Universidad Popular Autónoma del Estado de Puebla

Centro Interdisciplinario de Posgrados

e Investigación

Escuela de Ingeniería

Maestría en Logística y Dirección de la Cadena de Suministro

A literature review of the Pallet Loading Problem

Presenta

Saúl Vargas Osorio

Trabajo Terminal que para obtener el Grado de Maestro
en Logística y Dirección de la Cadena de Suministro

Puebla, México. Enero 2016

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Se aprueba el Trabajo Terminal llamado:

A revision of the Pallet Loading Problem to set the basis of a practical application throughout simulation

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Enero 2016

TransNav S.A. de C.V.

Cuautlancingo, Puebla, 10 de diciembre de 2015

Centro Interdisciplinario de Posgrados
Universidad Popular Autónoma del Estado de Puebla

P R E S E N T E

Reciban un cordial saludo. Por medio de la presente me dirijo a usted para extender mi reconocimiento por la promoción de proyectos que permitan poner en práctica herramientas para la planeación y el control de las operaciones propias de las empresas, ya que eso permite generar puentes de comunicación entre nuestro sector y el educativo, favoreciendo entre otras cosas la retroalimentación, la mejora continua y el trabajo colaborativo.

Por otro lado me permito comunicarle que hemos autorizado el trabajo de investigación y uso de información de la empresa para el desarrollo de la tesis denominada: "A literature review of the Pallet Loading Problem".

Sin más por el momento, nuevamente extiendo mi reconocimiento y agradecimiento por contribuir a la creación de mecanismos de asesoría externa a la empresa, puesto que con ello podemos continuar mejorando y conociendo nuevas formas de operación.

Atentamente

Iván de Jesús Carvajal Hernández
Logística de Comercio Exterior

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INTRODUCTION

Most actions in the field of Logistics aim at seeking the highest possible efficiency in all kids of operations in order to achieve benefits such as savings, productivity or profits. In this matter, space utilization is a key factor associated to transportation and warehousing, as well as their costs. Logistics as a full system comprises different activities, which enable the companies to improve the utilization of their monetary and physical resources with the aim of satisfying their customer's needs (Bouka 2010). Thus, one of the firms' priorities should consist of properly using all available resources such as spaces in warehouses, transportation means and all packaging materials as all this implies savings, which cause a successful fulfillment. Time and money are usually linked to success or failure along the supply chain.

There is a clear awareness of the importance of achieving efficiency in the industries through different actions in fields such as Logistics, which comprises a wide variety of activities with a direct effect on profits. So, whenever the minimal saving can be achieved in areas such as transportation or warehousing management, the benefit can become measurable and fruitful. Any logistic decision has a direct impact on the profitability of a business. In this field, storing and transportation costs normally account for an important share of production and distribution costs. Because of that, a reduction in any of these concepts causes benefits for the company by increasing the profit margins (Bouka 2010).

Palletizing products (action of placing, stacking, or transporting goods on a pallet) has become a common activity for most kinds of businesses involved in the supply chains since this provides protection for the products by avoiding loss or damage during handling, transportation and shipping; as well as the reduction of risks for human labor involved in these processes. (Bouka, 2010).

Nowadays modern distribution centers deal with a growing logistics challenge resulting from the need to prepare and dispatch many orders so that they deliver on time with a near-to-zero tolerance of errors. Usually, distribution centers must deal with a huge variety of products in an assortment of package styles (boxes of all sizes, cans, jars in cardboard trays, open and closed cartons, bags, and large, unstable tissue packages, etc.). Then, such packaged goods must be stored, picked and stacked on pallets or roll cages so as to be efficiently loaded onto the transport in order to achieve the proper use of labor and reduce operational costs (McMahon, 2010).

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 (Zuñiga, Piera and Narciso, 2011).

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, if a deficient palletizing, can imply less used space in the means of transportation and 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 (Bouka, 2010).

As previously revised, palletizing is a logistic action, which can contribute to save or lose money due to its implications. Therefore, this case of study is intended to provide the basis of a more thorough research to achieve a higher efficiency for TransNav, S.A. de C.V. along its logistic operations by improving the palletizing of the products supplied to its customers in the United States of America.

For the development of this case of study, a literature review of the pallet loading problem and its variants is presented. Thus, it comprises different methodologies employed to solve the pallet loading problem and the proposal of simulation as an applied tool to reach efficiency in palletizing inside a real company and its circumstances.

1. THE PALLET LOADING PROBLEM AND RELATED PACKING PROBLEMS

Due to its importance in the supply chain, 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 (Egeblad, 2008).

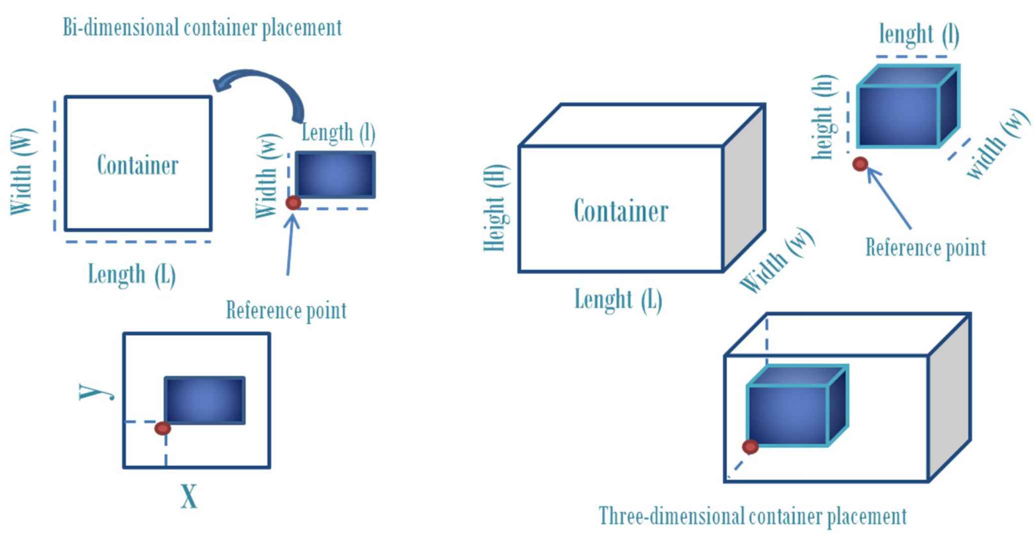

Figure 1 Bi and three dimensional packing problems

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 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 the any of the previously mentioned problems are present (Egeblad, 2008).

1.1 THE KNAPSACK PROBLEM

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 (Figure 2) (Pisinger, 1995).

Figure 2 Representation of the Knapsack Problem

The distribution of the items and the knapsacks cause existing variation on the Knapsack Problem, such as (Pisinger, 1995):

- The *0-1 Knapsack Problem* implies the selection of each item of the set at most once. The expected profit sum should be achieved without exceeding the knapsack's capacity.
- The *Bounded Knapsack Problem* originates whenever there is a limited quantity of each item type.
- The *Unbounded Knapsack Problem* represents a generalization of the Bounded Knapsack Problem in which there is no limitation on the availability of each item type.
- The *Multiple-choice Knapsack Problem* takes place when the items should be chosen from disjoint classes.
- The *Multiple Knapsack Problem* occurs when multiple knapsacks must be filled at the same time.

It is important to state that a common factor in all the variations of the Knapsack Problem is the existence of items (with a profit and a weight) to be packed in one or more knapsacks with a specific capacity (Pisinger, 1995).

Due to its nature of being NP hard, no exact solution can be found for the Knapsack Problem, but an enumeration of the solution space. Different techniques have been used with the aim of solving the problem: branch-and-bound, dynamic programming, state space relaxation and preprocessing (Pisinger, 1995).

1.2 THE BIN PACKING PROBLEM

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 (Figure 3). This problem can be bi-dimensional (2D) and three-dimensional (3D) (Crainic, Perboli and Tadei, 2008).

This problem 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 (Liu, Chu and Wang, 2010).

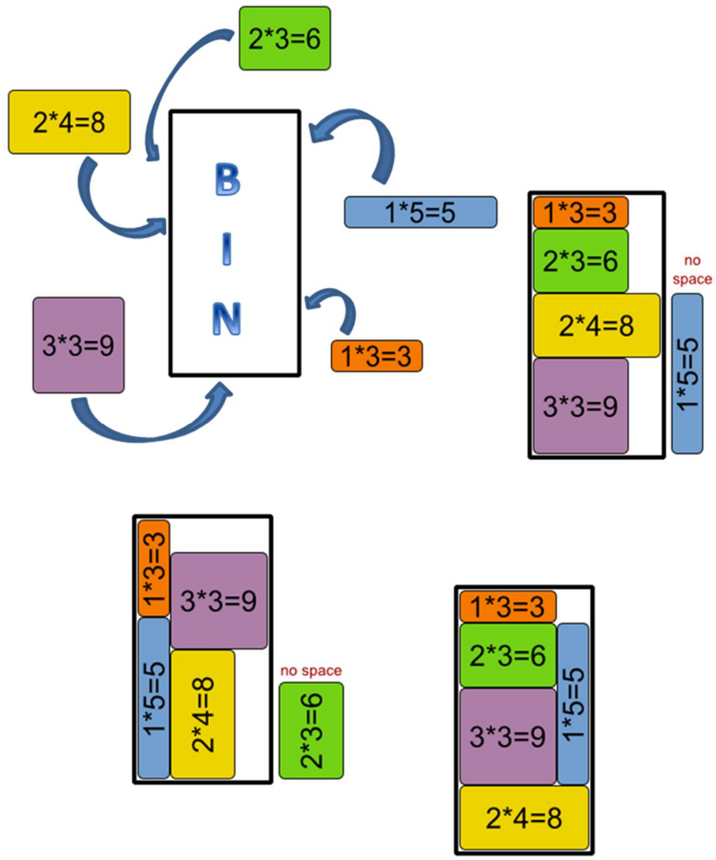

Figure 3 Graphic illustration of the Bin Packing Problem

The Bin Packing Problem has been studied with techniques such as the Integer Linear Programming, consisting of a formulation with the use of discrete coordinates to allocate the items; the application of metaheuristics like Tabu Search, the utilization of exact algorithms like Branch and Bound or other algorithms based on the Knapsack Problem; and the Graphic Theory (Lodi, 2002).

1.3 THE CONTAINER LOADING PROBLEM

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 (Ho et al, 2013). 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 (Figure 4) (Liu, Zhanga and Yueb, 2012).

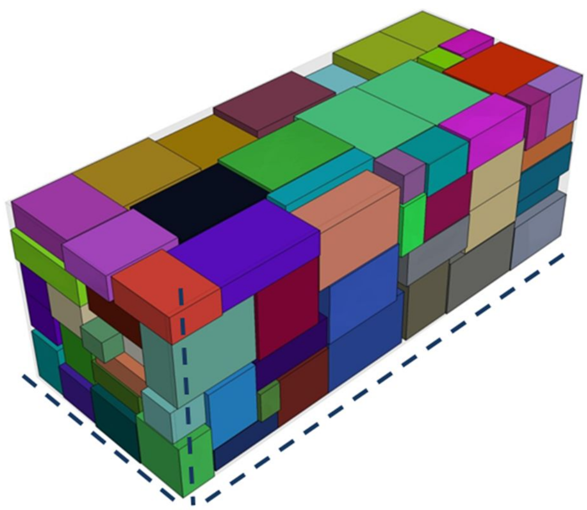

Figure 4 Illustration of the Container Loading Problem

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 (Ho et al, 2013).

There has been a wide variety of approaches in the search of optimality concerning the Container Loading Problem. At first, linear, integer and / or binary models have been chosen as they allow the use of standard software and facilitate the supply of information values and bounds of the optimal objective function. With the structural analysis of such models, it is possible to find ways to develop advanced solution techniques based on column generation, branch-and-bound and branch-and-cut among others. Exact and Approximate Algorithms have also been a source to seek for a solution of this problem, highlighting the Branch and Bound algorithm and the Tree Search Algorithm. Certain heuristics or metaheuristics have been developed such as:

- The Wall-Building and Layering Heuristic.
- The Stack Building Heuristic (also known as the Tower Building Heuristic as it consists of towering up the containers to fill the container).
- The Cuboids or Blocks Arrangement Heuristic, which intends to fill the container with cuboid arrangements of similar boxes (Bortfeldt and Wäscher, 2012) (Ho, Lee, Majid and Seow, 2013).

The most common arrangement is the wall-based building which is characterized by having the small items loaded in the container in the formation of horizontal or vertical walls. Even when the items are cubic, the geometrical shape of the container will keep on varying every time a new item is packed. Hence, the new shape to be loaded must be divided among the remaining items every time until completion. It is especially useful in the transportation industry (Liu et al, 2012).

1.4 THE PALLET LOADING PROBLEM

The Pallet Loading Problem (PLP) arises when small items must be placed onto a large pallet in manufacturing workshops and other logistic areas (Figure 5) (Alvarez-Valdes, Parreño and Tamarit, 2005).

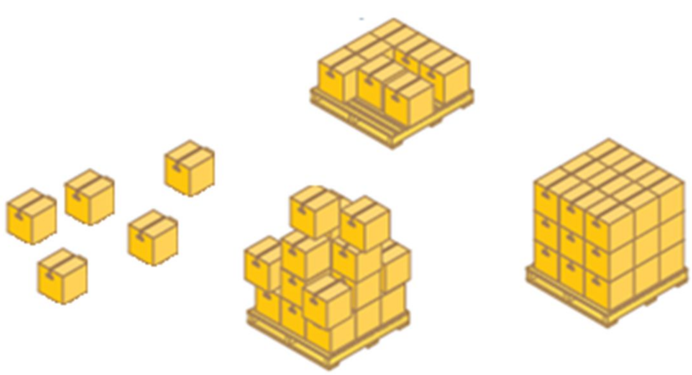

Figure 5 Most common PLP's representation

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 (Scheithauer and Terno, 1996). The Pallet Loading Problems can be classified in:

1. The *Manufacturer's Problem:* occurring when there are homogenous cargoes to be efficiently placed onto a pallet.
2. The *Distributor's Problem:* it arises when it is necessary to stack heterogeneous pieces onto a pallet (Scheithauer and Terno, 1996).

The general PLP is quite complex and therefore, NP hard. The difficulty of an instance of the PLP is related to the ratio between the pallet's dimensions and those of the boxes, but in any case, the encoding demands only four integers. That differs from the other NP-complete problems (said to be intractable because possible solutions require exponential time to occur, as well as the consumption of high computational resources) in which larger instances imply larger input lengths (Alvarez-Valdes at al., 2005) (Leyton-Brown, Hoos, Hutter and Xu, 2014).

In the obtainment of a solution for the manufacturer's problem, the organizations have used modern technology as a key tool since 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 (Abdou and Elmasry, 1999).

The manufacturer's problem, applicable in different areas such as production and other logistical areas, has been defined as of type 2/B/O/C which means there is an assignation of a maximal quantity of small identical rectangles (boxes) onto a large rectangle (the pallet). It causes an arrangement of boxes oriented orthogonally on the pallet to get a regular, stable and optimum number layout (Yi, Chen and Zhou, 2009). Here, the manufacturer produces goods to be packed in boxes with the same size (length, width and height) which must be placed in horizontal layers onto pallets of a determined size (Length, Width, Height). The height of the pallet will be variable and restricted according to different factors such as the stability, requirements of a customer, resistance of the boxes, etc. An important assumption is that the boxes are available in large quantities and all of them should be placed orthogonally on the pallets (the sides of the boxes parallel to the sides of the pallets) (Birgin, Morabito, and Nishihara, 2005).

The analysis of one of the above problems (Knapsack Problem, Bin Packing Problem o Container Loading Problem) could become the guidance for another, granted the fact that all of them imply the efficiency of utilization of space to get benefits. It is also clear that the solution techniques are common to all these problems.

1.5 SOLUTION TECHNIQUES FOR THE PLP AND OTHER RELATED PROBLEMS

The above-mentioned problems have been subject of study for many years in the field of Operations Research through the development of models in order to find feasible or optimal solutions. It is remarkable to underline that due to the complexity of packing problems, the solution methods combine techniques from the fields of computational geometry, operations research and algorithms (Egeblad, 2008).

In general, there are different methods to find a solution to these and other instances, reason for which it is important to present them at a glimpse:

- *Combinatory optimization* consists of seeking the optimal solution of a problem, granted all solutions are related to a determined value. The term combinatory refers to the mathematical branch, which studies finite collections of objects to satisfy specific criteria, focusing particularly on the scrutiny of such collections (enumerative combinatory) and on the determination of the existence of certain object (extremal combinatory). On the other hand, optimization means the search of the best value, something not always resulting in all instances. Through the Combinatory Optimization, it is expected to reach the most optimal solution amongst a discrete, and therefore, finite set of items. Broadly speaking, any constructive or search algorithm should be able to find such a solution, even when it can't be guaranteed.
- *Graph Theory* represents an efficient aid to model and solve diverse combinatory problems. It comprises a representation mode and a mathematical basis to find solutions. In general terms, the basic components of the Graph Theory are the vertices (nodes or points) and the linking edges / lines between each of them, conforming together a network. This theory could be useful in some industrial

management situations such as Project Programming, Inventory Control, Route Design, Sequencing, etc.

- *Dynamic Programming* is a method consisting of seeking the optimal sub-policies with more unitive phases so as to find the most optimal policies.
- *Queuing Theory* is a modelling method describing the behavior of queues in systems where entries and / or services occur in irregular intervals. Usually, the most common results of the Queuing Theory refer to systems of a single stage with entries and exits, which follow exponential distributions. This tool is especially useful to design structural elements such as web servers, shared processors, etc.
- *Systems Dynamics* in its essential approach provides a way to observe the human systems, emphasizing the importance of some structural aspects just like the feedback control. In artificial intelligence, this is useful to understand the function of other complex systems so as to improve them through simulation.
- *Game Theory* is a good tool in the decision making process which is compared to a game where an individual experiences a particular behavior by ignoring his opponent's under specific known rules.
- *Heuristics and Metaheuristics* can provide solutions close enough to the most optimal. In artificial intelligence, a heuristic refers to the technic, method, or intelligent procedure used to solve a real problem with a good performance regarding the quality of the solutions and the resources utilized, time and computer processing in particular. Throughout time, many successful heuristics have been developed and therefore, their essence has been taken for the resolution of other problems or more extended contexts. All this has led to the development of metaheuristics which constitute a superior level of heuristics as their performance has been widely proven in the resolution of various instances and their improvement has been continuous. Hence, metaheuristics are intelligent strategies to design or improve general heuristic procedures with a high performance.
- *Simulation* is another tool amongst the quantitative methods, which has become quite popular with the development of computers and their graphic capacity. It is particularly utilized to model the flow of materials and information. An adequate application of simulation requires a big effort to guarantee the worth of the results obtained. Indeed, simulation can be compared to experimentation, and therefore, it is necessary to face the same difficulties found in conventional experimentation (Garcia and Maheut, 2011).

Throughout time, packing problems have been widely studied with similar or the same methods due to common factors among them. Therefore, it is relevant to revise each problem and its solution approaches so as to understand their context, features and development with the aim of finding out what best is applicable in a company under its particular business field. For TransNav with a wide variety in the size of its products, the PLP appeared to be a reality to be studied so that the company can obtain an important benefit with an efficient stacking of boxes onto pallets for an appropriate storing, handling and cheaper transportation.

2. LITERATURE REVIEW

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 (Fanslau & Bortfeldt, 2010).

Packing problems have been broadly studied since the nineteen-sixties, originating a wide variety of solution methods of heuristic origin in particular. However, there has also been an important development of exact and approximation algorithms in the search of a solution for these problems (Egeblad, 2008).

2.1 PREVIOUS STUDIES ON THE PALLET LOADING PROBLEM

In the search of the solution of the PLP, there has been an extensive development of metaheuristics (methods used in order to find near-optimal solutions to problems with the avoidance at the same time of remaining stocked in an unsatisfactory local optimum) based on tabu search, genetic algorithms and strategic oscillation (Alvarez-Valdes et al, 2005).

Likewise, in the obtainment of achieving 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 (Abdou and Elmasry, 1999).

In summary, 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 way the solution has been reached.

One of the initial approaches published, corresponds to Dowsland-A (1987), who focused on the manufacturer's pallet loading problem, providing an exact three search algorithm based on the graph theory. Thus, pallet was equaled to a graph with points in specific coordinates, which became the vertices of the possible positions of the boxes in the search of an optimal layout. There had to be no box overlapping and stability had to be a consequence of the arrangement. Due to the complexity inherent to the millimeter accuracy, the quantity of vertices had to be reduced with the application of bounds and the utilization of equivalent classes which had proven that the pallet's layout for certain quantities of boxes followed the same patterns. The algorithm was tested with 1000 instances (generated randomly with different sizes for the boxes in consideration and also different-sized pallets, including the most commonly used at that time in the world) in a computer VAX 780, obtaining a solution for the majority in not more than one second and only 16 remained unsolved in a time of not more than 100 seconds.

Another study of the same author, (Dowsland-B, 1987), involved the creation of an algorithm to solve particularly complicated PLP situations in five minutes. This algorithm resulted in a package called POSY (Pallet Optimization System) that focused on the manufacturer's PLP with homogenous boxes placed orthogonally on the pallet with a bi-dimensional treatment. FORTRAN (Formula Translating System) has been the programming language to write POSY. POSY bases on a tree search whose nodes represent partial layouts of the boxes on the pallet. These layouts change with the addition or reduction of a box up to the point of finding an optimal solution. A selected sample of 1000 instances according to the box ratio, the pallet ratio and the area ratio was used to test POSY's performance. The results proved that POSY could solve 95% of this sample in a rank between one and 10 seconds depending on the computer in use (a VAX computer, which gave a better performance or an IBM-PC which provided a slower response).

The introduction of a polynominal time algorithm (Block-L Pattern) via dynamic programming to solve the manufacturer's PLP, which provided a new approach to deal with this problem, was presented in (Tarnowski, Terno and Scheithauer, 1994). This proposal implied the reduction of the PLP to bi-dimensional with homogeneous rectangles to be placed on a pallet. All figures in use are required to be integers. It is called guillotine pallet loading problem as it considers a pattern obtained by cutting the large rectangle into pieces or positions for the boxes from one of its edges to the opposite and parallel to the other two edges remaining for each layer on the pallet. From this point, the efficiency to utilize the whole surface of the pallet is prosecuted by creating patterns with the shape of the letter L (horizontally and vertically or vice versa with an orthogonal placement regarding the pallet). With each iteration and the creation of an L-pattern, the stacking area reduced and therefore, the new L-pattern had to be placed in a smaller rectangle, implying new calculations. As result of the whole analysis and development of the formulation of the algorithm, it was proven that the PLP could be solved in polynominal time (fast).

The development of a new research by Abdou and Yang (1994) on the 3D PLP took into consideration the factor that the boxes have different sizes regarding their base (length and width), being grouped by a common height, although boxes with a different height could be allowed in the upper layer. The position of the boxes can be rotated according to the z-axis, keeping an orthogonal position concerning the pallet and the maximum height of the loaded pallet cannot be exceeded with the different layers of boxes. Demand is an element in consideration for the algorithms derived from Brown's Linear Equation, which is an approach, developed to solve the 2D bin packing problems. Boxes are organized in blocks before they are stacked on the pallets. There is a revision of the resulting conformation of every layer, according to the achieved efficiency of its layout and specific criteria (pallet utilization, stability and WIP – work in process), so as to select the best final solution for the whole palletization problem. This heuristic approach was tested with the utilization of seven different types of boxes to be stacked on to a single pallet. The resulting layouts allowed the authors state the space utilization of the pallet had been

100% used. They could obtain six possible layouts of the complete loaded pallet, choosing the one with the highest stability.

On the other hand, the solution of the Distributor's PLP is tackled by Bischoff and Ratcliff (1995) in order to load efficiently more than one pallet with a somehow large consignment of items for a customer in boxes of different sizes so as to supply a given order. There is a restriction of the height per pallet (3D treatment), only certain quantity of boxes cannot be exceeded and stability is a must. There is a focus to apply the efficient arrangements subsequently.

The method consists of a heuristic algorithm which starts with the construction of the loading pattern of the pallet per layer from the lower in the bottom to that on the top according to the height limit with the inclusion of not more than two types of boxes. The selection of the sorts of boxes and their orientation depends on most efficient utilization of the pallet's surface. The process starts with a list of the whole set of unpacked boxes which make up the consignment so that there is a conformation of blocks to be stacked onto the pallet with an orthogonal position. The pattern to be chosen is the one with the highest use of the pallet's surface. At first, these blocks are preferred to be constituted with one-type boxes or boxes with the same height so that there is a large flat surface to stack the subsequent layer. The list with available boxes is decreased after the conformation of each layer of the pallets, being an iterative process. It is important to note that it was necessary to carry out different experiments so as to set the mechanism to make the algorithm work in sequence so that the operation could continue after completion of each pallet. In a second stage, it was tested to stack simultaneously a specific number of pallets so that possible combinations were an alternative for all the pallets at a time, avoiding the probability of a more suitable pattern for a different pallet than that were it got stacked. Both options were tested with 9600 instances with up to 30 different types of boxes.

Comparatively, it could be observed that the best results came out from the sequential approach as the results provided more space occupation on the pallets.

The situation of loading pallets with non-identical items has also been subject of a specific study prepared by a team of researchers (Bischoff, Janetz and Ratcliff, 1995) in order to deal with non-homogenous boxes to be arranged onto a set of pallets (the least, the better) to supply an order of a customer (the distributor's pallet loading problem). In this case, the importance of stability was not left aside with the algorithm the authors developed as it provided an efficient arrangement of the boxes onto the pallets.

The algorithm's loading procedure went from bottom upwards up to a specific height clearly known, checking possibilities to create single layers of not more than two non-identical sorts of boxes at a time. The election of the type of box and its orthogonal orientation depended on the resulting highest utilized space of the layer onto the pallet's surface. It is important to mention that the layers to be chosen had to constitute a large flat surface for the placement of the consecutive layers. Layers with higher gaps or spaces should be preferred because these kinds of spaces can be more easily filled in posterior stages. After several iterations took place, it was possible to check and compare the results in order to choose the one which represented the most efficient solution. The results with the utilization of up to 20 types of boxes showed an efficiency of up to 80%.

The search for a solution for the Distributor's Pallet Loading Problem and its challenges led to the development of a new heuristic approach from an academic group (Scheithauer and Terno, 1996). For this purpose and in addition to the importance of efficiently utilize the surface of the pallets, it was also essential to take into account the minimum number of feasible packing patterns so as to fulfill the demands of the products contained. This work also considers elements such as the orthogonal position of the boxes regarding the pallet, a possible rotation on the pallet, a maximum height per loaded pallet, and the avoidance of any overlapping. However, there are other important considerations like a limited probable weight per pallet, the density of the boxes which can restrict their position on the pallet; the possibility of having a large demand of a specific type of box that may result on having a loaded pallet with homogenous boxes unless having mixed cargo results in less utilized pallets; and the consecution of stability for transportation purposes of the loaded pallet.

At first, the development of the algorithm in this approached based on the so called G4 - Heuristic which creates four sub-patterns to efficiently form one final pattern which represents a layer of the pallet (it works on a bi-dimensional basis). From this, there is an estimation of the total number of pallets to be required in order to pack the whole shipment demanded. However and due to the elements involved such as height and stability, the algorithm also incorporates branch and bound. Stability is left aside up to a postprocessing action when there is a revision to assure that there is sufficient large area of at least two boxes beneath the one placed on top of them. It was proven that the algorithm was able to get an optimal solution with the inclusion of ten different types of boxes with a specific demand, which were stacked in three pallets. The proposal constituted an initial research to be further treated so as to be enriched to provide the response to other factors.

From the point of view that the PLP is useful for the development of an appropriate logistics, a new heuristic was conceived to solve the manufacturer's Pallet Loading Problem in (Morabito and Morales, 1998). Here, the main considerations are: homogenous boxes bi-dimensional presentation, (essence of the manufacturer's PLP), orthogonal location with regards to the pallet (being possible the rotation of the box) and overlapping avoidance. There was no consideration to possible constraints of weight, density, fragility, etc. of the load. The initial coordinates correspond to 0,0 (x,y), which are taken as the left lower corner of the big rectangle representing the pallet. The development of the final solution method resulted in the implementation of three algorithms to reach for the most efficient solutions. Such algorithms were based on the Bischoff and Dowsland Heuristic (referred as B&D Heuristic), which deals with the conformation of rectangular blocks which occupy the whole surface of the pallet so that finally, each of these blocks is filled with the rectangular boxes on a specific position. The algorithms were developed in Pascal (Delphi 2) and C. As a final result, it was proven that the algorithm number three was able to find an optimal solution for most of the examples analyzed (there was only a failure to do so with 18 out of 20,000 examples).

With a new procedure called random stacking whose aim is the stacking of heterogeneous boxes on pallets without a previously defined pattern, a new research was carried out in (Abdou and Elmasry, 1999). The focus was to provide a better inter-locking of the boxes to cause stability of the wholly stacked pallet. Thus and under this procedure, the researchers proposed a heuristic algorithm to seek for the maximization of the volumetric pallet utilization, the minimization of work-in-process and the time of robot palletization immerse in the distributor's pallet loading problem. It is important to mention that the boxes involved get to the pallet stacking zone in a conveyor line, they are heterogeneous, their stacking is done by robotic manipulators, there is a temporary holding area for non-in-the-moment-stackable boxes (only one box per type can remain here), and they are randomly stacked onto the pallet. As in other approaches, boxes can be rotated, but their position will remain orthogonal to the pallet and there is a defined height for the fully stacked pallet.

For the simulation of the palletization process, they developed a computational program in Turbo C++ and executed ten simulations to get the solution of different random sequences. The trials comprised eight different types of boxes and a standard pallet of 48x40 inches. The final results showed a volume completion of the pallet between 87% and 96% granted 100% is not feasible due to the characteristics of the boxes.

As in the developed world, the PLP also caught the interest of researchers in other latitudes in the third world (Farago and Morabito, 2000). In Brazil, there were important developments in the search of a solution on this problem with the utilization of a heuristic method based on Lagrangean and Surrogate relaxation, comparing the results with other previous proposals. The model was developed with an integer 0-1 program. Boxes in the model are considered as bi-dimensional and with identical dimensions (length & width) of integer values. Boxes are stacked orthogonally to the pallet with the objective of utilizing the maximum surface of such a pallet, avoiding any overlapping. In the past, other researchers have worked on a similar approached, which did not integrate the surrogate relaxation and based on a more general PLP. The initial formulation of the model comprises the coordinates on the left lower corner of the rectangle representing the pallet. Boxes could be placed horizontally or vertically concerning the pallet's length and width. There was the definition of a function to state restraints to avoid any box overlapping. The Lagrangean and Surrogate relaxation provided necessary limitations and reduction of the size of the problem to reach a more feasible solution after iterations.

To execute the model, the researchers developed two computation programs called LAGSUR and LAG which were tested with instances involving up to 100 boxes. Both were based on the Pascal Language (compiler Delphi 4) and comprised reductions techniques for the problem as well as a Lagrangean heuristic. The results provided better feasible solutions for the real situations analyzed regarding a transportation company, but the performance was not that good for examples from literature. Computational time was substantially reduced. However, it was reported that the program LAG provided a better performance by finding optimal solutions more often than LAGSUR with the same information (90% against 80%). Additionally, LAG achieved a better performance by 50% regarding real loads in most cases.

The interest in the PLP has originated a wave of proposals such as the development of a strategic oscillation algorithm in (Amaral and Wright, 2001), which does not only focus on feasible solutions, but spends some time exploring unfeasible solutions. Therefore, piece positions are added or removed during constructive or destructive phases respectively. The process consists of five stages:

- The generation of an initial solution by randomly stacking boxes on the pallet avoiding overlapping just until the moment it is not possible anymore.
- Addition of new boxes reaching an increasing unfeasibility due to overlapping. However, each box added is placed in such a position to enable the reduction of overlapping.
- All overlapped pieces are removed to reach feasibility, again. Gaps appear.
- It is a destructive phase in which specific boxes are removed to create a large gap. However, the pieces removed should be the ones, which should require less boxes to be added. This causes a maximizing effect regarding the new feasible piece positions.
- Return to the feasible boundary by filling the gap created in the previous stage with the use of a greedy procedure. This implies the return to stage B, unless the stopping criterion is satisfied (a certain number of iterations or the arrival to an optimal solution).

Due to some problems such as cycling, the model experienced adjustments in the above-mentioned stages as well as the setting of some parameters based on experimentation. The algorithm allowed the stacking of instances of ranges of 10 - 40 boxes packed in an optimal solution as well as a large scale optimization with 97 boxes. The code was written in C.

Having the previously developed tabu thresholding algorithm for the solution of the Manufacturer's PLP, there was a new approach corresponding to Yamassaki and Pureza (2003), which intended to refine it for a better result with the implementation of tabu search under a bi-dimensional treatment.

The general rules of the PLP are applied: no overlapping, orthogonal placement of the boxes and efficient utilization of the pallet's surface. Hence and from an initial coordinate located on the left lower corner of the pallet (0, 0) the algorithm performs several iterations with the permission of overlapping with the aim of observing the best solution. Solutions with overlapped boxes are disregarded and only those with the conformation of the pattern with the highest coverage of the pallet's surface are selected. Whenever overlapping persists, the algorithm picks out a box so as to search for an efficient solution with the existence of no overlapped box (zero overlapping).

The algorithm was implemented in Borland Delphi 4.0 and it was restricted to a maximum of 1,000 iterations to find a solution with no box overlapping. To check the performance of this improved algorithm, it was tested with eight instances implying the utilization of the ranks 10 to 19 boxes and 20 to 30 boxes, finding a solution for all of them. However, when it was intended to find a solution with the use of more than 30 boxes, time was a major issue as it took an average of eight hours. Because of that, the algorithm was reformulated to add a feasibility procedure which consisted of the location of the box which caused more overlapping and the adjacent ones so as to block their use for a latter re-execution of the algorithm which led to their proper stacking on the pallet. This caused the reduction of time (by around 46%) and even helped find the solution for all the instances with more than 30 boxes and less than 40 boxes.

Back in Brazil, Pureza and Morabito (2004) made some experiments with a simple tabu search algorithm to solve the the manufacturer's pallet loading problem. The model developed incorporated a simple tabu search to construction heuristics (known as block heuristics) for the construction of a functional algorithm from an initial loading pattern. These block heuristics consist of forming one or more blocks of boxes arranged in the same orientation. It is important to state that simple tabu search elements are bound to short term memory structures, which store and penalize some characteristics or attributes of previous solutions for a specific number of iterations. Another distinctive element of this algorithm is its design to search only for feasible patterns, something that involves the selection of active blocks of boxes in a specific direction. Its expansion usually requires the modification of other inactive blocks so as to maintain the feasibility of the solution to be obtained. Therefore, these inactive blocks can be split out, decreased in size, or have their original box orientation changed, creating in this way new patterns. The algorithm was implemented in Delphi 5. The algorithm provided an optimal result for 17 out of 21 instances as follows:

- 10 of a first set (23 to 97 boxes)
- Seven of another set (53 to 100 boxes)

Computational time became an issue for large trials.

A group of researchers (Alvarez-Valdes et al, 2004) worked on a branch-and-cut algorithm for the pallet loading problem, providing a solution proposal for the manufacturer's PLP. Their algorithm comprised a 0-1 formulation and focused on finding an optimal solution for problems involving more than 100 boxes. As in other studies, the position of the boxes is orthogonal to the pallet and it is indicated according to coordinates (positive integer pairs), being the initial one, the bottom left corner in the rectangle representing the pallet. Boxes can be placed horizontally or vertically, but they cannot overlap.

The formulation of the whole algorithm contains a complete set of reductions of constraints or variables to achieve a relaxation of the problem to simplify it in such a way it is faster and more efficient to find optimal solutions. Thus, it results in branches with feasible solutions among which the algorithm must choose the most complete to base the efforts on it. Possible wastes are limited to occur only on the top or the right of the pallet, but nowhere else. The goal was reached and the algorithm was able to solve hard problems with more than 100 boxes, even when 241 out of 2433 problems implied very long computing times (up to 15 hrs.) to get an optimal solution.

Throughout time, there have been specific studies to apply the PLP in a particular situation such as an algorithm to efficiently load various sets of products (drinks) in boxes of different sizes onto as few pallets as possible prior their ground transportation as in (Lel, Creighton & Nahavandi, 2005). With the intention of reducing the quantity of combinations in the algorithm, it was necessary to set a methodology which grouped the products in boxes with the same size, making these sets the input data. It was necessary to set a rule to specify the minimum percentage of a specific product to be contained in a pallet so that the pallet could be acceptable in the fulfillment of an order of a certain customer in a precise date. The algorithm's allocation of boxes onto the pallets consisted of different steps as follows:

- All boxes which could constitute a complete pallet on their own would be stacked first.
- All remaining boxes after the procedure above constitute the base for new grouped boxes to be stacked onto pallets, taking into account the volumetric occupation, the product class and the minimum percentage of product to be contained on the pallets. This step results in complete or partial pallets which get completed after the process of grouping identical or similar boxes takes place over and over.
- The pallet's completion cannot be superior to 120% of the allowed volume.

In a first experiment, the algorithm stacked 403 boxes in six pallets, obtaining a completion of 71.38% as the lowest in one pallet and 100% in two pallets in only 50 milliseconds of running time. The second and more ambitious test in its last stage implied the use of up to 2800 orders and 222187 boxes which could be efficiently stacked in 3862 pallets (only 19 boxes lower than the manual maximum pallet requirement of 3881 pallets) in a running time of 8.79 seconds.

The algorithm was written in C+ programming language and ended up with the creation of a computer program to arrange a shipment onto various pallets efficiently.

Treated as a bi-dimensional loading problem to reduce its difficulty, a new heuristic solution was proposed by Young-Gun G. and Kang (2001) with the integration of the 5-block structure to solve the manufacturer's PLP. Dimensions in all cases are positive integers; the box location is orthogonal; the pallet's surface cannot be exceeded; and there must be no box overlapped. For this, the algorithm in question creates blocks of boxes with a specific orientation (horizontal or vertical), being a procedure called FindBlockLayout. When these blocks are stacked onto the pallet (creating a structure of five blocks of boxes onto the pallet), there is the formation of a hole and an overlapped area which are treated again up to the moment when the hole is reduced to the minimum and no overlapping occurs.

The algorithm was coded in C++ 6.0 and tested with instances involving up to 97 boxes. With the exception of six instances out of 30, optimal solutions were obtained within one second in all cases. However, the largest instance which implied the stacking of 6800 boxes on the pallet's surface took 16 minutes till the moment when the optimal solution occurred.

With an enhancement of the so called L-approach (dynamic programming) utilized in the search of solutions for the manufacturer's PLP, a new approach by Birgin, Morabito and Nishihara (2005) provided a runtime reduction by using a different data structure. Such time reduction is relevant because it makes the algorithm more useful in the actual pallet loading decisions. The name of L-approach comes for the fact of stacking boxes of a rectangular bi-dimensional shape (length l, width w) into a larger rectangle or L-shaped item representing the pallet.

This study maintained the following main considerations: it is reduced to a bi-dimensional instance, all boxes are homogenous, their position is orthogonal regarding the pallet and they must not overlap. The L-approach algorithm based on a dynamic programming recursive formula was implemented in C language in a Linux operating system. An important feature of this approach is its essence of storing and retrieving information of previous successful solutions to be applied in the resolution of other sub-problems. This implementation of the L-approach was able to get optimal results for instances comprising up to 100 boxes.

Comprising the use of elementary number theory to analyze the structure of optimal solutions and the incorporation of duality bounds to constrain the empty regions on the pallets in optimal solution, Mascarenhas (2005) sketched a new exact algorithm to be developed to solve the Manufacturer's PLP. Again, the main considerations imply that boxes are placed orthogonal to the pallet in a horizontal or vertical position and there is no allowance of any box overlapping.

The sketched proposed exact algorithm implies the settlement of a lane which covers the whole solution area to show the filled area and the constraint of the areas that can be left empty so as to locate the empty parts of the pallet. This combination was expected to provide an efficient solution for the Manufacturer's PLP, but it was opened for further investigation and future implementation. Therefore, no results are provided.

The Manufacturer's Pallet Loading Problem has been repeatedly treated in different ways, being the Lagrangean relaxation with clusters (LAGCLUS) another solution method explored in (Mattos-Ribeiro and Nogueira-Lorena, 2005). LAGCLUS presents a conflict graph that can be partitioned in clusters which become sub-problems that can be independently attended. Each vertex of the conflict graph stands for the left-lower corner of the boxes onto the pallet. There is the application of a Lagrangean relaxation of the constraints in the MPLP which refer to the possibility of having vertices (edges) in the same position and therefore, causing overlapping. If that is the case, an adjacent constraint to every found pair so that there is not such a situation and the solution can occur for each cluster.

This method works on the solution of the PLP, taking it as bi-dimensional with boxes of the same size and with the goal of having as many boxes as possible stacked onto the pallet. As in other proposals, there must be no box overlapping; boxes are orthogonally stacked onto the pallet; and there can be a 90° rotation of them so that the box position is either horizontal or vertical.

In this case, the algorithm's code was written in C++ while the sub-problems were solved with CPLEX with the use of METIS (a heuristic used for graph partitioning problems) for the graph partitioning task. The algorithm proved to find an efficient solution for the most difficult instances.

Having tabu search as the base for a new approach, there was a contribution with a new heuristic algorithm to solve the manufacturer's Pallet Loading Problem in (Alvarez-Valdes et al, 2005). The new model made use of blocks (sets of boxes with the same orientation) instead of individual boxes. The main considerations for the development of the algorithm are: all boxes have the same size, placement is orthogonal to the pallet, boxes can be rotated, the initial coordinates correspond to the bottom left corner of the pallet, no box overlapping is allowed, and all figures must be positive integers. The model takes into account feasible solutions only.

The algorithm creates blocks of boxes, which fit the length or width of the pallet completely or partially. Whenever the block fits partially, there is a waste or unoccupied space that must be completed with the augmentation of a box. However, this free space (waste) can also end up with the elimination of a box so that another complete block can be placed to use the space more efficiently. As a definition, blocks must tend to situate in the corners of the pallets, leaving empty spaces in the center. It is important to mention that the algorithm also comprises the formation of G-4 structures. Therefore, it must iteratively select a set of blocks (either horizontal or vertical) or a G-4 structure to complete the available space of the pallet in the most efficient possible way.

C++ was the selected language to write this algorithm. Results proved the algorithm to be effective to solve problems with not more than 50 boxes in not more than one second. With regards the next level, which comprises up to 100 boxes, the algorithm could not find optimal solutions in all cases (45 cases) in a time not superior than five minutes. The algorithm could even produce an optimal solution with the stacking of 149 boxes onto a pallet.

With the application of integer linear programming to solve the manufacturer's Pallet Loading Problem, Wu and Ting (2007) developed a two phase algorithm whose initial phase provides a layout pattern with the maximum number of boxes to be placed onto the pallet's surface (both vertically and horizontally) per row and then, there is the application of a constraint programming model in the second phase. The algorithm's constraints in the second phase imply the impossibility of overpassing the pallet's dimensions, the exclusive use of integer variables, no box overlapping and the allowance of a 90° rotation of the boxes to get the best possible location. The second phase with constraints must result in an equivalent pattern layout as that obtained in the previous one.

For the solution of the model, CPLEX 9.1 (IBM's optimization software package) was used, while Borland C++ Builder 6.0 constituted the tool to draw the layout pattern. The algorithm was tested with two instances which involved from 23 to 97 boxes and from 53 to 100 boxes, getting an optimal solution in an average of 392.45 seconds in all.

With the knowledge that the bi-dimensional problem which involves the efficient orthogonal placement of small rectangles into a larger one (boxes onto pallets, pallets in trucks or stowing cargo in ships) without overlapping, a new research in (Birgin, Lobato and Morabito, 2008) explored other alternative of solution by combining a recursive five-block heuristic and an L-approach. The resulting algorithm uses the recursive five-block heuristic to divide the whole surface of the rectangle representing the pallet in smaller rectangles, which should become the position of one or more boxes (also rectangles) in the search of the most efficient space utilization of the pallet. Then, there is the integration of the L-approach, which, in this case, meant the division of the rectangle into two L-shaped forms in order to compare the results obtained with the five-block heuristic. With that combination, it was possible to select the most optimal solution.

As a result, it was possible to obtain an optimal solution for problems involving up to 100 boxes and even cases with more than 100 units. The algorithms were written with the use of C/C++ language.

Seeking to solve the manufacturer's PLP, with the application of new bounds, heuristics and an exact algorithm, a recent proposed model created by Martins and Dell (2008) focused on problems comprising up to 100 identical boxes, which had to be stacked on a pallet with the avoidance of any overlapping, a possible 90° rotation and an orthogonal location (due to stability and safety) with regards to the pallet. Resulting figures must be positive integers and there must always be at least on box onto the pallet. This study implements at first three different bounds (Maximum Product Bound, Minimum Area Ratio Bound and Barnes bound), followed by the one-block, two-block, Hollow Block, and five-block heuristics to stop whenever a placement equals the best bound. These techniques proved to be efficient to solve the different instances involving up to 100 boxes. However, no optimal solutions were reached for all the instances despites the high performance because only 5% of the instances involving up to 100 boxes could not be solved. The unsolved instances were subject to the Single Homogeneous Perfect Partition Bound and the same heuristics previously mentioned, achieving an optimal solution for some others, but not for the whole set. Therefore, there were successive new attempts for the unsolved instances with the application of the Single Perfect Partition Bound, the Relaxed Class Bound, the Combined Perfect Partition and Restricted Class (CPPRC) Bound; G5-Heuristic, the Higher-Order Non-Guillotine (HONG) heuristics, and the HVZ algorithm. The whole procedure proved to solve all instances involving up to 100 boxes, although for the last trials with the HVZ, it took long computation times as it took more than 24 hrs. until the moment an optimal solution was reached.

Besides the interest in achieving the maximal utilization of the pallet surface, Kocjan and Holmström (2008) worked on a new research that also focused on an optimal stability when feasible solutions were obtained. In order to do so, there was a conception of an algorithm based on Integer Programming formulation with the aim of proving that the stability criteria can be the main objective without leaving aside the requirement of maximal completion of the pallet's surface. As in other approaches, the main considerations are: all boxes are homogenous, there must be no overlapping, the position of the boxes is orthogonal to the pallet and the boxes can be rotated to achieve the best space possible occupation. The algorithm's execution was organized in three phases:

- The maximal quantity of boxes and maximal layout is calculated.
- There is a calculation of the patterns of the two first layers so that their arrangement meets the required stability criteria.
- The whole load is set by stacking boxes according to the calculations in the previous phase up to a certain height.

Of the three phases, the main one is the second because if there is a fail to meet the stability criteria, there is a re-start of the process, but if it works properly, the third stage is carried out. The algorithm was proven with a pallet of 110 cm (length), 110 cm (width) and a possible maximal height of 140 cm for the wholly stacked loaded pallet. On the other hand, the boxes go increasing one centimeter from the following ranks:

- Length: from 30 to 40 cm
- Width: from 20 to 30 cm
- Height: 40 cm. in all cases.

That represented 121 box sizes to be tested and a maximum of 50 boxes per layer. Thus, the evaluation showed that optimal solutions resulted in more than 95% of the cases.

With the introduction of a pinwheel pattern (square or rectangular contour with one or more inner holes) as a solution alternative for the manufacturer's Pallet Loading Problem in (Yia, Chen and Zhou, 2009), the researchers carried out a new algorithm which can solve instances with up to 76 boxes. A pinwheel pattern contains the arrangement of holes (with a size inferior to that of a box so that there is a base for the upper layer), the formation of leaves and orientation. As in all cases, box location on the pallet is orthogonal; box overlapping is not permitted; dimensions of the boxes must be positive integers; and it is possible to use blocks of boxes with the same orientation (horizontal or vertical). In this case, the PLP is simplified to bi-dimensional to reach the most efficient utilization of the pallet's surface, but right after that it is again treated as three-dimensional so as to take into account the stacking layers and stability of the load as a whole which depends on the loading pattern, the nature of the product, the mode of transportation and other factors. The conformation of the pinwheel can result from single boxes and / or blocks of boxes together. There are three possible pinwheel patters to result: simple, block and nested.

The algorithm was meant to reach a near-optimum solution with a satisfactory number of boxes and a proper pattern shape. In most cases, the pinwheel pattern must be completely symmetric, meaning it can be rotated for the stacking of upper layers. Nevertheless, there are few instances in which an asymmetric patter can also provide an efficient arrangement.

The focus on profit has not always been the main goal in the PLP in which the efficient use of space has been the guideline. However, in the case of forwarders it is a must due to the store penalty they face under certain circumstances which cause a limited availability of space in airplanes, particularly. Hence, a group of researchers (Lau, Chan, Tsui, Ho and Cho, 2009) made up a hybrid algorithm with the use of a profit-based heuristic and genetic algorithms to search for a solution of the three-dimensional profit-based multi-pallet loading problem, formulated as a nonlinear integer programming problem. This algorithm deals with the stacking of heterogeneous boxes, calculating the profit by subtracting the cost and penalty from the revenue. The formulation of the algorithm incorporated specific constraints such as an impossibility of exceeding the maximum permissible weight or volume, the use of storage during a period going from zero to the maximum allowed number of days, or the limitation of values of variables to 0 and 1, exclusively.

Loading pallets depend on the profit of the cargoes to be stacked, their delivery dates and airlines companies for their transportation, as well as the adequate pallets to be rented. Therefore, specific loads are stacked on one or other specific pallet to be transported in this or that airline on certain dates according to convenience. In this way, genetic algorithms work as in nature where fitter individuals have more survival and reproductive chances. The algorithm's good performance depends on having the most profitable cargos onto the pallets, but also stability is an important factor as well as the efficient utilization of all available room by avoiding empty spaces. This algorithm was tested with the employment of 600 weakly heterogeneous boxes. Simulations were part of the tests to prove the higher efficiency of this algorithm in comparison with previous solution methods based on Tabu search, branch and bound, and simulated annealing.

Dynamic programming with a 0-1 linear formulation and the integration of a recursive partitioning approach is another solution method used in (Birgin, Lobato and Morabito, 2010) to deal with the unconstrained bi-dimensional distributor's PLP, also known as the two-dimensional knapsack problem. The aim in sight consisted of finding the most adequate pattern to maximize the sum of the pieces packed. Common with most researches, it is a condition to avoid overlapping, to have an orthogonal placement and to utilize the surface of the big rectangle involved (being a pallet, a steel plate, a truck, etc.). A 90° rotation is allowed and the left-lower-corner of the large rectangle represents the coordinated 0-0. The intention of this PLP application approach was not properly that of loading a pallet, but the efficient utilization of a big rectangle representing steel plates, large textiles or glass to be cut into pieces of different sizes for different purposes.

The recursive partitioning integration approach combines the recursive five-block heuristic (the subsequent division of the big rectangle into a maximum of five smaller rectangles) in the first phase and the L-approach (there is a division of the L-shaped main rectangle into two L-shaped pieces) in a second stage if optimality is not achieved. The algorithm can discard any piece that does not fit in an optimal solution so as to reach efficiency by getting the desired sizes of the sets. The algorithm was coded in C/C++ language and took into consideration 95 instances of the PLP, involving from five to 200 pieces of different sizes. In a conclusive statement, this unconstrained algorithm was found to be able to find an optimal solution in all cases under a bi-dimensional treatment.

Using optimized pattern and trajectory generation algorithm in (Lim, Yu, Han and Kang, 2010), a new research provided an analysis and solution for the operation of an industrial robot used for palletizing with the application of dynamic programming. Therefore, the pallet loading problem is revised. The revision of the PLP uses simulation to show the way rectangular boxes should be stacked onto a pallet by an industrial robot located in a certain position. Hence, it ends up providing an application, which combines an optimized pallet pattern algorithm, an industrial robot simulator, and a modified trajectory optimization algorithm. It was worked on a 2D basis, which was later completed with the addition of one dimension (height) for the optimal solutions so as to work with simulation to have the final multi-layer complete pallet.

For the PLP, this work uses what they call the fast algorithm which is based on the on the 4-block pattern heuristic algorithm, which initially finds a solution by combining the length and width of the four blocks created locating them on the four edges of the pallet. However, this initial solution ends up producing unutilized spaces with enough room to fit a box or overlapped areas. Therefore, the different lengths and widths are re-arranged so as to obtain a couple of solutions to choose the one proving more efficiency, getting rid of any hole or overlapped area. The implementation of the algorithm occurred in Visual C++6.0. The maximum quantity of boxes loaded was 97 and the minimum was 23 in different problems (variation of dimensions of pallets and boxes). Balance and stability of the boxes were not considered.

With the objective of searching for the highest possible efficiency when loading heterogeneous boxes onto a common pallet, Al Shayea (2011) proposed a solution for the three-dimensional PLP, which used a mixed 0 - 1 model. Thus, it explored a solution technique with the use of a branch and bound technique and LINDO software. In the development of such a model, no restrictions were considered regarding stability, the dimensions of the boxes, the pallets, or the quantity of different box sizes to be taken into account. Instead, it considers the three-dimensional essence of the problem, the boxes' orientation on the pallet (length and width, but height cannot be alternated), possible varying dimensions of the boxes, orthogonal placement, avoidance of box overlapping, space utilization, and the inclusion of weight restriction (the total weight of the boxes must not exceed the permissible total weight to be loaded onto the pallet). In all moment, the coordinates for the placement of a box take into consideration the lower left corner of the pallet for the location of each box. This model provides an exact optimal solution, defines with precision the number of each box size as well as the coordinate of position for each of these boxes onto the pallet.

Memory capacity and time duration became a problem when running the model with an increasing number of boxes to be taken into account. In particular, when the situation implied different orientations to form 12 position shapes with four different box sizes, the execution stopped and there was a message showing out of memory, taking 3 hours and 40 minutes up to that point. The difficulty could be left aside when constraints started to be removed.

The PLP has also been intended to be solved with other methods such as a discrete event system approach to minimize logistic costs in a work presented in (Zuñiga et al, 2011). The study in question goes on the search of a high efficiency on the PLP based on the three-dimensional bin packing problem that seeks the stacking of non-identical rectangular cargo-boxes inside the minimum quantity of three dimensional bins or containers. The formalism utilized for the development of the model in this approach is the Colored Petri nets, which provides advantages such as conciseness by comprising both static and dynamic structures, availability of the mathematical techniques of analysis and a graphical nature. A significant obtainment is a flexible model for the solution of the PLP even with the use of time restrictions. The study took into consideration different attributes of the boxes such as fragility, weight, size and others. Also, there are two important aspects in this approach:

- The orthogonal placement of the boxes on the pallet.
- Once a box is stacked on the pallet, its surface decreases and the available space is fragmented so that it can be occupied by another box and so on. The boxes to be stacked can fit or not in the available space given several possible arrangements.

The approach was limited by the quite long computational time, which forced the creation of two heuristics to decrease such processing time. The results proved to stack efficiently up to 16 boxes with different dimensions and with minimum unoccupied space. CPN tools has been the software used in this approach.

Table 1 Summarized comparison of the different revised approaches on the PLP

	Revised approaches in chronological order by author	(Dowsland-A, 1987)	(Dowsland-B, 1987)	(Tarnowski et all, 1994)	(Abdou and Yang, 1994)	(Bischoff and Ratcliff, 1995)	(Bischoff et al, 1995)	(Scheithauer and Terno, 1996)	(Morabito and Morales, 1998)	(Abdou and Elmasry, 1999)	(Farago and Morabito, 2000)	(Amaral and Wright, 2001)	(Young-Gun G. & Kang, 2001)	(Yamassaki and Pureza, 2003)	(Pureza and Morabito, 2004)	(Alvarez-Valdes et al, 2004)	(Lel, Creighton & Nahavandi, 2005)	(Birgin et al, 2005)	(Mascarenhas, 2005)	(Mattos-Ribeiro and Nogueira-Lorena, 2005)	(Alvarez-Valdes et al, 2005)	(Wu and Ting, 2007)	(Birgin et al, 2008)	(Martins and Dell, 2008)	(Kocjan and Holmström, 2008)	(Yia, Chen and Zhou, 2009)	(Lau, Chan, Tsui, Ho and Cho, 2009)	(Birgin, Lobato and Morabito, 2010)	(Lim et al, 2010)	(Al-Shayea, 2011)	(Zuñiga et al, 2011)
Revised PLP variation	Manufacturer's PLP	X	X	X					X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X					
	Distributor's PLP				X	X	X	X		X							X										X	X	X	X	X
Treatment	Bi-dimensional (2D)	X	X	X					X		X	X	X	X	X	X		X	X	X	X	X	X	X	X			X			
	Three-dimensional (3D)				X	X	X	X		X							X									X	X		X	X	X
Solution method	Exact algorithm	X	X	X	X				X			X	X		X	X		X	X	X	X	X	X	X	X	X	X		X		
	Simulation									X																			X		X
	Heuristic method					X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	
Software or encoding language	FORTRAN		X																												
	DELPHI								X						X																
	C++								X	X	X	X	X				X	X		X	X	X	X	X				X	X		
	CPLEX													X						X		X									
	LINDO																													X	
	CPN Tools																														X
	Undefined	X		X	X	X	X	X											X						X		X				

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 (Dowsland-B, 1987) and (Farago and Morabito, 2000) 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, 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 (Lel, Creighton & Nahavandi, 2005), 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 222187 boxes which could be efficiently stacked in 3862 pallets in a running time of 8.79 seconds.

In other cases, C+ in its different versions has been the predominant language for the development of the algorithms as referred in (Morabito and Morales, 1998), (Abdou and Elmasry, 1999), (Amaral and Wright, 2001), (Lel, Creighton & Nahavandi, 2005), (Young-Gun G. & Kang, 2005), (Birgin et al, 2005), (Alvarez-Valdes et al, 2005), (Wu and Ting, 2007), (Martins and Dell, 2008), (Birgin, Lobato and Morabito, 2010) and (Lim et al, 2010).

DELPHI is another programming language which researchers have used to develop their solution algorithms on the PLP as in (Morabito and Morales, 1998), (Farago and Morabito, 2000) and (Pureza and Morabito, 2004). 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

(Yamassaki and Pureza, 2003), (Wu and Ting, 2007), (Al-Shayea, 2011) and (Zuñiga et al, 2011).

Table 1 aims to summarize the technique used in the approaches. 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 is the heuristic method more widely employed when solving the PLP in either of its two variations as in the works of (Bischoff and Ratcliff, 1995), (Bischoff et al, 1995), (Scheithauer and Terno, 1996), (Lel, Creighton & Nahavandi, 2005), (Young-Gun G. & Kang, 2005), (Wu and Ting, 2007), (Martins and Dell, 2008), (Kocjan and Holmström, 2008), (Yia, Chen and Zhou, 2009), (Birgin, Lobato and Morabito, 2010) and (Al-Shayea, 2011). These solution methods became a trend because they allowed the possibility to reduce computational time.

Other researchers such as (Morabito and Morales, 1998), (Yamassaki and Pureza, 2003), (Pureza and Morabito, 2004), (Alvarez-Valdes et al, 2004), (Birgin et al, 2005), (Lau, Chan, Tsui, Ho and Cho, 2009) and (Al-Shayea, 2011) 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.

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.

The positive results obtained with the use of the above mentioned techniques caused the interest of other researchers to develop hybrid methods which mixed 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 in (Amaral and Wright, 2001), (Mattos-Ribeiro and Nogueira-Lorena, 2005), (Alvarez-Valdes et al, 2005), (Birgin et al, 2008) and Lau, Chan, Tsui, Ho and Cho, 2009).

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

Revised approaches in chronological order by author	(Dowsland-A, 1987)	(Dowsland-B, 1987)	(Tarnowski et all, 1994)	(Abdou and Yang, 1994)	(Bischoff and Ratcliff, 1995)	(Bischoff et al, 1995)	(Scheithauer and Terno, 1996)	(Morabito and Morales, 1998)	(Abdou and Elmasry, 1999)	(Farago and Morabito, 2000)	(Amaral and Wright, 2001)	(Young-Gun G. & Kang, 2001)	(Yamassaki and Pureza, 2003)	(Pureza and Morabito, 2004)	(Alvarez-Valdes et al, 2004)	(Lel, Creighton & Nahavandi, 2005)	(Birgin et al, 2005)	(Mascarenhas, 2005)	(Mattos-Ribeiro and Nogueira-Lorena, 2005)	(Alvarez-Valdes et al, 2005)	(Wu and Ting, 2007)	(Birgin at, 2008)	(Martins and Dell, 2008)	(Kocjan and Holmström, 2008)	(Yia, Chen and Zhou, 2009)	(Lau, Chan, Tsui, Ho and Cho, 2009)	(Birgin, Lobato and Morabito, 2010)	(Lim et al, 2010)	(Al-Shayea, 2011)	(Zuñiga et al, 2011)
Stability	X			X		X	X		X															X	X					
Demand				X			X									X														
Limited height							X																							X
Weight of the pallet							X																						X	X
Profit																										X				
Preservation of the boxes																							X							X
Unspecified considerations		X	X		X			X		X	X	X	X	X	X		X	X	X	X	X	X					X	X		

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, see Table 2. In this sense, stability has been the factor that more models include 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. Some other studies also consider a specific maximum height or weight, the demand of the customers for a specific product packed in a certain box, or even safety.

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 and benefits from the PLP make it a subject of continuous analysis in the search of solution alternatives for the diverse situations involved.

3. CASE STUDY: TRANSNAV, S.A. DE C.V.

3.1 GENERAL OVERVIEW OF THE COMPANY

TransNav, S.A. de C.V. is a Mexican company, belonging to an international group devoted to the production and commercialization of plastic automotive parts as well as other plastic products such as shopping carts.

The group was founded about 30 years ago in Michigan in the United States of America where the headquarters remain up to date. In Mexico, the company settled in 1996 in FINSA Industrial Park with the objective of locally supplying its products to Volkswagen de Mexico. Later, the company moved to its current location in Cuautlancingo Industrial Park (Figure 6).

Figure 6 TransNav's location and site

The TransNav Group (Figure 7) carries out different activities such as the design and development of products, injection mold fabrication, plastic parts molding and complete assemblies, etc. All of this has granted the group an important growth both economic and structural. The successful global participation of TransNav has been possible due to the conformation of an experienced team and the confluence of partners, assuring together the of quality products from the very essence of its design.

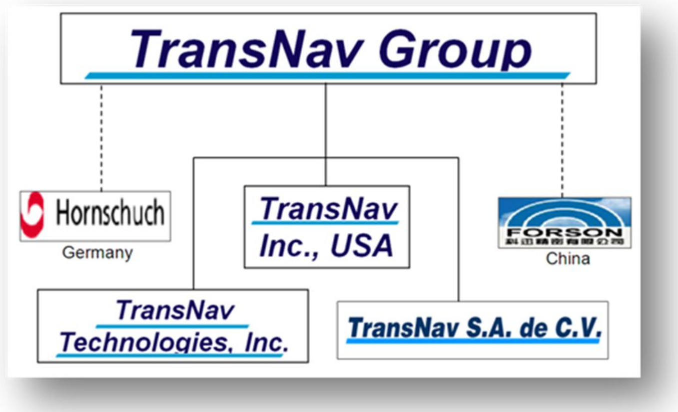

Figure 7 TransNav Group

Due to the importance of its assets in the production of its products, TransNav invests in modern equipment and infrastructure in order to remain competitive by delivering products with the accomplishment of high quality standards as requested in the automotive industry. The company focuses on dynamic, effective and proved processes in order to guarantee effectiveness and quality in its production.

At the same time, TransNav keeps an emphasis on innovation, developing and patenting several products, which have had an impact in different industries. The company has also maintained a continuous commitment with ecology by improving its environmental policy.

Due to the versatility of the plastic molding process and the machinery, TransNav, S.A. de C.V. manufactures and sells a wide variety of products from little plastic screws, plastic guides, and brackets to wheel liners or door panels (Figure 8). Currently, the main customer for the company is General Motors in all its locations in Mexico as well as some others in the United States of America. Nevertheless, the company is also supplying directly or indirectly to other car manufacturers such as Volkswagen, Ford, Chrysler and Nissan.

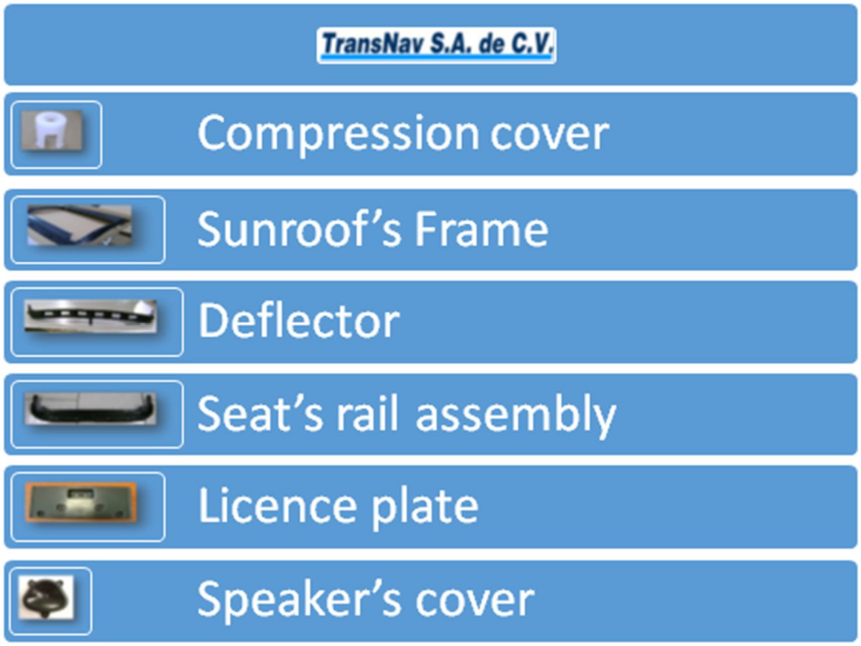

Figure 8 Sample catalogue of products made in TransNav, S.A. de C.V.

TransNav, S.A. de C.V. has a well-defined philosophy contained in its Quality Policy, its Vision and its Mission below:

- Quality Policy:
  The General Director and his directive staff assume the commitment of developing the Quality Policy, Vision and Mission whose focus is the satisfaction of the customers, employees and the surrounding environment. Therefore, quality is a keystone in every activity so as to meet all expectations and achieve the customer's satisfaction.

  "Committed with customer service, TransNav bases its manufacturing processes (molding injection and assembly) on continuous improvement, variation reduction, safety preservation at work and protection of the environment".

  The company's Policy of Quality also contains the organizations objectives so that there is whole awareness of them (Figure 9). This document must be well known by all the employees and it is often revised so that it can keep updated and adequate to the company's reality.

TransNav S.A. de C.V.

POLITICA DE LA CALIDAD

"Con un compromiso de **servicio al cliente**, en TransNav mantenemos nuestros procesos de manufactura por **inyección y ensamble** bajo un modelo de **mejora continua**, **reduciendo la variación** de los procesos, preservando la **seguridad** en el trabajo y la protección del **medio ambiente**".

OBJETIVOS DE LA CALIDAD

Eficiencia productiva ≥ 90%
PPM's con cliente ≤ 10
PPM's internos ≤ 4000
Rotación ≤ 3%
CERO accidentes
100% de satisfacción de nuestros clientes

Director
HUGH HEIERMANN

Agosto 2013

Figure 9 TransNav's Quality Policy

- VISION
  "Be leaders in the manufacture of injection molding plastic parts and their assembly, acquiring new technology to adapt to the market requirements".

- MISSION
  "Satisfy the customers' demand with regards to their specific, legal and regulatory requests".

In the development of the company's activities and the search of a good performance, the leading positions and the whole breakdown of Logistics are the following (Figure 10):

Figure 10 Organizational Chart of TransNav, S.A. de C.V.

3.2 PROBLEM'S DEFINITION

In order to understand the focus of this work, it is important to revise the whole background of the supply chain from TransNav to its customers.

The purchase orders from the customers constitute the beginning of the whole logistic process in TransNav (Figure 11) as these documents state the conditions and agreements between the companies. Then, the schedule releases or orders become the specific requirement as they define the delivery date and the quantity to be delivered according to the conditions on the purchase order.

Once the scheduled releases or orders are received, the next step consists of planning the acquisition of the necessary materials to manufacture the products demanded. At the same time, these orders allow the development of the production planning according to the capacity of the machines, the personnel involved, the delivery dates requested and so on.

The acquisition process involves processes such as transportation of materials from the supplier's, customs clearance, inventory controls, etc. On the other hand, the production planning depends on the availability of the machines and the personnel on the right time once the necessary inputs have punctually reached the company.

Once the production lots of the products are complete, the machines and personnel can take care of the manufacture of other items so that the cycle remains uninterrupted. During the productive process, the pieces get packed, inspected by quality so as to assure their conditions according to the customers' directions, and packaged. All finished goods are stored in the warehouse prior delivery. Whenever it is necessary to prepare mix pallets, the products are gathered in the shipments preparation area to complete such an action. Once the shipments are ready, they are taken to the shipping area where a final inspection is performed so as to assure that they meet the requirements on the loading orders and the conditions are good enough to be sent to the customers. Right after the arrival of the vehicle for transportation, the shipments are loaded and the necessary paperwork is issued (invoices, packing lists, shipping instructions, etc.).

Figure 11 Logistic Productive Process of TransNav

TransNav, S.A. de C.V. manufactures and supplies its products to national and international customers, mainly in the automotive industry. Currently, the company supplies directly to two car manufacturers: General Motors and Volkswagen de Mexico. Nevertheless, the parts and assemblies TransNav sell may also be finally incorporated in other company's cars such as Ford, Chrysler or Nissan after a final integration in other assemblies of intermediate firms such as Benteler, Faurecia, Eissmann, IACNA (International Automotive Company North America) and so on.

Regarding supply terms, TransNav uses basically two:

- EXW TRANSNAV, S.A. DE C.V. (Ex-Works / Ex-Factory).
- DAP DICEX LAREDO (Delivered At Place).

In the case of all the national customers, all deliveries are EXW. Therefore, TransNav must take care of production, packaging and delivery of the shipments at its site to the carrier the customer had previously assigned and notified.

However, in the case of its foreign customers in the United States of America and Canada the agreed delivery term is DAP Dicex Laredo. Because of that, TransNav must control and take care of the transportation of all parts demanded by the customers up to Laredo. Thus, the operation is somewhat more complex, implying other costs and activities which must be efficiently handled so that the logistics process develops punctual and properly.

As a firm, TransNav is also developing for and by the profitability of its core business, surrounded by a fierce local and international competition. Hence, the implementation of any improvement to achieve a higher efficiency is not dismissed and always considered for the improvement of the company's performance.

The wide variety of products from very small parts like plastic screws to the big wheel liners imply the utilization of boxes of different sizes to be stored, handled and transported both internally in the site and warehouse, and externally to the customers. Because of this, it has been considered that the more adequate pallet loading can cause a better utilization of the company's warehouse and the transportation means.

Most of the deliveries to the customers are EXW (in the premises of TransNav), it has been considered that the pallet optimization can be first applied to the company's export items which must be delivered to the customers in a warehouse in Laredo, Texas under a DAP delivery term.

TransNav must set up a permanent inventory of customer's demanded parts (Figure 12) in the warehouse of DICEX in Laredo so as to assure the supply of parts on the right time at the arrival of the trucks assigned by the customers. In the case it does not occur, the customers charge a penalty, which forces TransNav to assume all transportation costs up to the customer's site, expediting the process to guarantee the delivery on a specific date.

As foreseen, the availability of parts in Laredo requires a good planning based on the schedule requirements of the customers. It also demands transportation, the consideration of time (for the transit and the customs clearance process involved) and resources. Therefore, the general manager has instructed the personnel involved to analyze the different elements to dispatch Full Truck Loads with the necessary inventory on the right time to avoid the disruption of the supply, taking care of the proper administration of the resources.

Customer	Customer's item number	TransNav's item number	Description	Packing box part number
Autosystems	34025	PR1742	Bezel	EMCC01
Autosystems	34024	PR1851	Bezel	EMCC01
General Motors	20904550	PR1865D	Bracket - rear fascia	EMCC01
General Motors	20904549	PR1865I	Bracket - rear fascia	EMCC01
General Motors	20907398	PR1866D	Bracket assembly - rear fascia	EMCC01
General Motors	22804736	PR1866I	Bracket assembly - rear fascia	EMCC01
General Motors	25776399	PR1867D	Bracket assembly assembly - front fascia	EMCC08
General Motors	25776398	PR1867I	Bracket assembly assembly - front fascia	EMCC08
General Motors	22806472	PR1868D	Bracket-front fascia	EMCC01
General Motors	22806471	PR1868I	Bracket-front fascia	EMCC01
General Motors	25776408	PR1869A	Bracket-front license plate North America	EMCC08
General Motors	25776409	PR1870A	Bracket-front license plate Europe	EMCC08
General Motors	25776410	PR1871A	Bracket-front license plate China	EMCC08
General Motors	20904552	PR1873	Bracket assembly - rear fascia	EMCC25
General Motors	22868774	PR1874D	Wheel liners	EMCC34
General Motors	22868772	PR1874I	Wheel liners	EMCC34
General Motors	22868768	PR1875D	Wheel liners	EMCC34
General Motors	22868766	PR1875I	Wheel liners	EMCC34
General Motors	25798619	PR1881	Bracket-front license plate	EMCC24
General Motors	25829699	PR1882C	Air deflector front (central)	EMCC25
General Motors	25782871	PR1882D	Air deflector front (right)	EMCC27
General Motors	25782872	PR1882I	Air deflector front (left)	EMCC27
General Motors	25829698	PR1882K	Air deflector front (kit)	EMCC28
General Motors	20823533	PR1934D	Bracket-rear lower fascia (right)	EMCC01
General Motors	20823532	PR1934I	Bracket-rear lower fascia (left)	EMCC01
General Motors	20846070	PR1977A	Deflector assembly-front fascia (air)	EMCC08
General Motors	95939549	PR3920	Bracket assembly-front license plate	EMCC24
General Motors	95473897	PR3920A	Bracket assembly-front license plate	EMCC24
General Motors	95387175	PR4029D	Guide assembly - rear fascia (right)	EMCC08
General Motors	95387174	PR4029I	Guide assembly - rear fascia (left)	EMCC08
General Motors	95330354	PR4162D	Shield Underbody (Aeroblade) right	EMCC08
General Motors	95330353	PR4162I	Shield Underbody (Aeroblade) left	EMCC08
General Motors	22890050	PR4274D	Wheel liners	EMCC34
General Motors	22890052	PR4274I	Wheel liners	EMCC34
General Motors	22890043	PR4275D	Wheel liners	EMCC34
General Motors	22890044	PR4275I	Wheel liners	EMCC34
General Motors	22890046	PR4276D	Wheel liners	EMCC34
General Motors	22890048	PR4276I	Wheel liners	EMCC34
Inergy Automotive Systems	7320623AB	PR4317	Screen controller bracket	EMCC01
SL Tennessee	87584	PR4030D	Bracket	EMCC01
SL Tennessee	87583	PR4030I	Bracket	EMCC01
TransNav Technologies	01497-02-AA	PR1497D	Frontal fascia support	EMCC01
TransNav Technologies	01497-01-AA	PR1497I	Frontal fascia support	EMCC01
TransNav Technologies	01498-02-AA	PR1498D	Lateral fascia Support	EMCC01
TransNav Technologies	01498-01-AA	PR1498I	Lateral fascia Support	EMCC01
TransNav Technologies	01499-00-AA	PR1499A	Bracket - front license plate	EMCC08
TransNav Technologies	01500-02-AA	PR1500D	Fascia board support	EMCC08
TransNav Technologies	01500-01-AA	PR1500I	Fascia board support	EMCC08
TransNav Technologies	01501-02-AA	PR1501D	Hindquarter support	EMCC08
TransNav Technologies	01501-01-AA	PR1501I	Hindquarter support	EMCC08
TransNav Technologies	01575-02-AA	PR1575D	Front fascia support	EMCC08
TransNav Technologies	01575-01-AA	PR1575I	Front fascia support	EMCC08

Figure 12 List of products and customers with a DAP delivery in Laredo

Thereby, a more efficient palletizing in TransNav can end up providing important savings in a deeper analysis. In the meantime, this case study focuses on providing an example with the use of simulation to show the stacking of a pallet with homogenous boxes. To prepare the simulation approach, the box number EMCC01 was selected because it is one of the most recurrent boxes used in these operations. This box's dimensions are 0.585 m (length), 0.285 m (width) and 0.225 m (height). Additionally and according to the information in the company, the most common pallet in use is the item number EMTA01, which has a surface of 1.20 m (length) and 1.20 m (width) (Figure 13).

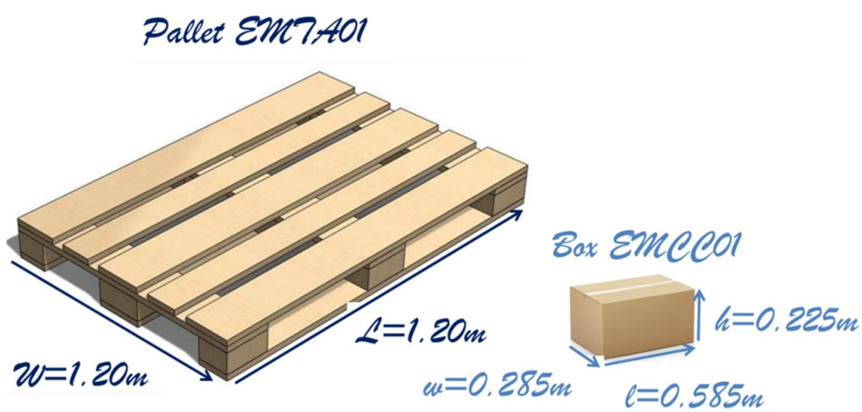

Figure 13 Pallet and box subject of the simulation approach

According to an initial approach with the personnel in charge of preparing pallets in the company, each layer takes around three minutes to be complete.

Granted the fact that the present case of study presents a simulation example to show the pallet loading problem with homogenous boxes, it is important to revise more thoroughly this solution approach. In order to verify the reality, study of time and movements was performed to determine the real duration of the preparation of the pallets so as to use the data for its inclusion in the simulation approach to be carried out.

Due to its closeness to reality as it constitutes the imitation of a real-world process or that of a system, simulation has become very important and popular due to the increased use of this technique in different fields. 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 (Banks, Carson II, Nicol and Nelson, 2002).

Simulation represents a fruitful technique since it generates an artificial history of a system, which provides the base for inferences with regards of 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.

Nowadays, simulation is widely used in fields such as engineering, business, sociology, mathematics and statistics, anthropology, sociology, psychology, medicine, physics and so on due to its versatility by allowing the design and analysis of activities on the smallest of motions and on the largest of systems. Evidently, these are the reasons why it is of interest of the private and public sectors. It is important to state that objects, events, processes, activities, equations and the combination of all of these can be modeled (Banks et al, 2002).

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 with high complexity. Thus, this resulted in the application of simulation which implies repetitive continuous experimentation without high costs, under safety environments and helpful for the training of people. 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 (Banks et al, 2002).

Simulation is an appropriate tool whenever the following purposes are sought:

- The possibility of studying and experimenting with the internal interactions of a complex system or a subsystem within a complex system.
- The observation of the effect of informational, organizational and environmental changes on the model's behavior.
- It is possible to advise improvement actions in the system under investigation through the knowledge gained in designing the simulation model.
- There is always a chance to determine which the most important variables are in the system and their interactions by altering the inputs in the simulation model and observing the resulting outputs.

- The reinforcement of analytic solution methodologies could result of using simulation as a pedagogical device.
- Forecasting happenings after the implementation of new designs or policies is also a result to be revised with the utilization of simulation. That could lead to a preparation stage.
- The use of simulation helps verify analytic solutions.
- If it comes to the simulation of the capabilities of a machine, it is possible to determine the requirements.
- As previously stated, simulation can be a training tool.
- The animation of a simulated operation provides a visualization of the way the plan should occur in reality.
- The high complexity of the interactions in modern systems (factories, service organizations, etc.) can be treated through simulation (Banks et al, 2002).

The utilization of simulation grants advantages such as:

- The possibility to confirm any decision artificially.
- The model can be re-utilized over and over again.
- Compared with other analytical techniques, simulations can be more easily created and demand fewer simplifications.
- The definition rules of the model are easily 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.
- As a result of using simulation, it can be expected to spend less time in the cycle of design and fewer requirements for initial resource investment.
- The use of simulation grants economic benefits 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 (Wainer, 2009).

Simulation is used to model a ***system (or real-world process)***, which can be defined as a set of objects linked by some regular interaction or interdependence over time, concerning the consecution of some purpose. It is important to state that such objects can be people, machines, etc. Changes in the system environment may end up affecting it in one or other way. There is a boundary between the system and its environment that must be taken into account when modeling a system as it can affect the reason of the study to be developed. It is important to underline that the ***model*** is the set of assumptions related to the operation of the system. Such assumptions represent the mathematical, logical and symbolic relationships between the objects of interest of the system. Whenever the model has been developed and validated, it can be used to revise other suppositions or potential changes about the real-world system in order to predict any possible impact (Banks et al, 2002).

On the other hand, a system is made up of the following elements:

- Entity: the object of interest of a system.
- Attribute: the property of the entity.
- Activity: a specific period of time.
- State of a system: the collection of variables required for the description of the system at any time.
- Event: a sudden occurrence that can alter the state of the system.

The events and the activities can occur inside the system (defined with the term endogenous) or outside in the environment, but affecting the system directly (defined with the term exogenous) (Banks et al, 2002).

Systems can be either continuous or discrete, depending on the state variables and their behavior in time. Nevertheless, it must be clarified that no system is completely continuous or discrete and the determination is related to the predominating type of change. In a continuous system, the state variables change continuously, while in discrete system the variation only occurs in a discrete set of points in time.

Regarding models, the basic classification is: mathematical or physical. A simulation model belongs to the mathematical models, which comprise symbolic notations and mathematical equations for the representation of a system. Beyond this, simulation models can be categorized as *static* or *dynamic*, *deterministic* or *stochastic*, and *discrete* or *continuous* (Banks et al, 2002).

Whenever a system is represented at a specific point in time, it will be a *static simulation model*. In contrast, if the model is revised as it changes over time, it is a *dynamic simulation model*.

A *deterministic simulation model* will be in course when there are no random variables and therefore, a known set of inputs will end up providing a unique set of outputs. A stochastic simulation model contains random variables why random inputs result in random outputs. Discrete and continuous simulation models are defined analogously as the discrete and continuous systems previously mentioned above (Banks et al, 2002).

During the 1960's, the techniques for Discrete-Event Simulation (DES) became quite popular, resulting, in many cases, in the development of advanced simulation languages such as SLAM, Arena, Simula and SimScript (Wainer, 2009).

According to the types of techniques, the classification of models is (Wainer, 2009):

- *Conceptual modeling*: it arises from the creation of an informal conceptual model, which provides communication of the basic nature of the process. Here, there is a provision of a vocabulary for the application and the entity's general description for modeling.
- *Declarative modeling*: the focus of these techniques is the evolution of the model represented as states and the transitions involved. In a graphic representation, these models will show the entities as vertices and the transitions as arcs.
- *Functional modeling*: the model constitutes a black box whose input is a signal defined over time and its output is related to the internal function. The model can utilize discrete or continuous functions.
- *Spatial modeling*: the notions of space are taken into account (for instance, the relationship between time and space).

A simulation study requires the following steps:

1. ***Problem formulation:*** there should always be a statement of the problem.
2. ***Objectives set-up and overall project plan:*** the objectives represent the answers to be obtained with simulation. On the other hand, plans will show the alternative systems to be considered and a method for their evaluation. This also comprises

the resources required in terms of personnel, costs and time to perform and complete the study.

3. ***Model conceptualization:*** this process involves an abstraction action in order to find the essential features of a problem so as to select and modify basic characteristics of the system, and then, to enrich and elaborate such a model so as to get a useful approximation. Complexity of the model must not be superior to what is required to accomplish the purposes for which the model is intended.
4. ***Data collection:*** it is a time consuming activity and therefore, the necessary information should be gathered in early stages.
5. ***Model translation:*** all information must be in such a format that it can be recognized by computers.
6. ***Verified?*** This is an action to be performed by the computer program to be used for the simulation.
7. ***Validated?*** This step allows determining that the model represents accurately the real system.
8. ***Experimental design:*** it is necessary to determine the alternatives to be simulated. In every system being simulated, there must be an evaluation of the length of the initialization period, the duration of the simulation runs, and the number of repetitions to be made of each run.
9. ***Production runs and analysis:*** with the production runs of the model and their analysis, it will be possible to estimate measures of performance for the systems designs in simulation.
10. ***More runs?*** According to the analysis of the runs already performed, it is necessary to determine the necessary additional runs if necessary.
11. ***Documentation and reporting:*** it is important to elaborate the corresponding paperwork regarding the model and its execution so as to be able to modify it or continuing its future experimentation. Decisions can be made, basing on the documentation.
12. ***Implementation:*** A successful implementation is linked to the good performance of the other previous steps (Banks et al, 2002).

Within simulation, Discrete – Event Simulation consists of modeling a system over time with the development of changes on its state at discrete points in time. It develops after producing a sequence of system images, representing the evolution of the system through time (Banks et al, 2002).

Focused on Discrete-Event simulation where dynamic, stochastic systems change in a discrete manner the major concepts to be considered are:

- *System*: an organized whole consisting of interacting elements and enduring over time in order to reach a goal.
- *Model*: it constitutes an abstract representation of a system. In order to describe the system, it contains structural, logical or mathematical relations concerning the state, entities and their attributes, sets, processes, events, activities and delays.
- *System state*: it is a set of features, which provide the information to depict the system at any time.
- *Entity*: it could be defined as the focus in the system, being any object or component, which must be explicitly represented in the model (a customer, a machine, etc.). A group of entities in one study may become only a subset in the complete system of another.
- *Attribute*: this is the property of an entity such as the priority of a waiting customer).
- List: a group of, either permanent or temporary, associated entities with some logical order (all customers in a waiting line, ordered by first come, first served, or by priority).
- *Event*: it is a sudden occurrence which affects the state of the system (the arrival of a new customer).
- *Event notice*: the registration of an event to take place in the present or in the future together with any associated information so that such an event is executed. At least, it must include the type of event and the time of its occurrence.
- *Event list*: This element, which is also known as the future event list contains a series of event notices for future events.
- *Activity*: a period of time of a defined length that is known at the moment it starts (a service time or an inter-arrival time). It is possible to specify its duration in different ways:
    - Deterministic (for instance, five minutes always).
    - Statistical (randomly among certain figures with the same possibilities).
    - A function related to the system’s variables and / or the attributes of the entity (loading time for a vessel depending on its allowed cargo weight and the loading rate in tons per hour).

- *Delay*: a certain period of time of unspecified indefinite length, which is only known when it finishes (a customer's delay in a last-in, first-out waiting line dependent on the future arrivals when it begins). It is also called Conditional Wait.
- *Clock*: this is a variable, which represents the simulated time.

It is important mentioning that the names of these concepts may vary in every simulation package available or according to the authors (Banks et al, 2002).

4. SIMULATION APPROACH

The development of the model in the simulation software based on a diagram showing the axis X and Y to structure the pallets surface and the location of the boxes within specific coordinates on the corners of each box (Figure 14).

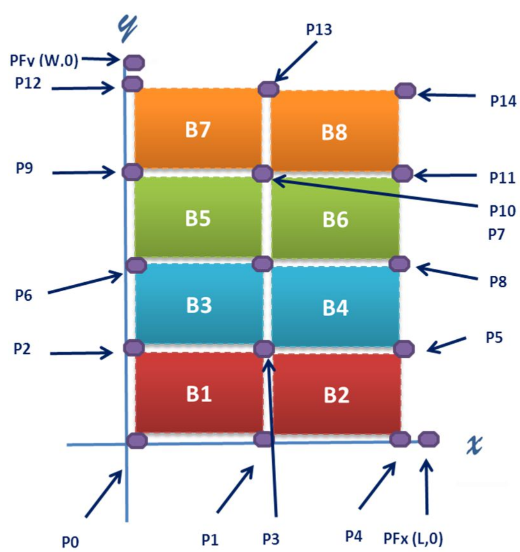

Figure 14 Structural diagram for the development of the simulation model

Then, the PLP problem has been modeled using mainly 3 types of objects, nodes, paths and servers. The source object is used to model the incoming boxes (***entity***). Each box position is modeled with the utilization of ***nodes***. The ***server*** object is used to model the box being stacked.

It is important to underline that for this first approach, it has been assumed all boxes are homogeneous and their placement is orthogonal to the pallet, on a horizontal position concerning the X-axis (Figure 15).

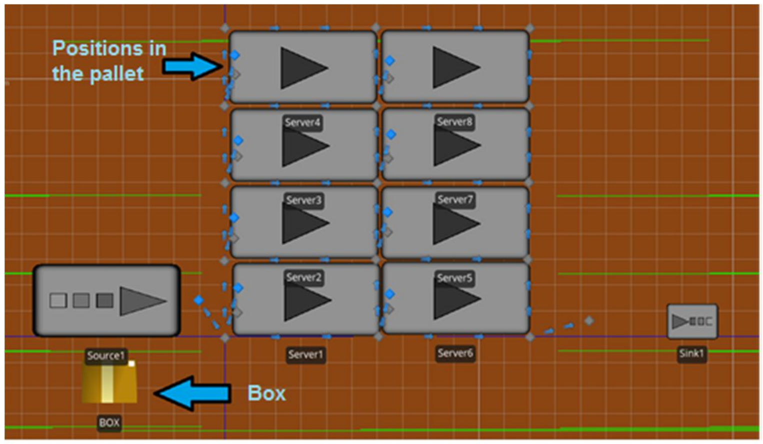

Figure 15 Initial model in Simio

There is a node to divide the pallet into equal parts according to the total number of boxes which can fit on the pallet (two of 0.60 m regarding X-axis and four of .030 m on the Y-axis).

During the first execution, it was observed there was a warning from the software when the completeness percentage reached 71% due to different errors in the model, making it a logic failure preventing the software to continue its execution. After a first revision, it was observed that the connector to the input of ***server 4*** was wrongly directed, impeding the flow of the boxes.

However, the complete first layer of the pallet did not complete as only five of the eight positions were occupied. In addition, the results showed that 17 boxes took part of the process when the maximum should be only eight (Figure 16).

Processes | Definitions | Data | Results

Drop Filter Fields Here

Average — Drop Column Fields Here

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
ModelEntity	BOX	[Population]	Content	NumberInSystem	Average	7.9591
					Maximum	12.0000
			FlowTime	TimeInSystem	Average (Mi...	0.6190
					Maximum (Mi...	3.0158
					Minimum (Min...	0.0135
			Throughput	NumberCreated	Total	17.0000

Figure 16 Revision of results to verify the quantity of boxes created.

This represented a modeling problem because it is necessary to achieve the completion of the pallet with the eight boxes or else in the real life it would imply a big inefficiency since despites the availability of boxes, they would not be stacked on the pallet. Evidently, if this first layer is not complete, the rest of the layers would not, either. This situation occurred because there was no limitation to the quantity of boxes which could get in each position and also because the model didn't have a clear instruction to direct each created box to a specific position.

In order to limit the pass of only one box per path at a time, avoiding the accumulation, the properties of each path were adjusted to ***one*** in the ***initial traveler*** parameter. After this action was implemented, the model was executed and it was possible to verify that only eight boxes were involved (Figure 17). In spite of this, not all of the servers were yet utilized as there was no specific instruction on the position the box had to occupy.

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
ModelEntity	BOX	[Population]	Content	NumberInSystem	Average	6.5730
					Maximum	8.0000
			Throughput	NumberCreated	Total	8.0000
				NumberDestroyed	Total	0.0000
Path	Path1	[Travelers]	Content	NumberOnLink	Average	0.0025
					Maximum	1.0000

Figure 17 New results after the adjustment on the Initial Traveler Capacity

In the reality it would mean that the pallet's layer would be incomplete, making it worthless to continue with more layers upwards (Figure 18).

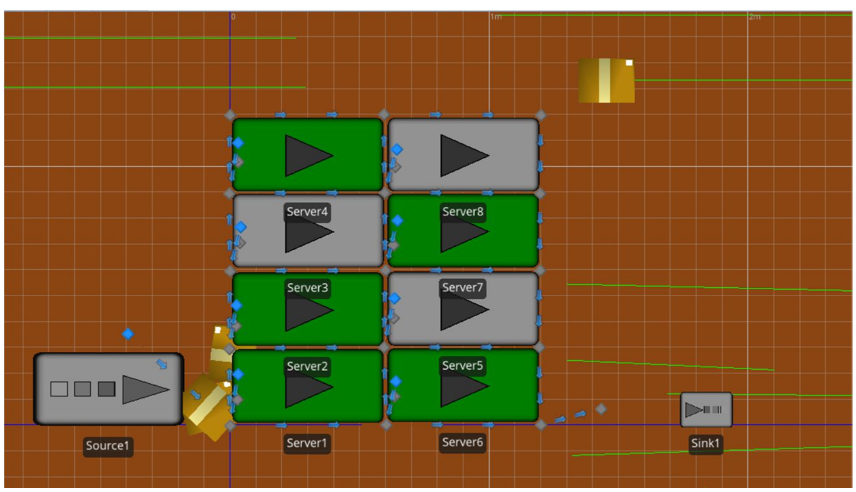

Figure 18 Model view after a new execution

In a new step to develop an adequate model to simulate the palletizing process in TransNav with homogeneous boxes, seven additional entities (constituting a box) were added with the intention of specifying the position each of the boxes should be placed so as to constitute the complete first layer. The addition of these boxes caused to have a set of eight boxes as required in the model. Thereby, this linkage of each box with a specific position led to the creation of sequence tables, working together with such an aim.

Therefore, these tables were linked to the model, by modifying the properties of the source object (Figure 19).

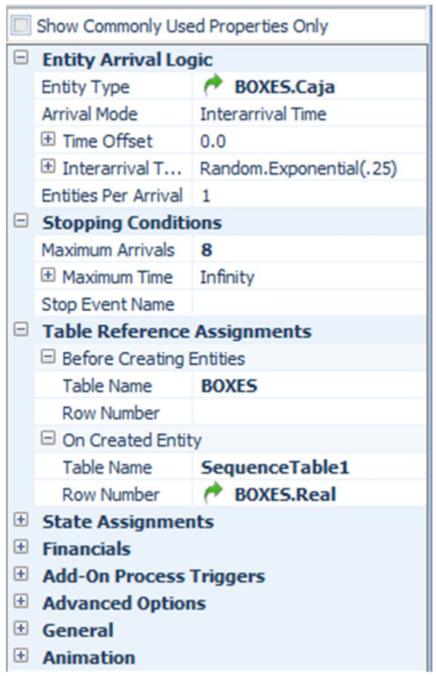

Figure 19 Modified properties on the source object

At the same time this revised model required the re-structuration of different specific elements in order to make it efficient. All basic nodes linked to the servers were changed to transfer nodes so that their properties could be edited. At the same time, several aspects of style and particularization were introduced such as the addition of a color to the boxes and all servers were re-named as ***position*** with a number, all this for tracking purposes and proper arrangement of the model. In this way, it could be proven visually how the directions stated in the properties of the model fulfilled as foreseen (Figure 20).

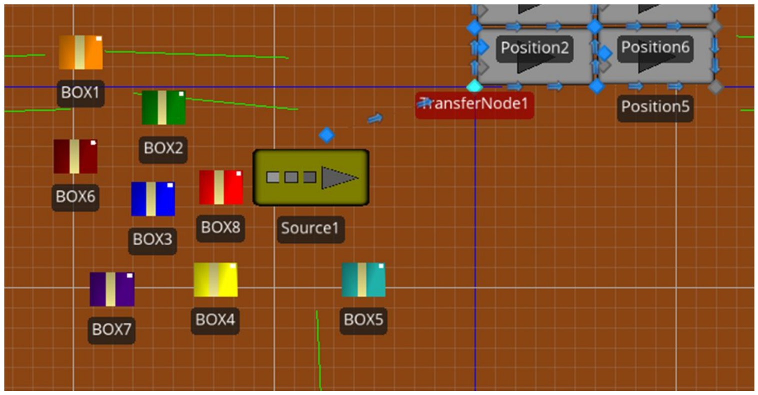

Figure 20 Re-structured model

However, when the model was executed, it could be observed that only the orange box took part in the simulation whilst the rest of the boxes were not utilized at all. Not to mention that the objective of having a complete pallet could not still be achieved because there were unoccupied positions as well as boxes in processing queues. As a consequence, a new action was implemented, consisting of modifying and adding new tables so that every position on the pallet was reached. All added tables contained the specific route each box / entity should follow by indicating each node it had to pass before occupying the desired position on the pallet's layer. Therefore, each table traced the routes for the eight boxes.

In order to relate the sequence tables, it was necessary to create a data table to set the route and direct each box according to the sequences (Figure 21).

BOXES | Sequence Position4 | Se

	Sequence
1	TransferNode1
2	TransferNode4
3	TransferNode6
4	TransferNode7
5	Input@Position4
*	

BOXES | Sequence Position4 | Sequence Position3

	Sequence
1	TransferNode1
2	TransferNode4
3	TransferNode6
4	Input@Position3
*	

BOXES | Sequence Position4 | Sequence Position3 | Sequence Posit

	Box Order	Quantity	Destination
1	BOX1	1	SequencePosition4.Sequence
2	BOX2	1	SequencePosition3.Sequence
3	BOX3	1	SequencePosition2.Sequence
4	BOX4	1	SequencePosition1.Sequence
5	BOX5	1	SequencePosition8.Sequence
6	BOX6	1	SequencePosition7.Sequence
7	BOX7	1	SequencePosition6.Sequence
8	BOX8	1	SequencePosition5.Sequence

Figure 21 Example of sequence tables for two positions and data table

Then, in the properties of each transfer node, the ***entity destination type*** was set ***by sequence***.

The recently created data table was completed with a new column called ***arrival time***, which contains a time distribution for each sequence with the aim of having a box placed on each position at certain intervals of time (Figure 22).

Sequence Position4 | Sequence Position3 | Sequence Position2 | Sequence Position1 | Sequence I

	Box Order	Quantity	Route	Arrival Time
1	BOX1	2	SequencePosition4	Random.Exponential(1)
2	BOX2	2	SequencePosition3	Random.Exponential(1.2)
3	BOX3	2	SequencePosition2	Random.Exponential(1.3)
4	BOX4	2	SequencePosition1	Random.Exponential(1.4)
5	BOX5	2	SequencePosition8	Random.Exponential(1.5)
6	BOX6	2	SequencePosition7	Random.Exponential(1.6)
7	BOX7	2	SequencePosition6	Random.Exponential(1.7)
8	BOX8	2	SequencePosition5	Random.Exponential(1.8)
*				

Figure 22 Addition of the Column: Arrival Time

On the other hand, it was decided to set a process in order to orderly read the directions on the data table so that the result could be achieved (Figure 23).

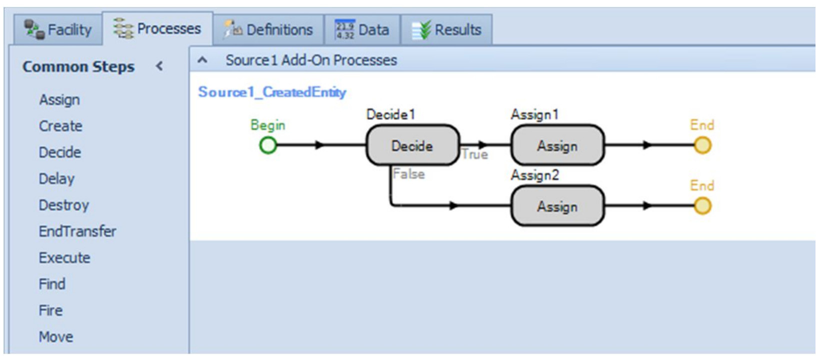

Figure 23 Process assignment

This process included a counter, which was called ***Index***. This counter bounded the model to have eight boxes to be shared out in each position or server.

With these additions, the model was run and the result was reached when each of the boxes occupied a position and remained there just as it was intended before creating a new layer (Figure 24).

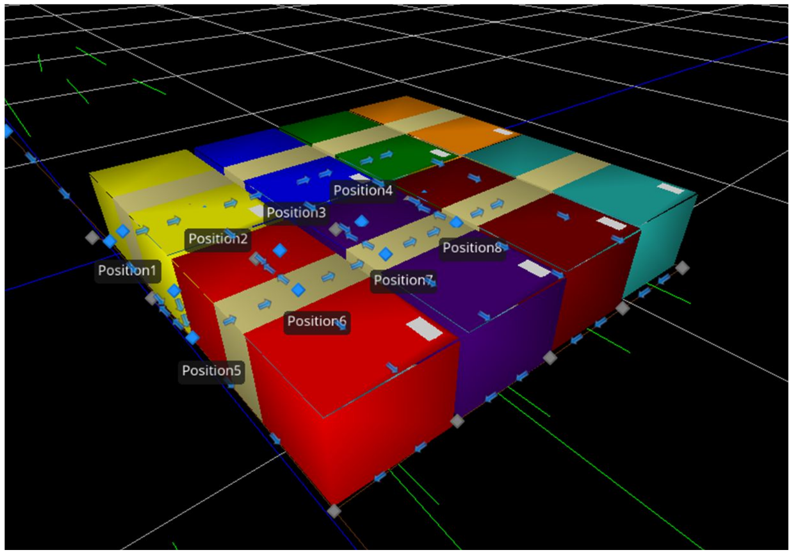

Figure 24 Final view of the model (first layer of the pallet)

With the successful completion of the first layer of the pallet, it was the time to add new layers to the model so as to have the simulation of a loaded pallet. At first, the model was enlarged to the double (16 boxes), action which required the inclusion of new elements. The graphic representation implied the addition of new ***transfer nodes***, ***paths*** and ***servers***, taking care of the measures, volumes and positions so as to make the model as real as possible. In order to make the model functional to make it look like a complete pallet, it was necessary to include additional ***sequence tables***, increase the rows of the ***data table*** and modify some data in the properties of the ***index*** so that the routes were specified and all the boxes occupied the determined position on the second layer just as it had occurred on the first one The same actions were repeated again in order to increase the number of positions / boxes up to 24 to constitute a three-layered pallet (Figure 25).

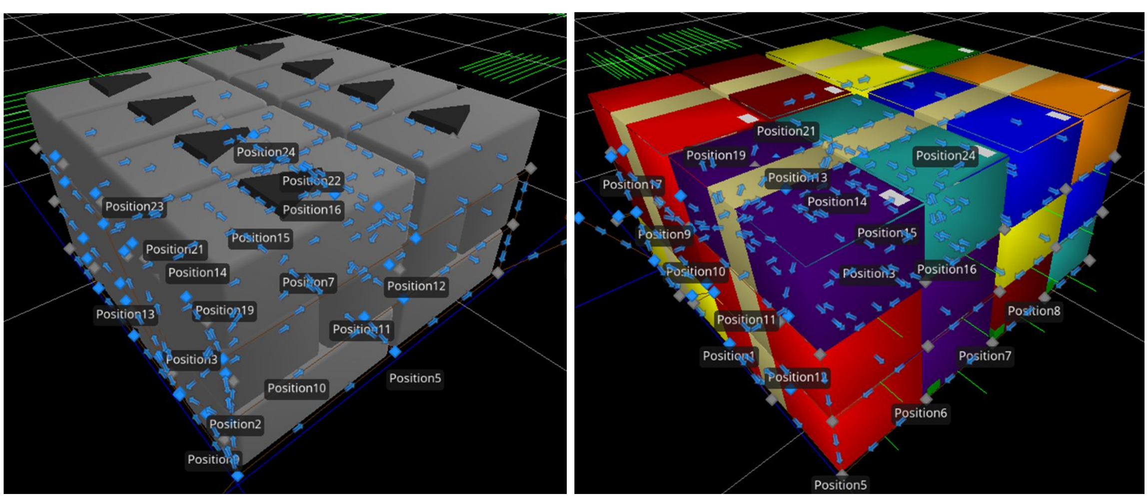

Figure 25 Complete model with 24 boxes

With the information of the study of time and movements, the data table was modified with the inclusion of real times obtained during such a study, setting a triangular with the minimum and maximum value observed (Fig. 26).

Sequence Position16 | Sequence Position17 | Sequence Position18 | Sequence Position19 | S

	Box Order	Quantity	Route	Arrival Time
1	BOX1	2	SequencePosition4	Random.triangular(6,7,10)
	BOX2	2	SequencePosition3	Random.triangular(10,10,12)
	BOX3	2	SequencePosition2	Random.triangular(12,15,15)
	BOX4	2	SequencePosition1	Random.triangular(15,18,20)
	BOX5	2	SequencePosition8	Random.triangular(20,20,21)
	BOX6	2	SequencePosition7	Random.triangular(20,21,22)
	BOX7	2	SequencePosition6	Random.triangular(21,21,22)
	BOX8	2	SequencePosition5	Random.triangular(20,21,21)
	BOX1	2	SequencePosition13	Random.triangular(20,21,22)
.0	BOX2	2	SequencePosition14	Random.triangular(21,22,22)
.1	BOX3	2	SequencePosition15	Random.triangular(21,22,23)
.2	BOX4	2	SequencePosition16	Random.triangular(21,21,23)

Figure 26 New data table with the inclusion of real values according to a study of time and movements

CONCLUSION

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, the graph theory or Discrete Event Systems. 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.

Stability is the most widely incorporated factor because no pallet can be efficiently transported or stored if it is not stacked in such a way that it is stable or else it could simply collapse. 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.

As a method to achieve an efficient pallet loading, this work has intended to present the basis for the development of a whole proposal through simulation for the company TransNav, S.A. de C.V. located in Cuautlancingo, Puebla. For this company, space utilization related to pallet loading is important for handling, transportation and storage of its products inside and outside its premises. Evidently, it can also facilitate and reduce the cost of transportation as the size of its products implies the use of boxes of different sizes. Simulation has been regarded as the ideal solution method because it can include and prove more viability due to its reflection of reality. The case of TransNav can contribute to the development of the Distributor's PLP due to the variety of size of products and consequently of boxes of the company and the final utilization of them in the production lines of the customers or just as service parts. Hence, considerations such as demand, height and stability constitute restraints which make this case interesting and worthy to be studied.

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ANNEX

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