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A Literature Review on the Pallet Loading Problem

Una Revisión Literaria del Problema de Carga del Pallet

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Abstract. Nowadays, businesses face a fierce competition. Hence, implementing strategies to achieve competitiveness is elemental. For that purpose, in the logistics field, the proper use of resources is a must. According to several experts, storing and transportation have a high impact in the overall supply chain profit. Therefore, lowering their impact by increasing efficiency contribute to a higher profitability. An efficient palletizing can cause to easily ship more goods onto a pallet with the consequent savings in transportation and storage. The denominated *Pallet Loading Problem* (PLP) focuses on finding space optimization to load the maximum quantity of packed product onto the pallet.

This article presents a literature review of the most prominent approaches with the objective of showing the main characteristics and solution methods proposed by researchers. Thus, the understanding of these solution approaches can help in the development of new strategies or approaches to deal with the palletizing.

Keywords: Logistics, Transportation, Pallet, Literature Review, Pallet Loading Problem.

Resumen: Actualmente, las empresas enfrentan una competencia agresiva, por lo que implementar estrategias para alcanzar la competitividad es elemental. En este sentido, en Logística, el uso adecuado de los recursos es imprescindible. El impacto en la ganancia que tienen el almacenaje y el transporte, conlleva la implementación de acciones para contrarrestarlo. Un paletizado efectivo puede contribuir a reducir costos.

El Problema de Carga del Pallet (PLP) procura la optimización del espacio del pallet para lograr cargar la mayor cantidad de producto debidamente empacado. El uso práctico y beneficios del PLP han dado pie a su estudio en la búsqueda de solución.

Este artículo presenta una revisión literaria de los principales estudios para mostrar las características principales y los métodos de solución propuestos, generando una base de entendimiento que permita dar sustento a la elaboración de nuevos modelos y estrategias en la solución del PLP.

Palabras clave: Logística; Transporte; Pallet; Revisión Literaria, Pallet Loading Problem.

1. INTRODUCTION

There is no doubt that in Logistics, transportation and storage are key elements since they imply costs at the time that they also allow to supply the demands of the customers. For instance and in comparison with other process of the supply chain, the palletizing loading efficiency of any type of transport causes direct saving of the total logistics costs. These saving rank between 20-25% of the storage cost and up to 30 of the transportation costs [4], [7], [21] and [22].

Therefore, achieving a high loading efficiency regarding the space utilization on a pallet means to ship more products with a possible lower transportation cost per unit, making it more profitable for the company. Obviously, if the space is efficiently utilized, it is feasible to supply a bigger quantity of products with a lower cost and an increased satisfaction of both parties involved (customers and the company). Considering that the main goal of logistics consist on getting the right goods at the right time under the best conditions at the lowest cost, an increment on the utilization of the available space with as many products as possible in the means of transportation and the utilization of less storing space are a must.

In the last decades, researchers have studied and revised the packing problems such as the Knapsack problem, the Bin Packing Problem, the Container Loading Problem, and the Pallet Loading Problem. Perhaps and due to their nature, the most prominent in the Logistics field are the Container Loading Problem and the Pallet Loading Problem even when all of them have the possibility to be applied in very similar situations to obtain benefits in one or other way.

It has been proposed a wide range of solutions using different techniques and methodologies. The most common approaches employ heuristics such as the wall building approach presented in the 80's. This approach is a heuristic to load the pallet building columns of boxes i.e., stacking vertically a set of boxes no higher than a maximum height. However, this type of approaches can lead to non-efficient final solutions. Other studies employ optimization technique such as integer programming, taboo search, simulated annealing and simulation, among many.

Each of the review studies present advantages and disadvantages both in the modeling and resolution approach which are essential to understand if an innovative approach wants to be proposed. Therefore, this work presents a literature review on the Pallet Loading Problem, focusing on the most prominent approaches and characteristic modeled within it. Stability, maximum height allowed and weight constraints are some of the characteristics highlighted in the literature review done in this work.

The organization of this work is as follows: Section 2 provides an overview of the packing problems, focusing on the pallet loading problem and its characteristics. Section 3 presents the literature review on the pallet loading problem analyzing each work characteristics and comparing them. Finally conclusions and future work is presented.

2. BACKGROUND

Researchers have studied and revised packing problems such as the Knapsack problem, the Bin Packing Problem, the Container Loading Problem, and the Pallet Loading Problem. Perhaps and due to their nature, the most important in Logistics are the Bin Packing Problem, the Container Loading Problem and the Pallet Loading Problem even when all of them have the possibility to be applied in very similar situations to obtain benefits in one or other way.

The need of stacking efficiently a set of items within one or several containers represents the appearance of packing problems, which share common features:

- The involvement of two sets of specific elements: a set of large elements and another of smaller elements.
- Both given sets of elements may imply homogenous or heterogeneous dimensions (single or multidimensional) (See figure 1).
- A specific quantity or all the smaller items, grouped into one or more subsets, must be placed inside the larger objects where they must fit entirely without overlapping [36].

It is important to mention that in literature, a packing problem is a synonym of the so called cutting problem because the determination of the optimal way to cut

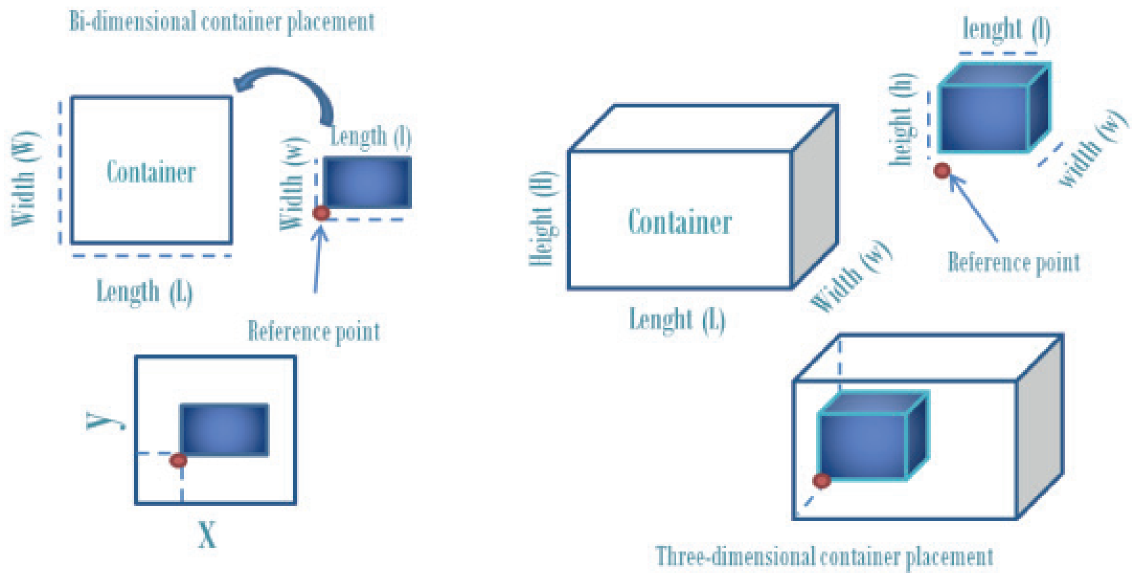

Fig. 1 Bi and three dimensional packing problems

a large object into smaller pieces equals the search to place optimally a set of pieces into a larger one. Therefore, many authors refer to packing, cutting or packing and cutting problems whenever any of the previously mentioned problems are present [36].

The Knapsack Problem (KP) is NP-hard (nondeterministic polynomial time) and comprises an extensive family with various applications in the industry and financial management such as cargo loading, cutting stock and budget control, among others. This problem can be defined as the maximization of the profit sum obtained by the placement of a subset of given items to be chosen, in the knapsack without exceeding its capacity [35].

The Bin Packing Problem (BPP) arises when a set of items must be packed in a certain number of bins of the same size, maximizing the space to be utilized. Thus, the whole quantity of items must be packed in as few bins as possible. This problem can be bi-dimensional (2D) and three-dimensional (3D) [27].

The BPP has got several uses in the industry, especially in cutting (wood and glass) and packing for transportation and warehousing. As previously stated, most researchers refer to bins of the same sizes, but there are studies, which use bins of different sizes in the resolution of this problem that arises in industries like wood, steel, paper and cloth [30].

If one comes across with the necessity of loading a subset of goods or parcels of different sizes into a three-dimensional rectangular container with specific dimensions with the aim of maximizing the volume of packed boxes, then the Container Loading Problem (CLP) becomes present [41]. It is three-dimensional and as foreseen, its essence consists of finding the optimal layout of a set of sorts of small three-dimensional cubic items (boxes, for instance) to be loaded in a container with specific dimensions [16].

In the CLP, the objective is the optimization of the available space inside a container with as many boxes as possible, meeting all possible constraints. There are three categories for this problem:

- Homogeneous: all boxes to be placed in the container have the same dimensions.
- Weakly heterogeneous: few different box types with many identical boxes of each type.
- Strongly heterogeneous: all boxes have different dimensions.

Constraints in the CLP include box orientation and stability [41].

The Pallet Loading Problem (PLP) arises when small items must be placed onto a large pallet in manufacturing workshops and other logistic areas

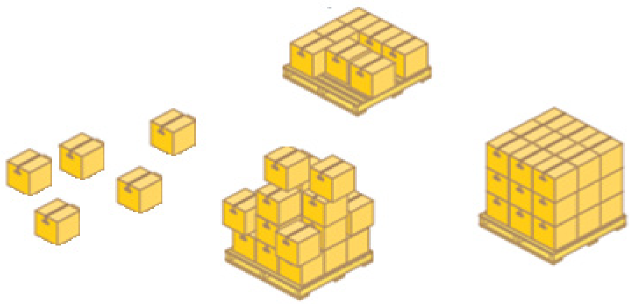

Fig. 2 Most common PLP's representation

(Figure 2) [23]. Evidently, the stacking objects may be of different sizes, nature, weight, value and shapes. Order demand, placement and weight conditions, together with stability, constitute the most important constraints in the PLP [34].

As it can be clearly observed, the different packing problems above described comprise different common elements, which make them similar in spite of the differences. Packing problems seek for the optimal use of resources which, in this case, are basically represented with the capacity utilization of packaging space which is related with the material and transport capacities, being of great economic importance in the process of production and distribution. Thus, there is also a contribution in the use of natural resources economically, in the limitation of already complicated traffic, and, as a whole, in the careful treatment of the environment. Evidently, it all can be translated into monetary savings [28].

Due to its importance in the supply chain, researchers have studied and revised the different packing problems whose applications in Logistics are widely spread and only, its utilization will depend on the focus of the situation (most valuable products in a recipient, efficient use of the space in as few containers as possible, etc.).

Focusing on the Pallet Loading Problem, it is important to remark that an efficient arrangement of cargo onto a pallet is time-consuming, and requires stability and space considerations with regards to the utilization of the pallet. The more efficiently the pallets are utilized, the less quantity of them are demanded to stack cargo. Beyond that, the impact of this activity on transportation and warehousing is evident as both costs are directly related to the use of space as well as the type of pallets and the quantity of them in the conformation of a shipment [4].

Thus, an efficient palletizing may cause a reduction of the space utilization within any transportation modes with a consequent saving on the cost associated to it. Nonetheless, even when efficient palletizing can imply less used space in the means of transportation, it also causes additional costs along the supply chain granted the pallet is also new element which, does not exist in bulk shipments. For instance and in comparison with bulk shipments, loading efficiency of a sea container with palletized cargo is lower by 5% and causes higher total logistics costs in a rank between 25% and 33%. In contrast, there are remarkable savings (up to 37%) made at destination where this sort of cargo can be mechanically manipulated with the use of forklifts and other devises. The saving estimations concerning risk account for around 29%. In summary, total savings resulting from palletizing end up being superior to any possible extra caused with this action in particular [21].

The Pallet Loading Problems can be classified in:

- The Manufacturer's Problem: occurring when there are homogenous boxes to be efficiently placed onto a pallet.
- The Distributor's Problem: it arises when it is necessary to stack heterogeneous pieces onto a pallet [34].

The general PLP has been stated to be NP hard, i.e., it is said to be intractable because possible solutions require exponential time to occur, as well as the consumption of high computational resources [23], [20].

In the obtainment of the best possible arrangement in the manufacturer's problem, the organizations have used modern technology with the integration of the developed algorithms as a key tool because automated handling systems have become the means to load pallets. On the other hand, the distributor's problem has a distinctive nature of being non-repetitive and finding a solution through mathematical programming, heuristic models and other techniques is long-time demanding. Whenever the dimensions of the pallets as well as those of the different box types are pre-specified, and the availability of boxes is certain, the mathematical approach fits correctly. The use of heuristics depends on different criteria, methods or principles to make the most effective decision, among several courses of action. Time is a key element as trying to find an optimal solution requires a long while, particularly in some specific events such as having boxes of different sizes coming on a conveyor line in a random sequence to be loaded optimally onto a pallet [12].

3. LITERATURE REVIEW

The extensive application and usefulness of an efficient pallet loading has made the PLP a widely revised problem throughout time by researchers all over the world. Thus, it is worthwhile presenting a summary of some of these approaches with the expectation of providing a vision of the complexity of the situation, the analysis of this problem and the proposals to solve it. This lays down the basis to choose the most suitable approach and characteristics in future approaches to the PLP.

As it can be observed in Table 1, both of the PLP variations (the Manufacturer's and the Distributor's) have been extensively studied, although the Manufacturer's PLP has been more widely revised, probably because of being "easier" than the Distributor's PLP.

Also, it can clearly be viewed that most of the researchers have treated the PLP as bi-dimensional so as to simplify it as the inclusion of height to make it three-dimensional increases the degree of complication to achieve efficiency.

It is important to remark that the PLP in general implies an orthogonal stacking in relation with the pallet. The pallet loading action also demands the possible rotation of the boxes in order to find their most adequate position in the search of the highest space utilization of the pallet's surface per layer and the proper pattern. In any of the variants, no box can overlap with other in a layer or else the solution becomes unfeasible, making it dismissible.

As it can be seen in Table 1, some of the exact algorithms developed in the works of [19] and [24] ended up with the creation a computational program to solve the PLP, such as POSY, LAG and LAGSUR, respectively. POSY proved to be efficient to solve 95% of the 1000 instances chosen in a period of time between one and 10 seconds. On the other hand, in words of the authors, LAG had a better performance than LAGSUR solving up to 90% with the involvement of up to 100 boxes in a maximum of 80 seconds. In the case of [38], their work also produced a computational program to solve the PLP, although there is no reference of a given name for it. This program accomplish an efficient solution in its last stage with the implication of up to 2800 orders and 222 187 boxes which could be efficiently stacked in 3862 pallets in a running time of 8.79 seconds.

In other cases, programming languages such as C+ in its different versions have been the chosen language for the development of the algorithms as referred in [3], [8], [10], [12], [14], [23], [25], [26], [31], [37] and [39].

DELPHI is another programming language which researchers have used to develop their solution algorithms on the PLP as in [24], [25] and [29]. On the other hand, existing software like CPLEX, LINDO and CPN Tools has also been employed in the research of a solution for the PLP in [1], [4], [5] and [37].

Table 1 was developed to summarize the technique used in each of the approaches reviewed. It could be observed that the majority of them use exact algorithms with the incorporation of heuristics. The conformation of blocks (G4, G5), patterns or groups the heuristic method more widely employed when solving the PLP in either of its two variations as in the works of [1], [6], [7], [10], [14], [17], [31], [34], [37], [38] and [39]. Heuristics are normally used within these solution methods because they allowed the possibility to reduce computational time for this NP-hard problem.

Other researchers such as [1], [5], [8], [15], [22], [25] and [29] focused their researches on the use of specific techniques: B&D heuristic, Lagangrean relaxation, Tabu Search, branch-and-cut, L-approach and Branch and Bound, to mention some.

It is important to state that even when all methods have proved efficiency to solve the PLP in one or other way, they end up having limitations. For instance, the block or pattern methods cause spaces which cannot be completed in some instances causing a lower efficiency. In other methods, long time consuming and high demand of computational resources for big instances end up getting no efficient results.

Table 1

Summarized comparison of the different revised approaches on the PLP

	Revised PLP variation		Treatment		Solution method			Software or encoding language						
Revised approaches in chronological order by author	Manufacturer's PLP	Distributor's PLP	Bi-dimensional (2D)	Three-dimensional (3D)	Exact algorithm	Simulation	Heuristic method	FORTRAN	DELPHI	C++	CPLEX	LINDO	CPN Tools	Undefined
(Dowsland-A, 1987) in [18]	X		X		X									X
(Dowsland-B, 1987) in [19]	X		X		X			X						
(Tarnowski et all, 1994) in [2]	X		X		X									X
(Abdou and Yang, 1994) in [11]		X		X	X									X
(Bischoff & Ratcliff, 1995) in [6]		X		X			X							X
(Bischoff et al, 1995) in [7]		X		X			X							X
(Scheithauer & Terno, 1996) in [34]		X		X			X							X
(Morabito & Morales, 1998) in [25]	X		X		X		X		X	X				
(Abdou & Elmasry, 1999) in [12]		X		X		X				X				
(Farago & Morabito, 2000) in [24]	X		X				X		X					
(Amaral & Wright, 2001) in [3]	X		X				X			X				
(Young-Gun G. & Kang, 2001) in [31]	X		X		X		X			X				
(Yamassaki & Pureza, 2003) in [5]	X		X				X				X			
(Álvarez-Valdés et al-A, 2005) in [22]	X		X		X		X							
(Lel, Creighton, Nahavandi, 2005) in [38]		X		X			X			X				
(Birgin et al, 2005) in [8]	X		X		X		X			X				
(Mascarenhas, 2005) in [40]	X		X		X									X
(Alvarez-Valdes et al-B, 2005) in [23]	X		X		X		X			X				
(Pureza & Morabito, 2006) in [29]	X		X		X		X		X					
(Wu & Ting, 2007) in [37]	X		X		X		X			X	X			
(Mattos-Ribeiro & Nogueira-Lorena, 2007) in [13]	X		X		X		X			X	X			
(Birgin et al, 2008) in [9]	X		X		X		X			X				
(Martins & Dell, 2008) in [14]	X		X		X		X			X				
(Kocjan & Holmström, 2008) in [39]	X		X		X		X							X
(Yia et al, 2009) in [17]	X			X	X		X							
(Lau et al, 2009) in [15]		X		X	X		X							X
(Lim et al, 2010) in [26]		X		X	X	X				X				
(Al-Shayea, 2011) in [1]		X		X			X					X		
(Zúñiga et al, 2011) in [4]		X		X		X							X	
(Birgin et al, 2012) in [10]		X	X				X			X				

Table 2
Considerations in the development of the researches on the PLP

Revised approaches in chronological order by author	**Stability**	**Demand**	**Limited height**	**Weight of the pallet**	**Profit**	**Preservation of the boxes**	**Unspecified considerations**
(Dowsland-A, 1987) in [18]	X						
(Dowsland-B, 1987) in [19]							X
(Tarnowski et all, 1994) in [2]							X
(Abdou and Yang, 1994) in [11]	X	X					
(Bischoff & Ratcliff, 1995) in [6]							X
(Bischoff et al, 1995) in [7]	X						
(Scheithauer & Terno, 1996) in [34]	X	X	X	X			
(Morabito & Morales, 1998) in [25]							X
(Abdou & Elmasry, 1999) in [12]	X						
(Farago & Morabito, 2000) in [24]							X
(Amaral & Wright, 2001) in [3]							X
(Young-Gun G. & Kang, 2001) in [31]							X
(Yamassaki & Pureza, 2003) in [5]							X
(Álvarez-Valdés et al-A, 2005) in [22]							X
(Lel, Creighton, Nahavandi, 2005) in [38]		X					
(Birgin et al, 2005) in [8]							X
(Mascarenhas, 2005) in [40]							X
(Alvarez-Valdes et al-B, 2005) in [23]							X
(Pureza & Morabito, 2006) in [29]							X
(Wu & Ting, 2007) in [37]							X
(Mattos-Ribeiro & Nogueira-Lorena, 2007) in [13]							X
(Birgin et al, 2008) in [9]							X
(Martins & Dell, 2008) in [14]						X	
(Kocjan & Holmström, 2008) in [39]	X						
(Yia et al, 2009) in [17]	X						
(Lau et al, 2009) in [15]					X		
(Lim et al, 2010) in [26]							X
(Al-Shayea, 2011) in [1]				X			
(Zúñiga et al, 2011) in [4]			X	X		X	
(Birgin et al, 2012) in [10]							X

The positive results obtained with the use of the above mentioned techniques caused the interest of other researchers to develop hybrid methods which combined Lagrangean and Surrogate Relaxations; Lagrangean Relaxation and Clusters; Tabu Search with G4, Five-block Heuristic with L-approach; or Profit-based Heuristic with Genetic algorithms as in [3], [9], [13], [15] and [23].

Simulation has not been widely used as a solution method for the PLP in the past. However, in recent studies, as in the work of [4] and [26], simulation has proved to be useful to find proper solutions for it.

Due to its closeness to reality as it constitutes the imitation of a real-world process or that of a system, simulation has become relevant and popular due to the increased use of this technique in different fields such as engineering, business, mathematics and statistics; anthropology, psychology, medicine, physics and so on. It is quite versatile since it allows the design and analysis of activities on the smallest of motions and on the largest of systems. It comprises a mixture of the engineering concepts of design controlled with the experimental approach of science, as mathematics is a component in the solutions of problems and their verification [32].

Simulation represents a fruitful technique since it generates an artificial history of a system to provide the base for inferences with regards to the operating characteristics of the real system. With that, it gives certainty on the decisions due to its correct course of action. It is broad and flexible, providing a basis for continuous improvement according to the initial results and their performance.

The appearance and development of computers as well as their systems have provided access to an endless source of tools to find alternatives for the solution of a wide variety of situations in all kind of fields regardless their complexity. This is extensive to simulation which implies repetitive continuous experimentation without high costs, under safety environments, being also a training tool. Computer simulation allows the obtainment of an individual solution for a particular problem while analytical methods only provide general approaches. The application of computer simulation has allowed an easy experimentation with virtual environments with such an important level of detail even in complex problems [33].

Within the manufacturing industry, simulation is widely common due to advantages such as:

- Decisions can be confirmed artificially.
- The model can be re-utilized.
- Compared with other analytical techniques, simulations can be more easily created and demand fewer simplifications.
- The definition rules of the model are modifiable to alter its behavior.
- Special cases can always be taken into account during the execution of a simulation for experimentation.
- An interaction between the user and the simulator is always possible as well as the analysis of such an action.
- The use of simulation can cause to spend less time in the cycle of design and fewer requirements for initial resource investment.
- With simulation, economic benefits can be obtained since Research and Development cycles are feasible to get improved.
- The study does not affect the original entity (main matter of study) which can continue to be used [33].

The previous literature review on some of the existing approaches for the PLP has shown that many of the researchers took into account few of the vast considerations present in the reality, during the development of their model.

In this sense, stability has been the most widely included factor in the models granted that without it, a stacked pallet is difficult to be handled properly under the present circumstances of transportation and storage. As it can be seen in Table 2, seven out of 30 of the works take stability as one of the important factors because no pallet can be efficiently transported or stored in a pallet. If it is not stacked in such a way that it is stable or else it could simply collapse.

Some other studies like [1], [4] and [34] also consider a specific maximum height and / or weight, the demand of the customers for a specific product packed in a certain box, or even safety characteristics, so the PLP is represented as realistic as it can be. Height and weight can always imply a restriction during transportation or handling, causing a limit to palletizing of various sorts of products in their respective box. In the automotive sector, customers usually provide packing standards in which they establish the maximum permissible height of a pallet, making it mandatory for all suppliers involved. Height is also important because the transportation vehicles, storing racks or other handling devises have been designed with certain dimensions which cannot be exceeded. Weight causes another limit for palletizing due to restrictions in transportation, customers' requirements, handling capacities, etc.

Other factors as demand can clearly represent a bounding element in distribution centers because pallets must not be stacked with any box, but those containing the required products. Demand in the Distributor's PLP can complicate or simplify the degree of heterogeneity regarding the boxes to be stacked onto the pallet (s).

Hence, the influence of factors as the previously mentioned should always be part of a field approach in a business so that the benefits of an efficient palletizing can become tangible.

It is relevant to mention that the application of PLP is not limited to packaging since it can also be used in production processes when glass, metal plates or other rectangular sheets of materials must be cut into pieces of different or homogeneous sizes, making the most efficient utilization of their surface.

In summary the importance of the PLP and its benefits make it a subject of analysis in the search of solution alternatives for the diverse situations involved.

4. CONCLUSIONS

Nowadays, the fierce competition that companies face makes it necessary for them to look for actions, which can provide savings or more efficient procedures so as to keep profitability of their businesses. Evidently, this may lead their managers to implement different strategies in various fields such as Logistics and all the activities involved in it, noticing that this comprises the procurement process, the productive cycle as well as the supply to the customers. During all this chain, transportation and warehousing are key elements for each companies due to the costs and impact they cause. Because of that, whenever it is possible to reduce the impact of these two activities, companies can experience a higher efficiency.

Palletizing has an essential role during transportation and storage of many products in the present as it facilitates handling and enables the good utilization of the space in all kinds of premises. The awareness of this has made pallet loading a matter of extensive study throughout time, causing the development of different methods to achieve the most efficient stacking of identical or different-sized boxes onto the pallet under different circumstances as revised in this work.

Some of the solution methods have used heuristics such as Tabu Search or G4, the graph theory or Discrete Event Systems, to mention some. It could be observed that the manufacturer's PLP has been the most widely studied in particular reduced to bi-dimensional so as to ease its analysis. In contrast, the distributor's PLP has a deeper complexity since there are usually more considerations to take into account, making its solution more complicated. There is always an awareness of the complexity of the PLP due to different factors involved and therefore, many researchers have considered stability, height, weight or demand in their approaches.

As a method to achieve an efficient pallet loading, this work presents a literature review of the different solutions methods to understand how the PLP has been treated. Understanding all PLP characteristics, modeling approaches and technique allows to have the basis for the development of an innovative modeling and solution proposal.

As future work, it is intended to propose an innovative modeling approach which takes into account most of the characteristic mentioned on the works reviewed such as weight priority height limitations and priority rules among others. An optimization- simulation approach can be explore to cope with these complex problem, taking advantages of the characteristic of both methods. Simulation can tackle the stochastic parameters while optimization can provide a fast and feasible solution.

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