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Analytical and economic methodology for storage of large heavyweight equipment in industrial processes

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ABSTRACT

Numerous studies concerning warehouse-design methodologies have been performed focused on the storage of products on pallets or of intermediate size and/or moderate weight loads. These studies, however, do not provide with optimal results for industries that work with equipment or objects of uncommon sizes and shapes and with large weights, which are difficult to move and involve high costs and complex operational actions, affecting to the production processes and interfering with the logistic processes or the supply-chain of a company. This study proposes an analytical methodology using economic and technical qualitative criteria that can be applied specifically to large and heavy equipment warehouses. Both quantitative aspects, such as availability and cost of space, and also qualitative considerations, such as flexibility requirements, impact on manufacturing process and risks associated, are evaluated. To determine an optimum implementation solution, several decision-making methods, such as Electra I & II and Analytic Hierarchy Process are employed with due consideration of multiple criteria. The results obtained are modulated and reinforced using a SWOT (strengths-weaknesses, opportunities- threats) and a Risk analysis to verify this single ultimate solution. The said process led to the establishment of a decision-making methodology suitable for any organization possessing large-scale storage systems.

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1. Introduction: background

Warehouses are a key element of modern industrial supply chains (Frazelle, 2002). Many large companies are oriented towards directly supplying to their customers, which implies an adaptation of the design of its installations to their needs (Xiao & Hu, 2017). Storage of manufactured items within a production centre form an important component of industrial supply-chain operations, especially from the perspective of logistic costs (Van den Berg, 1999). One can appreciate the need to reduce

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the time spent by customers facilitating availability of optimized warehouse designs (Harrison & Van Hoek, 2005). Based on this principle, a series of criteria and methods concerning design and dimensioning of warehouses have been developed and discussed throughout the available literature.

- Rowley (2000) and Christopher and Towill (2001) tackled the said problem based on technological and operational needs of the company in conjunction with a thorough review of the available information concerning the associated economic costs. These studies are rather beneficial regarding the maintenance of a strategic inventory, at the point of decoupling of the supply chain, to address Lean manufacturing problems, such as bottlenecks, especially in volatile markets.
- Higginson and Bookbinder (2005) argued that supply and distribution can be complex enough as to result in a need for goods to be consolidated in the exploitation of inventory at production centres, especially in cases of dispersed demands.
- Thomas and Meller (2015) focused on designs based on impact reduction of operational costs without affecting customer service that, in turn, derived on the analysis of required equipment, internal distribution of the warehouse, collection systems, etc.

However, many authors (Goetschalckx et al., 2002; Rouwenhorst et al., 2000) observed a lack of theoretical base in these design methodologies, and highlighted the non-existence of 'a comprehensive methodology based on science for the general design of storage systems'. The design guidelines discussed above are, therefore, not applicable to all type of industries.

The cost of inventory associated with storage of large and heavy products necessitates of the proposition of a model that facilitates the decision-making process during the design phase of a warehouse. Data from the United States indicate that operational costs of large items in warehouses correspond to, approximately, 22% of the overall expenses of a logistic business (Meyer & Meyer, 2005). Moreover, studies performed in Europe report similar figures with average disbursements of 25% (Dwivedi, 2016).

Heavy products (weighing tons) and large dimensions (in the order of m^3) require particular storage system compared with the models generated for the common type of reference product in warehouse design studies. These special items are characterized by their rather difficult and expensive handling. The limited volume of a warehouse and the average duration of stay, subject to more random and modified facilities customized for these weights and dimensions as indicated by Accorsi, Baruffaldi, and Manzini (2017). Thus, appropriate treatment through specialist designs is essential to the success of major companies (Azad & Moshkov, 2017; Rouwenhorst et al., 2000).

This study presents a method of analysis applied to these storage systems of heavy and bulky products that define guidelines with which to propose solutions based on compliance with minimum desirable requirements. It also establishes criteria to evaluate and compare each one of the solutions that arise, validating and reinforcing the optimal solution using the SWOT (Strengths, Weaknesses, Opportunities and Threats) and the Risk analysis tools (Ventura, Valdebenito, & Golany, 2013).

2. Methodology

The proposed study aims to establish a methodology based on the analysis of current storage systems by settling a guideline for the proposal of solutions, evaluating candidate designs and comparing them in accordance with multiple criteria, as presented by Hermoso-Orzáez, Gago-Calderón, and Armenteros-Ruiz (2018).

Baker and Canessa (2009) established their own method of decision support for warehouse design. Although their research-oriented analysis facilitated the inclusion of complex models and methods, it is generally easy to assess and communicate (Gu, Goetschalckx, & McGinnis, 2010). Any design method must establish a process to be executed through a series of phases: concept, data acquisition, functional specifications, technical specifications, selection of media and equipment, and design and selection of planning and control policies (Bartholdi & Hackman, 2014). Alternatively, these decisions can be located at either strategic, tactical or operational levels (Lerher, 2016). Although the selection of storage systems is strategic and whereas their sizing and design are tactical decisions, control policies generally belong to the operational level (Accorsi, Baruffaldi, et al., 2017). Thus, most decision criteria are interrelated. However, the hierarchical framework outlined reflects the different horizon of decisions (in long, medium or short-term) while higher-level solutions act as constraints for lower-level design problems (Rouwenhorst et al., 2000; Wang, Luo, & Hua, 2017). These methodologies enable not only to extract the knowledge by experts but also to find the causes and effects that help to make the best decision. In order to do so, techniques to seek information, like Delphi or Checklists, as well as diagram tools such as Cause and Effect or Strengths, Weaknesses, Opportunities and Threats (SWOT) graphs are applied. The categorization and prioritization of the risks detected will be carried as a complement to a previous Analytic Hierarchy Process (AHP) used in the design stage (Guerrero-Liquet, Sanchez-Lozano, Garcia-Cascales, Lamata, & Verdegay, 2016).

In these cases, it is advised to follow a top-down (general-specific) approach, instead of a bottom-up methodology (Guerriero, Musmanno, Pisacane, & Rende, 2013). The ideal design method groups together all the related problems at the same level and simultaneously derives optimized solutions to various sub-problems to facilitate the achievement of a global optimum solution (Fontana & Nepomuceno, 2017; Liu, Liao, Huang, & Yang, 2018).

To finish with the description of the methodology presented, different preliminary aspects are described along with a detailed explanation of the application of the tools used in the multi criteria approach designed for the proposal.

2.1. Analysis of current storage system

A detailed description of current storage systems is presented herein to provide accurate information concerning equipment, facilities, and products areas used for possible solutions. Subsequently, an analysis of the annual cost associated with storage activity is performed. Warehouses are often optimized under cost reduction guidelines; the maximum performance that must be achieved, therefore, becomes the main design criterion in conjunction with minimum investments and operational costs (Gu et al., 2010) to take decisions concerning the following items that conform the storage space.

2.1.1. Description of equipment, facilities, and areas available

- Lifting Equipment

Lifting equipment currently used in storage processes as well as other machinery available for the same objective (Manzini, Accorsi, Baruffaldi, Cennerazzo, & Gamberi, 2016) can be listed, based on observation of their maximum lifting capacity of loads, as follows—cranes, gantry cranes with hydraulic systems, mobile-type hydraulic jacking systems, or trucks equipped with crane arms.

- Equipment for product transfer

Machinery used for the movement of produced units from the manufacturing sections to the storage area and, ultimately, to the dispatch parcel are analysed (Ekren & Heragu, 2010; Hamzheei, Farahani, & Rashidi-Bajgan, 2013). It is possible to highlight, amongst them, the following systems: skidding on rails with the availability to use a railcar transfer table, Self-Propelled Modular Trailers (SPMTs), air casters or bridge cranes, and gantry cranes.

- Support systems and associated units:

Large dimensions and weights of stored units require different support systems, which can be more complex compared to those used in most warehouses (Manzini et al., 2016). Such support systems include storage on rails, use of wheels on platforms, metallic supports on wooden or metallic pillars, and vertical self-supporting units.

- Recruitment of external logistic services:

The outsourcing of the logistic services can be an alternative to the use of in-house equipment and facilities within production centres, especially for cases wherein equipment limitations exist, albeit with a direct impact on costs associated with storage activities.

- Storage areas and access routes:

All the areas utilized for storage activities as well as others available within the scope of the production centre must be analysed (Accorsi, Bortolini, et al., 2017) focusing mainly on aspects such as the location within the plant or factory, surface storage, land state, access to storage area, and accessibility to means of transportation: road, railway or sea.

2.1.2. Description of storage procedure used

A detailed description of current storage systems is required concerning the use of available equipment and facilities; storage areas and access points used are systematically analysed to provide an estimate of personnel involved at each stage (Li, Moghaddam, & Nof, 2016).

Within the storage unit, it is possible that different processes are presented, depending on certain parameters or features of the products to be stored (Baker & Canessa, 2009), in such a way that products can be classified and treated differently according with certain parameters (weight, size, type of transport to be used, customer requirements). It is, therefore, essential to define clearly such a classification with the aim of applying it in the alternative solutions approach (Gu et al., 2010).

2.1.3. Economic analysis of current procedure

Similar to above, current storage processes must also be analysed from an economical perspective (Park & Kim, 2010). To this end, indicators can be used to measure the economic viability of different alternatives, such as the Net Present Value (NPV) and Internal Rate of Return (IRR), affected by the Capital Cost and the Payback.

Here, the prominent design criterion is the storage capacity, and the main design objectives include low investment and operational costs. Working storage systems possess other requirements, since the demand is mostly unknown in advance, and warehouse recovery must be fast enough to avoid production delays or gaps. This might lead to a rather limited design with respect to the time elapsed between a purchase requisition and its completion. Especially, with regard to heavy products that occupy a large volume, different concepts and costs associated with storage may, in fact, have their origin in, or depend upon, different areas or departments within the company, such as logistics, maintenance, or production. Therefore, the first step in the economic analysis comprises compilation of concepts and costs associated with the storage activity. A typical cost breakdown analysis is presented in Table 1, where the different types of costs according to their typology are described and classified: costs of space and facilities dedicated to storage inside and outside the production buildings, handling costs and stock ownership and administrative expenses.

Generally, in industries that manufacture products over a wide range of weights and dimensions with reduced warehouse volumes, storage is usually associated with waits, until items are shipped to their final destination, or a temporary storage service, under certain conditions prescribed by customers. This implies that storage does not usually fulfil stock functions to cope with the many possibilities available. This feature, in certain cases, facilitates the consideration that costs associated with a possession of a certain stock and the administration expenses are constant and independent of the storage method used, since the general warehouse volume remains unchanged.

Another cost-related concept with significant relevance is the saturation cost within the storage space (Lee & Elsayed, 2005). This cost is associated with the overrun expenses required to find and prepare a temporary storage solution when the

Table 1. Classification of storage costs.

Cost Type	Costs Associated
Costs of space dedicated to storage inside and outside of centres of production	Rent and amortization of land used for storage Funding in the event of acquiring land Maintenance: repair, painting, study of the state of soil, etc. Insurance Taxes imposed on the building and space Costs of storage-space saturation
Costs of facilities both within and outside the centre of production	Rent and amortization of fixed or mobile facilities employed within storage Funding in the event of acquiring or adapting facilities Repair and maintenance
Handling costs	Personnel involved in storage Amortization of lifting equipment and transfer of goods purchased in the property Rentals of lifting equipment and transfer of goods to external logistic companies Equipment repair and maintenance Supply of electricity, fuel, and water
Cost of stock ownership	Investment immobilized by stock in warehouse Insurance of stored goods
Administrative costs	Administrative personnel expenses Equipment costs

inventory volume exceeds the maximum capacity of the storage system employed. As it has already been mentioned, the time that each unit of a certain product remains in stock, and therefore its volume, have a largely random character that depends on various non-controllable and difficult-to-estimate factors such as dates of freight availability for final transport, customer preferences regarding product-delivery dates, and so on. This fact, along with the high cost that may result from an increase in the storage capacity of the current system (in terms of acquisition of new land, adaptation of facilities, etc.) and the application of temporary solutions to space saturation (rental of new warehouses, outsourcing of equipment and transport, or storage logistics services), gives to this concept a certain relevance that requires a detailed analysis.

In this way, with regard to cost analysis of storage systems currently used as well as their alternatives to be proposed, it is necessary to define temporary solutions associated with different cases or space-saturation levels and to calculate the cost associated to each solution (Gambari, Grassi, Mora, & Rimini, 2008).

Storage-cost analysis aims to establish an annual storage cost in order to be able to compare solutions and carry out economic feasibility investigations. However, the concepts of space-saturation cost and the other expenses within the established breakdown possess a random character associated with the volume of inventory that requires to be statistically calculated. Therefore, for an accurate estimation, it is necessary to consider the volume of inventory as a probability density function (normal, uniform, etc.) with a proper adjustment based on the historical values of the storage volume and the associated inventory rotations (Jacopo-Pontormo, 2017). In this way, given a storage volume 'Y' defined by a probability density function '$f(Y)$' with the upper and lower limits given by 'b' and 'a', respectively, the estimation of the space-saturation cost can be defined as expressed in equation 1.

$$Cost\ space\ saturation = \int_a^b f(Y) \times C_{saturation}(Y) \quad (1)$$

where $C_{saturaci\square n}(Y)$ denotes the cost associated for a given inventory volume. A similar approach can be used for other concepts of costs with random or dependent character, say inventory volume or others (Mogale, Kumar, García Márquez, & Tiwari, 2017).

2.2. Definition of goals or objectives to be achieved

The improvement of storage systems must begin with the clear definition of a series of objectives to be achieved. This task assumes a large relevance in the process, since these points can be used as a common guide to assess current storage systems as well as any possible alternative to be considered later (Accorsi, Baruffaldi, et al., 2017).

These objectives may be economic, logistical, operational, or safety at work, and they will mark some general rules or guidelines to propose alternative solutions, as well as being used as the assessment criteria of the same (Poulos, Rigatos, Tzafestas, & Koukos, 2001). In order to use these objectives as elements in multi-criterion decision methods, it is necessary to assign a weight or relative importance value to each of them. Major objectives to be accomplished within this type of industry include:

- Reduction of their overall storage costs.
- Economic viability of prescribed solutions (based in NPV, IRR, or Payback). It is necessary to know the investment required for the implementation of the new systems that are being proposed.
- Capacity of the proposed system to adapt itself to future expansions in inventory volume, caused by any possible factors, and thereby reducing the possibility of space saturation.
- Capacity of the system to adapt itself to new/additional customer specifications and/or market requirements, within the scope of their temporary storage, or some process that has already established itself as a common practice within the industry.
- Compliance with the minimum requirements of health and safety at work or the improvement of the existing conditions.
- Mitigation of existing limitations within current storage systems in terms of weight, dimensions, maximum storage, morphology, materials, etc.
- Simplification, improvement or slight impact on the conditions of operation of other areas affected by the task of storage: reception of materials, dispatch of units completed, etc.

2.3. Definition of evaluation criteria

It is necessary to define in detail the criteria that would facilitate the evaluation and comparison of alternative solutions being proposed (Ventura et al., 2013) as the first step to build a selection method as proposed in the flow diagram given in Figure 1. Some of these criteria are based on objectives previously enumerated. The major

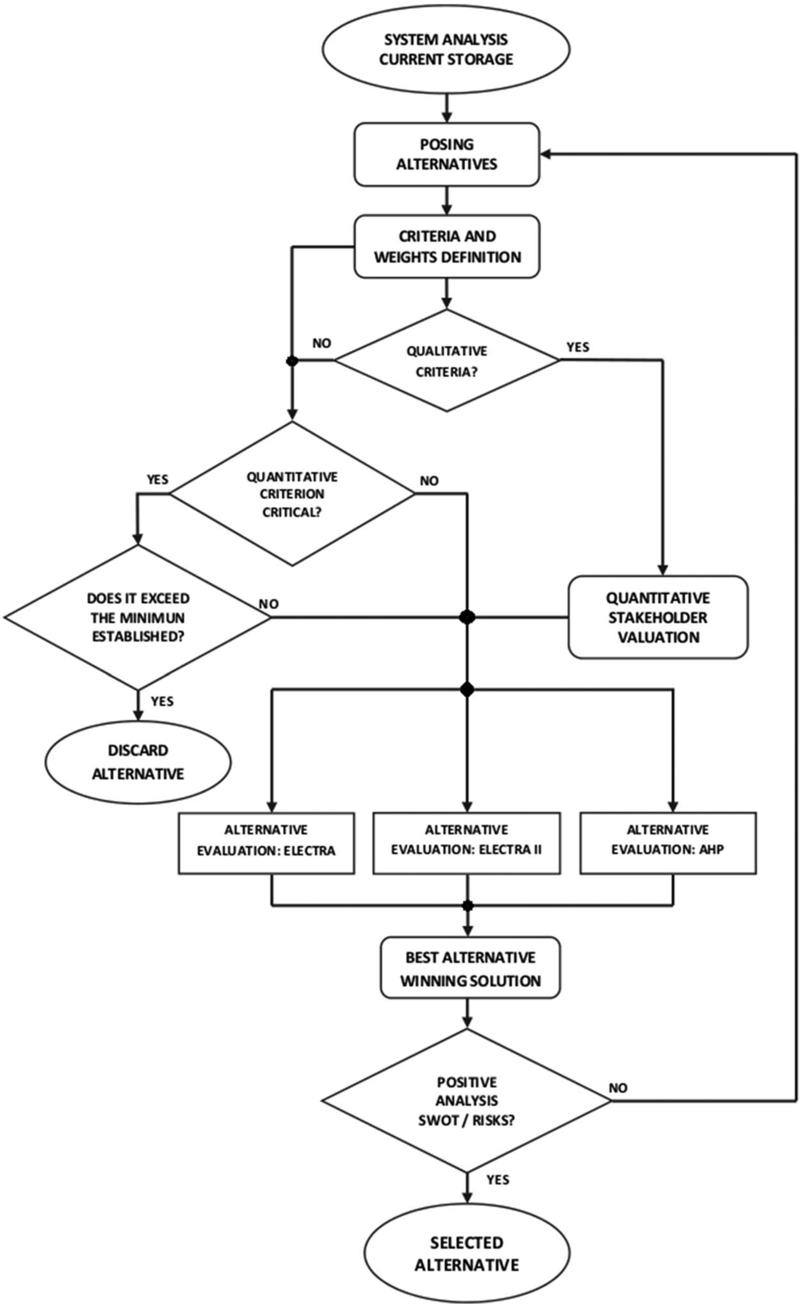

Figure 1. Flow diagram of the proposed selection method (multi–criteria analysis via AHP and Electra I and II) modulated at the end by SWOT and Risks analyses.

objectives behind the definition of such criteria include the reduction in the number of proposed solutions and simplifying the search for the best one. Certain criteria, established for purposes of assessment and comparison can be defined as critical factors that act as a first filter to obtain a set of conducive solutions. The set of criteria must acquire a minimum value to be guaranteed, preferably in a quantitative way, so that solutions that do not comply with any of these factors are discarded by the evaluation process. Commonly, these critical factors have mainly an economic or financial nature owing to the great importance of these aspects in terms of decision-making within the company.

Regardless the set of criteria being considered as critical factors or not, they may be either of quantitative (reduction of annual maintenance cost, NPV associated with investment required, etc.) or qualitative type (such as security). Irrespectively of their classification, as mentioned, these criteria must be associated with a relative weight to facilitate their use in conjunction with the multi-criteria decision methods. The establishment of these weights is crucial for the definition of optimum solutions for the enterprise as a whole. This requires the participation of all the departments that may be affected —directly as well as indirectly—depending on interests and concerns of each area but arriving at a consensus for the fulfilment overall objectives of the company (Dey, Bairagi, Sarkar, & Sanyal, 2017). Equation (2) shows the criteria to assign different weights (‘wj’) to be applied to each evaluation concept (‘Cj’).

$$\begin{gathered} C\ (set\ \ of\ \ N\ \ criteria) = (C_1,\ \ C_2,\ \ C_3,\ \ \ldots, C_N) \\ w_j = relative\ \ weight\ \ of\ \ criterion\ \ C_j \\ \sum_{j=1}^{N} w_j = 100\ \ \% \end{gathered} \tag{2}$$

The method of evaluating solutions set out within functions of different criteria over a rating scale of 1–9, wherein a value of 1 implies the worst rating obtained by a solution under the given criteria, and 9 corresponds to the best rating possible. Those quantitative criteria allow an assessment of the solutions more objectively, even considering the simplification that a linear weighting between the minimum and maximum level within the set of alternatives is done. However, criteria of the qualitative type require a more objective-based assessment in accordance with actual needs of the company based on the collaboration and the consensus of all the areas involved (Mangalan, Kuriakose, Mohamed, & Ray, 2016).

A set of criteria that could be considered critical in the design of warehouses have been indicated below.

- Reduction in storage costs: defining the minimum savings in the cost of annual storage compared to current systems.
- Economic viability: establishing the minimum requirements of certain criteria: NPV, IRR or Payback.
- Compliance with the minimum requirements for safety and health at work. This criterion, used as a filter, can be evaluated by means of a simple *checklist* to identify hazards along with the required prevention measures to be complied.

2.4. Description and analysis of alternative solutions

Always, a large number of alternative solutions in terms of storage systems based on different criteria can be proposed (Accorsi, Bortolini, et al., 2017). Several methods, such as brainstorming, expert consultation, proposition of solutions employed by similar industries and production centres, can be used to find or define new different solutions.

2.4.1. Description of alternative solutions

This relates to the initial analysis that evaluates a proposed storage system, its operation, feasibility, and limitations as well as an estimate of the maximum capacity or volume of inventory that the proposed system would be able to contain in comparison against the current system.

2.4.2. Study of saturation of space

As mentioned before, the saturation of the warehouse space and its effects on the costs incurred have a great impact on operation of the production centre and leads to significant increase in overall costs. Therefore, each solution requires a detailed study of the maximum volume of inventory that the system is able to accommodate along with the associated probability of space saturation (Tappia, Marchet, Melacini, & Perotti, 2015). Again, we may note that calculation of this probability could be based on the statistical consideration of the historical data of volume of inventory.

Equally, the saturation of space leads to a series of temporary measures to accommodate more units. At this stage of analysis, it is necessary to define the temporary solution to be executed for each levels of saturation of the warehouse space in terms of renting external space, hiring outsourced logistic services, premature shipping toward destination, and so on.

2.4.3. Material, construction, and equipment required

The description of a proposed solution entails the enumeration of the materials and equipment to be procured for its implementation. This include the warehouse start-up process and its corresponding operation, as well as any other modifications and civil works to be performed concerning the available facilities (both in the warehouse as well as in other spaces within the production centre, such as vehicle accesses or gates in the entry and exit routes).

2.4.4. Customer-specific requirements, market, or industry

As mentioned before, a potential target for the introduction of alternatives to the current version of a warehouse corresponds to the upgrade of the current storage system based on new customer-specific requirements or common practices being developed within the industry. This objective requires a thorough verification to be performed to assess the possibility of including these requirements under the proposed system in addition to quantifying all the additional costs associated.

2.4.5. Analysis of overall space required and load capacity

Another fundamental aspect of warehouses -especially with regard to the type of industries that store heavy large-sized products- is the compatibility of a proposed solution with the expected dimensions and weights of the stored products (Park & Kim, 2010). It is important to perform a detailed checklist of aspects such as:

- Estimated the dimensions of the products to be stored and all the space available within the proposed facilities
- Compatibility of the facilities for the accommodating heavy loads of stored products
- Check for sufficiency of available space for safe manoeuvre of product lifting and moving equipment, such as trucks, cranes, SPMT vehicles, external logistic equipment …
- Minimum safety distance between elements required
- Access to additional storage areas located at a sufficient safety distance from the main location
- Space available for the execution of remaining foreign operations within the production centre

2.4.6. Compliance with established health and safety criteria

As discussed above, this criterion often forms a critical factor for mandatory compliance in any possible solution. With the objective of facilitate standardized verifications, it is proposes the development of a checklist that encompasses all aspects of health and safety requirements associated with the system (Otto, Boysen, Scholl, & Walter, 2017; Trab et al., 2015).

2.4.7. Costs associated with each alternative solution

The costs related to an initial investment for the implementation of a new storage system are listed below in terms of the expenses associated with materials and equipment procurement and the construction works to be executed (Goh, Jihong, & Chung-Piaw, 2001).

- Total cost associated with the execution of a work: adaptation of the concrete floor, demolitions, etc.
- Costs of the acquisition of new equipment and facilities: cranes, SPMT vehicles, ferries, rails, etc.
- Costs associated with the logistic implementation—these are associated with the impact of execution and implementation of new storage systems based on the normal warehouse operation. This is mainly due to the destruction of part or all of the current storage system, incurring in a series of costs similar to those that would occur in case of space saturation since it would be necessary to find a temporary solution during the execution of the work and the adaptation of the facilities. 'CI_j' represents the cost of the initial investment for the alternative solution 'j' which takes values from the '1' to the 'n' possible solution as presented in Equation (3).

$$CI_j = \textit{Initial investment cost} \text{ corresponding to } \textit{alternative solution} \text{ '}j\text{' } (€) \quad (3)$$

Based on the breakdown of the proposed storage costs, a more detailed calculation of the annual expenses associated with this activity must be performed. This demonstrates the significance of the cost of saturation of space that can be investigated statistically. The annual savings in the storage cost of an alternative solution ('AA_j') is represented in Equation (4).

$$AA_j = CAA_{current} - CAA_j \left(\frac{€}{año}\right)$$
$$CAA_j = Annual\ cost\ of\ storage\ of\ alternate\ solution\ 'j' \left(\frac{€}{año}\right) \quad (4)$$
$$CAA_{current} = Annual\ cost\ of\ storage\ of\ the\ current\ solution \left(\frac{€}{año}\right)$$

As mentioned above, one of the main objectives that can be set as a critical factor is the minimum saving in the annual cost of storage. In this sense, the annual savings of the proposed design could be expressed in the form of annual net profit, which would eventually result in the cash flow during the economic viability analysis.

2.4.8. Economic and financial profitability of each alternative solution

In this section, the economic and financial indicators used to evaluate the viability of the investment required to modify the plant design of a warehouse are defined. On the one hand, there is, for each alternative, an initial total investment cost ('K') and periodic quasi-rents ('Q_j') representing the annual savings associated with the storage costs ('AA_j'). On the other hand, the capital cost ('i') or the interest rate of the loan necessary to make the investment in a number of periods or years ('n') must be estimated.

Considering the annual cost of storage of the current solution ('$CAA_{current}$'), compared with the annual storage costs incurred for each alternative proposal ('CAA_j'), it is possible to calculate the annual savings in the storage cost for that solution ('AAj') taking into account the initial investment ('K') for the implementation of the storage facilities. The economic-financial study with these variables can be carried analysing the economic viability of each alternative solution using dynamic methods, economic-financial indicators such as NPV, IRR and the amortization period (Kerzner & Kerzner, 2017; Zevgolis, Mavrikos, & Kaliampakos, 2004).

As mentioned earlier, the annual savings in storage cost ('AA_j') could be considered as a cash flow or positive annual income. It can be considered constant in terms of calculating the economic viability of each proposed solution (Franco et al., 2016).

The economic-financial indicators considered are:

- The Net Present Value (NPV). It can be calculated using Equation (5).

$$NPV = -K + \sum_{z=1}^{n} \frac{Q_z}{(1+i)^z} \quad (5)$$

$$K = CI_j = Initial\ investment\ cost\ of\ alternative\ solution\ 'j'\ (€)$$

$Q_z = AA_j = Annual\ savings\ in\ storage\ cost\ of\ alternative\ solution\ 'j'\ for\ year\ 'z'$ (€)

i = discount rate (%)

n = number of years to the study of the investment

- Payback (P). It can be calculated using Equation (6)

The recovery or return period represents the number of years (or periods in general) that have to pass to recover the initial investment with the updated cash flows.

$$K = \sum_{z=1}^{P} \frac{Q_z}{(1+i)^z} \tag{6}$$

P = recovery period of investment.

The Payback will be the number of periods that elapse from the initial moment of a project until the sum of the updated net cash flows is exactly equal to the investment 'K' executed.

- The Internal Rate of Return (IRR). It can be calculated using Equation (7).

It can be defined as the interest rate that makes the NPV null. Hence, it can also be called as the marginal efficiency of capital. The rate is internal because it does not depend on exogenous factors to the investment. Thus, the IRR is calculated obtaining the rate 'r' which satisfies Equation 7.

$$NVP = K + \sum_{z=1}^{n} \frac{Q_z}{(1+r)^z} = 0 \rightarrow \mathrm{K} = \sum_{z=1}^{n} \frac{Q_z}{(1+r)^z} \tag{7}$$

n = number of years to the study of the investment

Only projects that meet the condition of 'feasibility' will be viable: 'r' > 'i', where 'i' is the interest rate that corresponds to the 'cost of capital'. The larger the value of 'r' is achieved, the more profitable the investment becomes.

2.4.9. Assessment of solutions

Finally, an assessment of the alternative solution proposed must be performed. First, on the basis of the criteria referred to as critical factors, which facilitate verifying whether a solution complies with minimum requirements or act as filters and discard solutions corresponding to negative cases. Once a proposed system has been evaluated in accordance with the critical factors and is found to meet all the necessary requirements, it is assessed in accordance with the other criteria and allotted a rating on a scale of 1 to 9, as established above.

2.5. Evaluation and comparison of proposals

Once the solutions raised in accordance with previous steps have been analysed, and those that do not fulfil critical requirements defined have been discarded, a comparative study of valid solutions must subsequently be performed with the objective of determining the optimum solution (Borovinsek, Ekren, Burinskiene, & Lerher, 2017).

Table 2. Quantitative assessment of economic and financial criteria for each alternative considered.

	Alternative solution 1	Alternative solution 2	…	Alternative solution z
Initial investment cost (€)	Cia_1	Cia_2	Cia_3	Cia_z
Annual storage cost (€)	Caa_1	Caa_2	Caa_3	Caa_z
Storage cost savings (€)	Aa_1	Aa_2	Aa_3	Aa_z
Storage cost savings (%)	ACa_1	ACa_2	ACa_3	Aca_z
NPV (€)	$NPVa_1$	$NPVa_2$	$NPVa_3$	$NPVa_z$
IRR (%)	$IRRa_1$	$IRRa_2$	$IRRa_3$	$IRRa_z$
Payback (years)	PBa_1	PBa_2	PBa_3	PBa_z

Table 3. Array of alternative solutions modulated by the assessment criteria.

	Alternative solution 1	Alternative solution 2	…	Alternative solution k	Relative weight criterion
Criterion 1	u_{11}	u_{21}	u_{a1}	u_{k1}	w_1
Criterion 2	u_{12}	u_{22}	u_{a2}	u_{k2}	w_2
…	…	…	…	…	…
Criterion j	u_{1j}	u_{2j}	u_{aj}	$*u_{kj}$	w_j

$*u_{kj}$ = qualification of the alternative 'k' according to the criterion 'j' $\in .[1,9]$

As previously explained, it is necessary to establish a relative weight to each criteria through the participation and the consensus of company stakeholders related with the storage activity, so that Equation (2) can be verified.

Subsequently, each alternative solution can be rated in accordance with each criteria on a scale from 1 to 9. For cases wherein the assessment criteria are quantitative, evaluations are simplified because a rating of 1 could be allotted to the solution performing the worst during quantitative assessment while a rating of 9 could be allotted to the best solution, thereby establishing a proportional and linear evaluation for the remaining solutions. On the other hand, qualitative criteria that mandate the decision to be made by experts within the organization itself are quantified using standard techniques (such as groups of experts, Delphi method, brainstorming, etc.). It is helpful for a simple assessment of the quantitative criteria to summarize the key economic aspects of each solution in accordance with Table 2.

Once all the alternative solutions have been evaluated, an array organized by assessment criteria can be compiled as in Table 3. An integer value in the range from 1 to 9 is given to each of the criteria assessed for each of the alternatives formulated.

Once the above assessment techniques were established, mathematical modelling techniques can be used to design warehouses (Fontana & Cavalcante, 2014; Sanei, Nasiri, Hannover, & Moattar-Husseini, 2011). Using multi-criteria decision-making methods facilitate the evaluation process to concrete the optimum solution possible in accordance with the established objectives (Fontana & Nepomuceno, 2017; Hermoso-Orzáez et al., 2018; Ventura et al., 2013).

In this case, the methods included are:

- AHP (Baudry, Macharis, & Vallee, 2018; Nam-Tae & Gi-Tae, 2019; Saaty, 2008).
- Electra I (Huang & Chen, 2005)
- Electra II (Fernandez, Figueira, Navarro, & Roy, 2017)

Table 4. Results obtained via use of different multi-criterion decision methods (Electra I, II and AHP).

Order/(weight)	Classification according to Electra I (w = 25%)	Classification according to Electra II (w = 25%)	Classification according to AHP (w = 50%)
1th	EIa_1	$EIIa_1$	$AHPa_1$
2th	EIa_2	$EIIa_2$	$AHPa_3$
…			
K	EIa_k	$EIIa_k$	$AHPa_k$

The use of these same multi-criteria decision-making methods is frequent in those cases where simpler systems, such as the weighted average of factors are limited as in problems or decisions of greater complexity that require the participation of a set of subjects that have different interests and perceptions (Macharis, Springael, Brucker, & Verbeke, 2004).

Likewise, the use of other multi-criteria decision-making methods can be considered in addition to those listed above (Bortolini, Faccio, Gamberi, & Pilati, 2015; Marttunen, Lienert, & Belton, 2017). The main objective is to be able to quantify the order of preference of the alternative solutions according to the additional methods. The preference order established for each alternative solution can be summarized is this case as in Table 4.

Most of decision-making methods are interrelated. However, the outlined hierarchical framework reflects the horizon of (long, medium, or short-term) decisions while higher-level solutions act as constraints for lower-level design problems (Rouwenhorst et al., 2000; Wang et al., 2017) in the event that discrepancies with the winning alternatives by the different methods are found. The AHP Methodology, due to its hierarchical character, its capacity to check inconsistencies through a number of par-wise comparisons (Ramanathan, 2001) and the possibility of assessing quantitative and qualitative criteria in problems of selecting alternatives for large storage in size and weight, is considered to be the most suitable and the preferred one. (Nam-Tae & Gi-Tae, 2019). Therefore, twice the weight of relevance compared to the ELECTRA Methods (Laosirihongthong, Adebanjo, Samaranayake, Subramanian, & Boon-Itt, 2018) is assigned. This is justified by the suitability indicated by different authors that have studied the usage of the AHP Method in the evaluation of problems oriented to the design of warehouses. For example, González, Folleco, and Sarache (2005) propose this AHP method preferably as it allows a good approach to reality in replacement decisions in large industrial equipment. Likewise, authors such as Oeltjenbruns, Kolarik, and Schnadt-Kirschne (1995) apply the AHP in order to determine the best alternative when replacing several milling machines of large size and weight of the German airline Deutsche Aerospace Airbus using both economic and technological criteria.

Thus, the method proposed uses the AHP as the main reference of decision building a hierarchical model where numerical values are given to the judgments studied, managing to measure how each element of the hierarchy contributes to the immediately higher level from which it emerges (Aznar & Guijarro, 2012; Delgado, Herrera, Izquierdo, & Perez, 2011).

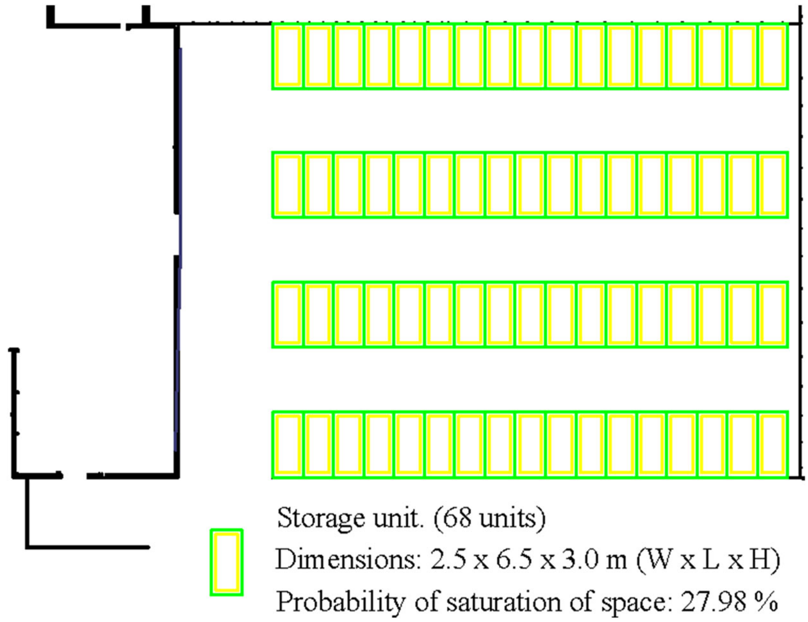

Figure 2. Detailed view of stored-product arrangement at departure site.

In Table 4, the structure of results obtained for each alternative option evaluated is represented in an orderly manner. Only in case of a tie, the weights established for each method will allow to undo it and choose the best alternative. However, it is always at the expense of sending the winning alternative to a SWOT or Risk analysis, which will allow the final solution chosen to be argumentatively reinforced (Guerrero-Liquet et al., 2016).

2.6. Simulation results for a case study

A case study was set to test the methodology in the redesign process of a warehouse of products of great size and weight for the storage of large power transformers within a real manufacturing company. It is proposed to decide the best design from 3 different alternatives (and with several sub-alternatives in some of them) from an original distribution given as presented in Figure 2. This currently used storage system, framed within the description detailed in paragraph 2.1, has the following features:

- Maximum capacity: 68 units with dimensions measuring $2.5 \times 6.5 \times 3.0$ m ($W \times L \times H$) along with an additional 1 m considered as the safety distance between individual units and a similar 0.5 m clearance from the site contour.
- Probability of space saturation of the warehouse: 27.98%.
- Volume of inventory defined in accordance with a normal distribution with mean a value (μ) of 61 and standard deviation (σ) of 12 units. In this way, let X be the volume of inventory at any time, you can consider that $X \sim N(\mu, \sigma) = N(61, 12)$.

- The current storage procedure use external logistic services, which provide rentals for lifting machinery and transfer of goods/cargo from carrier ships to the point of storage within the area depicted in Figure 2. The products are placed directly on the ground using cranes or jacking systems.
- After the completion of economic analysis of the current procedure, as indicated in section 2.1.3, the annual cost associated with the storage maintenance, including the cost of saturation of the warehouse space, was calculated to be approximately 1,347,852.01 €/year.

Subsequently, the improvement goals to be achieved over the current storage system include:

- Reduction of annual storage cost associated
- Achieve an economic viability of the new solution based on the NPV, the IRR and the Payback.
- Reduction of the impact of operations associated with storage information during operation and normal function of the production centre.
- Increase the capacity of the proposed solution to store products within a room equipped with a roof that protects stored products against environmental impact. This requirement is framed as one of the conclusions drawn from the market and client requirements analysis.
- Put forward the flexibility of the warehouse in order to be able to adapt it to future expansions in inventory volume, space, incorporation and adaptation of new equipment, and products having greater weight and/or dimensions.

The objectives listed above are synthetized as evaluation criteria as follows:

- Criterion 1: reduction of the annual costs associated with storage (being a 20% the minimum achievement allowed).
- Criterion 2: Obtain economic viability of a solution based on:
  - NPV > 0 (up to 10 years and considering 'i' $= 3.15\%$)
  - IRR $> 3.15\%$
  - Payback < 5 years (considering 'i' $= 3.15\%$)
- Criterion 3: Increase in any value the capacity to store products within an enclosure equipped with a roof and protected from environmental impact.
- Criterion 4: Improve the level of flexibility of the solution.
- Criterion 5: Reduce the impact of the warehouse procedures on the normal factory operation.

The first and second criteria are, respectively, the most significant evaluation items and their relevance decreased as the list advances. The specific relative weights chosen are presented in Table 5.

As indicated, 3 different storage-system designs were considered in this study (alternative 1, 2 and 3), including two variations for cases 1 and 3 (Alternative 1.1, Alternative 1.2, Alternative 3.1 and Alternative 3.2). The design configurations of

Table 5. Relative weight of each selection criterion.

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
W	30%	25%	15%	20%	10%

these alternatives are shown in Figure 3 and the detailed list of their main characteristics are grouped in Table 6. The sub alternatives maintain the same design of their tree with or without including a cover protection system for the equipment stored.

Alternative 1

- Installation of a railcar transfer table and provision of annexed rails to accommodate loads on benches with wheels. Provision of 13 rows of pairs of rails with a capacity of 7 units in each line.
- Minimum safety distance: 1 m.
- Maximum capacity: 91 units.
- Probability of space saturation: 0.62%.
- Use of two sub-alternative solutions considering the use of comprising insulated-steel sandwich panel covers to protect the stored products.

Alternative 2

- Use a gantry crane to transfer the products toward their storage point. Disposal of products within 9 rows comprising 7 units each.
- Minimum safety distance: 1 m.
- Maximum capacity: 63 units.
- Probability of saturation of space equalled 43.38%.
- The option of using cover-protection systems is not available.

Alternative 3

- Use of SPMT vehicles and metal benches. Distribution of products with 4 rows, each comprising 17 units. Distances between products were sufficient to facilitate manoeuvring of SPMT vehicles.
- Minimum safety distance: 1 m.
- Maximum capacity: 68 units (equalled).
- Probability of space saturation: 27.98% (equalled).
- 2 sub-alternative solutions considering the use of comprising insulated-steel sandwich panels to protect stored products against environmental impact. This system was highly rated by customers.

The results of the evaluation process of the alternatives are presented in Table 7. In accordance with the critical criteria defined, Alternative 1.2 is rejected straight forward because it does not comply with the minimum Payback requirements. Alternative 1.1, on the other hand, meet all the minimums established as well as solutions 2, 3.1 and 3.2 that fulfil all the requirements set.

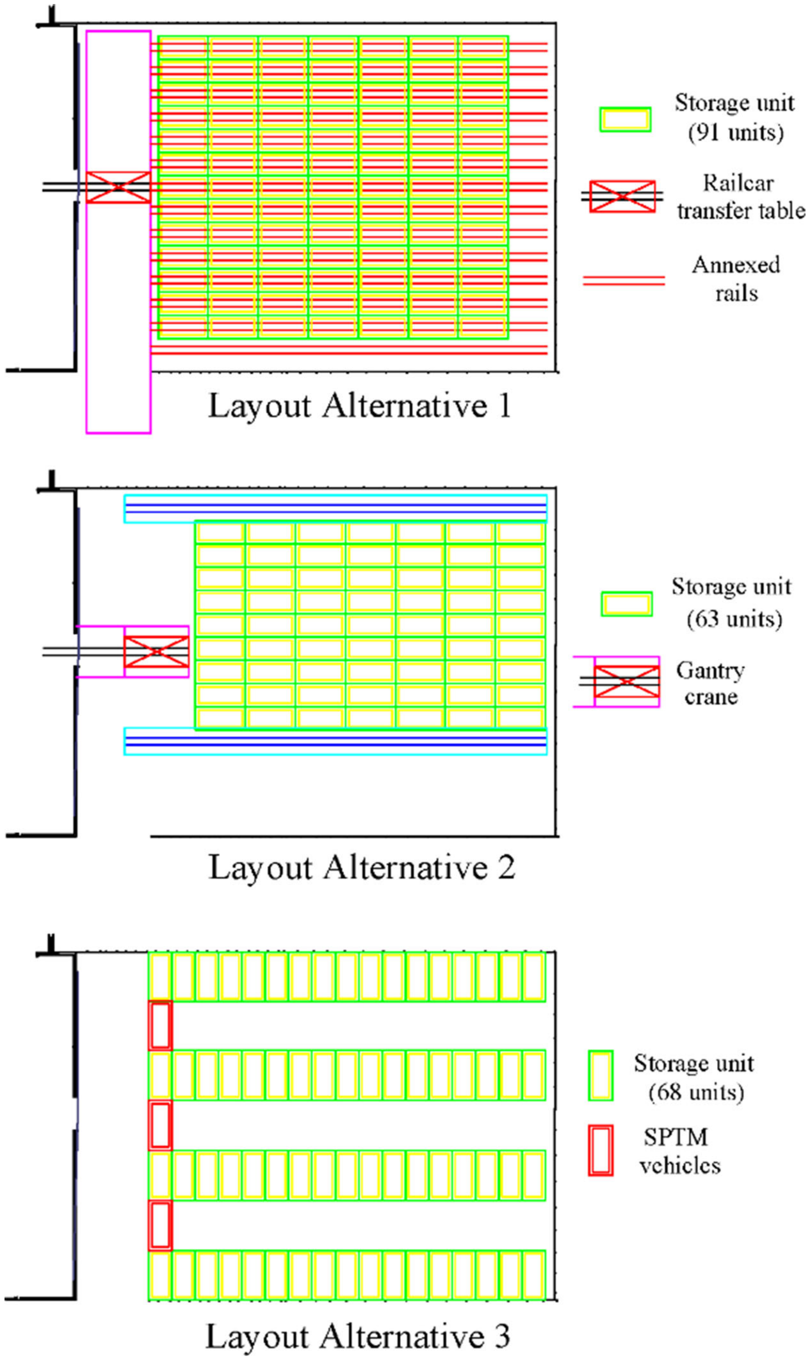

Figure 3. Detailed view of arrangements of stored products—Alternative 1: use of a railcar transfer system; Alternative 2: use of a gantry cranes; and Alternatives 3: use of SPMT vehicles.

Taking into account that five assessment criteria with different weights ('W') have been defined in agreement with the different agents involved, the following list can be compiled.

• Criterion 1: Reducing storage costs	W: 30
• Criterion 2: Economic Viability NPV	W: 25
• Criterion 3: Storage Capacity with oil	W: 15
• Criterion 4: Flexibility of the solution	W: 20
• Criterion 5: Impact on the rest of operations	W: 10

Once the unfeasible alternatives are discarded based on economic profitability, the results obtained with the remaining options applying the Electra I and II and AHP methods are presented in Table 8.

Lastly, Table 9 presents the rankings of alternatives evaluated with the 3 methods employed. The alternative 3.1 in this case is the solution that globally acquires the

Table 6. Main characteristics of the alternative solutions presented for the design of the warehouse.

Alternative 1		Alternative 2	Alternative 3	
Use of railcar transfer table and attached rails		**Use of gantry crane**	**Use of SPMT vehicles**	
Alternative 1.1	Alternative 1.2		Alternative 3.1	Alternative 3.2
Without cover protection system	With cover protection system		Without cover protection system	With cover protection system

Table 7. Results of cost and profitability analysis performed for alternatives 1.1 and 1.2.

	Alternative solution 1.1	Alternative solution 1.2	Alternative solution 2	Alternative solution 3.1	Alternative solution 3.2
Initial investment cost (€)	4,058,355.02	4,188,464.66	3,177,964.38	3,310,518.55	3,448,285.94
Annual storage cost (€)	403,022.61	447,269.10	411,461.96	341,628.45	388,478.03
Storage cost savings (€)	944,829.40	900,582.91	936,390.05	1,006,223.56	959,373.98
Storage cost savings (%)	70.10	66.82	69.47	74.65	71.18
NPV (€)	3,939,884.11	3,435,215.91	4,748,833.37	5,207,438.97	4,673,077.11
IRR (%)	19.29	17.05	26.70	27.77	24.78
Payback (years)	4.69	5.11	3.65	3.53	3.88

Table 8. Ranking of the proposed alternative solutions as evaluated by AHP, Electra I and Electra II.

Order of Preference (Electra II) (25 %)	Alternative	Order of Preference (Electra I) (25%)	Alternative	Order of Preference (AHP) (50%)	Alternative
1th	3.1	1th	3.1 and 3.2	1th	3.1
2th	3.2	2th	2	2th	3.2
3th	2	3th	1.1	3th	2
4th	1.1			4th	1.1

Table 9. Summary of rankings in accordance with use of different methods.

Order	Classification according to Electra I (25%)	Classification according to Electra II (25%)	Classification according to AHP (50%)
1th	3.1 and 3.2	3.1	3.1
2th		3.2	3.2
3th	2	2	2
4th	1.1	1.1	1.1

best rating, becoming the optimum design according to the minimum criteria set out and the corresponding company objectives.

3. Result modulating using SWOT and RISK analysis and possible variations in the discount rate

Although the optimum solution obtained in this case study is the Alternative 3.1, it is recommended to analyse each specific case following SWOT and RISK analysis to ascertain the feasibility of the obtained solution based on existing constraints, equipment, materials, and space available (Thomas & Meller, 2014). In these analyses, the participation of all the departments involved and affected during this activity, especially logistics, maintenance and quality, is essential.

Such studies also facilitates the analysis of the investment and the economic viability of the solutions in greater depth. They should also present the impact of the different discount rates to be employee: WACC (Weighted Average Cost of Capital),

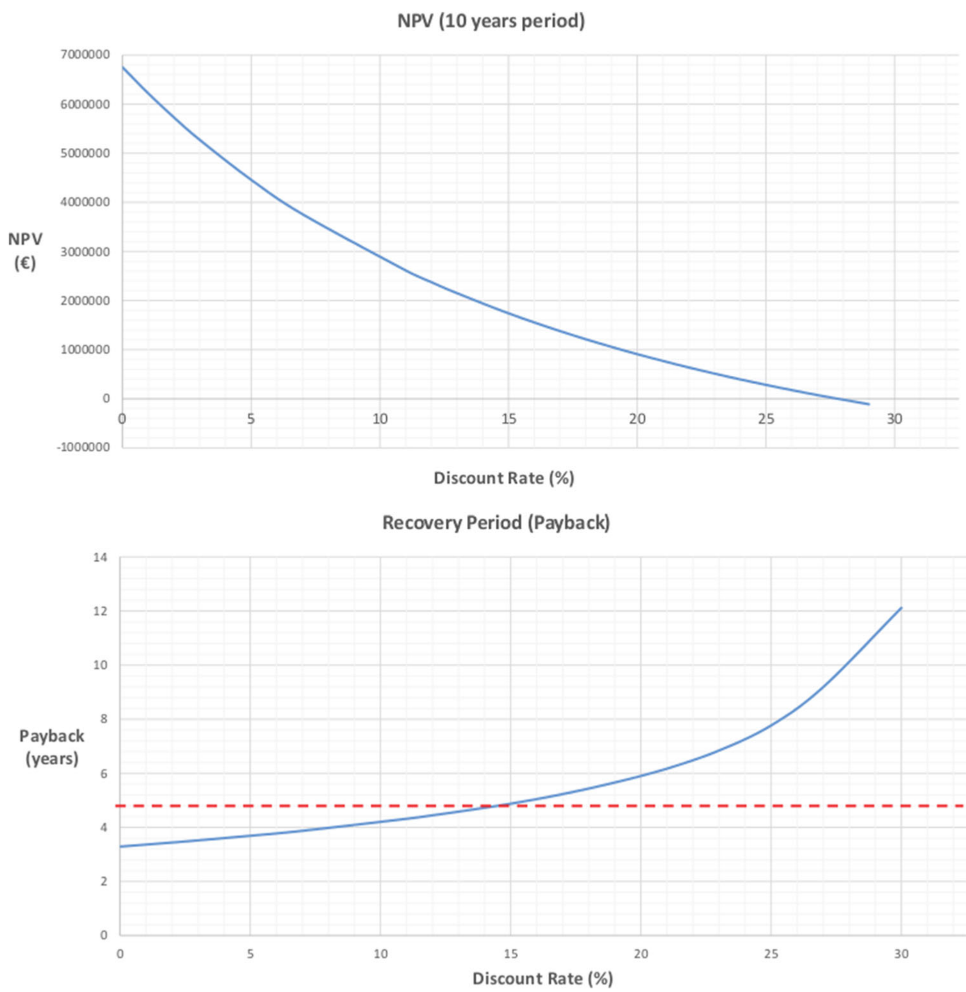

Figure 4. Variation of the NPV and Payback with different discount rates in the case study.

LIBOR (London InterBank Offered Rate)…. This evaluation for our case study is shown in Figure 4.

As presented in other multi-criteria optimization studies for industrial facilities (Zhai, 2015), it is also advisable to perform a SWOT analysis to identify and frame the internal characteristics of the project within those of its own environment but also from other stakeholders (Tan, Yifei, Zhang, & Hilmola, 2014). This is another valuable indicator of the feasibility of the optimized alternative selected within the activities of a company and its objective market (Amin, Razmi, & Zhang, 2011). Although these techniques are generally used at a strategic level, they are applied also to the tactical or operational level to reinforce the decision taken with the proposed methodology and to validate (or not) this choice and to avoid conflictive situations that can be predicted (Batzias & Pollalis, 2008). These methodologies enable not only to extract the knowledge by experts but also to know the factors and the effects that help to take a good (the best) decision. Techniques to seek information, such as Delphi and Checklist, as well as diagram techniques such as cause and effect diagrams or Strengths Weaknesses Opportunities and Threats (SWOT) are applied. The categorization and prioritization of risks will be carried as a complement to the weighted results of the AHP and ELECTRA methods. The selected proposal of the case study is submitted to the following techniques: Delphi and the Judgment of the Experts to focus the advantages, disadvantages, strengths and weaknesses of the alternative warehouse design solution chosen in the previous chapter, as well as the opportunities and threats of the environmental analysis. The results are presented in Table 10. This environment generated is a limited field of study in comparison to which it would be desirable for a complete SWOT analysis at the strategic level of a company, since in this particular case the objects obtained are related mainly to the manufacturing activities which is assumed to have the biggest impact on the storage activity.

Finally, complementary to the SWOT analysis and taking advantage of part of the extracted information, it is also advisable to perform a Risk Analysis (Romero-Faz &

Table 10. Results of the SWOT analysis (case study).

Strengths
Reduction of annual storage cost.
Reduction of dependence on external logistical services
Simplified storage system thanks to use of single transport and lifting equipment
Storage of products on metallic benches above ground level.
Lower investment costs for start-up of a new storage system.
Capacity to include further environmental protection systems, such as metallic tents, with lower cost.
Weaknesses
System dependent on key elements without immediate replacement (E.g. SPMT vehicle).
Outdoor storage system without environmental protection.
Use of available storage space, adding margins for manoeuvre of SPMT vehicles.
Previous assumptions considered during the approach of the current solution may differ from reality in the short-term—lower inventory volume, larger product dimensions, higher storage weights, etc.
Opportunities
Customer's tendency to outsource product storage in adapted areas.
Capacity to increase storage space using simple techniques with low impact on cost.
Threats
Storage periods dependent on external factors, unpredictable and out of control customers, delivery dates, unexpected on-site events, etc.
Possible damage to equipment used for transport of out-of-service products.
Possible collapse of metallic benches.
Customers may require storage of their products to be environment protected.

Table 11. Risk assessment matrix: probability and impact.

Classification of risks		Impact: Under	Medium	High
Probability	Low			3, 5, 9
	Medium	2	1, 10	7, 8
	High		4, 6	

Camarero-Orive, 2017), since the initial stages of a risk management plan are inherent within any project of this magnitude (Marotz, 2017).

The said initial steps of the Risk Analysis (Trab et al., 2015) include:

- Identification of risks.
- Analysis of risks, defining their likelihood and impact.
- Approach of a strategy to reduce or mitigate the likelihood and impact of the risks.

During the Risk Analysis process, the international standards related to the management of the supply chain risks -ISO 28000 and ISO 21500- will be referenced as well as other standard that has been considered convenient to our porpoise: ISO 31000: risk management in projects. Both ISO 31000 and ISO 28000 reflect the need for risk management not only in the supply chain, but also in all parts of an organization like the warehouse design and its management (Leitch, 2010).

This task facilitates the anticipation of possible problems, which may be encountered during the planning, commissioning or operation of this system, as well as the possibility of finding certain limitations that had not previously been considered (Makaci, Reaidy, Evrard-Samuel, Botta-Genoulaz, & Monteiro, 2017). For a clearer vision of which risks are found to require a priority treatment, results obtained via the Risks Analysis of our case study are summarized in Table 11 -where risks and their probability and impact are listed- and in Table 12 -where these risks are classified-.

4. Discussion

The methodology presented can be especially useful in the design of plants for heavy industry warehouses dedicated to the storage or maintenance of large, high size and difficult handling equipment.

In these cases, there are several more issues with larger relevance than in conventional storage facilities:

- Significant space problems and constraints due to higher dimensions but also further requirements for the displacements and others internal operations
- Large economic and time-consuming costs of handling and moving the equipment, since this kind of loads require procedures where security, flexibility and operability are key elements.

Based on these specifications, the design process relies more on the tactical or operational levels than in the strategic one. Consequently, the AHP Methodology fits well with

Table 12. Risk assessment matrix: description and classification.

	Risk	Probability	Impact	Strategy of prevention/mitigation
1	SPMT vehicle out of service	Medium	Medium	Maintenance with higher frequency; vehicle-replacement plan in advance.
2	Delays in execution of work, which may impact normal operation of remaining tasks	Medium	Low	Periodic project monitoring and control along with coordination between remaining tasks to ensure they remain unaffected; planning of this kind of work in times of decreased activity.
3	Increase in dimensions of products stored in for short term.	Low	High	Location of units in areas with the greatest width, ensuring availability of safety distance or alternative storage in other areas within production centre.
4	Increase in the dimensions of products stored in for long term.	High	Medium	Expansion of dedicated storage area to ensure safe distance and manoeuvre; reduction in on-site storage capacity.
5	Increased weight of products stored beyond rated storage capacity	Low	High	Reinforcement of metallic structure used as well as storage-area foundation.
6	Increased weight of products stored beyond rated storage capacity in the long term.	High	Medium	Reinforcement of metallic structure used as well as storage-area foundation.
7	Inventory volume over the next 10 years with statistical distribution having a higher mean than estimated.	Medium	High	Expansion in dedicated storage area.
8	Deterioration of the only access to storage area.	Medium	High	Adaptation and strengthening of current means of access along with implementation of alternative pathways.
9	Overhead crane going out of service.	Low	High	Special plan for increasing frequency of maintenance operations; plan for advance replacement of bridge crane.
10	Normative change mandating use of a storage with protection from external impact.	Medium	Medium	Using of system approach that includes protection from external influence (Alternative 3.2) employing a metal tent.

this case due to its hierarchical character and its adaptability to the selection of problems of similar characteristics in any heavy industry, which make it the most suitable decision-making method. However, the complemented analysis of the ELECTRA I and II can modify the final decision giving more relevance to different selection criteria, as it has been found with the case study developed within this document. Because of this variability, a significant aspect of the methodology is the inclusion of a final evaluation stage to submit the final solution to a SWOT and a Risk Analysis which allow to strengthen the design with the inclusion of implementations used to face, mitigate or eliminate the possible risks that can be stablished for this final proposal.

Two major findings can be considered concerning the study of large industrial storage system. The proposed methodology:

- Presents a model for storage costs covering a compilation of most of the concepts that affect the different operations of a company and its storage requirements (elements, equipment, facilities, procedures and all the areas/departments involved) associated with similar activities. It has been highlighted that the cost of space saturation is a concept of great importance with regards to the storage of heavy, large-sized products.

- Offers a means for assessment, evaluation, and determination of the most optimum solution based on scientific methods and multi-criteria evaluation, with the participation and consensus of all the stakeholders which could be affected. The collaborative and participatory nature of decisions, such as definition of decision-making criteria and their relative weights, evaluation of alternative solutions, as well as the SWOT analysis and risk management, provide to the proposed methodology a guarantee that the selected solution is the most appropriate according to global interests of the company. In fact, a clear and concise definition of steps to be followed eases the repetition of the analysis in the event of new additional alternative solutions, changes in the decision team or in operating conditions and environment of the warehouses.

A large part of the calculations on which the proposed methodology is based begins with a statistical consideration of the inventory volume to be stored according to available historical data. Therefore, the greater success and accuracy of the result to be obtained relies on the quality and realism of available data from an historical database.

5. Conclusions

A methodology capable of effectively solving the problem of storage of very heavy and large equipment has been discussed and justified due to their economic relevance in the operation of factories or similar manufacturing business related to this activity. There are many significant examples in the basic industry of every country considering cases of storage of containers for maritime transport or electrical equipment such as large power transformers. The latter is the example that has served as a model or reference for the case study developed. Specifically, a design problem for a large power transformer warehouse in factory.

Designers of warehouses that store great volume and tonnage equipment can include the implementation of quantitative and qualitative aspects within their developing strategies focusing on the need of an objective evaluation of variables using multi-criteria decision-making techniques. The proposed method allows the comparison between present and alternative proposed solutions whilst ensuring that the evaluation of candidate solutions considers interests of all the industrial dimensions and stakeholders involved, so that the selected solution meets global interests and provides a collaborative and participatory character to this approach. The singularity of the industries that require the storage of large products presents, under this analysis, several particular analytic characteristics that differentiate them from other warehouse-design models. The proposed methodology presents aspects capable of dealing with these peculiarities allowing:

- The definition of clear criteria used as guideline for the identification of the optimum solutions, as well as means for the assessment of candidate solutions

- The determination of a costs model of the storage structure that involves all subjects related to this activity
- The attainment of a costs model and economic evaluations, which include the cost of space saturation, which may have a large impact in this type of industry
- The attainment of an evaluation and decision-making method adapted to the subjective nature of this problem, and that guarantees consensus of all affected areas in the company (internal stakeholders), in accordance with their interests, thereby taking advantage of their experience

Thus, it is necessary to stablish the key categories or criteria in the design and operation of this type of great weight and size equipment warehouse and to explore the extent to which current valuation techniques and decision-making models lead us to achieve efficiency and capacity to optimum storage in industries subject to space constraints. This work opens the doors for future studies that allow facing and solving problems of a similar type, related to other different activities in the company.

The novel aspects of this study is the selection of an optimal design tailored to the operations of the warehouses based on selected quantitative (investment costs, indicators and economic and financial profitability and maintenance costs) and qualitative criteria (security, adaptability and flexibility of the solution adopted). Moreover, the preferred solution delimited using these variables is subjected to a SWOT and a risk analysis to reinforce the soundness and solvency of the proposal. A case study based on the specification of large transformers manufacture industry has been used to test and present the results that offers the methodology, guiding to an optimized solution considering the strategic, tactical, or operational levels of the company.

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