 - Comparison of annual buffer cost.

	Annual buffer transferences	Annual buffer cost
With Project	710	326 518 €
Without Project One-Site	945	434 829 €

From table 1 it is possible to presuppose that, with the implementation of project One-Site, a significant decrease in buffer cost will be attain. In fact, considering the last year of the time horizon, it corresponds to a 25% reduction of buffer cost. For this comparison it was assumed that, in both cases, every time the storage requirements exceeded the real capacity of warehouses (95% of installed capacity), the corresponding pallets where sent to buffer.

Relatively to the dimensioning of the new warehouse, this decision is tightly coupled with the one related with the storage equipment. The characteristics of the equipment selected will directly influence the area required for the warehouse. However, it should be considered that the available area for storage equipment is 7781m^2. Moreover, as it will be seen in the two following subsections, this area will have to accommodate both packaging materials and the order picking area. Therefore, the available area for storage equipment dedicated to finished products corresponds to 7181m^2.

4.2.2 Packaging materials storage

Nowadays, the packaging materials storage is performed in both facilities. In Luso there are 300 m^2 dedicated to these materials, while in Cruzeiro there is a secondary warehouse with around 1200m^2 dedicated to this storage.

With the implementation of project One-Site, it will be required to augment the capacity in Cruzeiro. We concluded that an additional 400m^2 would cover both the extinction of capacity in Luso and the predictable increase of storage requirements regarding these materials.

4.2.3 Pallet handling area

Currently, only 2% of the total number of orders delivered from Cruzeiro require pallet handling, since most of SAL clients order entire pallets that do not need any handling after production. Inside the current warehouse of Cruzeiro, there is however an 116m^2 area dedicated to this activity.

With the implementation of project One-Site, and considering the predictable increase of the number of orders, we concluded it will be required to increase this area to 200 m^2.

4.2.4 Global warehouse sizing and dimensioning

Table 2 resumes the sizing and dimensioning of the three sections that will compose the new warehouse.

Table 2 - Capacity and areas required in Project One-Site

		Cruzeiro (Project One-Site)
Finished products	Capacity	**16 898 pallets**
	Area	**7 181 m^2** (Maximum useful area available at main warehouse)
Packaging material	Area	**1 200 m^2** (Secondary Warehouse) **+ 400 m^2** (Main warehouse)
Pallet handling	Area	**200 m^2** (Main warehouse)

4.3 Dock dimensioning

In order to properly dimension the dock of the new facility, it was necessary to analyse the behaviour of the loads performed in the current shipping area. One of the main conclusions refers to the number of loads, which is affected by seasonality both monthly and annually.

Around 35% of monthly loads are verified during the last week, compared with 20% share occurring in the first two weeks. This month seasonality is not higher because in the beginning of the month SAL sends more loads to its 3PL in order to buffer for the high demand verified in the last weeks. Relatively to the annual seasonality, during summer the number of loads is approximately twice as much as in winter, being August the month with higher annual percentage of loads (13,5%, compared with 5~6% during winter months).

Another important studied aspect was the punctuality of the trucks currently arriving at SAL. It was concluded that the company who performs all loads is punctual, since only 15% of the trucks arrive late, of which only 5% verified delays higher than 15 minutes (see table 3). This will allow a better planning in terms of loads and space associated.

Table 3 - Punctuality of trucks.

	Average	Gap
% trucks arriving late	**15%**	**12% - 17%**
Delay < 15 min.	**10%**	**8% - 13%**
15 min ≤ Delay < 30 min	**3%**	**1% - 4%**
Delay ≥ 30 min.	**2%**	**1% - 4%**

Lastly, it was studied the current load times. Table 4 resumes the most relevant results.

Table 4 - Load times.

	Average	Gap
Total load time	**40 min.**	**32 – 50 min.**
Time of lifting pallets and place them in truck	**10 min.**	**9 – 11 min.**

Regarding the total load time, since the truck arrives to the shipping area until it is load and leaves, an average equal to 40 minutes is verified. This comprehends the peak values during summer months, with load times reaching 50 minutes. Since currently there is not a dock in the facility, but only a simple shipping area, so around 10 minutes from the total load time are spent lifting pallets and placing them in the trucks.

Therefore, within the project One-Site, we propose the construction of docks, enabling the increase of efficiency during shipping. It should be implemented a preparation area near the dock, where forklift drivers would be able to prepare the loads for the following trucks in advance. This is a common practice in most warehouses and helps drivers to increase their efficiency by diminishing dead time. To increase both flexibility and operability we propose that each dock should have two preparation areas.

Figure 2 shows the average variation of the number of trucks arriving at SAL during a day of the last week of August (week with highest number of loads in the year) along with the new capacity for load preparation.

Nowadays, the workforce is dimensioned to be able to respond to the loads peak per hour observed during the first hours of the day. However, with the implementation of the preparation area, it will be possible to attenuate this variation impacts. During the hours with fewer loads the drivers will be able to prepare the loads for the next peak hours. With this procedure the workforce allocated to the docks could be dimensioned to respond to a decrease of 20% in the number of loads per hour.

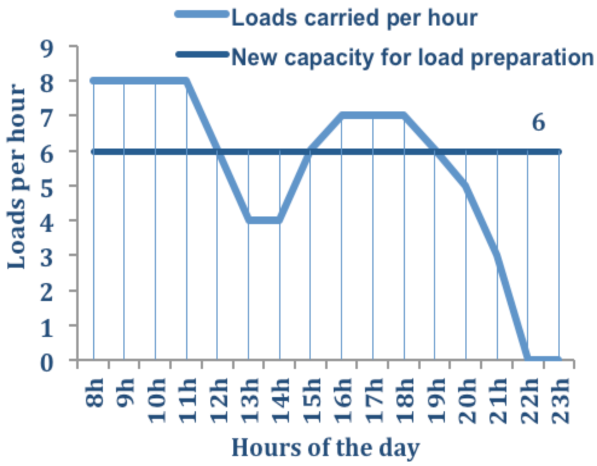

Figure 2 - Loads carried hourly and load preparation

With the implementation of these new docks it is now possible to have in place another common procedure in many warehouses where the actual truck driver is the one that carries the pallets from the preparation area to the truck. Currently, when the forklift drivers are responding to an order, they have to: (i) pick the pallets inside the warehouse and (ii) lift them and place them in the truck. As above mentioned, the second operation takes about 10 minutes of the total load time. With this operation improvement the lifting time will be eliminated, allocating the forklift drivers to the operation where they are really needed. According to the measurements made in another warehouse, the truck drivers will take about 30 minutes to load the truck that, on average, will imply a 10 minutes reduction of the utilization time required for each load in the dock.

Taking into account all the above mentioned aspects, and considering the week with highest number of loads as well as the expected increase of this number in line with the increase in storage requirements, the new warehouse should have 4 docks. This calculation considered also a 20% safety margin for possible delays and contretemps.

4.4 Equipment selection

4.4.1 Storage equipment

As stated previously, the selection of storage equipment will directly influence the required area for the new warehouse. Currently the capacity of Cruzeiro's warehouse is divided into two types of storage: racks (7202 pallets) and plaque (7300 pallets). Each type has its advantages and disadvantages, and tries to meet the specific characteristics of the pallets. In particular, plaque storage is cheaper and is a good alternative for pallets that are stackable while racks are more expensive but help maximize storage space.

Moreover, we are trying to maintain the investment made in the existing racks, and respecting the area and capacity restrictions, while looking for the minimal cost solution. Therefore, the choice of the best proportion rack/plaque to implement in the new warehouse is not trivial.

To help in this decision process we developed a linear programming optimization problem that considers all the mentioned restrictions and looks for the minimal implementation cost solution (Mestre, 2011). This optimization model was implemented in Excel utilizing the Solver tool. The results stated that the optimal solution implies having 13346 pallets of rack storage and 3552 of plaque storage, which requires the utilization of the maximum available area for storage equipment in the new warehouse (7181 m^2). These results also determine that the total area for the new warehouse will have to be 14147 m^2, which corresponds to the maximum available area for this redesigned facility in Cruzeiro.

After analysing the heights of the pallets of products of SAL and considering the height limitation of the warehouse, we concluded that all the new racks should present 3 levels in height and have capacity to accommodate pallets with 1.7 meters of maximum height.

Taking into consideration the proposed layout of the new warehouse, which will be further described, we determined the characteristics of the 23 storage blocks that will be present in the new warehouse, of which twenty are racks and the other three are plaque.

4.4.2 Forklifts and hand pallet trucks

Presently the only handling equipment that exists in SAL is rented forklifts. They meet the operational requirements and should be maintained. However, with the extinction of the Luso facility one of them will not be needed anymore. One the other hand, within project One-Site, we will require 1 hand pallet truck for each existing dock for the truck drivers to load the pallets. According to the equipment supplier this change will not mean any additional cost.

4.5 Warehouse layout

4.5.1 Preliminary analysis

A warehouse should be structure so that it can minimize the travelled distances during both storage and dispatch. As above mentioned, the new warehouse will receive pallets from opposite sides of the facility, which carries an added complexity to the layout decision process.

Therefore, prior to the definition of the layout for the new warehouse, it was performed an analysis to the production levels of the each production lines. As we can confirm with the values from table 5, the main conclusion is that the majority of pallets will arrive at the warehouse from its right side (83.2%).

This conclusion will influence the layout of the entire warehouse, in particular the location of the storage equipment and of the docks, as we will see in the following subsection.

Table 5 - Percentages of production of production lines

Production Line	Relative percentage of production	Total percentage from each side
2L	5.5%	Left side 16.8%
3C	7.0%	
4C	4.0%	
2C	0.3%	
4L	30.4%	Right side 83.2%.
5C	1.9%	
5L	40.3%	
6C	10.6%	

4.5.2 Proposed warehouse layout

Figure 3 presents the proposed layout for the new Cruzeiro's warehouse whithin project One-Site.

Relatively to the docks location, it was chosen to be in the right side of the warehouse in order to minimize the distances travelled in the warehouse, since the majority of the pallets enter in the facility through this side. Logically, the load preparation areas will be placed nearby the docks.

Concerning the storage equipment for finished products, it should be mentioned that the majority of the current equipment was maintained in the same locations. From racks b1 to b14 only b9 and b10 were added to the existing layout. About the other blocks (b15 to b23), the first six are racks while the rest are plaque. These are the blocks with a better location for all products coming from production lines situated in the right side. We chose to locate the racks b15 to b20 in this "privileged" zone of the warehouse in order to maximize its storage capacity, while the plaque blocks b21 to b23 where placed here because there are a lot of high turnover products produced in the right side whose pallets are stackable.

Regarding the location dedicated for the storage of packaging materials, this is the least attractive place of the entire warehouse, since it is far from both the production lines and the dock area. Therefore, the choice for locating this area here was rather straightforward.

Relatively to the pallet handling area, it was chosen to be in a central zone of the warehouse in order to facilitate the regular operations of collecting pallets from the various blocks of storage.

Lastly, the aisles were dimensioned taking into consideration the safety norms of SAL.

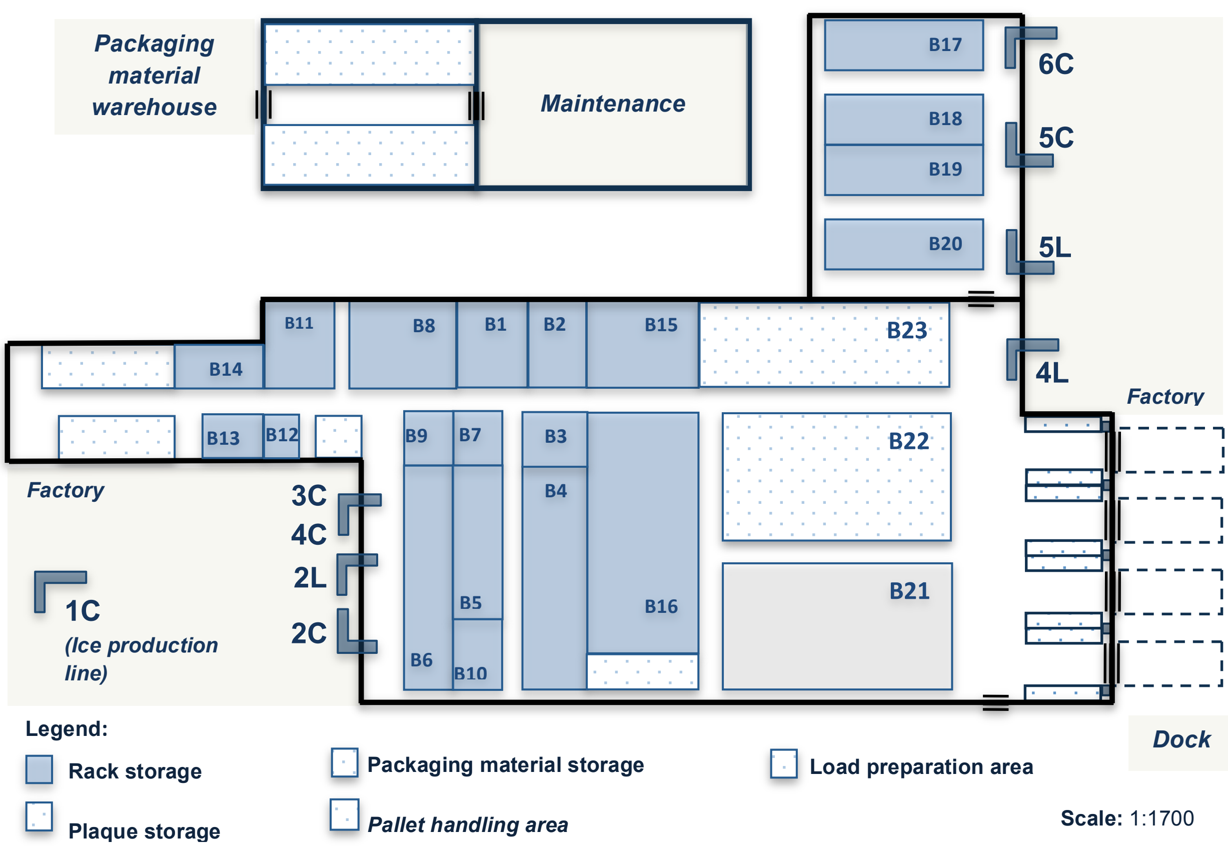

Figure 3 - Proposed layout for the new Cruzeiro's warehouse (project One-Site).

4.6 Operation strategy

4.6.1 Storage strategy selection

Determining the way pallets are stored in the warehouse is not a trivial question, especially when there are storage rules to obtain has there are in SAL. However, the selection of the best storage strategy is a key aspect for the efficiency of the operations performed in the warehouse.

Therefore, it was developed an optimization mathematical model that considers all storage rules and the characteristics of both pallets of products and storage equipment, and finds the optimal solution that minimizes the distance travelled by the pallets (Mestre, 2011). The data used to run the model was based on the day with the annual peak storage requirements, considering an annual growth rate of 0.5% in a time horizon of 10 years.

The Mixed Integer Linear Programming (MILP) model was implemented in GAMS software, through the ILOG CPLEX algorithm, to find the optimal solution. The MILP model was solved in a Two Intel® Xeon X568 computer with 2.66 GHz and 12 Gb of RAM.

The model is characterized by 4689289 variables and 35114 equations, and took about 13651 CPU seconds to reach a 2,58% gap solution, leading to the optimal solution of 25244895 meters.

Note that excluding the distance related with pallets sent to buffer in DLS, the real distance travelled in the warehouse by the stored pallets was 3154895 meters, where 1859745 meters correspond to distances travelled between storage racks/plaque and the dock and 1295150 meters to distances travelled between the production lines and the storage racks/plaque.

Taking into consideration the results of the model it was developed an allocation methodology that indicates the preferable storage racks/plaque to store a specific pallet based on the location of its production line and on the characteristic of the pallet being stackable or not (see figure 4).

4.6.2 Order picking method selection

Since in SAL all the stored products are entire pallets and the racks do not allow that more than one pallet is retrieved, order picking cannot be optimize through the optimization of the order picking routes. The only factor that contributes to a better order picking in SAL is the optimization of the allocation of pallets. Therefore, the order picking depends directly on the storage strategy selected.

4.7 Workforce dimensioning

The logistics department workforce of SAL has forklift drivers, operators and billing operators. Table 6 shows the reductions attained with the implementation of project One-Site.

Table 6 - Workforce reductions with project One-Site.

	Variation (with project One-Site)
Forklift drivers	- 37.5%
Operators	0%
Billing operators	- 17.5%
Total Workforce	- 31%

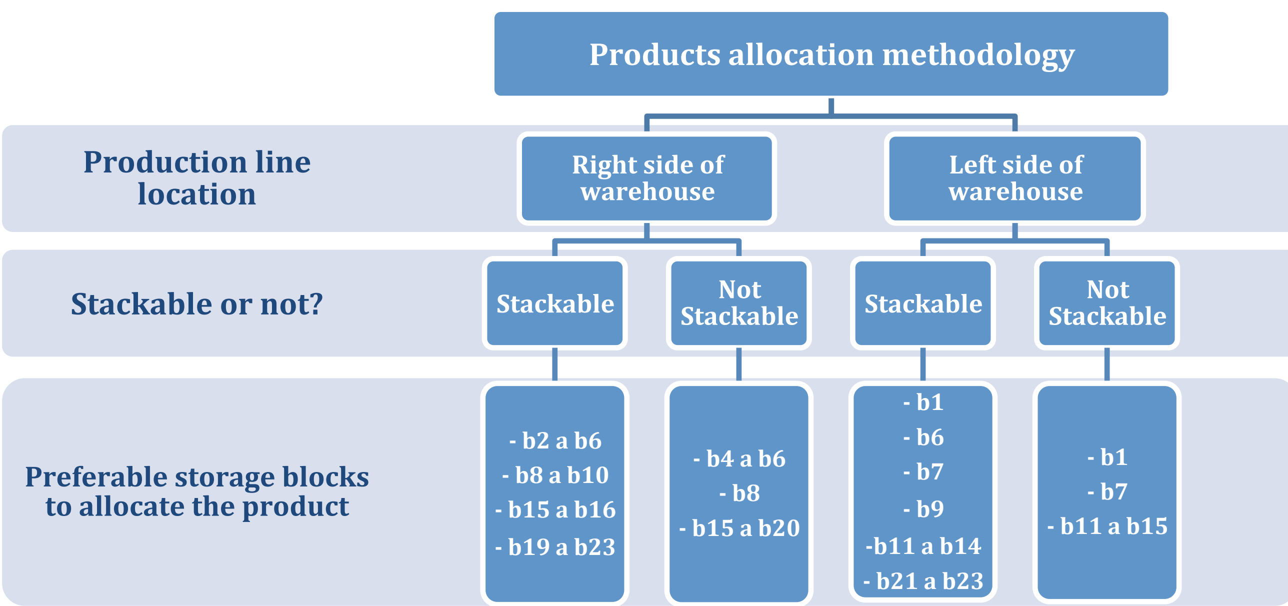

Figure 4 - Products allocation methodology.

The reduction in forklift drivers is achieved due to three major factors: (i) extinction of Luso facility which eliminates duplicated operations, (ii) better allocation of pallets in the warehouse through the new storage methodology and (iii) increase of efficiency in shipping operations related with the improvements in the dock area. While the reduction of billing operators is attained solely by the extinction of Luso facility, eliminating duplicated operations.

5. Project *One-site* evaluation

5.1 Financial analysis

In order to properly assess the viability of project One-Site, a financial analysis was performed. Table 7 shows the investment related with the project One-Site, while table 8 resumes the average variation of logistic costs attained, distinguishing between fixed and variable costs.

Table 7 - Project One-Site Investment.

	Investment
Masonry	280 500 €
Rack storage	276 480 €
Plaque storage	53 280 €
Docks	400 000 €
TOTAL	**1 010 260 €**

Table 8 - Average variation of logistic costs.

	Costs	Average variation of logistic costs
Fixed Costs	Wages	- 31%
	Forklifts and hand pallet trucks rental	0%
	Tents rental	- 100%
	Maintenance	0%
Variable Costs	Energy	0%
	Buffer	- 28%
	Transferences Luso-Cruzeiro	- 100%
Total Logistic Costs		**- 31%**

Project One-Site allows an average reduction of 31% of logistic costs. Since the related investment is equal to 1 010 260€, it was possible to determine that the payback for this investment is 2 years and 3 months.

Considering the main goals of SAL with project One-Site: (i) achieve a 25% logistic costs reduction and (ii) investment payback lower than 2 years and a half; we can conclude that both goals are achieved with project One-Site.

5.2 Performance evaluation

In order to evaluate the improvements achieved with the implementation of project One-Site the following performance indicators were calculated (see table 9). During this evaluation were considered indicators of productivity and of financial indicators that better illustrated the efficiency improvements achieved with project One-Site.

Table 9 - Average variation of performance indicators.

	Performance indicator	Average variation With project One-site
Productivity	Average number of pallets stored by a conductor in a day	+ 38,6%
	Average preparation time per load	- 30,5%
	Average number of loads performed by a conductor in a day	+ 36%
	Average load time in the dock	- 25%
Financial	Average logistic cost per sold pallet	- 31%
	Average buffer cost per sold pallet	- 28%

From the values presented in table 9 it is possible to conclude that the productivity and financial performance of project One-Site is considerably better than if this project was not implemented.

5.3 Sensitivity analysis

In order to support the final recommendations related to the project One-Site, the impact of possible variations of two specific parameters was studied: (i) annual variation rate of storage requirements and (ii) percentage of the annual peak storage requirements for which the warehouse is sized.

The first parameter was assumed to be +0.5% during the analysis above presented, and in this studied it assumed values from –5% until +5%. The main conclusions were that the project is not very sensitive to this specific parameter, since independently from the value considered, the logistic costs verified with project One-Site are always lower (at least -19%). The only cases in which the costs verified a variation lower than 25%, were related with variation rates that SAL

Regarding the second parameter, the warehouse was sized in order to accommodate 80% of the annual peak storage requirements. In this studied the value of this parameter varied from 71% until 100%. It was concluded that this is a sensitive parameter for the project, since it had a considerable impact especially in both investment required and its corresponding payback. It was also concluded that, if the warehouse was sized in order to meet 75% of the annual peak storage requirements, the two main goals of SAL would also be met, achieving a 25% reduction of logistic costs, with a related investment payback of 1 year and 11 months. Therefore, the impact of this parameter should be further analysed in a future work.

6. Conclusions and future work

In this work, an existing facility of a Portuguese company was redesigned, through the merge of two nearby facilities. In order to structure the analysis of warehouse design and planning it was followed the framework of Gu et al. (2007).

The main goal was to reduce 25% of the total logistic costs, while the investment payback of the project should not exceed 2 years and a half.

During the design and planning phase the characteristics of the new warehouse were determined, regarding its capacity, its area, the layout of its sections and the dimension of the required workforce.

The project evaluation demonstrated the great advantages of merging the two facilities. In particular, it was attained a 31% reduction of total logistic costs with a related payback investment of 2 years and 3 months. Therefore, it was proven the viability of project One-Site.

This work aims to serve as a basis for future warehouse redesigns, due to the scarce literature available on this specific theme of warehouse design.

As suggestions of future work it is proposed the study of the implementation of a WMS (Warehouse Management System) system in the new facility of SAL, which would enable the optimization of the allocation of pallets in the warehouse, in real time. A second suggestion of future work is related with the study of the simultaneous impact of both parameters considered in the sensibility analysis: annual variation rate of storage requirements and percentage of the annual peak storage requirements for which the warehouse is sized. With this study it would be possible to analyse what would be the optimal storage capacity for the new warehouse of SAL. The third and last suggestion is related with the storage equipment. It is proposed to perform a deeper analysis regarding the type of storage equipment that should be used in the new warehouse. In particular, it should be studied the storage racks that allow the storage/retrieve of two pallets at a time, what would increase significantly the efficiency of warehouse operations.

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