CRANFIELD UNIVERSITY

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DECISION SUPPORT SYSTEM FOR PALLET UTILISATION IN THE SHEET FEEDER INDUSTRY

SCHOOL OF APPLIED SCIENCES

MSc by Research Thesis

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Supervisor: Dr. Essam Shehab

March 2008

ABSTRACT

Keywords: *Sheet Feeder Industry, Pallet, Cardboard Sheet, Transport, Logistics, Decision Support Systems.*

This thesis aims at developing a decision support system for pallet utilisation in the sheet feeder industry. Furthermore, the research project has focused on providing an improvement to the current system of distribution of the customer order onto pallets.

The overall research objectives are to: (i) Establish the state of the art in areas related to the project; (ii) Identify the key variables such as pallet sizes, truck sizes, material features and customers' requirements for building the pallet utilisation model; (iii) Develop an analytical approach and a prototype system to improve the utilisation of the pallets and the truck volume; (iv) Validate the developed model and prototype system through real-life case studies and expert opinions.

A combination of research methodology approaches has been employed in this research study. Firstly, a familiarisation stage has been conducted through comprehensive literature review and visits to the sponsoring company. The second phase was to conduct semi-structured interviews with the shop-floor operators and operations directors to have a better understanding of the business needs. This was combined with measurements of the trucks and the pallets and internal documentation from the company. In this stage, the researcher also distributed questionnaires to other sheet feeder companies to know if the system could be applied also to more companies. In the third phase, the data gathered were analysed for the subsequent development of the system. Then the system has been developed following the logic rules obtained by analysing the data. Finally, the developed model and system has been validated, through real-life case studies and expert opinions.

The developed analytical model has been implemented in a prototype system. The developed system comprises a knowledge-based system, material handling modules, databases and user interface. The developed system for pallet utilisation encompasses pallet database, truck database and material features databases.

The developed model and system has the capability to estimate the number of corrugated cardboard sheets that should be loaded per pallet. Additionally the system predicts the number of sheets per stack and the type of pallet that should be used. The system provides the shop-floor operators with an effective tool for pallet utilisation in order to reduce their decision time. Therefore, the developed system provides cost and time savings in terms of improvements of the pallet and vehicle volume utilisation for the preparation and delivery of the corrugated board product. This system has given to the sponsoring company an improvement of 5% in the way of orders' management.

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CHAPTER 1

1. INTRODUCTION

1.1 Research Background

Towards the end of 2002, the UK paper and board packaging industry was in recession. However, in the last few years paper board and packaging industry has grown its business (Material Handling, 2000, Allen et al., 2004). In UK products made from corrugated board represent a high percentage in the industry of paper board and packaging. The sheet feeder industry provides a wide product range. Due to this product diversity, there is also a big variety in terms of the way the product should be loaded. Finding the best way to do it is the purpose of this project. The sheet feeder industry fights in a very competitive environment. The customers of this industry sector are very demanding because they require a very specific cardboard sheet size.

For packaging corrugated boards are the most suitable due to the protection that they offer. Hence, corrugated industry depends directly on the economic activity. Every business experiences different tendencies through the years. The main tendencies that could be found in corrugated business are (Material Handling, 2000, Allen et al., 2004):

- The demand has decreased because there is a tendency for customers to use smaller packaging in order to reduce the environmental impact at the same time as they save costs.
- The demand has decreased in United Kingdom because customers more and more are moving manufacturing and packaging tasks to foreign countries. As a consequence of this, the activities with suppliers are moved as well.
- The existence of stock in the warehouses has caused the closing-down of some sheet feeder companies in the United Kingdom.

- Nowadays, microflute is more used within the customers due to this type of flute, a light cardboard is offered. With this cardboard a lightweight and an effective packaging can be obtained. This feature allows to the cardboard to rival with plastic packaging. Paper and board remains the favourite packaging material and it is valued as a popular medium in the fast growing print for Packaging sector. Despite competition from plastic, corrugated packaging is beginning to play its strengths for dual purpose transit packs, for example as a material for protecting goods in transit and for open display at the point of sale.

In the last few years, corrugated industry has undergone different mergers and acquisitions; hence the cardboard business is immersed in a very competitive market where each company fights for being the best in terms of service, product quality and cost. As a result of this, nowadays companies are making a lot of effort in optimising the different tasks that are involved in their business: from the management of an order to the distribution of a product to the customer: Morabito et al. (2000) stated that “The mission of optimisation is to get the right goods or services to the right place, at the right time and in the desired conditions, while making the greatest contribution to the company”. Bennett (2002) reports that the aim of such improvement in the different tasks involved in the sheet feeder industry is mainly to satisfy customers. This philosophy refers to: just-in-time delivery, flexible and optimal production programming, accurate and fast information for customers and short cycle production. The producers of corrugated cases are the main customers for the companies producing of cardboard sheets.

The project develops “A Decision Support System for Pallet Utilisation in the Sheet Feeder Industry”. This research project has been conducted in collaboration between Abbey Corrugated and Cranfield University. The project presents a decision support system to arrange customers’ orders in the most suitable way.

1.2 Research Motivation

However, in the sheet feeder industry some improvements have been made in the reduction of waste material. A cardboard is a lightweight and sensitive material, so many cares should be taken into account for its transport. Sheet feeder industry is manufacturing cardboard sheets of many sizes which require different pallet sizes for their delivery. A pallet is a factor in the material handling line and any small improvement in its use will have a big impact for the company. The fewer pallets the company uses, the less time will be used to manage and transport the products. This is traduced in time and cost saving.

Deciding the optimal height for a pallet is not an easy task because customers sometimes have their own requirements and the pallet has its own restrictions as well such as maximum weight and height.

Another factor very important is the transport vehicle. The maximisation of the space available in the truck is another concern. Many pallets size is proportional to the space available in a truck. But for those pallets that have a specific size, because they are customers' bespoke pallets, the optimal use of the space in the truck is another issue.

The research will allow them to improve the current system to distribute the orders onto the pallet. Nowadays, the sponsoring company distributes the order equally onto the pallet. The consequence of this is that the current use of the volume of the truck is around 85%. Another issue is that the pallets are not used to their maximum capacity, so there is a waste of volume utilisation.

Any improvement in this area will suppose a gain for the company. Less number of pallets will be used for the delivery of an order which means cost and lead–time reduction. If the number of sheets per pallet is increased the utilisation of the volume of the truck will be increased. So, the cost of transport for the company will be less than with the current system.

1.3 Problem Definition

Cardboard weight as a variable is unusual when it is referred to a cardboard since it is a lightweight material. Therefore it should not be problems of weight. But in this case it is different because it is being treated a very delicate material which called microflute cardboard sheet. This type of cardboard is very thin and the weight has to be considered. Otherwise, this kind of cardboard can be damaged. Key factors in any business activity are operating costs and customer service. Both factors are directly linked to the company development and improvement. This research project will study the following issues:

1. Maximising the number of sheets, made of microflute, per pallet taking into account customers' requirements, different pallet and truck sizes and material features. All the variables taken into account are explained in Figure 1.1. The sponsor company needs to adapt to the new tendencies and nowadays microflute cardboard is very demanded by customers. Microflute is a very delicate material so it should be analysed carefully. With a light improvement in the palletizing system the company will get an efficiency increase.

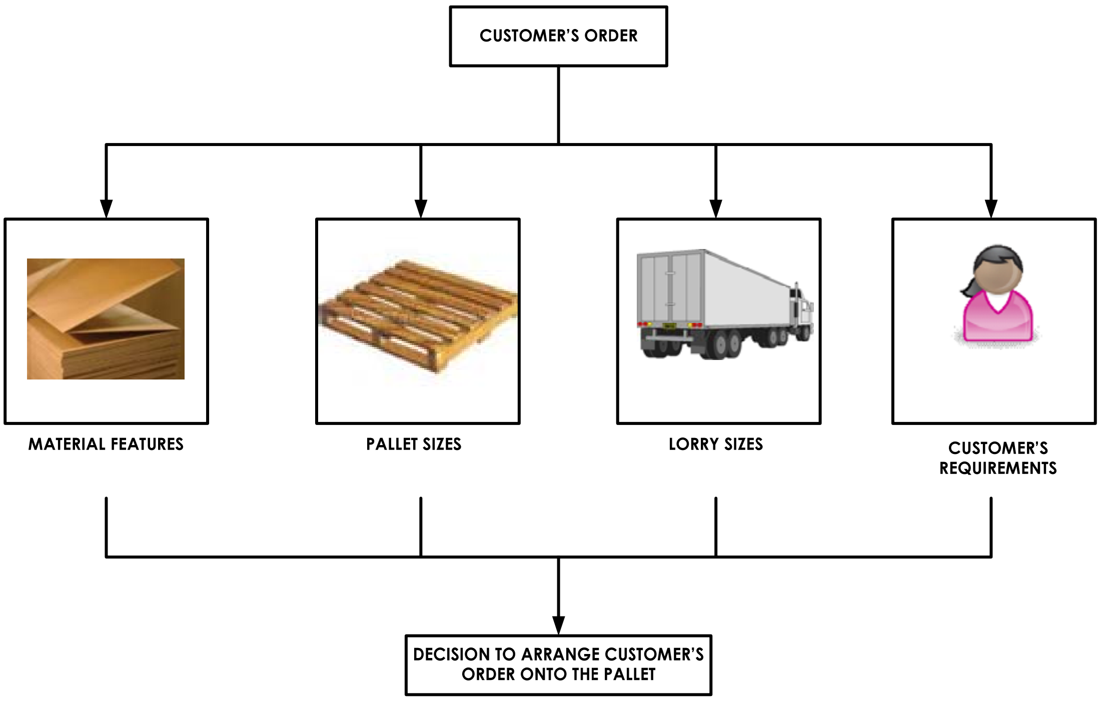

Figure 1.1: Factors Considered in the Research Project

2. Automating as much as possible customers' orders palletisation process. At the current moment, the company has an operator that makes that palletisation decision (this person decides which pallet fits better with each order). The company aims to standardize this process to avoid the variation and time of palletisation decision.

These improvements could help a sheet feeder company to maintain its leadership in the business because they will save time and cost for the customers' orders preparation. In the cardboard business there is a large quantity of companies that fights for the supremacy within the sector.

This will be hopefully result in a lower pallet and transport costs and a reduction in the plant bottleneck of materials handling. In the second part of the project the focus will switch to improving loading efficiency both by improving initial pallet selection logic and load building calculations. To maximize the number of boards per pallet and the percentage of full pallet, it must be taken into account customer and business constrains. Figure 1.2 illustrates the areas for improvements that have been taken into account in the project.

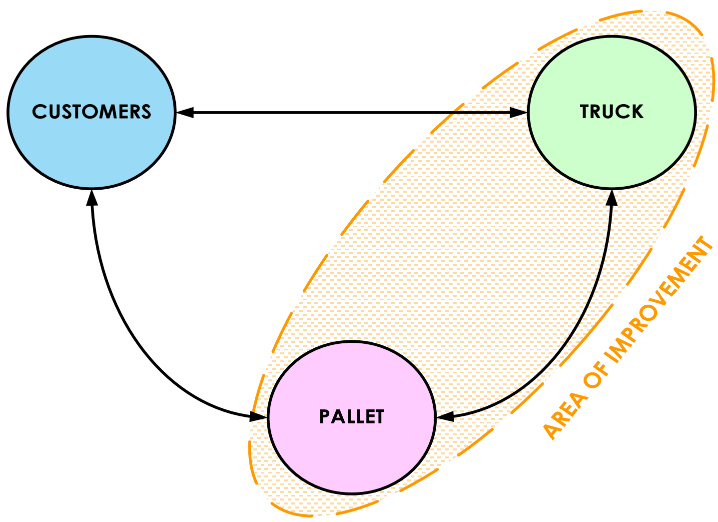

Figure 1.2: Areas for Improvement within the Scope of this Project

1.4 Industrial Collaborator: Abbey Corrugated

Operating in the UK for over 30 years, Abbey Corrugated is part of Packaging Division of the "DS Smith Plc" group of companies. DS Smith Plc is an international group focused on the production of paper and the manufacturing and distribution of office products (Abbey, 2007).

The group holds leading position in the markets in which operates:

- Liquid packaging and dispensing.
- Plastic returnable transit packaging and logistics.
- Recycled papermaking and corrugated packaging.
- Office product wholesaling.
- Manufacturing of envelopes, books and pads.

The group employs approximately 11,400 people, of whom 6,900 are located in the UK. In the 2005/ 2006 financial year the Group's revenue was £1,653 million, of which 58% derived from UK operations. Specifically, Abbey Corrugated has 175 employees and an annual turnover of £40 million.

Abbey Corrugated produces sheets of corrugated board in a wide range of paper grades and flutes, for conversion by customers into such products as boxes, transit trays and point of sale displays. Of the company's two facilities, Blunham is the primary site for conventional brown board and concentrates more on volume production to meet Just In Time (JIT) requirements. Kettering tends to focus on a specialist range of coated, single face and microflute boards; this is complemented by the innovative products in the Abbeylite range. The Abbeylite products minimise the weight of paper while offering high degrees of printability, rigidity, compression and burst strength. They are run at Blunham on a dedicated machine. Every order in Abbey Corrugated follows the steps shown in Figure 1.3.The order is received by the sales office, and then it is processed through the planning department that decides when and in which corrugator the order should be made. Corrugator is the machine that makes the cardboard sheet. The planning department introduces these data in the corrugator planning system. After this, the corrugator runs the order. And as final steps the order is palletized, a laser counts the number of sheets, the order is shrouded and strapped, stored, loaded onto the truck and delivered to the customers. The project is focussed on the areas of palletization and the loading onto the truck. An improvement in both areas will result in: an efficiency increasing and a cost reduction due to the overall number of pallets will be reduced.

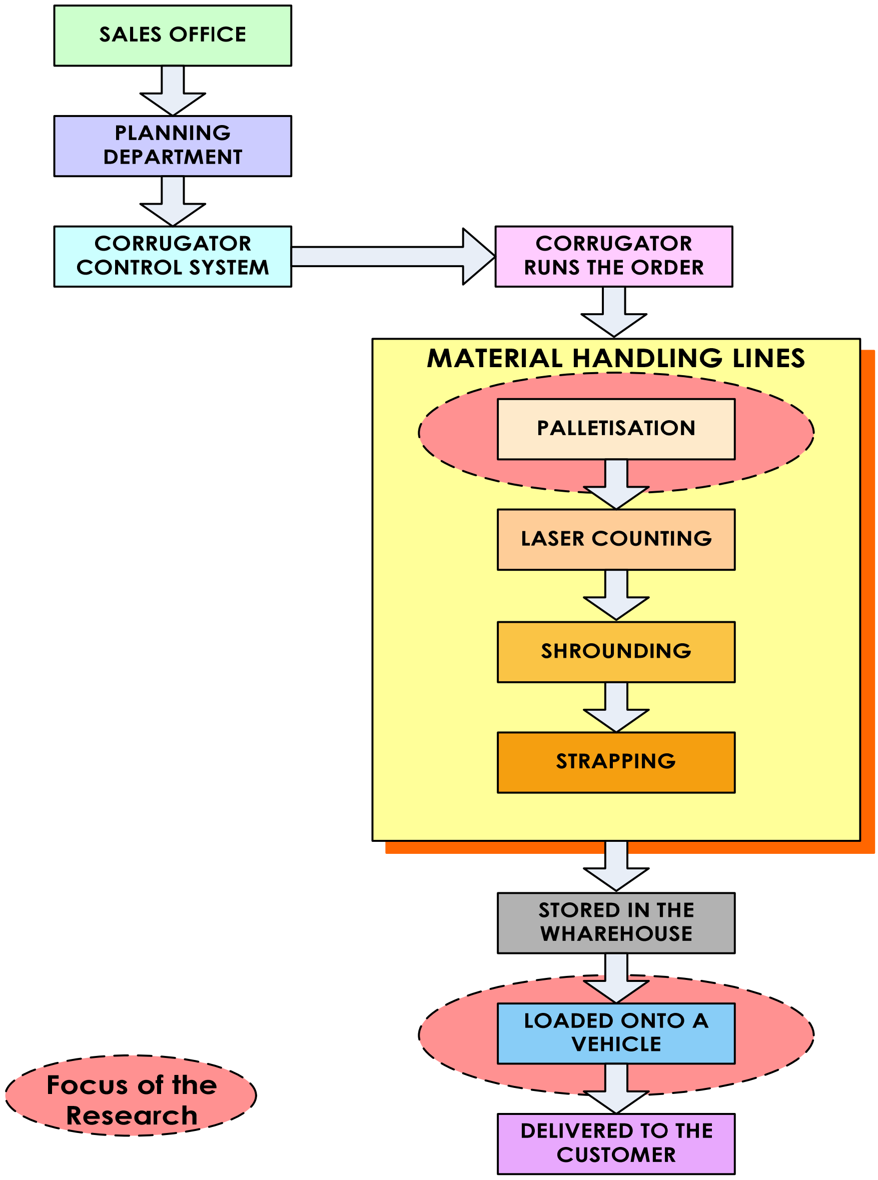

Figure 1.3: Process of Customer's Orders

With the optimisation in the distribution of customers' products, Abbey would save costs, in terms of order delivery, like transport, strapping, labelling, shrouding and pallet costs, and time in order to manage the orders. Because if one customer's order will be loaded on less number of pallets, the time required for packaging this order will be less than before. This would increase the amount of material per truck and would contribute favourably to the environmental impact because fewer pallets will be used. As it has been mentioned previously the business activity is focussed on the production of cardboard sheets. The company does not convert these sheets into boxes, etc. Figure 1.4 shows the process of the cardboard from the starting point (suppliers) to the end (customers); it also highlights the business activities of the company.

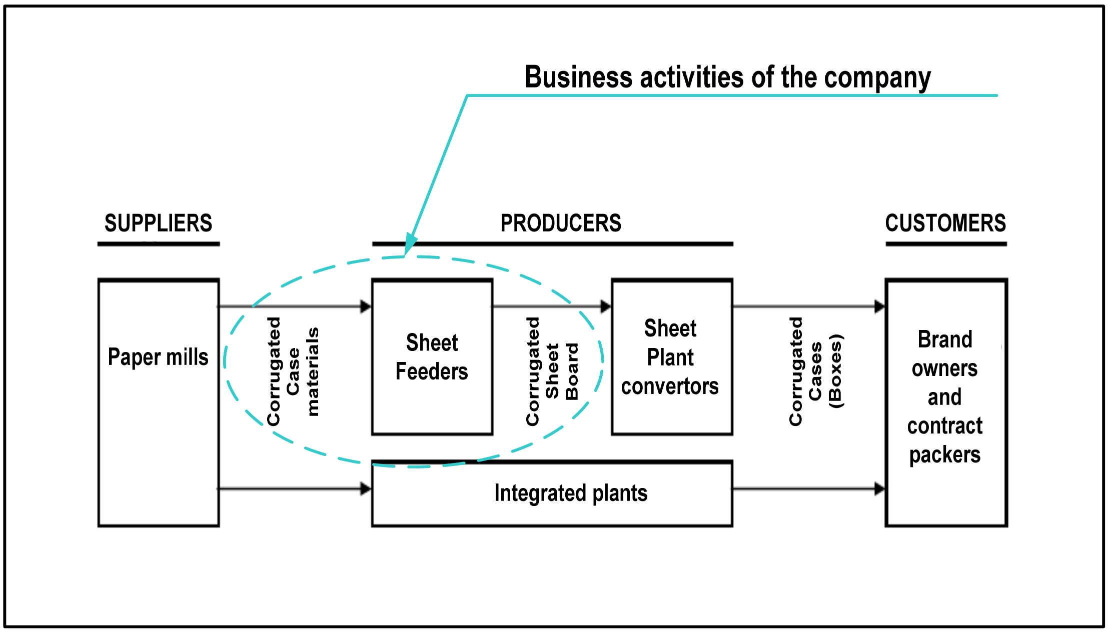

Figure 1.4: Process of the Cardboard

Abbey Corrugated is not only focussed in the improvement of their business, it is also trying to commit more with the environmental aspects. The base for this statement is that Abbey is trying to minimise the waste of paper (Hollins, 2002). To evaluate this environmental commitment, it has been analysed the raw material in three different stages: prior to production, in production and finished goods. And the conclusion was that most of the waste material appeared in damaged stock and from the current system for managing part rolls of material. The implementation of a new system to manage the rolls of material would save 173 tonnes of material. If the company eliminates this waste of material, this will result in a contribution to the environment as well as a cost reduction.

1.5 Aim and Objectives

The aim of this research is to develop a decision support system to improve pallet utilisation in the sheet feeder industry. The system will define the number of sheets per pallet and specify the kind of pallet that has to be used with respect to the size of the cardboard sheet.

This main aim has been broken down to a number of objectives which are to:

- Establish the state of the art in areas related to the project.
- Identify the key variables such as pallet sizes, truck sizes, material features and customers’ requirements for building the pallet utilisation model.
- Develop the analytical approach and a prototype system to improve the utilisation of the pallets and the truck volume.
- Validate the developed model and prototype system through real – life case studies and expert opinions.

1.6 Thesis Structure

An overview to the sheet feeder industry and the factors involved in the product delivery are described in Chapter 2. Chapter 3 presents the research methodology that has been adopted in this project. This methodology has been broken down in different phases. All the equations integrated into the system and the logic that has been followed for the development of the system are shown in Chapters 4 and 5. Chapter 6 explains how the system works and which its features are. And finally in Chapter 7 presents discusses and concludes of the overall research work. It also highlights the limitations and it is recommended future work.

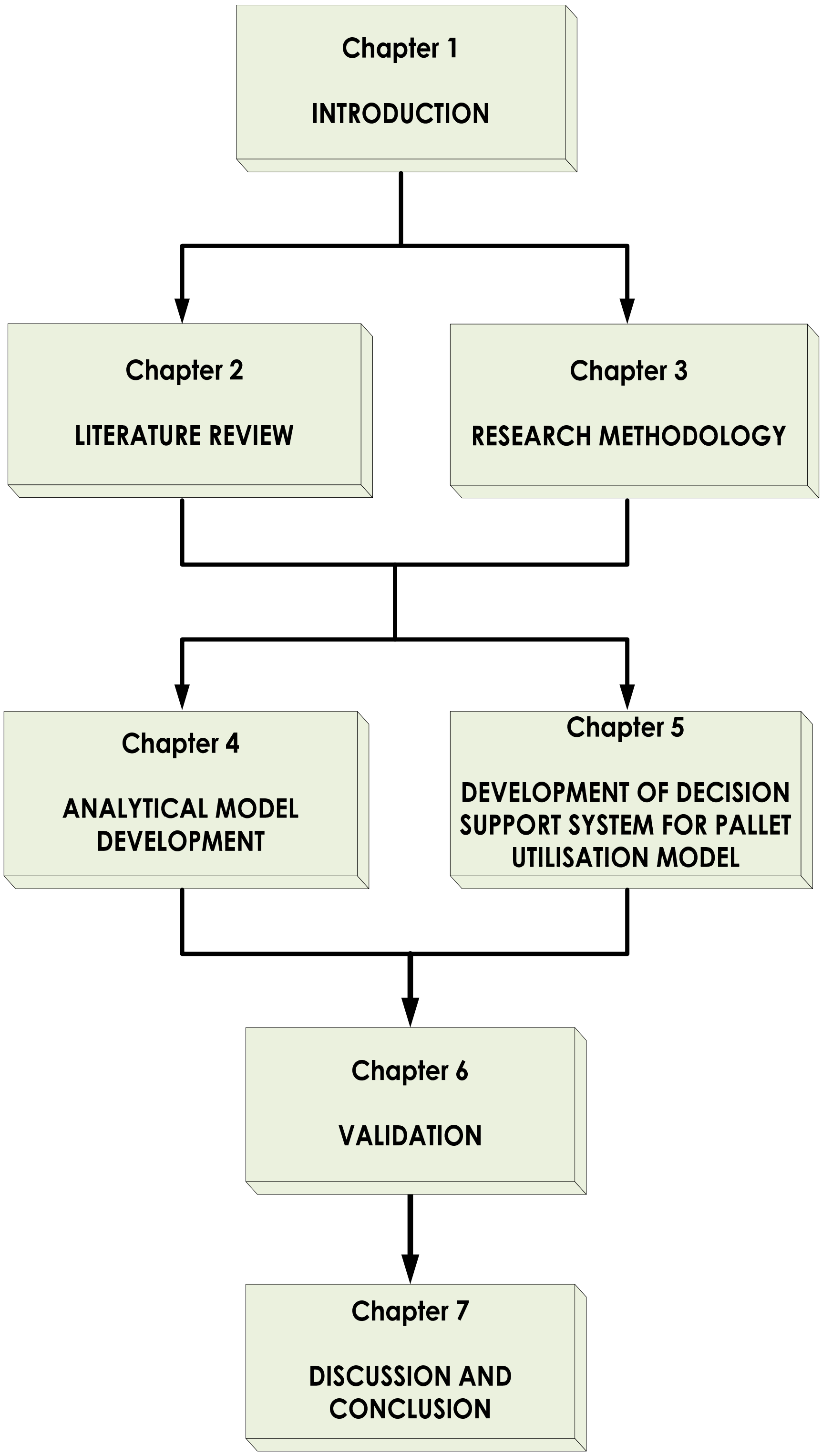

Figure 1.5: Overall Thesis Structure

1.8 Summary

The introduction conducted in this research has shown that there is research work to be carried out in the corrugated industry. In the background shown, it has been appreciated that in the sheet feeder industry the customers' orders have some requirements. So, it can be noticed that the sheet feeder industries fight for giving the best service within the corrugated business.

Along the years, the sheet feeder industry has been adapting to the new trends that were appearing. For this reason, these companies are making great effort in optimising the different tasks that are involved in their business.

In one of these improvements, the research project presented is focussed. The development of this decision support system for pallet utilisation in the sheet feeder industry will improve the current customers' orders management. This system maximises the number of cardboard sheets that are loaded per pallet. At the same time as it provides information about which pallet is the most suitable for the customer's order delivery.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Introduction

The project focuses on providing improvement to the current system of distribution of the customer orders onto pallets, taking into account different factors such as pallet and truck sizes, the customer requirements and the material features as shown in Figure 1.1 of Chapter 1. The main purpose of this chapter is to provide an overview of the related areas to the project including sheet feeder industry, cardboard sheet, pallet, transport, logistics and decision based systems.

This chapter provides a general knowledge about the different aspects involve in this research project. At the same time as it has helped to find a research gap related to the research area. Figure 2.1 presents the overall structure of this chapter. The chapter consists of 9 sections. An overview of the sheet feeder industry is presented in Section 2.2. Section 2.3 provides the manufacturing process of the cardboard sheet and the types of cardboard that are in the sheet feeder business. The aspects related to the pallet loading and management are contained in Section 2.4. Section 2.5 describes the transport techniques and different vehicles dimensions. The logistics aspects involved in the transport and pallet are explained in Section 2.6. Section 2.7 discusses the decision support systems. The research gap is presented in Section 2.8. Finally, Section 2.9 summarizes the literature review chapter.

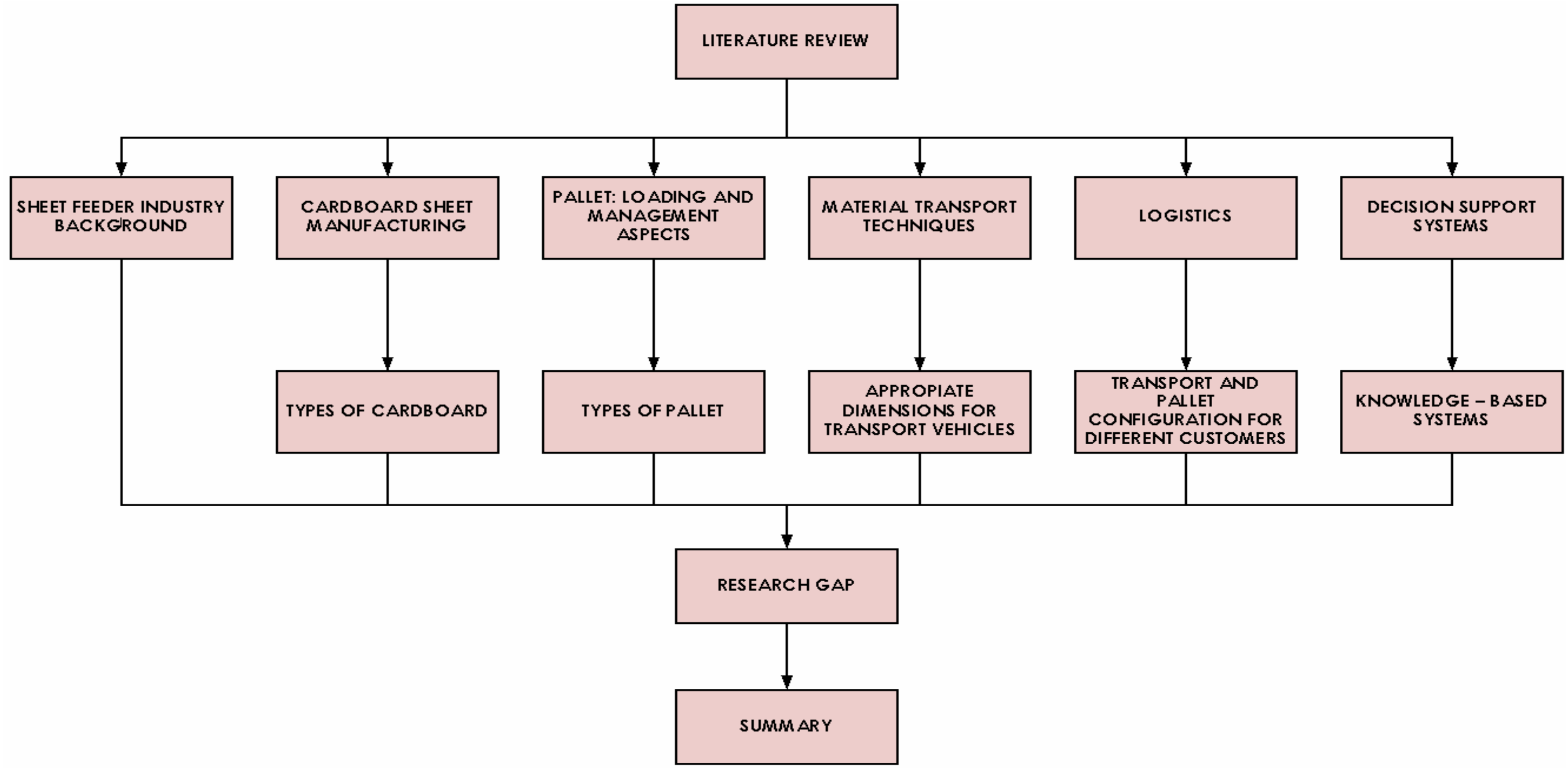

Figure 2.1: Structure of the Literature Review

2.2 Sheet Feeder Industry: An Overview

It is known that the manufacturing of paper has its origin in China, since 100 A.D. In that period, clothes, hemp, straw and herb were used as raw material. The technique consisted in beating these materials against the mortars in order to separate the original fibre (Teschke and Demers., 1997).

The first paper machines were patented between ninetieth and twentieth centuries and the wood grinding process in order to manufacture the pulp was introduced in 1840. This process enabled the manufacturing of paper at a lower cost. Ten years later the first chemical process was made in order to produce the pulp. This process helped to reduce costs as well.

In 1844, Federic Gotttlob Seller was the first one in obtaining wood paste by a mechanical process. In 1852, Meillier discovered cellulose and Tilghman patented a process that made wood paste using calcium bisulphide. Since then, all the efforts have been focused in the search of improvement of: the machines and techniques, the recycling of materials and the reduction of times in the production process (Papel, 2007), that are an important aspect for the sheet feeder industry. A little improvement in these areas is important due to the fact that the cardboard sheet should be produced following the exact customer specifications. Vicente and Ruiz (2003) add that the customers' habit to make changes in the last moment makes the cardboard manufacturing a very complex process.

Another aspect that has been tackled in the corrugated industry is the fact of cutting the cardboard sheets is the best optimum way. Barber (1996) reports that if the cardboard sheets are not cut in the best optimum way, it will generate wastes in material. This is a very important concern from the economic and ecologic point of view. Mainly, customers' orders are characterized for the amount of cardboard that they have (measured in kg), the type quality and the grammage of itself and the width of the sheet.

The manufacturing of paste, paper and derivatives from paper reach numbers that place the paper industry between the biggest ones in the world. The major paper manufacturers are: United States, Canada, Japan, Finland, Sweden, Germany, Brazil and France. And on the other hand, all countries are paper consumers. The paper consumption has an inherent cultural value due to the work that it makes in terms of spreading of the information (Teschke and Demers 1997).

Nowadays, the production tasks related to the cardboard manufacturing become more and more are ruled by computers (Balestrino and Pacini., 2006, Hyland, 1997, Barber, 1996). In this way, it can be known in advanced how to manage the orders and how to plan them because a computer rules many different activities in these companies (Hyland, 1997). For example, the trucks can be arranged how to load them (number of pallets inside the truck) and also the corrugators can be programmed (the computer can fix around what time and how many sheets should be manufactured in the corrugator machine). With the control of the process with the computer, mistakes are minimised because there is an exchange of information between shop-floor operators, customers and computer, for example: pallets are not forgotten because forklift operators are computer linked to all information about every truck load.

Although, computer programmes gives accurate rules to follow, there is a task that is very difficult to do in the sheet feeder industry business: give an accurate number of sheets per unit load (Balestrino and Pacini, 2006). The reason is that even if it is known the number of sheets that is produced, at the end usually this number is wrong because some cardboard sheets could be damaged in the production process. So, one option to know the number of sheets that have been loaded onto a pallet is by measuring the overall weight of the cardboards and then this is divided by the weight of the single cardboard. But this method has some disadvantages like that: it is needed a worker to be checking the weights, the production has to be slowed down and the estimation is not very correct because the weight of the single can vary. This is an example that shows that there is still a lot of effort to do in the corrugated industry in order to monitor some activities. Bennett (2002) defines that basically the goal of controlling the business with the computer is: cost saving and customer satisfaction. This philosophy includes just-in-time production, flexible and optimal production programming, precise flow of information for customers and quick product preparation.

The development of new business techniques in order to improve the service to its customers will make these companies able to compete stronger in the market. At the current time four tendencies could be highlighted: electronic commerce (E-commerce), returnable containers, custom packaging and cost effective solutions (Modern Materials Handling, 2000). E-commerce, apart from saving time of orders' management, has reduced the demand of pallets due to customers have tendency to make orders of smaller sizes. It should be also highlighted that companies are studying how to make the orders in such a way that it could be checked how the space of the truck is used. The second tendency refers to returnable containers (Modern Materials Handling, 2000). The companies use them because some customers only want to pay the containers that they use and other customers do not have space enough to store the containers. And the last tendencies referring to custom packaging and cost effective solutions tell that companies are working in managing the orders in such a way that these orders fit properly on standardized pallets.

Apart from cost saving and customer satisfaction improvements, a lot of emphasis is being made in the environmental aspect. This is because cardboard industry consumes a lot natural resources (for example: wooden, water and energy), so it is a big culprit of the water, air and ground pollution. This aspect is reflected in the big amount water contaminants caused by tonne of wood paste (Teschke and Demers., 1997).

2.3 Cardboard Sheet Manufacturing

The cardboard sheet is made of various corrugated elements (flute) fixed to one or more plane elements (liners) by an adhesive applied on the top of the waves (Alfa, 2007). The elements that the cardboard sheet is made of are shown in Figure 2.2.

Teschke and Demers (1997) explain that the manufacturing process of the cardboard sheet is similar to the process of the paste or paper. The process consists of the spreading of paper paste and water. Afterwards, the water is extracted, the sheet is dried and it is stored in a reel. The procedure is different from the process of paste or paper manufacturing in the way that it is given the thickness to the sheet, the combination of multiple layers and the drying process.

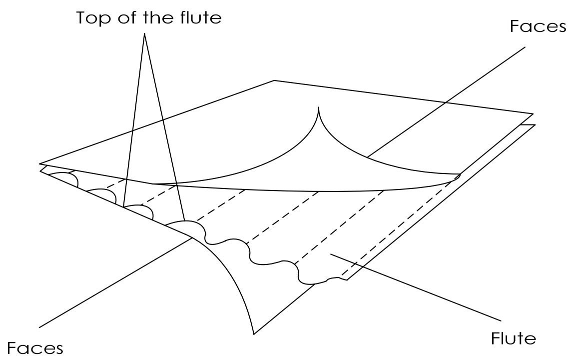

Figure 2.2: Elements of the Corrugated Cardboard Sheet

The cardboard could be done with sheets made of one or more layers, with core or without it. Generally, sheets are made of high quality Kraft paper paste and the core is made of a mixture of semi-chemical paste and cheap recycled paste. The cardboard sheets composition depends on the function of the container that wants to be obtained. Usually, the colour of the corrugated cardboard is linked to its quality. The different tonalities of the liner papers depend on the raw material that are made of and/or their production process (Alfa, 2007).

The cardboard sheet is made in a corrugator machine which works with two main elements: steam and adhesive, mainly made of starch. Figure 2.3 represents the process of manufacturing of the corrugated cardboard. Initially, a subgroup of the corrugator machine (1) makes a single wall that is a combination of a flute (2) and an inner liner (3). This is done by joining the flat element (inner liner) to the top of the corrugated element (flute). This single wall moves towards the bridge (4) and it is joined to the outer liner (6). Afterwards, these two faces are joined because the adhesive is applied onto the top of the flute in the glue system (7). Next, the cardboard sheet is put onto the dryer table (5) where the cardboard is dried and glued.

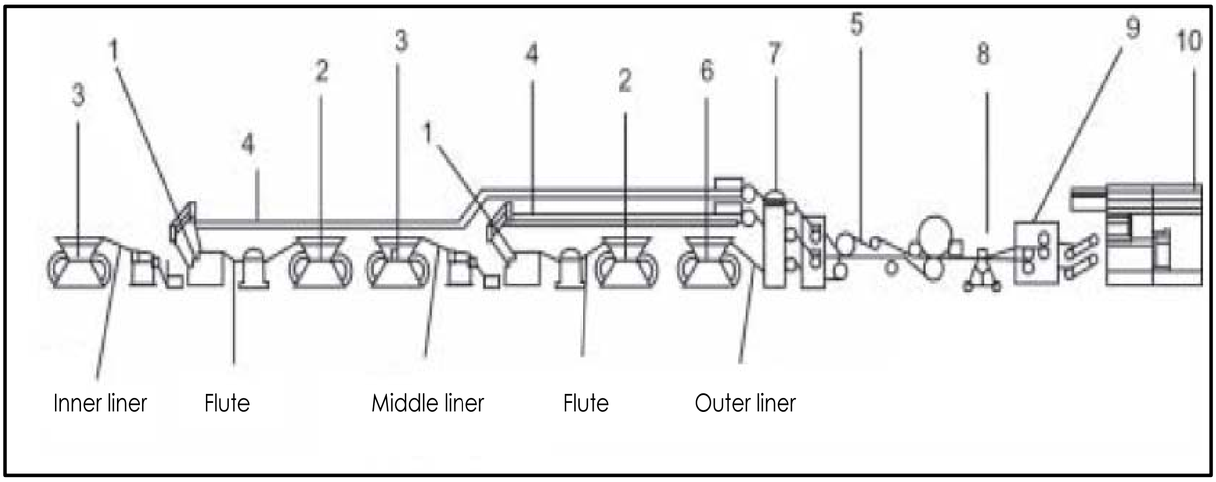

Figure 2.3: Process of Corrugated Cardboard Sheet Manufacturing. (Source: PaperMarket, 2007)

Normally, in this process the cardboard goes through units of longitudinal (8) and cross section (9). Finally, the cardboard sheets are piled up in one unit (10).

2.3.1 Types of Cardboard

The types of corrugated cardboard that can be found in the market are as follows (PaperMarket, 2007):

- Single face corrugated cardboard: it is made by a flute joined to an inner liner.
- Single wall corrugated cardboard: it is combination of a flute glued to an inner and outer liner.
- Double wall corrugated cardboard: it is made of two single wall linked together.
- Triple wall corrugated cardboard: it is made of three single wall glued.

The thickness of the cardboard depends on the type of flute used. Table 2.1 presents the types of flute currently that are in the market:

FLUTE	THICKNESS
N	Between 0.6 mm and 0.9 mm
F	Between 1 mm and 1.3 mm
E	Between 1.2 mm and 1.8 mm
B	Between 2.2 mm and 2.9 mm
C	Between 3.2 mm and 3.9 mm
A	Between 4.1 mm and 4.8 mm
D	Between 6 mm and 6.5 mm

Table 2.1: Types of Flute

2.4 Pallet: Loading and Management Aspects

A pallet is a portable, horizontal, rigid platform used to store, stack and hand loads as a single mass (Raballand and Aldaz, 2005, White and Hammer, 2005). Figure 2.4 shows an example of a pallet. Trebilcock (2002) and Fornicio (2000) explain that the pallet is the most used item to transport products from one point to the other. He also points out that the users of pallets are expected to buy the same number of pallets or more year by year. The most used pallet is the wooden one, followed by the plastic pallet. However, wooden pallets are down slightly in the last few years (Maloney, 2000). Different aspects of these items for the transport are looked when they are bought, like: durability, purchase price, availability, etc.

As well as being different materials to make a pallet, there are different pallet sizes in the market. The pallet dimensions are made in a way that they are submultiples of the place that will be used to transport the pallets (Albardiaz and Castillo, 2000). Nowadays, there are two normalized pallet dimensions: the Europallet (1200mm x 800mm) and the universal pallet (1200mm x 1000mm).

Figure 2.4: An Example of Wooden Pallet

The first one is more used in Europe and the second one is more usual in the Japanese and American market. Apart from the standard pallets that can be found, nowadays there is a tendency to make a pallet for new products. This makes an increase in the cost of pallet management and this variety causes less efficiency in the distribution chain. Trade costs increase too because those products that should be transported from one country to another (countries that have different pallets standards) at the border are unloaded from the initial pallet to the second one (Raballand and Aldaz-Carrol., 2005). Morabito et al. (2000) argue that another disadvantage is the lack of well-accepted standard pallets and compatible trucks designs for these standards that has as a consequence an undesirable empty space of the cargo loading.

Yaman and Sen (2005) point out that there is an option to fill these pallets when the customer makes an order to fill a pallet with few material, this is called mixed pallet. Instead of increasing or decreasing the amount of products of the order to fill a pallet, a pallet with products of different customers' products is loaded. But the use of this pallet may complicate the logistics. Firstly, the manufacturer needs to know how the products should be loaded onto that pallet; this decision is taken every time a customer order is placed. This pallet design should be efficient in terms of pallet space and it also should be stable. Because if the load is not stable enough the material can be damage and this is the main reason (Fletcher, 1990). Therefore, the design of these mixed pallets is a time consuming task. Hoffman (2006) reports that if the stability is improved, the productivity too, including the reduction of damage in transport. It could be found three groups of designers in the material handling field: designers of handling equipment, designers of the pallet and the designers of the packaging

(White, 1997). It is proved that the design of the pallet has a direct impact in the efficiency of the automated unit load material handling equipment. White (1997) reports the increase f efficiency from 18% to 55% between the years 1992 and 2000 in the warehouse automation. If there is no communication between these three groups the companies will have a poor balance between functionality and economy. A cost saving in any factor of the distribution chain will affect to the other factors involved in that area. White and Hammer (2005) point out that a cost reduction in the pallet will save money in those activities associated with the movement of products between the seller and the customer. For example, some designers invest efforts in redesigning the pallets because pallet interacts with other components of the supply chain like: vibration interactions during the loading and conveying, shock transferences while the forklift is handling the material, etc. In spite all of this, there is a special concern in saving transport costs.

It is another tendency that is to redesign the shape of the cases that contain the product in order to maximise the utilisation of the pallet space (Dowsland, 1995). There can be two phases in the process of redesigning a case. The first level is when it should be examined the size, stability and other type of constraints. And the second level is to look to other parameters related to the case like: case thickness, layer pads, dividers and internal spacing. These small details, that represent a small change in the case dimension, could have a big impact on the palletisation efficiency.

Other issues should be taken into account while loading a pallet. Wood gives the example that the material that is loaded onto the pallet should be lined up because if it is not a 40% of the strength is lost. Therefore, overhang should be avoided because material corners are weak so the material could easily be damage (Wood, 2001). Another disadvantage of this material overhang is that if this is more than 4 or 5 inches, the forklift can have difficulties while managing the load. Garcia and Prado (2005) state that in terms of load weight there are some restrictions as well, the maximum weight is 1000kg including the weight of the pallet. There three maximum heights for palletized loads specified of the Europallet (800mm x 1200mm): 1.15m, 1.45m and 2m (including the height of the pallet). Furthermore, the companies can load more than one palletized load, one above the other with a maximum height for each load of 1.35m (Garcia and Prado, 2005).

Nowadays, companies have different alternatives for the pallet management. This management is based on the way they get, transport and disposal of the pallets in the companies (Albardiaz and Castillo, 2000). The management options that could be found are as follows:

- *Private management:* the companies buy their own pallets and they manage their use and elimination according to the possibilities.
- *Group management:* there are associations of different companies (providers and customers) that they decide to share the management of the pallets. However, many of these associations fail because there is almost always a company member that does not carry out its commitment. This is the reason why there are organized systems like pool systems.
- *Pool systems*: they consist on being member of a bursary of pallets. This bursary is made of a group of companies associated. These companies are owners of a number of pallets. This system is controlled by a company that has the main task of controlling that the system is working correctly. The pallets are delivered to the "pool" members and to the raw material providers. Afterwards, the company delivers the pallets with their products to the final destinations. And once they are delivered these pallets are picked up and transported to the deposits. Finally, these pallets are classified and repaired in a workshop and delivered again to the manufacturers and providers. This kind of service is used by companies that prefer to focus in their business activities and leave the pallet manufacturing to experts.

Fornicio (2000) state that CHEP (Commonwealth Handling and Equipment Pool) is a business that provides services like management, collection and repair of pallets, especially in Europe. CHEP provides durable pallets and containers that could reduce the damage of the product (www.chep.com). CHEP has a pooling model that encourages the repair and reuse of its pallets. Figures from 2.5 to 2.9 represent, in a general way, the services that CHEP gives to its customers.

Figure 2.5: CHEP Service Step 1. (Source: Chep, 2007)

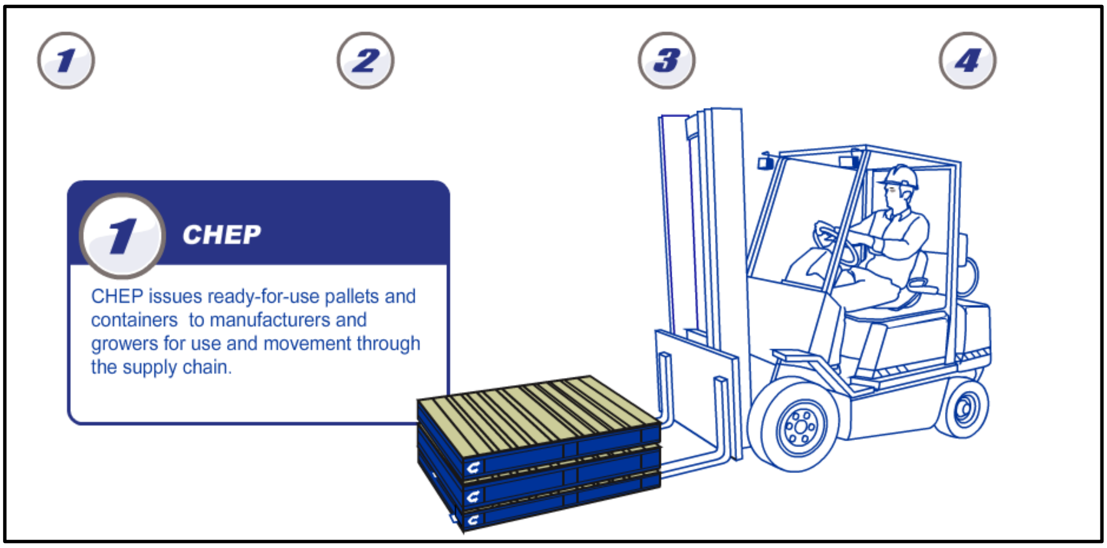

Figure 2.6: CHEP Service Step 2. (Source: Chep, 2007)

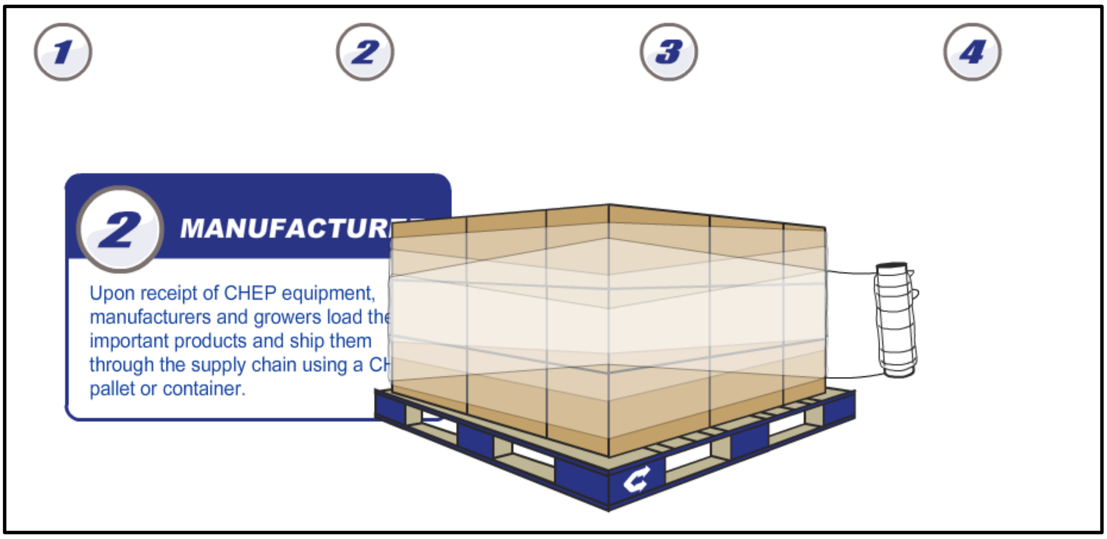

Figure 2.7: CHEP Service Step 3. (Source: Chep, 2007)

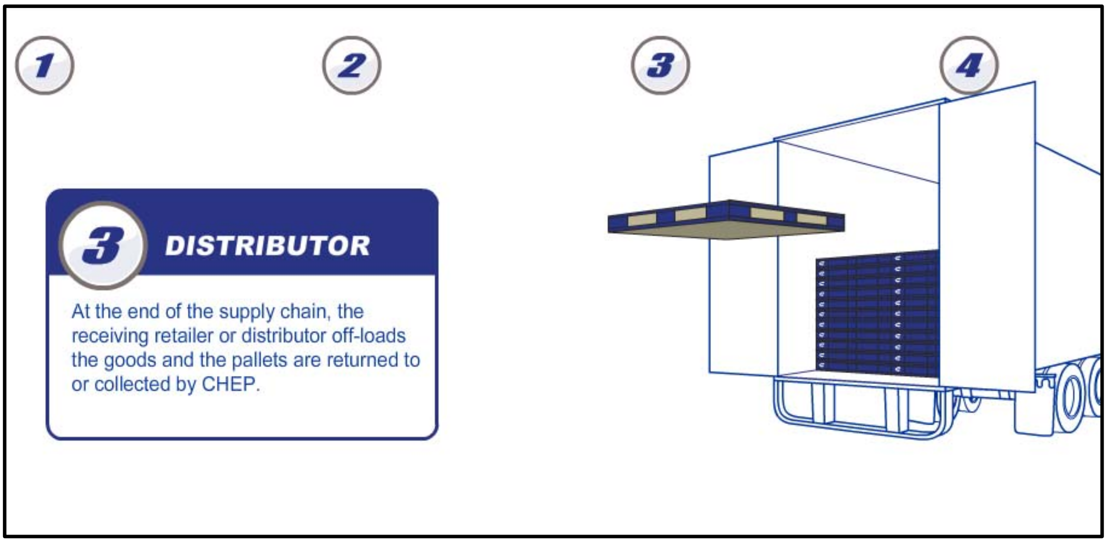

Figure 2.8: CHEP Service Step 4. (Source: Chep, 2007)

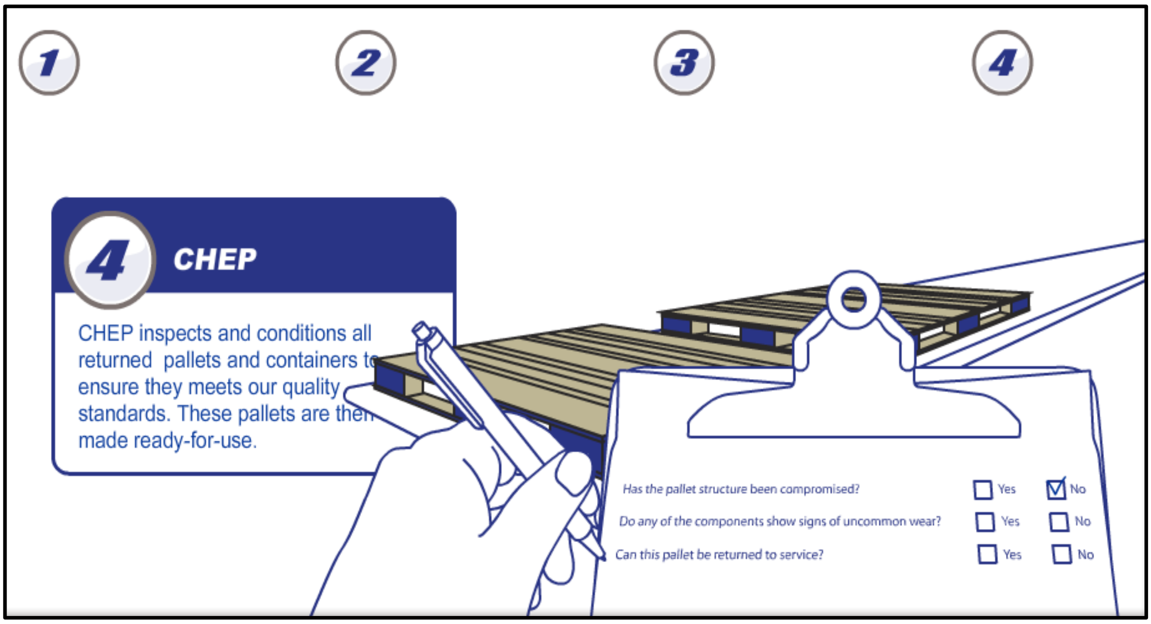

Figure 2.9: CHEP Service Step 5. (Source: Chep, 2007)

In UK, it has been found an alternative for the CHEP that is IPP (International Pallet Pool). This company offers a brown pallet. This pallet has a strong design, and it is well suited to automated production and it will be checked regularly for damage (Semple, 2005).

2.4.1 Types of Pallet

Currently, the main pallets that are used for shipment in the industry are wooden pallets and close to them the plastics pallets. Each of them has their advantages and disadvantages. Pallets made from wood have the following disadvantages: poor quality, absorption of moisture that can damage the product, not easy to clean, etc. (Fornicio, 2000). While in the plastic pallets these disadvantages do not exist because they are: resistant (they last two or three times more than the wooden pallet), less weight, stacked better, etc. The disadvantage of the plastic pallet against the wooden one is that it is much more expensive (around two or three times more). Although, all the advantages of the plastic pallet many companies continue using the wooden one because they believe that pallets could be lost in the distribution system. In the manufacturing of wooden pallets many cares are taking into account because the wood of these pallets can harbour insects (Reinchenbach et al., 2004). This is one of the reasons why the use of plastic pallet is increasing.

Fornicio (2000) states that there is a third alternative in the kind of pallets in the market that is the hybrid pallet which is made of wood fiber mixed with resin molded under high heat and pressure. The advantages of this kind of pallet are that it is not heavy, it is clean, it is not moisture absorbent and its price is similar to the wooden pallet.

It could be found as well a pallet made of Kraft paper and water based adhesives. This pallet is called Hexacomb pallet. It is a lightweight pallet and the only disadvantage is that it requires a special attachment to the fork truck (Fornicio, 2000).

The last tendency in this field is the use of slip sheets that are the cheapest option but they are not compatible with the warehouse rack system. These slip sheets are easily recycled.

2.5 Material Transport Techniques

In the last decade, the manufacturing and the optimization in the supply chain has acquired a big importance for the companies in the current competitive market (ECR Chile, 2001). This optimization requires cooperation and collaboration between the different factors involved in the supply chain, and from standards that allow an efficient flow of data, goods and money through this supply chain. In the case of the material flow, the earth transport plays an important role. An increase in the distribution efficiency and the transport is traduced in lowest costs and / or differentiation of service. Salagnac and Yacine (1999) points out that in an ideal company, all products delivered should be the correct ones, arrive on time and delivered to the right customer.

There are two alternatives in terms of material transport. The first one is the *flow through* in which complete pallets are received by the customers and stored by them.

The second practice is the *cross docking* where the provider sends the products arranged in pallets by point of sale. And afterwards, in the point of distribution to client, these pallets are moved to the mean of transport that finally will deliver the product to the customer. In the cross docking the commercial advisers exchange information with the shop-floor, these commercial advisers take different transport data: type of load that will be picked up, tonnage of the load, establish the day of departure and estimate the time of load arrival and where the load should be delivered (Arnulfo, 2000). Another consideration taken into account here is that a pallet may contain products from the same category, if the products belong to different categories they are loaded in different pallets (Sohrabi, 2003). In this type of product transport, if the overall load reaches the total load capacity of the truck this load is put into the truck, if not the company will wait to load the truck. This means that the load can be broken up for one of the clients. Once, the truck is prepared to be loaded, the material is ready to be placed into the truck. Before placing the load, the load is distributed in the truck, taking into account which product belongs for a client and the tonnage of each order. This means that each customer order will be placed in a specific zone.

The way the products are distributed to the customers has undergone many improvements. He also highlights that companies dependent on Just In Time (JIT), the scheduling of product flow seems to be the highest layer in the hierarchy, so management of transport resources is crucial to the success of the firm (Jespersen, 2004). An improvement in the transport of the products does not avoid only the damage of the material; it also can give to the product a better brand image (Shobrys and Mallik, 1999). It has been developed some models in order to improve the transportation issues. These models are broken down in three levels of decision making:

- Strategic planning: it makes decisions that could change the current transportation planning.
- Tactical planning: it decides individual movements in the current transportation system.
- Execution: it refers to the decisions that are related with the scheduling, volume, details of the actual movements.

Piasecki (2007 a, 2007 b) argues that there are different factors that influence the loading onto the truck and one of them is the weight because if the load is too heavy, the options for loading the truck will be limited. It is not easy to find the best method in order to load the truck due to it is usual that methods that increase cube utilisation will also increase the labour require to load and to unload the shipment. Piasecki (2007 a, 2007 b) defines four methods to load a truck, these are named: straight, turned, pinwheeled and distribution weight. Here it is shown a brief explanation of these methods and Figure 2.10 shows a graphic explanation:

- Straight loading: all pallets are loaded into the truck in the same direction, in the direction of the pallet stringers. Is the quickest method to load a trailer but it does not maximise the space available into the truck.
- Loading turned pallets: all pallets are loaded into the truck in the same direction, in the direction perpendicular to the pallet stringers. For this method it is needed a four-way pallet and it may not be used in overseas containers and refrigerated transport vehicles.
- Pinwheeling: this method combines the previous methods, straight and turned loading. This method is used when there is an inadequate width in the truck so it is not possible to load two pallets side by side. It maximise the space in the truck.
- Distributing weight: this method distributes equally the weight into the truck.

All these methods are applied to get a balance between productivity and transportation cost. If the space in the truck is optimised, the transportation cost will be reduced. The costs can be 30% less than in a situation with partly loaded trucks (Slagnac et al., 1999).

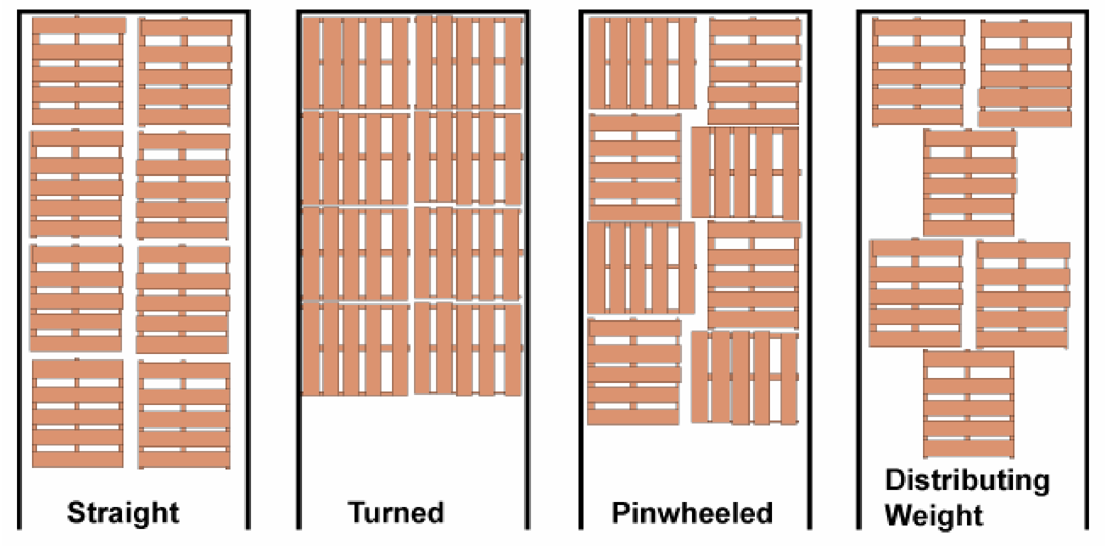

Figure 2.10: Truck Loading Methods. (Source: Inventory, 2007)

2.5.1 Appropriate Dimensions for Transport Vehicles

It is very important to standardize the transport units, especially the structure of the storage space in the truck, in order to make the most of the palletisation advantages. Thus, the material transport and the loading and unloading palletized loads will be improved (ECR Chile, 2001). This will be analyzed as follows (Table 2.2 shows the truck dimensions used for the standardization of the transport):

- *Load capacity:* it is the sum of the maximum capacity that the truck could transport and the weight of the bodywork.
- *Outer maximum length:* it indicates the maximum overall length of the truck.
- *Pallets (positions):* it is the maximum quantity of pallets that can be placed in the storage space, taking into account the recommended internal minimum dimensions of the truck.
- *Minimum inner length:* it indicates the minimum inner length of the bodywork that allows transporting the maximum quantity of pallets.
- *Minimum inner width:* it indicates the minimum inner width of the bodywork that allows transporting the maximum quantity of pallets. For its calculation it has been considered a space between pallets of 1.5 cm and a space between a pallet and the wall of 1.5 cm.

- *Minimum inner height:* it indicates the free height recommended for the bodywork in order that it can be superimposed two pallets.
- *Maximum height allowed:* for all the cases it is 4.2m.

Type	Maximum capacity (ton)	Outer maximum length (m)	Pallets (positions)	Inner length (m)	Inner width (m)	Inner height (m)	Inner volume (m3)
Van ¾	3500	11	N/A	4.5	2.1	2.1	20
Van 5000	5000	11	N/A	5.2	2.2	2.3	26
Truck	10000	11	12	6.26	2.45	2.6	40
Truck double bridge	15000	11	16	8.29	2.45	2.6	53
Truck with trolley	30000	20.5	32	16.41	2.45	2.6	105
Tractor trailer with Semi- trailors	27000	18.6	28	14.36	2.45	2.6	92
Tractor trailer with Semi- trailors	27000	18.6	30	15.25	2.45	2.6	97

Table 2.2: Dimensions Used for the Standardization in Transport. (Source: ECR Chile, 2001)

2.6 Logistics

Muñuzuri et al. (2006) defines the word “logistic” as crucial factor for companies, constituting a real competitive advantage for themselves. This means, logistics has the main goal of providing customers a good service at the same time as the reduction of costs related with the flow of material and information between companies. Hassel and Leek (2006) specifies that the logistic concept appeared in the 1960’s and in that time was referred to the physical distribution. Between 1970 and 1980 this was broken down into to areas: inbound logistics and outbound logistics. Inbound logistics refers to the acquisition of material for the production process and outbound logistics is focussed in the distribution of the finished products to the customer. Figure 2.11 represents the model of logistic management. This model ensures that customer requirements are carried out and it is important to reach the objectives of product quality and service assistance (Muñuruzi et al., 2006). The three main factors in this model are as follows:

- Responsibility of the management: it has the main task of establish, document and keep the system of logistic management and improve continuously its efficiency. The management of the logistic function has to define and establish the objectives for the system of logistic management. The criterions to carry out the objectives and the procedures and control for the logistic processes.
- Resources management: there are two kinds: human resources and information resources. Human resources define the responsibilities of the staff and ensure that all workers are qualified to carry out his/her tasks. At the same time that the company provides him/ her training courses. And information resources must document the procedures and the software used in those procedures, as well as all kind of information related with the company activities.
- Logistic operative processes: it is broken down in these areas.

    - Client service: its main task is to guarantee that the organization when an order of a customer comes has the capacity to carry out the logistic requirements of itself (product delivery conditions, product maintenance, delivery due date and other requirements). The second task is to look very carefully that those requirements are carried out.
    - Production planning: its main task is to guarantee that the production is planned taking into account the logistic requirements, like: the delivery due date, delivery conditions established and the capacity of the processes.
    - Providers' service: its main task is to guarantee that the purchases and the provisions carry out the requirements established for them.
    - Storage: its main task is to ensure the reception, storage and inside the warehouse until the consumption point of any material.
    - Inventory management: its main task is to ensure the product supply and reduce as much as possible the levels of stock.

- Transport and distribution: its main task is to ensure the right product delivery to the customer in terms of delivery due date, quantity and approval of requirements.
- Inverse logistic: its main task is to guarantee the return of defective or discard products with the aim of reusing and recycling them.

- Measure, analysis and improvement: this means that the logistic system should be followed very carefully in order to improve continuously the system itself.

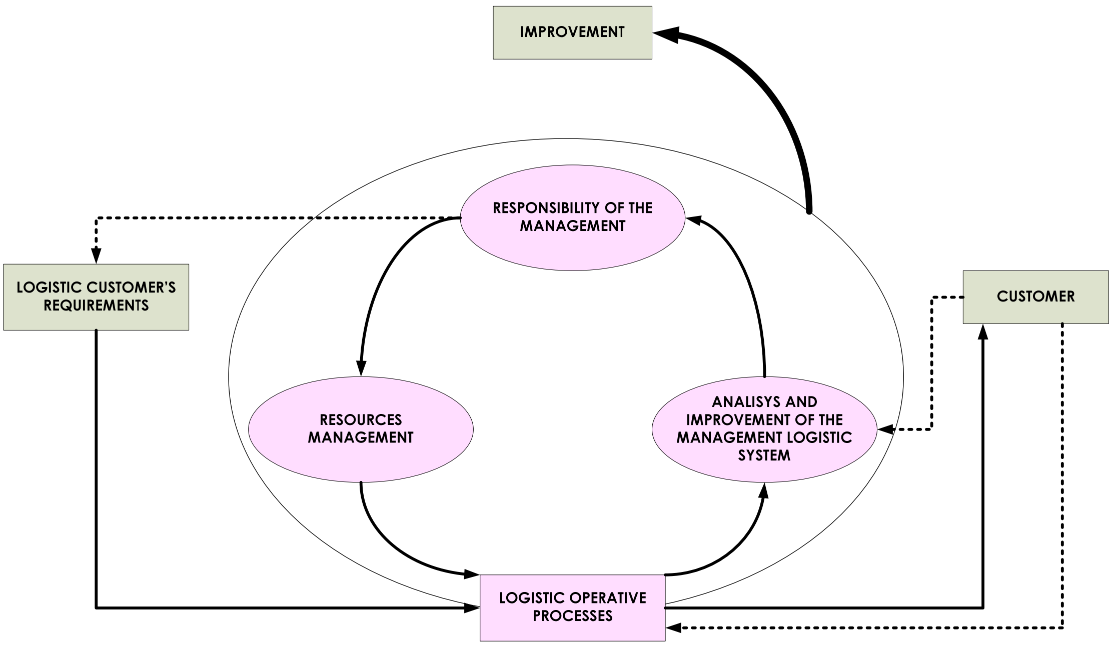

Figure 2.11: A Model of Logistic Management. (Source: Muñuruzi et al., 2006)

Gimenez (2003) defines a new concept that is appearing in some companies: SCM (Supply Chain Management). SCM is a philosophy that manages the flow of a business from the earliest supplier to the last customer. Some companies have realised that kind of logistics that only consider the company itself, without taking into account all the factors involved in the supply chain, it is no enough to have more competitive advantage. SCM looks the supply chain as a whole.

Many tendencies are being carried out in the logistic field. Some of them will be mentioned. In terms of packaging, Gooley (1996) and Hassel and Leek (2006) states that the size of the packaging is very important to reduce cost and time. Gooley

(1996) says that some companies have reduced the size of their products in order to fit them better to the size of the packing case. Another option is to package in the same box different products. Nowadays, the use of containers for the transport of products has reduced costs. The physical dimensions of product affects to the material handling because the way the product is packaged has a direct impact on the number of products that can be manage in a single movement (Hassel and Leek., 2006). Industrial packaging is linked to logistics where it is mainly focussed in the protection, easy handling and information display. Table 2.3 explains the consequences of the packaging related with logistics.

PACKAGING CONSEQUENCES	TRADE - OFFS
INCREASED PACKAGING INFORMATION	- Decreases order filling times. - Decreases tracking of lost shipments.
INCREASED PACKAGE PROTECTION	- Decreases damage in transport. - Increases weight. - Decreases cube utilisation from larger dimensions. - Increases product value.
INCREASED STANDARDIZATION	- Decreases materials handling. - Decreases customer customization.

Table 2.3: Consequences of the Packaging Related with Logistics. (Source: Hassel and Leek, 2006)

The main objective for material handlings is to minimise the number of times that the product has to be managed. The kind of packaging used has to be strong enough to support the weight of products stacked above it. If the material handling is improved it will be reduced the time used by the forklift, the human labour and the space in the warehouse. Another field that is affected by the packaging is transportation due to the packaging impacts the volume of the product.

Logistics also covers the field of the simulation of production processes because these simulations are traduced as a time saving and cost reduction. Gertosio et al. (2000) point out that a flexible manufacturing system (FMS) is made to combine high productivity and production flexibility. These simulations allow a quick flow of the information between the companies. Nowadays, two kinds of control framework are used:

- Centralized control framework: a central controller manages all information and decisions. This control framework is easy to implement but it is not flexible, for example when some changes should be done in terms of parameters.
- Decentralized control framework: a central controller manages local controllers, each one checking a process in the manufacturing system.

Lechuga et al. (2001) argue that when a simulation is taken place in a process that many variables are involved in it, it is very important to break down the problem in different modules.

Logistics can help as well to preserve the environment by establishing a flow in two directions. This return system tries to promote the reuse and recycling of the packaging with the aim of reducing the human wastes (Vicente and Ruiz, 2003).

2.6.1 Transport and Pallet Configuration for Different Customers

Sohrabi (2003) states that in the transport field there is a special concern in improving as much as possible the load onto the truck, at the same time that the reduction of costs. This is the reason why in the same truck different customers' products are loaded (EAN-UCC, 2001). Some companies do not allow mixing their products with the products of other companies; they want the truck to leave the distribution centre only with empty pallets or with some goods/material backs. The reasons for this are because:

- Security of the material: they argue that in some situations between driver and receptionist agreements the material could be stolen.
- Difficulties in the management of goods/material backs: if it is mixed different customers' orders in the same truck, it would be difficult to distinguish

between the orders that should be given back and the ones that should be still delivered.

- Some regulations prohibit that the same vehicle transport material for the sale and material to be returned.

The logistics recommendations to solve these problems are the following ones: security, product integrity and operative simplicity.

- Security: when the same vehicle transports different clients' products, the driver should state the material that is transporting when is entering the distribution centre.
- Product integrity: the vehicle with order of different clients will be allowed to enter the distribution centre if it does not have the task of collecting those materials to return.
- Operative simplicity: the load should be separated, palletised and completely strapped and identified with the consignee in each pallet.

In terms of scheduling the transport delivery, it is considered the length of the driving day and the number of pallets loaded onto the truck (number of times of loading and unloading a product) (Sohrabi, 2003).

Each company manages the products onto the pallet in a different way for the same product. This forces the provider to take up or take down the standard pallet which produces logistic inefficiencies (EAN-UCC, 2001). Each client makes the order regarding the dimensions of their racks in their warehouses. So there is no logistic recommendation that could be applied in the 100% of the cases. There are a lot of variables that should be taken into account when the decision of the high of the pallet. The ideal situation is to analyse the provider and the client together which the ideal high of the pallet could be. Firstly analysing the variables involved and later on making the necessary corrections.

2.7 Decision Support Systems

Shim et al. (2002) state that Decision Support Systems appeared in 1970. They report that these systems are focused on improving user decision efficiency. They define Decision Support System as a computer tool that helps making a decision. They report that this kind of systems is compounded by a database to get to all the data and information and knowledge and a powerful and simple user interface. Knowledge and information are different terms. Zack (2006) defines information as data processing and observation and he defines knowledge how the user manages this information. The aim of the Decision Support Systems is not making decisions. These systems should give a serial of assessment decision tools to improve the results of the decision (Jiancong et al., 2006).

Arnott and Pervan (2008) describes that there are seven subgroups into the Decision Support Systems. Next, the main groups are shown:

- Personal Decision Support Systems (PDSS): these kinds of systems are developed by a small number of people to support the decision of a task.
- Group Support Systems (GSS): they are a mix of Decision Support Systems and communication technologies. Their aim is helping the effectiveness of the work of the groups.
- Negotiation Support Systems (NSS): they are focused on the negotiation between opposite groups.
- Intelligent Decision Support Systems (IDSS): these systems apply artificial intelligence techniques.
- Knowledge Management-Based Decision Support Systems (KMDSS): management information systems that integrate many businesses associated to a company production and distribution tasks.
- Data Warehousing (DW): systems that storages a large–scale data for decision support.
- Enterprise Reporting and Analysis Systems: these systems include executive information systems, business intelligence and performance management systems.

Decision Support Systems main feature is that they should be flexible in the way they show the information (Wu et al., 2002). Shim et al. (2002) report that the future of the Decision Support Systems is electronic devices. This means that the decision could be done by mobile phone or wireless devices.

2.7.1 Knowledge-Based Systems

Dutta (1997) states that until 1970's the main task of the computers was to process data. And during the 70's a lot of efforts were made in order to achieve that computers were able to process information. This is the reason why knowledge-based systems appeared in 1980 (Dutta, 1997, Hayes-Roth and Jacobstein., 1994). A knowledge-based system can be defined as a computerised system that can solve problem about a certain scope that it has knowledge (Monografias, 2007). Dutta (1997) defines knowledge-based system as a system that captures the knowledge and/or the accumulated experience from humans. Hendriks and Vries (1999) and Rancan et al. (2006) add that these systems imitate human behaviour and that they help to make decision in different business areas.

This knowledge can be captured in two different ways: tangible knowledge (articulated) and intangible knowledge (tacit). Tangible is that knowledge that is taken from books, manuals, etc. And intangible knowledge includes the "culture of the company, experience of employees, etc." (Dutta, 1997).

The way this knowledge is analysed can be broken down as follows (Dutta, 1997):

- Individual: the knowledge captured from a worker is the fundamental unit for knowledge creation.
- Group: the group of individuals is the key unit for knowledge creation.
- Organizational: the body of the knowledge is based on the whole organization of the company.
- Knowledge links: it refers to the exchange of knowledge between companies.

Monografias (2007) and Hendriksand Vries (1999) report that the main elements that take part in a knowledge-based system are four (Figure 2.12 represents the architecture of the knowledge-based system):

- Knowledge base: it is the core of the system. It is where the base of the knowledge is stored. In this case, the knowledge will be stored as "if" <condition> and "then" <action / conclusion> rules.
- Database: represents the knowledge about the status of the system in a specific moment. In general, this knowledge is stored in a database and it is directly linked to the knowledge base.
- Inference engine: it is the core of the system with the knowledge base. It is a program that is between the user and the knowledge base. It is the responsible of giving conclusions from the data of the database and the knowledge base.
- Specific user interface: establish the communication between the user and the system. The user consults something and the expert system gives him results.

Kathuria et al. (1999) specifies that knowledge-based system is widely used in the manufacturing field. These systems are useful for the control and the scheduling of the production. That is the reason why Kathuria et al. (1999) states that the knowledge-based system should be validated by human experts.

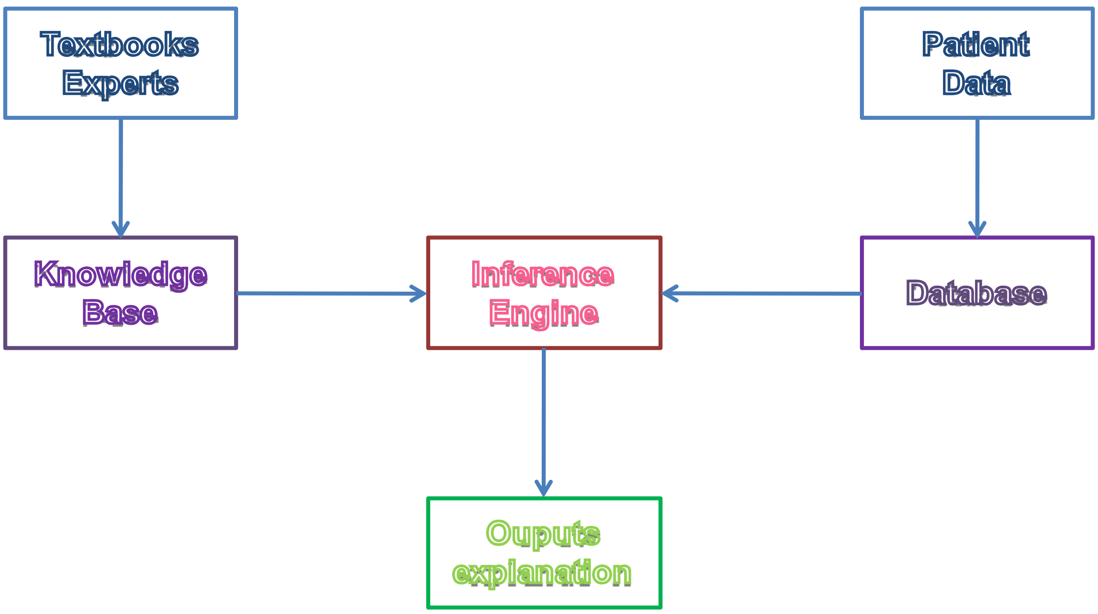

Figure 2.12: Architecture of Knowledge-Based System

The knowledge-based systems are applied in industry. Shehab and Abdalla (2001) develop a knowledge-based system for cost estimating. The developed system provides information about the cost associated to manufacturing the entire system or operating the system in separate parts (Shehab and Abdalla, 2002a, 2002b). The suggestions made by the system are based on the recommended process plan. This system has encoded the captured knowledge in order to solve in an easier way the problems. Shehab and Abdalla (2001) have represented this knowledge with “IF” and “THEN” rules. These rules have been developed with the knowledge obtained from literature review and interviews with experts in manufacturing from different firms.

2.8 Research Gap

Deciding the optimal height for a pallet is not an easy task. The reason is that the corrugated board customers have different requirements and the pallet has also its own restrictions such as maximum weight and height. Another very important factor is the transport vehicle. The maximisation of the space available in the truck is another concern. Some pallet sizes are proportional to the space available in the truck. Furthermore the optimal use of the space in the truck is another issue taken into consideration the customers’ bespoke pallets which have specific sizes (Morabito et al., 2000). Therefore, there is a need for a research project to address the different sizes of pallets and the best utilisation of a transport vehicle.

However, Yaman and Sen (2005) address different techniques about how to load a pallet from the manufacturer point of view. They have not taken into consideration the customer requirements of how the pallet should be loaded.

A number of authors highlighted that the weight of the cardboard should be taken into consideration when the pallet is loaded. For example, Garcia et al. (2005) explained that the maximum weight that a pallet can stand is an important factor. There is a little research on the maximum weight of the cardboard material can stand to be loaded onto the pallet. Especially when these materials are very special and delicate.

2.9 Summary

The literature review exercise presented has shown that the main goals in any business is reducing lead time and cost. For these reasons many new techniques have been developed in order to achieve both of them. Every factor involved in the process of a product is looked very carefully from the production process to the product delivery.

Once the product is finished, the material storing and handling is very important. The better the company stores a product the best use of the warehouse will be done. Some companies directly do not store, they work with a Just In Time business, so they do not have any cost related with the warehouse and any stock. For the storing and also for the product delivery the maximisation of the use of the pallet is another concern. All companies try to load as many items as possible per pallet, taking into consideration stability and weight issues. Apart from this, it is a cost saving as well in terms of the pallet acquisition, some companies prefer to have their own pallets and other ones prefer to have an external service that provides them the pallet that they need.

The last step for some companies is the product transport. The scheduling of the product delivery is very important because this will save money used for the fuel as well as time. The best utilisation of the truck volume is another concern. And the packaging of the material is also important, because the best the material is packaged, the less damage will suffer the product and this will provide a good company image.

Nowadays there is another tendency in these business improvements that is the environmental concern, what is called inverse logistics. Some companies take care of the return of the pallets, so that they can be reused and as a consequence the environmental impact is reduced.

The review has also highlighted the observations on research gaps not currently addressed. This literature review has outlined that there is a need for maximisation of the volume of the trucks.

CHAPTER 3

3. RESEARCH METHODOLOGY

3.1 Introduction

This research project deals with the palletising and storage issues. An improvement in this stage of the process could minimise the overall cost of the product. For this reason, it is necessary to carry out a research methodology to solve these problems. The research methodology describes the steps that have to be followed in order to analyse the needs and problems of a situation. The research methodology is adopted in order to apply the knowledge of the researcher to tackle these needs and problems.

This chapter consists of six sections. Section 3.2 presents an introduction to the different research methodologies. The qualitative research methodology is defined in Section 3.3. Section 3.4 introduces the quantitative research. Mixed research is described in Section 3.5. The research methodology that has been adopted in this project is introduced in Section 3.6. Finally, Section 3.7 provides a summary the overall chapter.

3.2 An Overview of Research Approaches

There are three main kind of research: qualitative research, quantitative research, and mixed research.

- *Qualitative research:* is a research that relies on the collection of qualitative data.
- *Quantitative research:* is a research that relies primarily on the collection of quantitative data.
- *Mixed research:* is a research that involves the mixing of quantitative and qualitative methods or paradigm characteristics.

Briones (1996) reports that methodology is the way the researcher approaches problems as well as the way he/ she looks for the answers to these problems. Figure 3.1 illustrates the difference between quantitative and qualitative research approaches. The various research methods are discussed in more detail in the following sections.

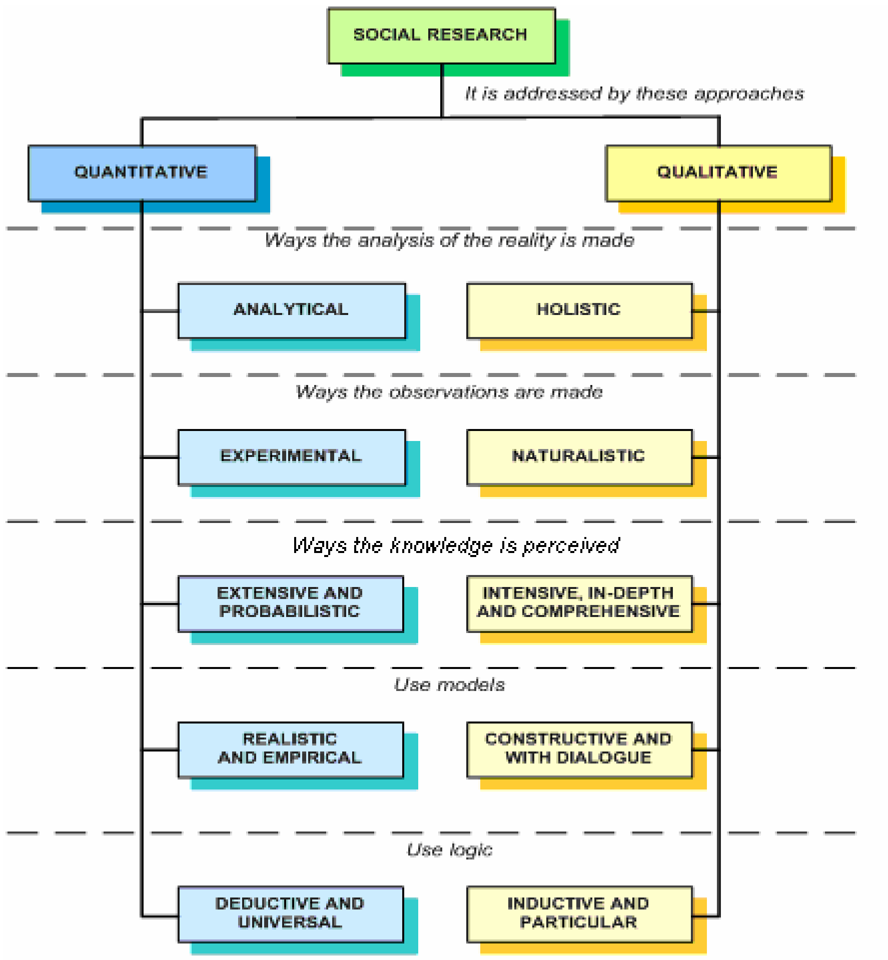

Figure 3.1: Differences between Qualitative and Quantitative Research (Briones, 1996).

3.3 Qualitative Research

Hancock (1998) points out that the aim of the qualitative research is the development of reasoning of social phenomena. Qualitative research tries to clarify why the world is the way it is. Table 3.1 shows the main differences between qualitative and quantitative research.

QUALITATIVE RESEARCH	QUANTITATIVE RESEARCH
- Takes into consideration personal opinions, experiences and feelings to produce subjective data.	- Does not take personal opinions. It only looks to the facts.
- Describes social phenomena as they occur naturally.	- It manipulates the situation under study.
- Has the whole perspective of a situation.	- Depends on the ability to identify a set of variables.
- Inductive approach: data are used to develop theories.	- Deductive approach: tests theories which have already been proposed.
- Qualitative data are gathered having interviews with the individuals or by observation.	- In quantitative research the interviews are not necessary because it does not look for personal points of view. It wants objective data.
- Qualitative sampling techniques are concerned with seeking information from specific groups or subgroups in the population.	- In quantitative research sampling seeks to demonstrate representativeness of findings through random selection of subjects.

Table 3.1: Features of Qualitative and Quantitative Researches

Four major types of qualitative research design are:

- Phenomenology
- Ethnography
- Grounded theory
- Case study

Another common research design is the survey. Surveys can be either qualitative or quantitative in their approach to data collection. Figure 3.2 reflects the four types of qualitative research and the main features of each one of them.

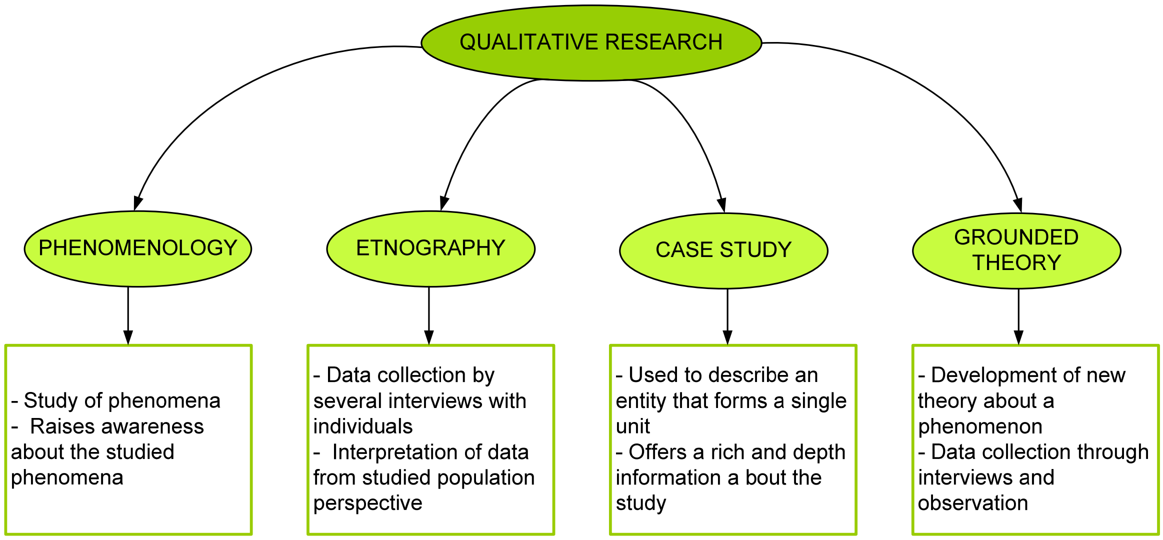

Figure 3.2: Qualitative Research Typology

3.3.1 Phenomenology

Phenomenology, as its name says, studies the phenomena. This type of research describes something that exists as part of the world where we live. Phenomena may be events, situations, experiences or concepts. In real life there are many phenomena which are not fully understood. Hancock (1998) argues that the reason why these phenomena are not understood could be because:

- The phenomenon has not been previously studied in-depth.
- Or the consequences of the phenomenon are not very clear.

Phenomenological research begins with the acknowledgement that there is a gap in our understanding and that clarification or illumination will be a benefit. Phenomenological research will not necessarily provide definitive explanations but it does raise awareness and increases insight.

3.3.2 Ethnography

Ethnographic involves the study of an extensive fieldwork. Formal and informal interviews are the most usual technique for the collection of data. In this kind of research, the researcher often interviews participants more than once at the same time as he/she observes to these participants. Because of this, ethnography is extremely time consumer as it involves the researcher spending long periods of time in the field. Analysis of data adopts an “emic” approach. This means that the researcher attempts to interpret data from the perspective of the population under study. Ethnographic research can be problematic when researchers are not sufficiently familiar with the social mores of the people being studied or with their language.

3.3.3 Grounded Theory

The main feature is the development of new theory through the collection and analysis of data about a phenomenon. It goes beyond phenomenology because the explanations that emerge are genuinely new knowledge and are used to develop new theories about a phenomenon. New theory begins its conception as the researcher recognises new ideas and themes emerging from what people have said or from events which have been observed.

Various data collection techniques are used to develop grounded theory, particularly interviews and observation although literature review and relevant documentary analysis make important contributions. A key feature of grounded theory is the simultaneous collection and analysis of data using a process known as constant comparative analysis.

3.3.4 Case Study

Like surveys, case study research is one of those research approaches which can take a qualitative or quantitative stance. The qualitative approach to case study is described wherein the value of case study relates to the in depth analysis of a single or small number of units. Case study research is used to describe an entity that forms a single unit such as a person, an organisation or an institution.

As a research design, the case study claims to offer a richness and depth of information not usually offered by other methods. By attempting to capture as many variables as possible, case studies can identify how a complex set of circumstances come together to produce a particular manifestation. It is a highly versatile research method and employs any and all methods of data collection from testing to interviewing.

3.4 Quantitative Research

In this kind of research is very important that the researcher does take a distant and no interactive attitude. This stance will allow exclude judgement or any other influence derived from the own researcher's and the objects' of the research view. This analysis and interpretation will give the results and the conclusions of the research. Blaxter et al. (2006) report that "quantitative research tends to involve relatively large-scale and representative sets of data and it is often in our view presented and perceived as being about of gathering of facts".

Quantitative research uses variables as a language, hypothesis, units of analysis, and causal explanation. Quantitative research is basically focussed on the identification of variables and the existing relationship between them. "Researchers who focus on casual relations usually begin with an effect and then search for its causes" (Lawrence, 1994). There are three types of variables:

- *Independent variable:* is that variable that causes the researcher's problem of study.
- *Dependent variable:* is the result of another variable.
- *Intervening variable:* is the combination of an independent variable and dependent variable and shows a way of linking them.

In a quantitative research, the observation and the analysis is focussed by the previous hypothesis and questions which try to bring forward the behaviour of the reality object of study. Both of them remain invariable along the research. Moreover, hypothesises are subject to empirical test.

A quantitative research should be done in a way that the researcher should pay attention to all the details because if the researcher only studies the numbers, these numbers could mislead him/her. If the researcher only relies on numbers without "insight", he/she will not have a support when things go wrong.

The major types of quantitative research are: fixed and flexible research. Figure 3.3 shows the two types of quantitative research and the main features of each one of them.

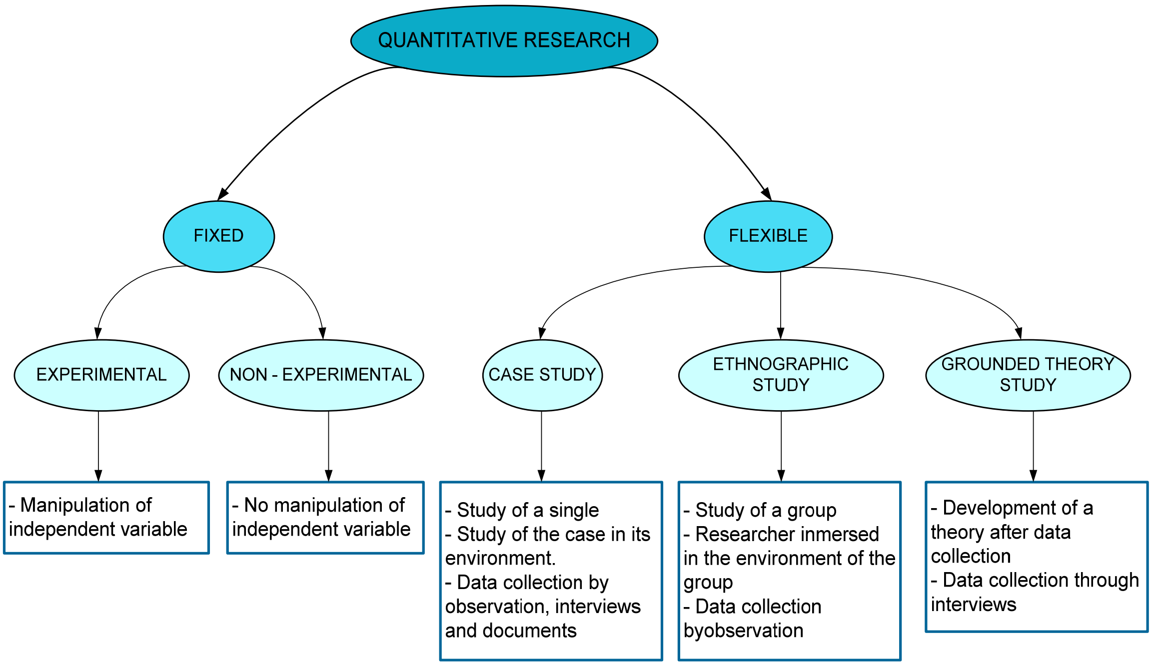

Figure 3.3: Quantitative Research Typology

3.4.1 Fixed Research

It is a type of quantitative research. This kind of research is broken down in: experimental and non-experimental research.

The purpose of experimental research is to study cause and effect relationships. Its main feature is that this research manipulates independent variables, it can be said that it is only experimental research when manipulation is present. Also, random assignment (equivalent groups) is used in this kind of research.

In non-experimental research there is no manipulation of independent variable, as well as there is no random assignment, in other words, if there is a relationship between variables in a non-experimental research, it can not be got a conclusion of cause and effect because there will be too many other alternative explanations for the relationship.

3.4.2 Flexible Research

It is another kind of quantitative research. It is broken down in: case study, ethnographic study and grounded theory study (Robson, 2001).

Case study is the study of a single case. Its main features are: selection of a single case, study of the case in its environment and data collection by observation, interviews and documents.

Ethnographic study is the study of the way of living of a group. Its main features are: study of a group, the researcher is immersed in the group environment and data collection through observation.

Grounded theory study develops a theory after data collection. It is useful in areas that are still new. Its main features are: it could be applied in many situations, it is based in interviews, gives a detailed description of the data analysed and theory.

3.5 Mixed Research Method

Mixed research is a general type of research in which quantitative and qualitative methods, techniques, or other paradigm characteristics are mixed in one overall study. There are two major types of mixed research: mixed method and mixed model research. Figure 3.4 reflects both of them.

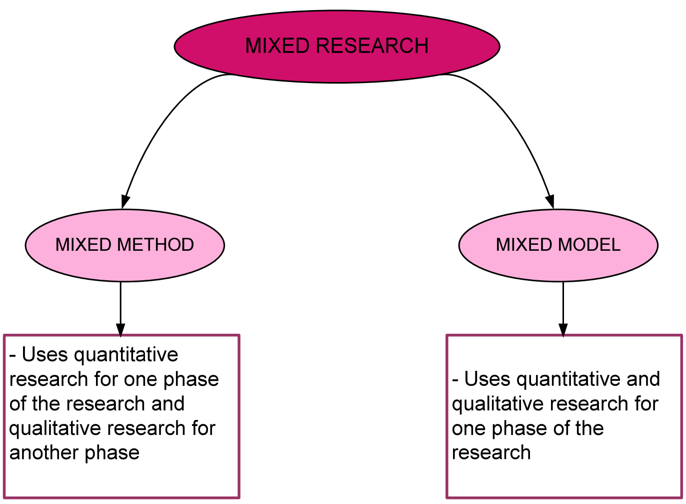

Figure 3.4: Mixed Research Typology

- *Mixed research method:* it is a research in which the researcher uses the qualitative research paradigm for one phase of a research study and the quantitative research paradigm for another phase of the study.
- *Mixed model research:* it is a research in which the researcher mixes both qualitative and quantitative research approaches within a stage of the study or across two of the stages of the process of the research.

3.6 Research Methodology Adopted

A quantitative research methodology has been designed to conduct this project. The researcher has gathered the data from interviews with the staff and internal documents of the company. She has taken the necessary numeric data and variables of the system development. The development of a framework that optimises the pallet utilisation required to gather a large quantity numeric data. The research methodology is divided into five phases namely (i) problem formulation and literature review; (ii) information and data collection; (iii) data analysis; (iv) development of analytical approach and the prototype system; (v) validation of the prototype system. Figure 3.5 illustrates the phases of the research methodology.

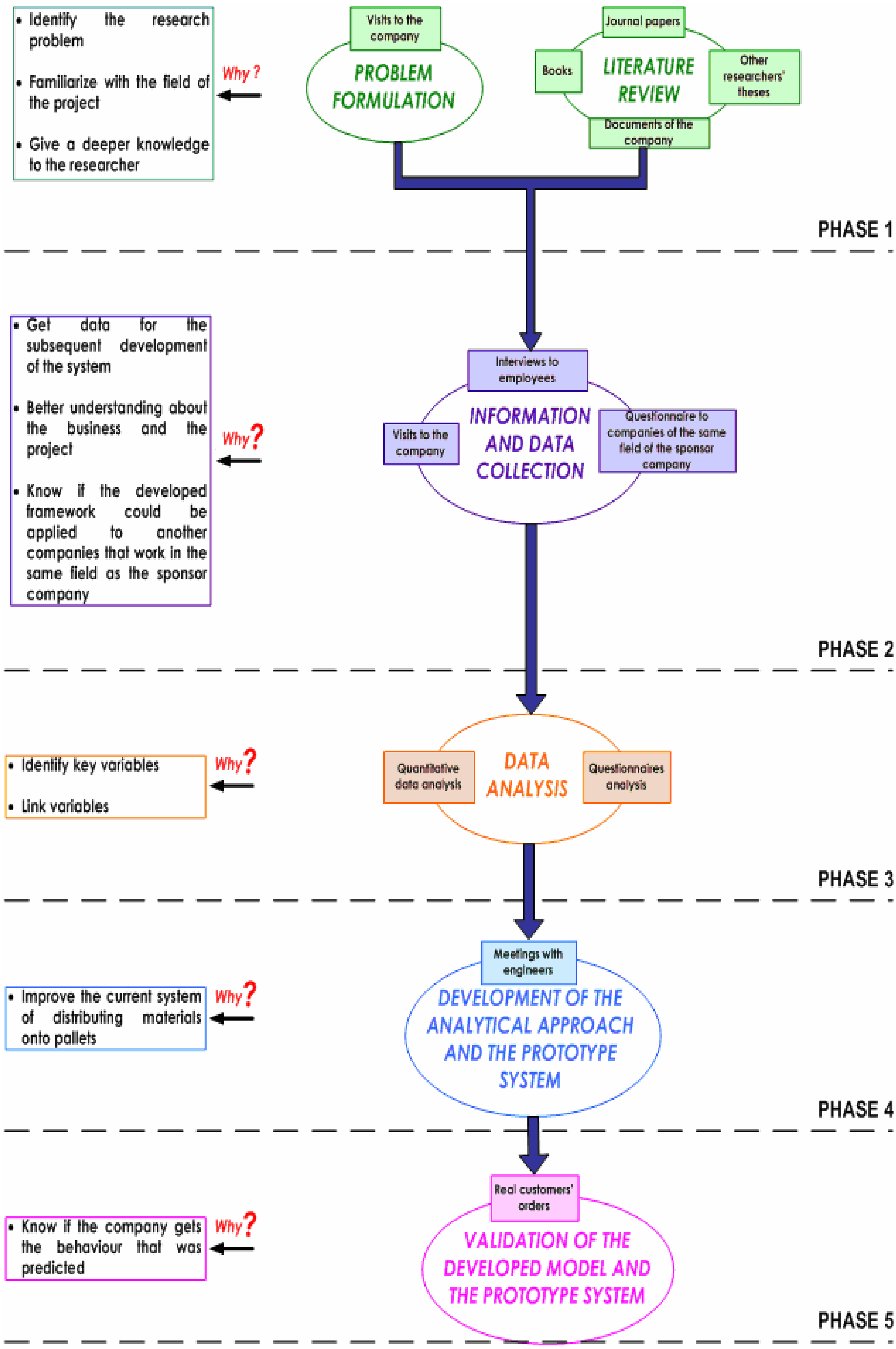

Figure 3.5: Research Methodology Adopted in the Project

1. PHASE 1: Problem formulation and literature review. The first step for the research project is the identification of the research problem. Firstly, the researcher will be focused on the study of the company internal business systems and flows to identify opportunities to maximize the number of full pallets produced. An early visits to the case study company conducted which aimed to gain knowledge in the company operations and the problem that the company needs to tackle. The sponsoring company needs to maximise the pallet utilisation. In other words they are interested in increasing the quantity of material per pallet.

   The second step in this phase is to conduct a literature review. The topic of the research is a new field to study for the researcher and due to this a literature review will be carried out in order to familiarize with the field of the project, as well as giving a deeper knowledge to the researcher. This literature review has been done by reading journal papers, internal documents of the company, another researcher thesis, etc; related with the topic of the project. Furthermore, internal documents of the sponsor company have been analysed. To select the journal papers, books, etc. related to the research topic some specific key words have been used. These key words have been the following ones: sheet feeder industry, pallet, cardboard sheet, transport, logistic and decision support system.

2. PHASE 2: Information and data collection. In this phase, the researcher gathered different relevant data. Different ways of gathering data have been carried out as follows:

   2.1. *Visits to the factory:* the aim of these visits is to be able to know directly how the company works and what issues the company has. Different tasks have been carried out, for example: going to the shop floor in order to make some measurements necessary for the development of the subsequent system (sizes of the trucks material features and sizes of the pallets), informal interviews to different employees (in these interviews the researcher has written down the explanations of the workers. At the same time as she records them in order not to loose any information that could be relevant. The purpose of these interviews is having a better understanding about the business and the project. In these interviews the employees will share their knowledge with the researcher in order to help her how to focus the project. In these visits the workers have given the researcher documents that could be useful.

2.2. *Semi – Structured interviews:* the researcher conducted semi – structured interviews with open questions. These interviews were made from operators of the shop-floor to the IT engineers. The aim of these interviews was to understand the business and identify the variables involved in the system.

2.3. *Documentation:* internal documents of the company were gathered to understand customers' requirements.

2.4. *Contact with companies of the same field of the sponsor company:* the use of questionnaires is a technique typical of a quantitative research, due to in the questionnaires precise questions are written. The aim of these accurate questions is to find the answers to the issue in which the researcher is interested (Blaxter et al., 2006). The researcher will contact with another companies that works in the same field as the sponsor company. This exchange of information will help to know if the framework that has been developed could be applied in other companies of the same field of the sponsor company. At the same time the researcher makes comparisons in the ways of working. By looking to the differences the researcher could have ideas about how to approach the topic of the project. This flow of information between the researcher and the companies will be done by delivering a questionnaire with some key closed questions that the researcher has previously considered relevant.

3. <u>PHASE 3: Data analysis.</u> Blaxter et al. (2006) report that data analysis will continuously move from the chaos to the order and vice versa. In the beginning, during the analysis, the researcher can find data that can seem poor, but as long as he/she study deeper the information these data can turn into relevant information. Similarly could happen with data that in the beginning will seem rich that is, they can change to deficient data. In this step of the research all the information that has been gathered will be analysed in order to

develop the system. To achieve this firstly it was necessary identify those variables that are key for the project. Once this has been done, the second step has been to classify the data into: constant data and variable data. This step is very important due to in the system that has been developed these data must be defined very clear. The last step it has been to study how these variables should be linked in order to get that the system optimises the pallet utilisation. Therefore for the analysis of the different variables that was taken into consideration, the restrictions that can be found were analyzed as well (customers' and material restrictions) and how these restrictions could influence to the search of the optimal solution by the system.

4. PHASE 4: Development of the analytical model and the prototype system. Once the researcher has gathered all data, the next step was the development of the analytical model and prototype system. In the process of the development of the system the rules that have been applied in the system were talked over with the engineers of the sponsor company. At the same time of the development of these rules the equations were developed. The reason of these meetings is to explain the logic that has to be followed in the development of the system to the engineers. At the same time, the engineers have corrected to the researcher those steps that they considered incorrect. Apart from this, these meetings have the aim of explaining the researcher how the design of the system should be. For the development of this system some algorithms, made with the data that has been analyzed, were introduced in order to improve the current system that the sponsor company had to distribute the material onto the pallets. These algorithms were developed by using the knowledge captured from the company.

5. PHASE 5: Validation of the prototype system. The prototype system has been validated through real-life case and expert opinion. For this validation the researcher has to do some visits to the company and he/she has to take random orders trying to cover many different situations. Some meetings with some engineers of the company have to be done in order to explain the logic of the framework and the new maximum quantities of sheets per pallet. The aim of these meetings is to approve some steps and maximum quantities applied in

the new framework and to discuss those steps that were considered not very clear. As a first step of the validation the new quantities calculated has to be introduced in the current planning program. Afterwards, these new quantities will be checked in the shop floor. Checking first if the cardboard can support the new weight and if the utilisation of space in the truck is maximised. Once the program has been agreed and checked with the company, the researcher has checked by an expert opinion.

3.4 Summary

The main objective of the research methodology is to specify how the problem has been identified and faced. For this reason, many visits to the company to do semi-structured interviews and gather documents have been done. Each objective of the project is linked with one of the phases of the research methodology. Figure 3.6 presents how each objective of the project is linked to the phases of the methodology that has been adopted.

The methodology adopted will help to develop a decision support system for pallet utilisation in the sheet feeder industry. The methodology that has been adopted can be describes as a case study quantitative. The reason why it is a quantitative research is because numerical data have been collected and the links between all variable have been analysed. And this research is classified inside case study research because it is focussed on the sheet feeder industry and the collection of data has been done by informal interviews, documents and observation of the business.

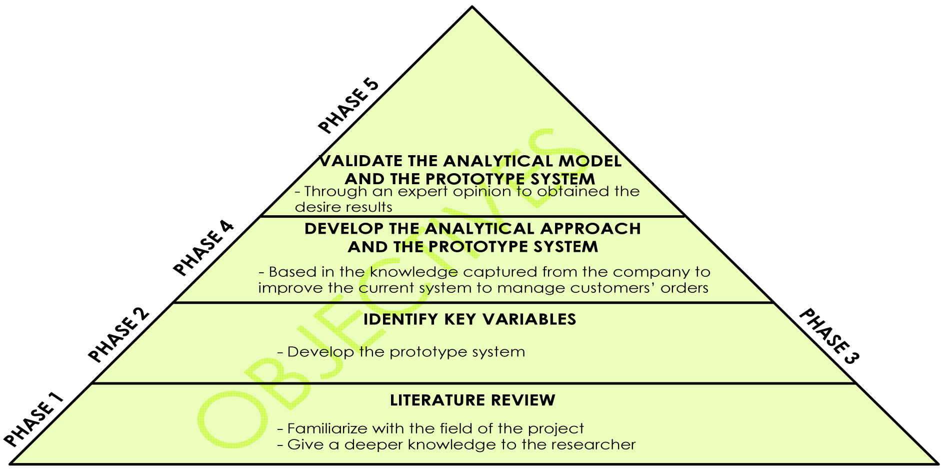

Figure 3.6: Link between Objectives and Phases of the Methodology

CHAPTER 4

4. Analytical Model Development

4.1 Introduction

For the development of the analytical model the researcher has studied how the company works and which variables are involved for the customers' orders management. The equations incorporated in the system were developed at the same time as the system rules.

The chapter is composed of five sections. Section 4.2 explains the method that currently the company uses to distribute the orders onto the pallets. Section 4.3 describes the variables that have been taken into consideration for the system development. Finally, Section 4.4 presents the equations that have been incorporated into the system. Finally, a summary of the chapter is presented in Section 4.5.

4.2 Current Cardboard Distribution Management

How the customers' orders were managed was analysed by visits to the shop-floor and informal interviews with the shop-floor operators and engineers. Currently, the customers' orders are managed as follows:

- Customers' orders (number of cardboard sheets) are distributed equally onto the pallets. For example, there is a customer's order of 1,200 cardboard sheets and the current maximum quantity of sheets per pallet (for the material of the order) is 500 sheets. Instead of loading two pallets with 500 sheets and another pallet with 200 sheets, 3 pallets of 400 sheets are loaded.
- Only one stack of material is loaded per pallet.

- The maximum number of sheets per pallet is fixed. This means, that it is not taken into consideration the different sizes of the trucks that deliver customers' orders.
- Once the order is running in the corrugator machine, the current system communicates with the shop-floor operator in order to select a pallet to fit with the order that is running in the corrugator machine. The shop-floor operator has to check the system report for any errors. Then he/she has to decide manually which pallet fits better.

4.3 Variables Involved in Customers' Orders Management

To improve the current palletizing system it is necessary to analyse all the variables and explore the links between them. The main variables that are involved in the palletizing system are shown in Figure 4.1. These variables are explained in more details in the following sections.

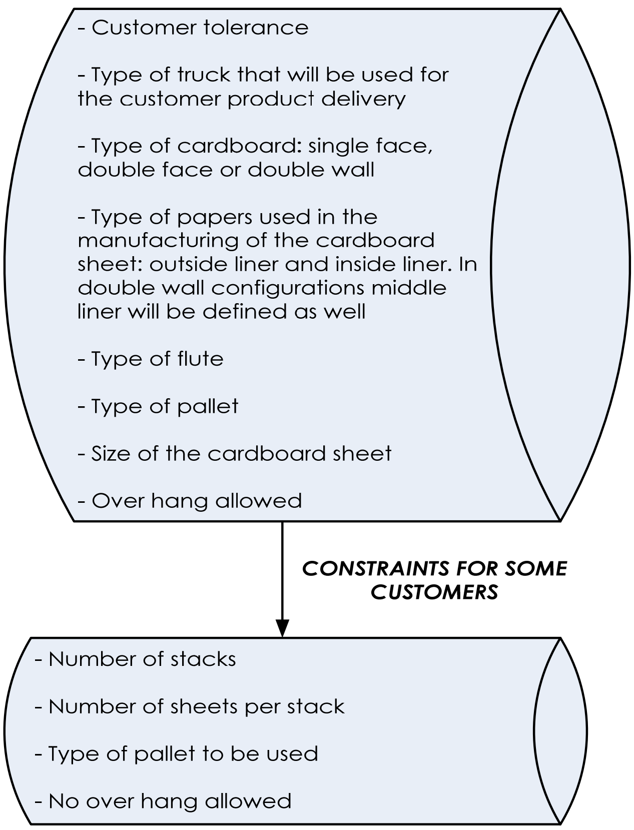

Figure 4.1: Variables Involved in the Palletizing System

4.3.1 Customers Orders' Tolerance

There are customers' terms and conditions on delivery quantity tolerances. These tolerances are employed in order to change the planned board quantity to get the last pallet as close to a full pallet as possible. This means that some customers allow the company to add or remove some cardboard sheets from their order. The number of sheets that can be added or removed is calculated by applying a percentage to the overall quantity of boards of an order. This percentage varies regarding the overall quantity of boards. There are four groups of customers' tolerance types. Table 4.1 shows the different groups of customers regarding the tolerance that they use.

	Order quantity up to 3000 sheets	Order quantity 3001 to 10000 sheets	Order quantity 10001 to 20000 sheets	Order quantity over 200000 sheets
CUSTOMER TYPE "A"	+10.00 / -10.00	+10.00 / -7.50	+10.00 / -5.00	+10.00/ -2.50
CUSTOMER TYPE "B"	+0.00 / -10.00	+0.00 / -7.50	+0.00 / -5.00	+0.00 / -2.50
CUSTOMER TYPE "C"	+5.00 / -10.00	+5.00 / -7.50	+5.00 / -5.00	+5.00 / -2.50
CUSTOMER TYPE "D"	+3.00 / -10.00	+3.00 / -7.50	+3.00 / -5.00	+3.00 / -2.50

Table 4.1: Type of Customers Orders' Tolerances

4.3.2 Types of Cardboard

There are three types of configurations for the cardboard sheet. The cardboard sheet can be presented in these ways: single face, double face or double wall. Figure 4.2 reflects these configurations. The cardboard sheet can be more or less thick; therefore its configuration can influence directly the number of sheets that can be loaded per pallet. In other words, the more thick the cardboard is the less number of sheets can be loaded per pallet.

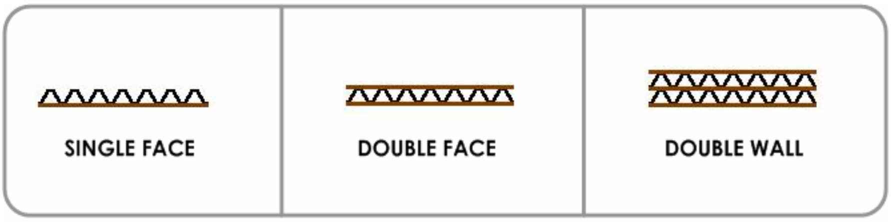

Figure 4.2: Cardboard Sheet Configuration

4.3.3 Types of Paper

For cardboard sheet manufacturing different kind of papers are used. There are thirty three types of paper which are used for the cardboard manufacturing. These papers have different weight. Table 4.2 presents the different types of papers that are used in the case study company to manufacture the cardboard sheet.

The weight of the cardboard is a variable that should be taken into consideration because the type of cardboard that is being managing is very delicate and thin. This type of cardboard sheet is composed of a microflute which is not a conventional cardboard. The maximum weight that this material can stand is 750 kg. Therefore, this limit must not be exceeded in order to protect the cardboard sheet from damage. The weight restriction is very relevant for microflute because it is a delicate material.

Paper	Weight (GSM)	Paper	Weight (GSM)
120FBK	120	150Y	150
125B	125	200T	175
125C	110	170FBK	170
125D	125	180W	175
125K	115	180Y	180
125L	120	190Y	185
125M	125	200K	175
125T	110	200L	180
125W	115	200M	175
150B	150	180D	180
150D	150	425BDC	425
150FBK	150	185Y	185
150K	140	135Y	135
150L	135	300K	275
150M	140	300T	270
150T	135	……..	90
150W	140		

Table 4.2: Types of Papers Used to Manufacture Cardboard Sheets

4.3.4 Types of Flute

There are seven types of flute and each of them has a different thickness which affects the number of cardboard sheets that can be loaded per pallet. For example, the thicker the flute is the less number of sheets are loaded per pallet. Table 4.3 shows each flute and its thickness.

TYPES OF FLUTE	THICKNESS
N flute	0.6 mm
F flute	1.2 mm
E flute	1.6 mm
NE flute	2.2 mm
B flute	3 mm
EE flute	3.2 mm
EB flute	4.6 mm

Table 4.3: Types of materials and their thicknesses

4.3.5 Types of Truck

Four types of trucks are used for the delivery of customers' orders. Each of these trucks has different size. Regarding the size of the truck more or less material can be loaded per pallet. Table 4.4 illustrates the different truck sizes used for the product delivery.

TYPES OF TRUCK		
British truck	Width	2.4 m
	Length	13.4 m
	Height	3 m
Irish truck	Width	2.5 m
	Length	13.5 m
	Height	2.6 m
Scottish truck	Width	2.4 m
	Length	13 m
	Height	3 m
European truck	Width	2.4 m
	Length	13.6 m
	Height	2.7 m - 2.9m

Table 4.4: Different Truck Sizes for the Product Delivery

4.3.6 Types of Pallet

Normally, the sheet feeder industry has 24 types of standard pallets which are stored in the warehouse. These pallets have a thickness of 13cm. Additionally there are bespoke pallets with a thickness of 14.20 cm which are delivered directly from customers. The company does not have these pallets beforehand. Table 4.5 reflects the sizes of the standard pallets available in the warehouse.

Type	Width (mm)	Lenght (mm)	Thickness (mm)
Pallet S_100	800	800	130
Pallet S_101	900	800	130
Pallet S_102	1000	800	130
Pallet S_103	1100	800	130
Pallet S_104	1200	800	130
Pallet S_105	1100	900	130
Pallet S_106	1200	900	130
Pallet S_107	1500	900	130
Pallet S_108	1000	1000	130
Pallet S_109	1100	1000	130
Pallet S_110	1200	1000	130
Pallet S_111	1400	1200	130
Pallet S_112	1100	1100	130
Pallet S_113	1200	1100	130
Pallet S_114	1600	1100	130
Pallet S_115	1200	1200	130
Pallet S_116	1300	1100	130
Pallet S_117	1300	800	130
Pallet S_118	1500	1200	130
Pallet S_119	1400	1200	130
Pallet S_120	1300	1000	130
Pallet S_121	1500	1000	130
Pallet S_122	1600	800	130
Pallet S_123	1600	1600	130

Table 4.5: Warehouse Standard Pallet Sizes

4.3.7 Size of the Cardboard Sheet

Customers can order any cardboard sheets size within a range which depends on the type of flute and corrugator machine. Figures 4.3 and 4.4 show these fixed maximum and minimum dimensions for each flute. For the manufacturing of cardboards there are two corrugator machines running which called corrugator 4 and corrugator 5. Corrugator 4 produces double face and double wall cardboard sheet and corrugator 5 creates single face cardboard sheet. Size of a pallet is chosen based on the cardboard dimensions. When a customer specifies a bespoke pallet and the board area is equal to 6512000 mm², two pallets are joined together. In the case of using standards pallets, two pallets are joined together when the board area is within the range of 2080000 mm² and 6512000 mm².

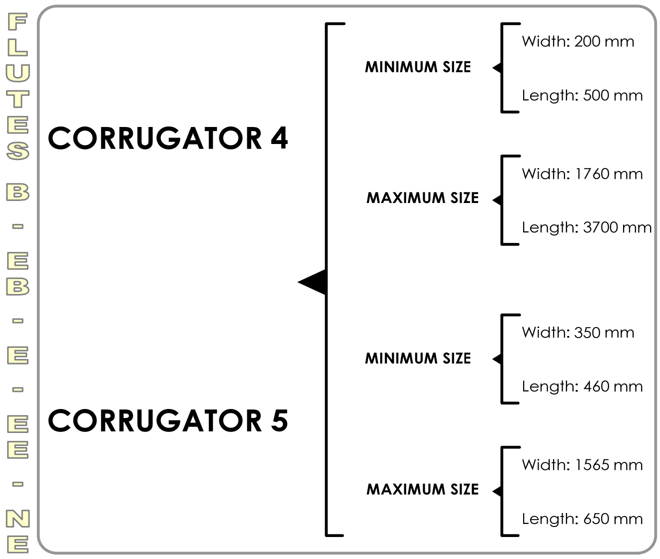

Figure 4.3: Minimum and Maximum Sizes for B, EB, E, EE and NE Flutes

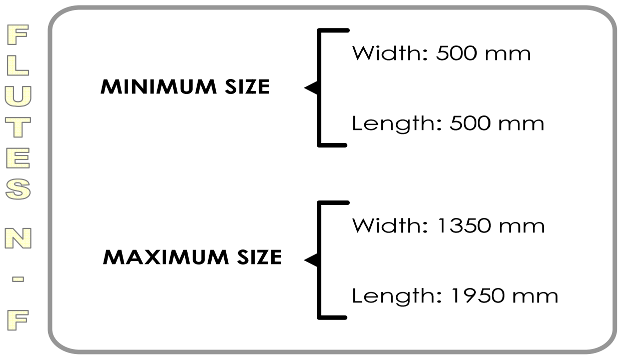

Figure 4.4: Minimum and Maximum Sizes for N and F Flutes

4.3.8 Over Hang Allowance

Some customers allow being the cardboard sheet longer than the pallet. This over hang allowance varies with the type of flute of the material. Table 4.6 explains the over hangs for each type of material

OVER HANG	**B**	100 mm
	E	50 mm
	EB	100 mm
	EE	100 mm
	F	0 mm
	N	0 mm
	NE	0 mm

Table 4.6: Over Hang for each Material

The variables that have just been mentioned are for all customers. But some customers have their own specifications for their orders. These constrains are the following:

- Number of stacks per pallet: some customers do not allow loading more than one stack of material per pallet.
- Number of sheets per stack: some customers have established a fixed number of sheets per stack. The reason is that they store the pallets with the materials into racks.
- Specific type of pallet: some clients specify the type of pallet to be used for their order delivery.
- No over hang allowed: some customers do not allow the cardboard to be bigger than the pallet. The cardboard should be fitted perfectly onto the pallet. On the other hand, no under hang is allowed as well. This means that the cardboard sheet can not be smaller than the pallet.

All these constraints have been taking into consideration for the analytical model development.

4.4 Analytical Approach

The following analytical model has been created by the researcher. This model is based on the knowledge captured from the shop-floor operators, operations directors and IT managers. Furthermore, the required data have been gathered by visits to the company, semi-structured interviews and internal documents of the company. Through data analysis, the model and the rules have been developed. With the development of the analytical approach and the decision support system, which will be explained in Chapter 5, for pallet utilisation, this process will be standardised as much as possible in the best way. The differences in pallet selection decisions from one shop-floor operator to another will be avoided. The cardboard material and pallet areas and cardboard height can be estimated from the following equations.

$$MaterialHeight = \frac{TruckHeight - SecurityGap - 2 \times PalletHeight}{2} \tag{4.1}$$

The height of the material has been calculated taking into consideration the space available in the truck for its storage. To optimise as maximum as possible this space, it should be loaded two pallets with the material in the vertical axe. Figure 4.5 represents the positions of the pallets inside a truck.

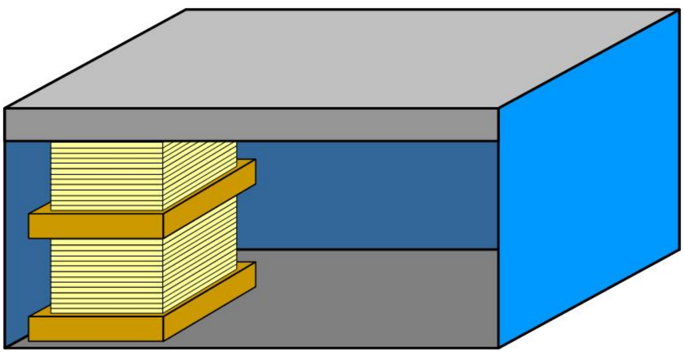

Figure 4.5: Positions of the Pallets into the Truck

The variables involved in the truck dimensions are described in Figure 4.6. The security gap is a fixed value which is 17cm.

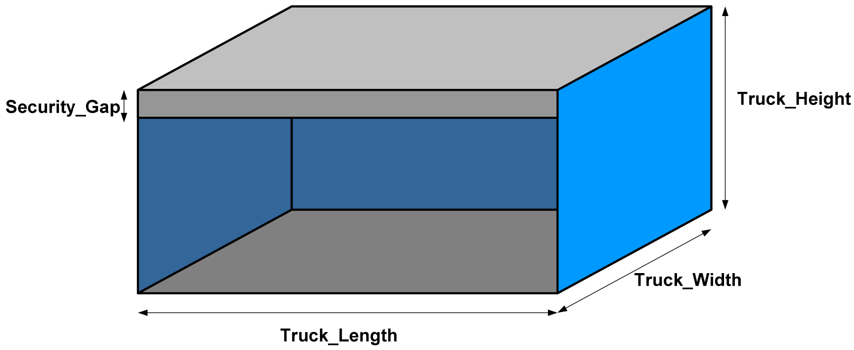

Figure 4.6: Truck Variables

The number of sheets that could be loaded per pallet taking into account only the restriction of the space available into the truck can be calculated by the equation 4.2. The first constrain is the maximum height of corrugated sheets on a pallet.

$$NumberSheetsPalletHeight = \text{int}\left[\frac{MaterialHeight}{FluteThickness}\right] \times NumberStacks \qquad (4.2)$$

The second restriction is the maximum weight that a pallet can stand which is 750 kg. Equation 4.3 shows how is calculated the maximum number of sheets that can be loaded per pallet taking into consideration the restriction of the weight.

$$NumberSheetsPalletWeight = \text{int}\left[\frac{750000(G)}{PaperWeight}\right] \qquad (4.3)$$

Both restrictions are compared to calculate the maximum number of sheets that can be loaded per stack. The lowest value between both restrictions will be taken to set the number of sheets per pallet. If the number of sheets is fixed by the variable “NumberSheetsPalletHeight”, the number of cardboard sheets per stack will be calculated by the equation (4.4).

$$NumberSheetsStack = \text{int}\left[\frac{NumberSheetsPalletHeight}{NumberStacks}\right] \qquad (4.4)$$

On the other hand, if the number of sheets is fixed by the variable "NumberSheetsPalletWeight", the number of cardboard sheets per stack will be calculated by the equation (4.5).

$$NumberSheetsStack = \operatorname{int}\left[\frac{NumberSheetsPalletWeight}{NumberStacks}\right] \tag{4.5}$$

As it has been mentioned, the weight of the material is a variable to be taken into account. Each order contains a stick that shows information about the customer's order. Figure 4.7 illustrates stick of an order.

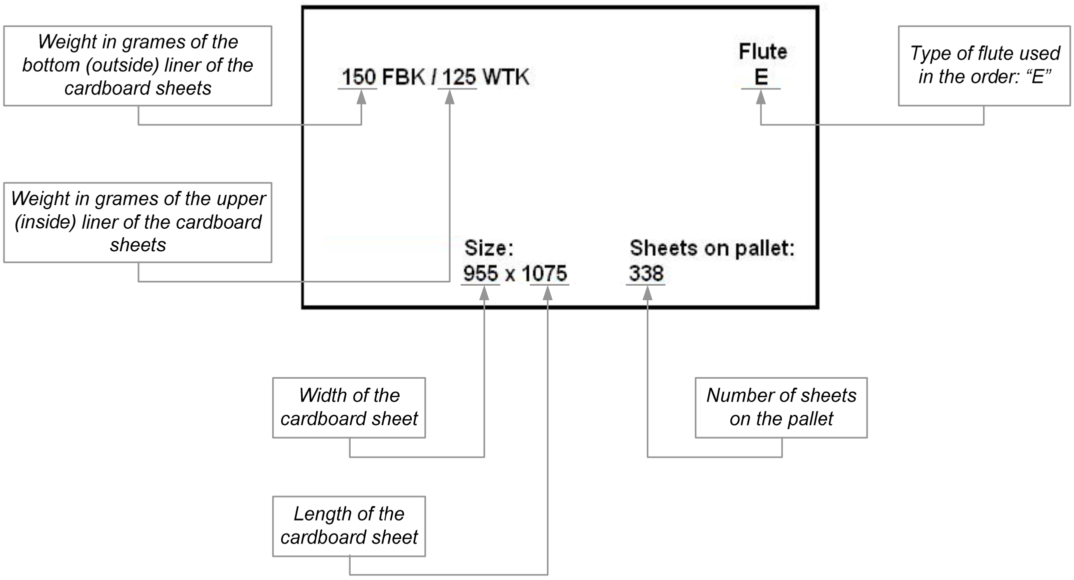

Figure 4.7: Stick of an Order

It is necessary to know the take up factor ("TUF") for each flute which represents the number of flutes per square meter. These factors depend on the type of flute.

F flute: take up factor = 1.2200 (GSM).

E flute: take up factor = 1.2521 (GSM).

B flute: take up factor = 1.3232 (GSM).

N flute: take up factor = 1.5100 (GSM).

EE flute: take up factor = 2.5042 (GSM).

EB flute: take up factor = 2.5753 (GSM).

NE flute: take up factor = 2.762 (GSM).

In order to calculate the weight of the cardboard sheet, the researcher had to take into consideration if the customer allows overhang and the configuration of the cardboard sheet such as single face, double face and double wall. Therefore the following equations have been developed taking into consideration both factors.

<u>If the overhang is allowed:</u>

$$FluteWeight = (TakeUpFactor \times 100) \times (2 \times Overhang + SheetWidth) \times \times (2 \times Overhang + Sheetlength) \tag{4.6}$$

<u>If it is a single face cardboard:</u>

$$PaperWeight = PaperWeight1 \times (2 \times Overhang + SheetWidth) \times \times (2 \times Overhang + Sheetlength) + FluteWeight \tag{4.7}$$

<u>If it is a double face cardboard:</u>

$$PaperWeight = (PaperWeight1 + PaperWeight2) \times (2 \times Overhang + SheetWidth) \times (2 \times Overhang + Sheetlength) + FluteWeight \tag{4.8}$$

<u>If it is a double wall cardboard:</u>

$$PaperWeight = (PaperWeight1 + PaperWeight2 + PaperWeight3) \times (2 \times Overhang + SheetWidth) \times (2 \times Overhang + Sheetlength) + FluteWeight \tag{4.9}$$

The variable “PaperWeight1” refers to the weight of the weight of the outside liner of the cardboard sheet. The variable “PaperWeight2” is the weight of the inside liner of the cardboard sheet. The weight of the middle liner has been represented by the variable “PaperWeight3”.

If the overhang is not allowed:

$$FluteWeight = TakeUpFactor \times 100 \times SheetWidth \times SheetLength \tag{4.10}$$

If it is a single face cardboard:

$$PaperWeight = PaperWeight1 \times SheetWidth + FluteWeight \tag{4.11}$$

If it is a double face cardboard:

$$PaperWeight = (PaperWeight1 + PaperWeight2) \times SheetWidth \times \\ \times SheetLength + FluteWeight \tag{4.12}$$

If it is a double wall cardboard:

$$PaperWeight = (PaperWeight1 + PaperWeight2 + PaperWeight3) \times \\ \times SheetWidth \times SheetLength + FluteWeight \tag{4.13}$$

The following equations have been developed to calculate the number of pallets that will be used to deliver the customer’s order.

If the overall number of sheet of customer’s order fits perfectly only in full pallets, the overall number of pallets that will be used to deliver the order is calculated by the equation (4.14).

$$OverallNumberPallets = \mathrm{int}\left[\frac{Quantity}{NumberSheetsStack \times NumberStacks}\right] \tag{4.14}$$

The variable “Quantity” is the overall number of cardboard sheets that the customer has ordered.

On the other hand, if the overall number of sheet of customer's order does not fit perfectly only in full pallets, the overall number of pallets that will be used to deliver the order is calculated by the equation (4.15).

$$OverallNumberPallets = \text{int}\left[\frac{Quantity}{NumberSheetsPallet}\right] + 1 \tag{4.15}$$

The analytical model has helped estimating the number of sheets per pallet taking into consideration factors such as: customer requirements, truck type, pallet type and material features. Regarding the value of these factors (the volume of the truck, the thickness and the size of the cardboard sheet and the pallet, etc.) the number cardboard sheets per pallet varies from one customer's order to another.

4.5 Summary

Firstly, in this chapter is studied how the company internal orders' management works. In the study of this management, the variables involved in the research project were recognised. The second stage was to develop the presented equations to incorporate them into the system development. The developed analytical model has been used with the aim of getting the numeric data of the number of cardboard sheets that should be loaded per pallet, the number of full pallets and the type of pallet that should be used. The third objective of this research project has been achieved in this chapter which is the development of the analytical approach for pallet utilisation. The developed model has been implemented into a prototype system in order to maximise the volume into the truck. The development process of such system is described in Chapter 5.

Chapter 5

5. DEVELOPMENT OF DECISION SUPPORT SYSTEM FOR PALLET UTILISATION MODEL

5.1 Introduction

Nowadays, many programs are developed for the simulation and control of the production in companies (Lechuga et al., 2001). This automation means an effective control and a time saving in the manufacturing of a product. However, little improvements are still possible.

The sponsor company has an automated system to manage the pallet for each order but it still has a shop-floor operator that has final last decision in the choice of a pallet. This research project aims to develop a pallet utilisation system to help the shop-floor operators in pallet selection decision. The decision of pallet's type that should be used depends on the size of the cardboard sheet of an order. The developed system also maximises the number of cardboard sheets that are currently load per stack of material. This will depend on the space available in the truck, the weight that a pallet can support and the type of material that will be loaded.

This chapter comprises six sections. The company questionnaire that was developed to know if the system was being developed correctly is described in Section 5.2. Furthermore, the questionnaire aims to explore if the system could be applied in more companies of the corrugated field. Section 5.3 presents the overall structure of the developed system. Section 5.4 explains the knowledge-based rules that have been followed for the development of the system. Section 5.5 highlights the system features. The system benefits are presented in Section 5.6. Finally, Section 5.7 summarises the entire chapter.

5.2 Companies Questionnaire

The researcher has collected the necessary information to understand how the different sheet feeder companies manage their orders. The main purpose is to understand better the sheet feeder industry, not only focussing on the sponsoring company. Furthermore, the researcher aims to find out if the development of this decision support system could be useful for the sheet feeder industry. For these reasons a questionnaire was sent to 40 Spanish and 14 English companies. The questionnaire is given in the appendix.

5.2.1 Questionnaire Design

In this research project, the researcher has adopted Chang et al. (2003) model to develop and analyse the questionnaire. They state that the research by a questionnaire should follow five phases that are the following ones:

- Phase 1: Specify the purpose.
- Phase 2: Development of the tool of questionnaire.
- Phase 3: Identify and select the sample.
- Phase 4: Analyse the information.
- Phase 5: Utilisation of the results.

5.2.2 Phase 1: Specify the Purpose

The purpose of this questionnaire is to identify the generality of this project. For this reason the questionnaire was designed in order to identify how the sheet feeder companies manage the orders in terms of: how they select the pallet, which kind of restrictions could affect in the pallet loading, and how they load the pallets. Mainly, this questionnaire is useful to compare the different sheet feeder companies in these areas.

5.2.3 Phase 2: Development of the Questionnaire

The design of the questionnaire can be split into three elements that are shown as follows:

- Determine the questions to be asked: in this research project the questions are related with the sizes of boards, pallets and trucks that they have in the company and how these companies manage the orders onto pallets.
- Select the question type for each question and specify the wording: the researcher has used two types of questions which are closed and open ended questions. Closed questions are favoured for two reasons:

  - Less time is required from the respondent to answer the questions.
  - Responses for closed questions are easier to analyse.

  The open ended questions are used because:

  - The respondent could feel himself more useful for our research.
  - His answer to the open question can be richer than the closed question.
  - His answer could give the researcher a better idea about the business.

- Design the question sequence and overall questionnaire layout: the questionnaire follows this order. It begins by asking how customers order the boards. Then, it continues with questions related to how the companies supply the orders. The next step is find out how the companies manage the boards onto the pallets. It finishes with questions about how the companies select the pallet that should be used and when they make this decision.

Once the questionnaire was made, this was given to some people piloting the questionnaire to identify the mistakes or misunderstandings in it. Afterwards, the researcher sent the final questionnaire to the different companies.

5.2.4 Phase 3: Identify and Select a Sample

The questionnaire sent to different types of companies: 40 Spanish companies and 14 English companies. Apart from being sheet feeder companies, some of them were converter companies. This questionnaire was sent by email and 10 of these companies replied to the questionnaire. This is traduced in a 22.72% response rate.

5.2.5 Phase 4: Analyse the Information

The information has been analysed by taking questionnaire by questionnaire, highlighting the differences and similarities between companies. These comparisons have helped to identify the generality of the project.

From the first results obtained from the questionnaires, the following general conclusions can be obtained:

- All the companies use a tolerance with their customers. Some of them only use one type of tolerance and other ones, for example 3 types. The variety of tolerances is not related to how big the company is.
- All companies manufacture any size of board having as a restriction a minimum size of the board and some of them also a maximum size for the board.
- Some of these companies allow an under hang.
- Most of them do not have weight restrictions because they make conventional corrugated cardboard sheet. And the ones that handle delicate cardboard (for example: single face cardboard), they deliver it in rolls.
- Most of them join two pallets together for big sizes of cardboard.
- Most of the companies do not have a system that gives them the number of sheets that should be loaded per pallet and the type of pallet that should be taken.

5.2.6 Phase 5: Utilisation of the Results

These results were used by the researcher in order to help her to find differences and similarities between different companies.

For the first results obtained it can be said that the development of this program could be useful within the corrugated industry due to many of them have a shop-floor operator that decides the kind of pallet that fits better with each order. So the development of this kind of systems will give them a time saving for the preparation of the orders.

It can be highlighted as well that from the first results in the development of this decision support system, it will be taken into consideration many variables that most of the rest of the companies do not consider, such as weight restrictions. Many of these companies handle conventional cardboard. Therefore this kind is not as delicate as the microflute cardboard. So in this program a new variable will be taken into account because the sponsor company manufactures very thin cardboard.

The proposed decision support system could help the sponsoring company and other companies in the corrugated industry sector, to improve their current way of managing the orders.

5.3 Overall Structure of the Developed System

The developed system has the aim of improving the current way of managing customers' orders onto pallets. The system has been developed in Visual Basic programming language and its main features will be explained in the following sections. The overall structure of the prototype system is shown in Figure 5.1.

The first step in the system is that the data related to the customer's order are inserted in the user interface of the developed system. The system consists of three databases. These databases have data of the different pallet and truck sizes and material features that are in the company. All these data interact with the user interface.

Inside the system it has been developed some logic rules and equations that with the data inserted and the databases give a decision to the shop-floor operator. This decision provides information about: how many sheets per pallet should be loaded, how many full pallet are used, if there is any part pallet and which pallet size should be used for the product delivery.

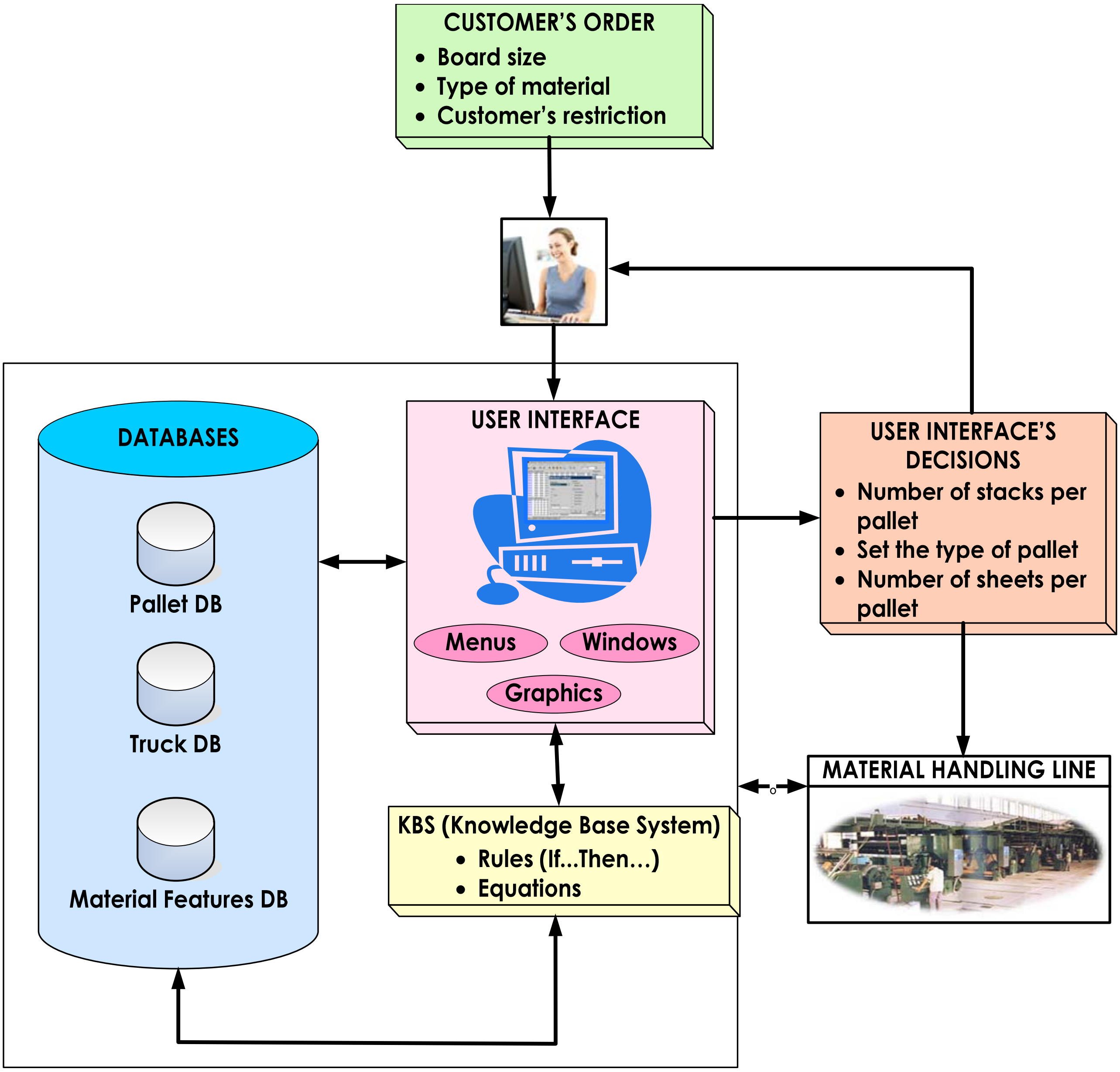

Figure 5.1: Overall Structure of the System

5.4 System Scenario

The system scenario is presented in figure from Figure 5.2 to Figure 5.6. The customer order is received by the sales office department. In this stage, the features of the order are introduced into the system: board size, flute, configuration of the board, customer requirements, type of papers used for the manufacturing of the cardboard sheet and type of truck used for the order delivery. The system using these inputs and the databases to make a decision about which pallet should be used and how customer's order should be managed onto the pallet. These databases contain the features of the pallets, the trucks and the material. The data contained in these databases have been explained in Chapter 4. This decision will be communicated to the shop-floor operator. Figure 5.2 illustrates the overall scenario of the developed system.

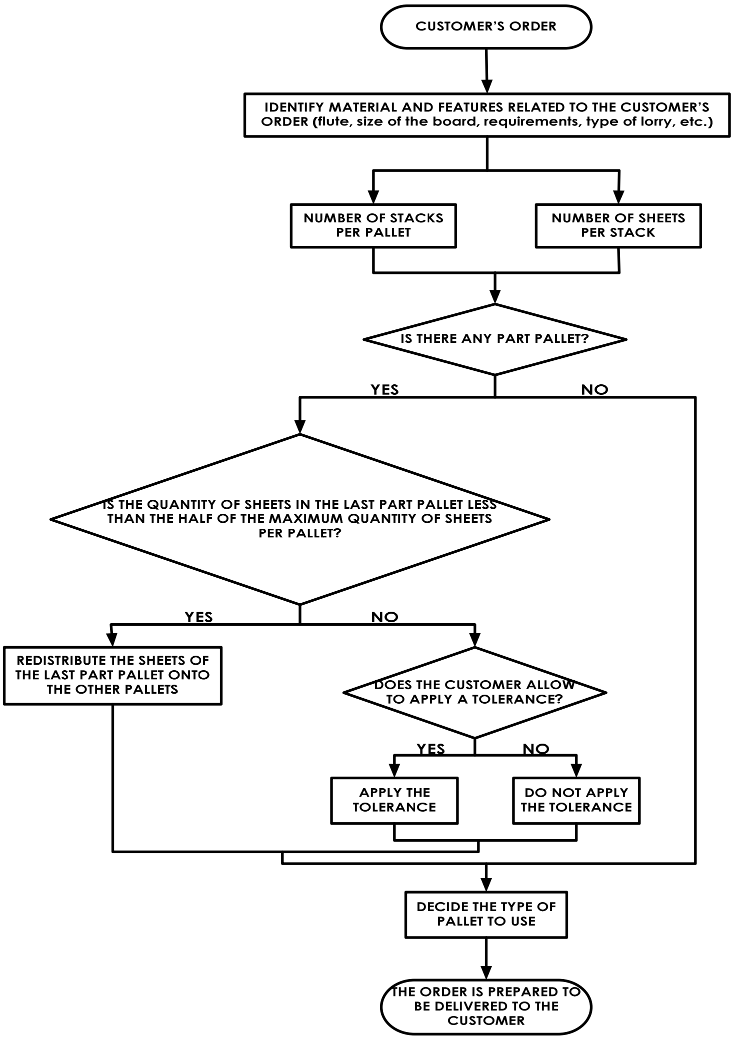

Figure 5.2: Overall System Scenario

Once the customer's order comes the system identifies: the material, type of truck used for the product delivery, etc. With all these data the system sets the number of stacks per pallet and the number of sheets per stack. The next step is checking if there is any part pallet. If that is the case, the system checks how many cardboard sheets are in the last part pallet. If the sheets in the last part pallet are less than the half of the maximum number of sheets that can be loaded per pallet, these sheets in the last part pallet are redistributed onto the other pallets. Therefore, this last part pallet is omitted.

On the other hand, the part pallet is employed if the number of cardboard sheets is more than the half of the maximum number of sheets that can be loaded per pallet. However, if the customer allows applying a tolerance the last part pallet should be utilised as a full pallet. Otherwise, the tolerance is not applied and the last part pallet keeps in the same way as it was. Then, the decision of which type of pallet should be used is completed. The next phase is to load the pallets into the truck.

The system scenario to estimate the weight of the cardboard is presented in Figure 5.3. The following are some examples of the rules that have been implemented in the developed system.

RULE CARDBOARD SHEET AREA:

IF

(Overhang allowed)

THEN

(The area of the cardboard is calculated adding the overhang that can be applied regarding the flute of the cardboard sheet)

ELSE IF

(Overhang is not allowed)

THEN

(The area of the cardboard sheet is calculated without applying the overhang)

RULE CARDBOARD SHEET WEIGHT:

IF

(Cardboard sheet configuration is single face)

THEN

(To calculate the weight of the cardboard sheet, it is taken into account the weight of the flute and paper 1)

ELSE IF

(Cardboard sheet configuration is double face)

THEN

(To calculate the weight of the cardboard sheet, it is taken into account the weight of the flute, paper 1 and paper 2)

ELSE IF

(Cardboard sheet configuration is double wall)

THEN

(To calculate the weight of the cardboard sheet, it is taken into account the weight of the flute, paper 1, paper 2 and paper 3)

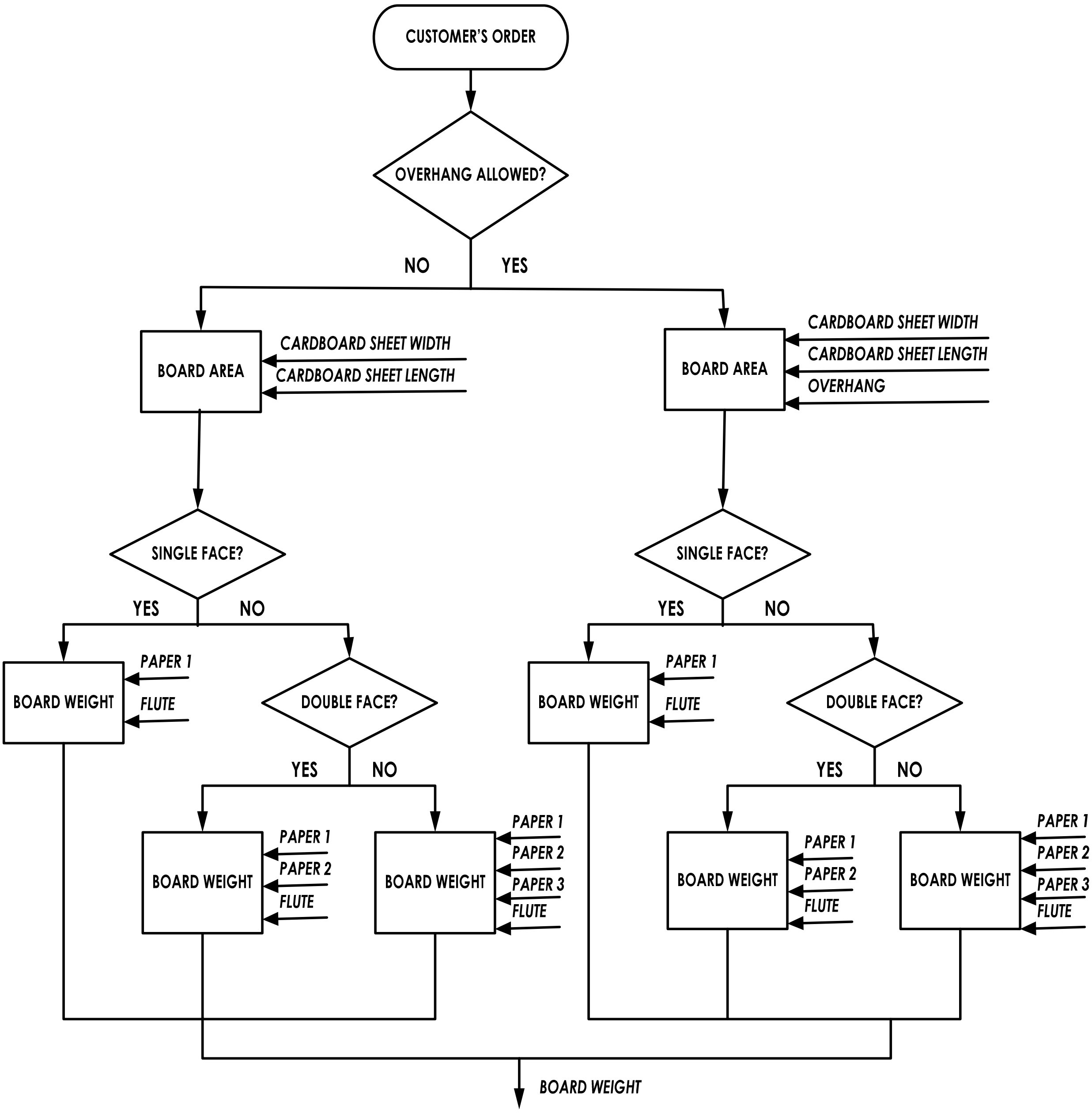

Figure 5.3: Cardboard Sheet Weight Estimation

The number of sheets per stack is estimated based on the flowchart presented in Figure 5.4. Examples of the rules which have been used in the system are given below.

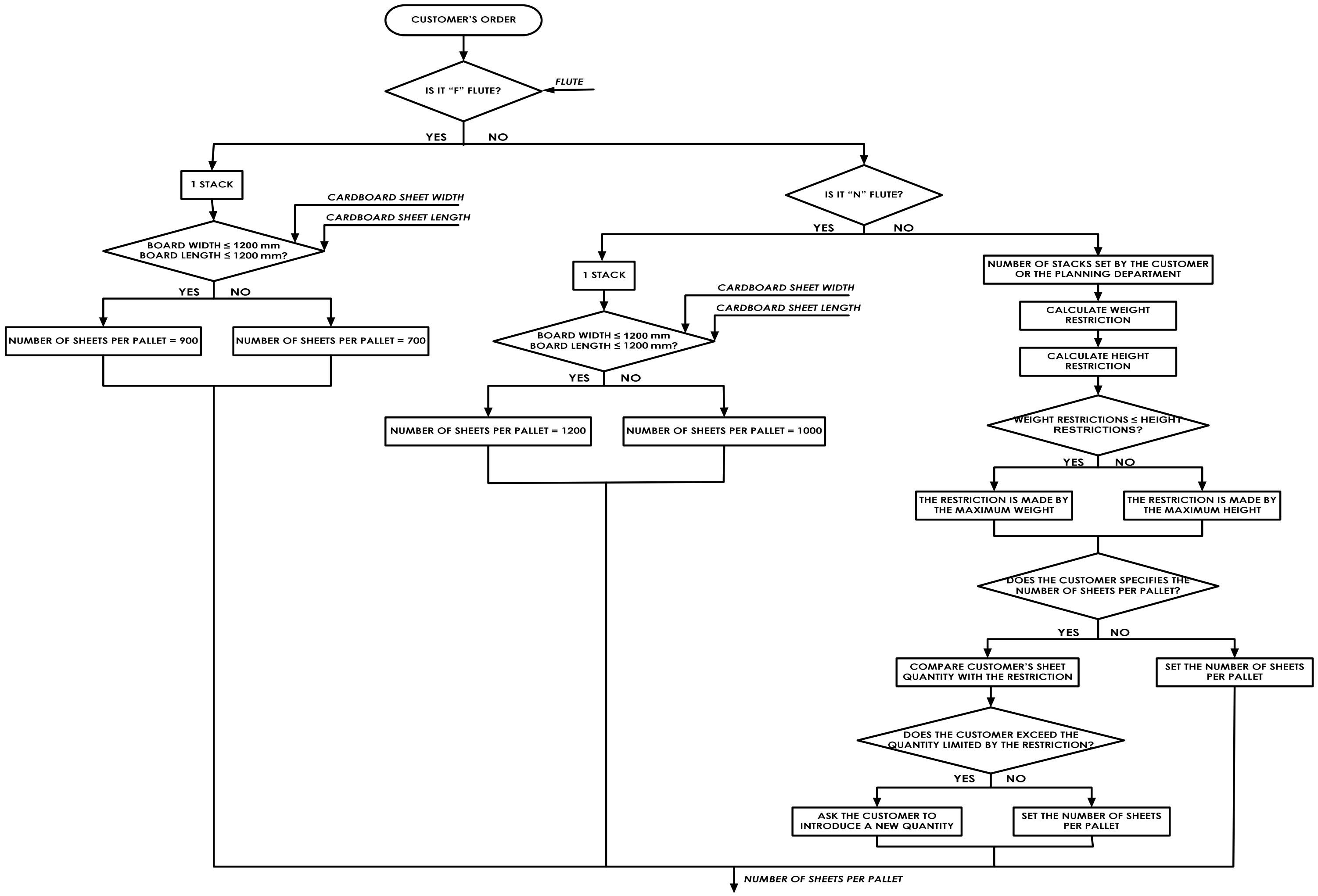

Figure 5.4: Estimation of the Number of Sheets per Pallet

RULE NUMBER OF SHEETS PER PALLET_1:

IF

(The cardboard sheet has “F” flute)

THEN

(The number of stacks per pallet is 1)

RULE NUMBER OF SHEETS PER PALLET_2:

IF

(The cardboard width and length are less than 1200 mm)

THEN

(Number of cardboard sheets per pallet is 900)

ELSE IF

(The cardboard width and length are more than 1200 mm)

THEN

(Number of cardboard sheets per pallet is 700)

ELSE IF

(The cardboard sheet has “N” flute)

THEN

(The number of stacks per pallet is 1)

RULE NUMBER OF SHEETS PER PALLET_3:

IF

(The cardboard width and length are less than 1200 mm)

THEN

(Number of cardboard sheets per pallet is 1200)

ELSE IF

(The cardboard width and length are more than 1200 mm)

THEN

(Number of cardboard sheets per pallet is 1000)

ELSE IF

(The cardboard sheet has “B”, “E”, “EB”, “EE” or “NE” flute)

THEN

(The number of stacks per pallet is decided by the customer or by the planning department) *AND*

(It is calculated the weight restriction) *AND*

(It is calculated the height restriction) *AND*

(Both restrictions are compared and the smaller one is the restriction that is taken)

RULE NUMBER OF SHEETS PER PALLET_4:

IF

(The customer specifies the number of sheets that should be loaded per pallet)

THEN

This quantity is compared with the restriction fixed. If the customer quantity is bigger, it is asked to introduce again a new quantity. If it is not bigger, the customer quantity specification is taken to load onto the pallet)

ELSE IF

(The customer does not specify the number of sheets that should be loaded per pallet)

THEN

(The system decides the quantity loaded per pallet taking into account the restriction fixed)

The system takes into consideration if there is any part pallet. The system scenario of the last part pallet management is represented in Figure 5.5.

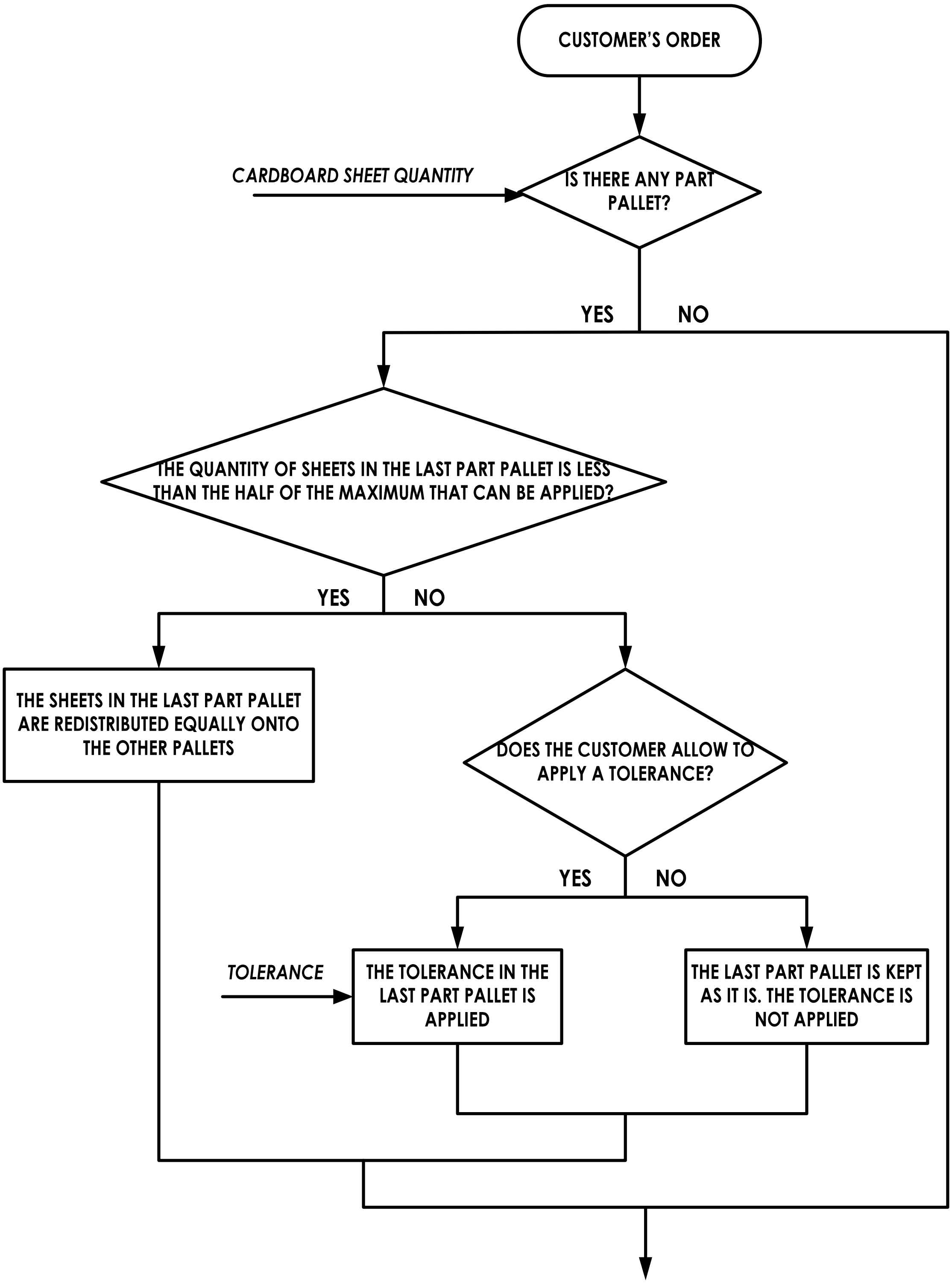

Figure 5.5: System Scenario of the Last Part Pallet Management

RULE PART PALLET_1:

IF

(There is a part pallet)

THEN

(It is checked how many sheets are in the last part pallet)

RULE PART PALLET_2:

IF

(The number of sheets in the last part pallet is less than the half of the maximum number of sheets that can be loaded per pallet)

THEN

(The sheets of the last part pallet are distributed equally onto the other pallets)

ELSE IF

(The number of sheets in the last part pallet is more than the half of the maximum number of sheets that can be loaded per pallet)

RULE PART PALLET_3:

IF

(The customer allows applying a tolerance)

THEN

(The tolerance is applied to the overall quantity of sheets of the order)

ELSE IF

(The customer does not allow applying a tolerance)

THEN

(The last part pallet is kept as it is. The tolerance is not applied)

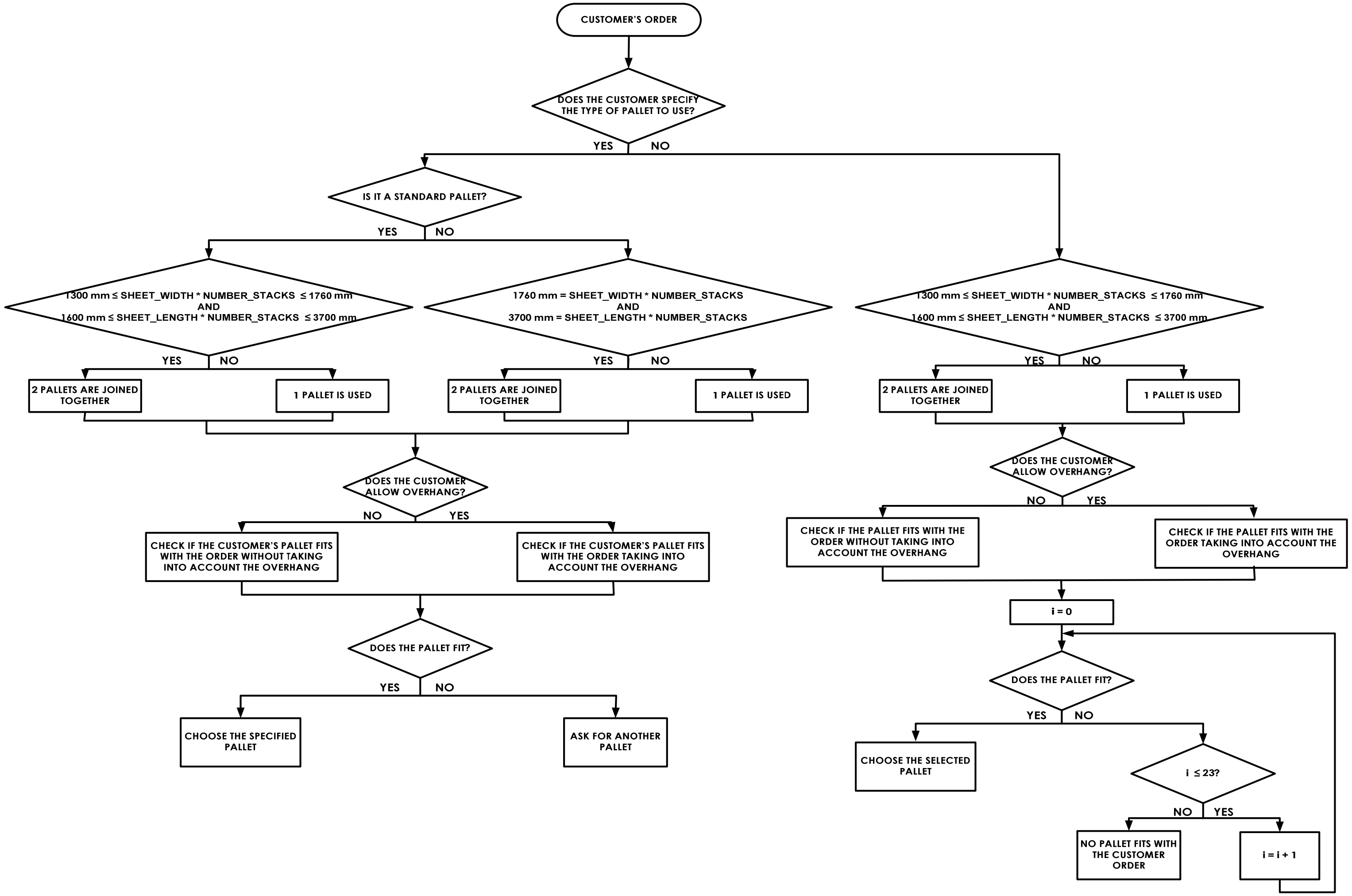

Figure 5.6: Logic of the Pallet Selection

Figure 5.6 shows the logic that the system follows for pallet selection. Examples of rules employed are as follows.

RULE PALLET SELECTION_1:

IF

(The customer specifies the type of pallet that should be used)

THEN

(It is checked if the pallet is a bespoke or a standard pallet. And taking into account this, the system joins two or one pallet for the product loading)

ELSE IF

(The customer does not specify the type of pallet that should be used)

THEN

(The system only takes standard pallet because they fit better into the dimensions of the truck. And taking into account this, the system joins two or one pallet for the product loading)

RULE PALLET SELECTION_2:

IF

(The customer allows overhang)

THEN

(The overhang is taken into consideration for the pallet selection)

ELSE IF

(The customer does not allow overhang)

THEN

(The overhang is not taken into consideration for the pallet selection)

RULE PALLET SELECTION_3:

IF

(The sizes of the cardboard sheet and the pallet fit correctly)

THEN

(The pallet is selected)

ELSE IF

(The sizes of the cardboard sheet and the pallet do not fit correctly)

THEN

(The system asks for another pallet if the customer has required a specific pallet. And if the system has the option of select the pallet, it continues comparing standard pallets until there are no more. The company has 24 standard pallets. So, after 24 comparisons the system stops and reports that no standard pallet fits with the customer order)

RULE PALLET SELECTION_4:

IF

(The number of sheets in the last part pallet is less than the half of the maximum number of sheets that can be loaded per pallet)

THEN

(The sheets of the last part pallet are distributed equally onto the other pallets)

ELSE IF

(The number of sheets in the last part pallet > than the half of the maximum number of sheets that can be loaded per pallet)

RULE PALLET SELECTION_5:

IF

(The customer allows applying a tolerance)

THEN

(The tolerance is applied to the overall quantity of sheets of the order)

ELSE IF

(The customer does not allow applying a tolerance)

THEN

(The last part pallet is kept as it is. The tolerance is not applied)

5.5 The System Features

The “*Pallet Loading Driver*” has been developed by means of the VBA programming language. This language which embedded in Microsoft Excel was seen as an ideal medium for achieving the goals of this research. In this section, the main features of the system have been described and some screenshots will be presented to clarify the concepts. Figure 5.7 illustrates the screenshot where the user of the system should interact to input a customer’s order.

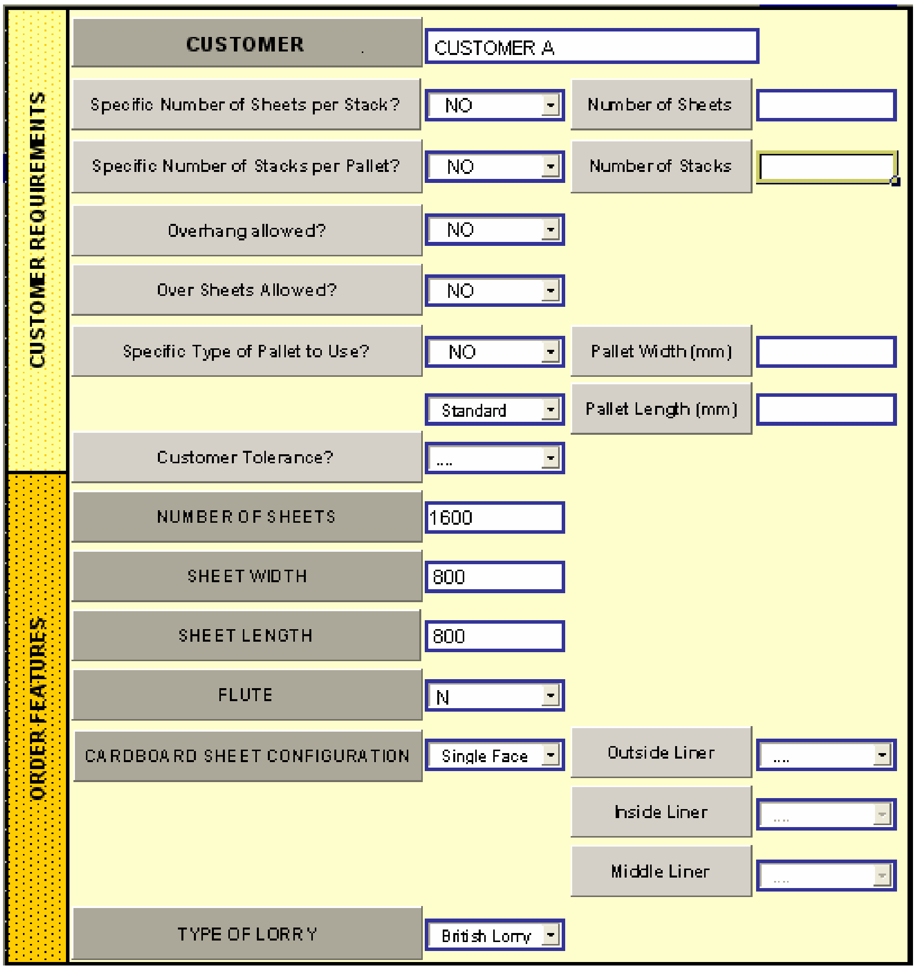

Figure 5.7: System Inputs Window

Firstly, the various data of the customer requirements are input to the system. The system prompts the user if the customer has specified the number of sheets per stack. If this the case, the user has to input the specified number of sheets which should be loaded per stack. Therefore the shop-floor operator has to follow the customer requirements.

The user has to specify if the number of stacks per pallet was a customer requirement. Otherwise, the planning department decides the number of stacks per pallet. The number of stacks per pallet is detailed. More customers' restrictions are required in the system. The overhang is a factor to consider because it affects to the system when it has to choose the size of the pallet for the customer order. If the customer allows overhang the system takes a pallet some centimetres smaller than the size of the cardboard. The value of these centimetres varies regarding the type of flute that the cardboard sheet is made of.

Another customer restriction is the possibility of applying over sheets to the number of cardboard sheets that are loaded onto the pallet. Some customers want a specific amount of sheets in their orders. If the customer allows over sheets a tolerance can be applied. This tolerance varies regarding the customer and the overall quantity of cardboard sheets per order. As it has been explained before, this tolerance adds an extra percentage of number of cardboard sheets to the overall quantity of the order. In another field of the system, this tolerance it is asked. So, that the system knows the tolerance that should be applied.

The last field to fill in the customer requirements section is if the customer requires a specific pallet to use. If that is the case, it is asked which are the dimensions of the pallet that he wants and if it is a standard or bespoke pallet. In this situation, the system checks if the pallet that the customer has specified fits properly with the order. If not, the system shows a message to the user advising him to ask the customer to require another type of pallet. The reason why it is important to ask if the pallet is standard or bespoke is because there is a difference of thickness between them. This difference of thickness it is traduced in the number of cardboard sheets that can be loaded per pallet. The thickest the pallet is the less number of cardboard sheets can be loaded. On the other hand, if the system has the freedom of selecting the type of pallet that can be used only standard pallets will be taken into consideration. The reason for this is because only standard pallets are known beforehand. Bespoke pallets are only considered when the customer requires them. Bespoke pallets are purchased when the customer asks for them. The second reason is that standard pallets are the ones that best fit into the truck because their dimensions are proportional to the dimensions of the truck.

Secondly, the features related to the order itself are required. In this section the first thing that the system requires is the overall quantity of cardboard sheets of the order.

Next, the dimensions of the cardboard sheets are introduced: the width and the length. If the customer does not specify the type of pallet to use the system compares the width and length of the cardboard sheet with the width and the length of the twenty four pallets available in the warehouse. And if the customer requires a specific pallet, the system compares these dimensions with the dimension of the cardboard sheet.

The flute is also specified because the type of flute affects to the thickness of the cardboard. Consequently, to the number of sheets that can be loaded per pallet if the system has the option of making this decision.

The cardboard configuration and the type of paper used for the manufacturing of these cardboard sheets are asked by the system. These factors affect directly to the weight and the height of the cardboard. For example, if the cardboard sheet required by the customer is single face, this kind of cardboard sheet will lighter and thinner than a double wall cardboard sheet. The reason for this, it is because this kind of cardboard sheet is made of less number of papers. It influences the type of paper used for the manufacturing of the cardboard as well because not all the papers weight the same.

Finally, the type of truck used for the product delivery is another factor included in the system. Regarding the truck, more or less space will be available for the product delivery. There four types of trucks in the company and they have different sizes.

After completing all the required fields, the system automatically creates the decision for pallet utilisation. Figure 5.8 shows an example of the outputs generated by the developed prototype system. The system provides the pallet width and the pallet length if the customer does not require a specific type of pallet. It matches the 24 standard pallets in a company to find out which pallet fit properly with the customer's order. The reason is that these standard pallets dimensions can fit with the dimensions of a truck.

The information if one or two pallets are joined for the product delivery is given, regarding the dimensions of the cardboard sheets and the type of pallet used (standard or bespoke). In some cases, if the size of the cardboard is too big two pallets are joined for the product delivery.
In the system is detailed as an output the number of full pallets that are used. It is called full pallet to a pallet filled to the 100% of its maximum capacity. It also specifies if there is any part pallet. It is called part pallet to a pallet filled less than the 90% of its maximum capacity.

As it has been mentioned before, if the number of cardboard sheets in the last part pallet is less than the half of the maximum capacity that can be loaded, a redistribution action is done. This means that the system redistributes these sheets onto the other full pallets. So, this last part pallet is removed. If in the last part pallet there are more sheets that the half of the maximum number of sheets that can be loaded per pallet, this last part pallet is kept. And the customer's tolerance is applied if it is possible. After applying the tolerance, the system details the quantity of cardboard sheets that are in the last part pallet.

If the system does not make the redistribution there will be only full pallets and it could be part pallets too. The number of cardboard sheets per stack and the number of sheets per pallet in the full pallets are specified.

Figure 5.8.shows the system output window. It can be appreciated that there are two outputs named "Number of Sheets per Stack 1" and "Number of Sheets per Pallet 1". They represent the number of cardboard sheets per stack and the number of sheets per

pallet. The overall number of stacks of the full pallets is defined by the button "Number of Stacks Type 1".

If the redistribution action is not carried out the system reports the user if there is any part pallet and the number of sheets in the last part pallet. If the system makes the redistribution action there will be two kinds of full pallets. The reason why there will be two kinds of full pallets is because the system proceeds to redistribute equally onto the other pallets those cardboard sheets of the last part pallet removed. So, it will add one cardboard sheet more per stack in the full pallets until there are no more cardboard sheets to distribute. So, some full pallets will have one sheet more per stack comparing to the rest of full pallets.

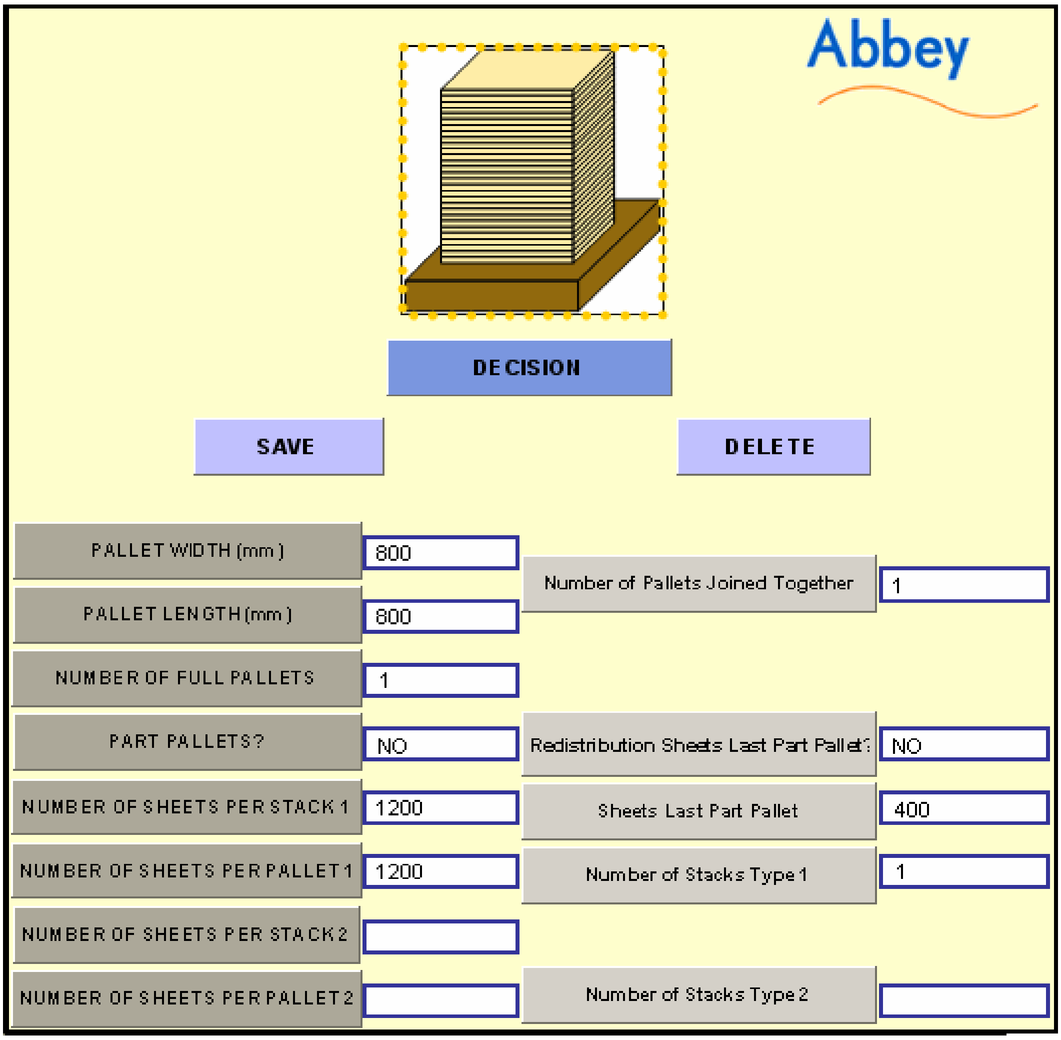

Figure 5.8: The System Outputs Window

5.6 System Benefits

Currently, the company does not maximise as much as possible customers' orders onto the pallet, as it has been mentioned in chapter 4. The company distributes the orders equally onto the pallets, so the stacks height is not maximised. This is traduced in a waste of cost and time in the preparation of the customer order and in a waste in the utilisation of the space of the truck. The purpose of this system is to improve the customers' orders management. This maximisation could be achieved by taking into consideration customers' requirements, product features and pallet and truck sizes. The developed system has taken into consideration all these variables and it has incorporated them to make the most suitable decision.

From the first results obtained the "*Pallet Loading Driver*" has given an improvement of 5% as a result of the changing maximum stack heights to the recommended levels by the system. This provides a reduction of time preparing customers' orders and cost savings. An example of the overall cost for the preparation of a customer order per pallet is shown in Table 5.1. The results show that there is a cost saving from the previous way of managing customer's order to the new system.

	OLD CUSTOMERS' ORDERS MANAGEMENT	DECISION SUPPORT SYSTEM FOR PALLET UTILISATION
MATERIAL	E	E
STACKS PER PALLET	1	1
CONFIGURATION	Double face	Double face
TRUCK	Scottish	Scottish
OVERALL NUMBER OF CARDBOARD SHEETS	2410	2410
NUMBER OF CARDBOARD SHEETS PER PALLET	750	803
OVERALL NUMBER OF PALLETS USED	4	3
PALLET COST	£7,2 x 4 = £28,8	£7,2 x 3 =£21,6
SHROUDING AND STRAPPING COST	£1,2 x 4 =£4,8	£1,2 x 3 =£3,6
TRANSPORT COST	£25 x 4 =£100	£25 x 3 =£75
OVERALL COST	£133,6	£100,2

Table 5.1: Example of the Management of a Customer Order with the Old System and with the Developed Decision Support System

5.7 Summary

The variables involved in the logic of this decision support system have been explained. The development of this system will change the current way of working of the company.

Currently, the sponsor company does not maximise the height of the pallet, what it does is to take the order and distribute the number of sheets evenly among the pallets. This gives an average volume used in the truck of 84.73%, so this quantity can be improved by a little increase in the height of the pallet. The number of sheets per pallet is not the only thing that will be changed from the current system, also the number of stacks. The number of stacks per pallet that the sponsor company uses is one, so changing the number of stacks will give the company more flexibility to manage the orders.

This chapter has achieved the third research objective: development of the prototype system. The developed prototype system has improved the current way of managing customers' orders. The system presented provides information about the number of sheets that should be loaded per pallet, the number of full pallets that are used for the order delivery, if there is any part pallet and the pallet size that should be used. This system has given to the sponsoring company an improvement of 5% in the way of orders' management.

CHAPTER 6

6. VALIDATION OF FRAMEWORK AND THE DEVELOPED SYSTEM

6.1 Introduction

The aim of this chapter is to both validate and demonstrate the capability of the developed system through two case studies. This capability includes estimation of the number of sheets per pallet and per stack, and the type of pallet that should be used, taking into consideration customers' restrictions, material features and different pallet and truck sizes. The first case study was based on the sponsoring company. The researcher has explained step by step the system scenario to managers and directors of the sponsoring company. This was achieved through focus group discussion.

The other case study was carried out with a planning engineer of another corrugated industry in Spain. In this way, the researcher appreciated that although there were differences in the way this Spanish company manages the customer's order, the system could help them to improve their current way of managing the orders.

The remainder of this chapter is structured as follows. Section 6.2 presents the validation of the system in the first sheet feeder industry. In Section 6.3 details the validation in the second case study company. The chapter is summarised in Section 6.4

6.2 Case Study 1: Company A

The first validation case study was carried out in the sponsoring company. Fifteen meetings were carried out where the managing director, operations director and IT director were present. The durations of these meetings were around two and three hours. A digital voice recorder was used for the gathering of the data and opinions.

The recordings were listened again and the notes were completed. Then, information and knowledge collected from these meetings was discussed privately with the planning engineer. In this way, the researcher made sure that she gathered and understood the correct knowledge.

During these meetings, the experts shared their opinion and knowledge to make the proper corrections to the researcher about the logic of the system. The operations directors and IT managers took part actively in this exchange of information about the aspects that they thought that could affect to the customers' orders management. For example, in one of these meetings one of the operations director commented: "Last week, we practise the new quantities calculated taking into consideration only the height restriction and it was observed that some materials crashed. I think that we should fix a weight restriction to 750kg". In this session another expert pointed out: "For N and F flute there is no flexibility in terms of the number of stack and cardboard sheets per pallet. There are some fixed values that they can not be modified. N and F flutes are very delicate materials and they can crash easily. So the shop floor operators fixed these values doing some proofs. For these flutes only one stack per pallet is loaded. And the quantities that we manage are: for N flute if the cardboard sheet dimension is less than 1200mm x 1200mm, the number of sheets that we load per pallet is 900. If the dimension is bigger we load 700 sheets. For F flute these quantities are different. For dimension smaller than 1200mm x 1200mm, 1200 sheets are loaded per pallet. For sheets with dimensions bigger than 1200mm x 1200mm, 1000 sheets are stacked". All these comments were collected and analysed by the researcher.

Once, the researcher wrote down all the data and understood the changes that she had to make in the logic that she was following. She implemented these comments again all the steps that the system must follow.

6.3 Case Study 2: Company B

Company B is a sheet feeder company leader in Spain, member of an international association of several sheet feeder industries. This association based in New York, USA. It is the first company in the world that manufactures products made of paper. The company has and cultivates more than 30,000 of forest.

It has around 70,000 employees all over the world with sales turnover 20,000 millions US dollars. It works in 27 different countries. In the last years, the average investment has been around 1,200 million US dollars and the manufacturing capacity of packaging has been more than 2,900,000 tonnes per year.

The case study company has been manufacturing corrugated cardboard packaging for more than thirty years in Spain. In the last years, the average investment of the company was around 6.5 million Euros. It has four mills allocated in Spain: Bilbao, Barcelona, Valladolid and Las Palmas de Gran Canaria. The facilities in Bilbao and Barcelona are the more recent corrugated companies in Spain.

The company is specialized in packaging of industrial products: electrical appliance, automotive industry products, detergent, chemical products and food industry. This company works with B, C, E and K flutes.

6.3.1 Company B Orders Management

The researcher had the opportunity of visiting the factory. The researcher was shown the shop-floor with the corrugator machine and the palletizers. At the same time, she was shown the warehouse where the orders and the pallets were stored. A planning manager explained to the researcher step by step how the company manages customers' orders and how they manufacture them. In all the meeting the researcher took notes about the orders' manufacturing and management.

The logic followed in the sponsoring company was shown to company B. With this aim, a meeting of 3 hours with a planning engineer was made.

The researcher found some differences comparing to the sponsoring company. Once, a customer order enters into the planning department the planner does not have any standard rule to manage customer's order. He/she made the decisions by his own experience. The planner estimates the number of cardboard sheets that should be manufactured using his knowledge. He/she always adds some extra sheets to the customers' order because as the corrugator machines are old, the last sheets (and sometimes the first ones as well), that it manufactures, always are defective. This quantity of faulty cardboard sheets can vary. For company B it is impossible to deliver the exact amount of cardboard sheets to a customer.

Another difference was that the company does not have a fixed overhang regarding the flute that can be applied to a cardboard sheet. Therefore, the planning engineer decides the size of the pallet adding the overhang. As well as the case study A, company B do not allow underhang. The company does not have any system that decides the type of pallet that should be used.

Unlike the sponsoring company, company B does not have bespoke pallets. The company does not provide the option to the customer to use his own pallet. The company only has standard pallets that are well known by the planning engineer, so that he can make a decision about which pallet should be used.

As it can be appreciated the number of sheets that should be loaded per pallet and the decision of the type of pallet that should be used is a quite manual work in company B. But on the contrary, the palletizing system is high automated. Once, the customer order is manufactured a sticker placed onto the order. This sticker, which has been printed by the planning department, has a code bar is read by infra-red and it is recognised the type of pallet that should be used for the order. An automated platform moves to the order point and it transports the order to a place where the pallet required for that order. In the sponsoring company this automated movement is made by a shop-floor operator.

After finding these differences, the researcher discussed with the engineer the system scenario for the customers' orders management. The engineer, from company B, using his own knowledge made some corrections to the logic development of the system. One of the corrections was that the researcher was comparing the cardboard sheet area with the area of the different pallets to choose the most suitable pallet for the customer order. The planner suggested that the best option was to compare the width and the length of the cardboard sheet and the pallet instead of the area. All his comments were collected and analysed to improve the decision support system.

These two case studies have been a good method for exploring the sheet feeder business field. This has provided the researcher of deep insight of the customers' orders manufacturing and managing in the sheet feeder industry. On the other hand, the weakness of this kind of research is that it is focussed on a small number of cases complicating the generalisation of the results.

6.4 Summary

This chapter has presented the process of industrial validation of the developed decision support system for pallet utilisation in the corrugated industry. Two case studies have been taken into consideration during the validation process. The chapter has also provided some comments that the experts did during the validation process.

Hence, the chapter has achieved the objective number 5: validate the developed model and prototype system through real-life case studies and expert opinions. Currently, the company is managing customers' orders with the new height quantities and this has been achieved by taking into account experts' opinions in the development of the system.

CHAPTER 7

7. DISCUSSION AND CONCLUSION

7.1. Introduction

The literature review presented in Chapter 2 helped the researcher to identify research gaps that were addressed for the development of the decision support system for pallet utilisation in the sheet feeder industry. Moreover, to validate of the developed framework, two case studies were performed with experts in industry. These observations have been discussed in Chapter 6. In this Chapter the aim and objectives are discussed. The main conclusions and contribution to knowledge are presented.

7.2. Discussion

It has been reported that the aim of this research study was to develop a decision support system to improve pallet utilisation in the sheet feeder industry. In order to achieve the above-stated aim, the researcher had carried out a number of objectives as follows. (i)Establish the state of the art in areas related to the project; (ii) Identify the key variables (pallet sizes, truck sizes, material features and customers' requirements for building the pallet utilisation model; (iii) Develop an analytical approach and the prototype system to improve the utilisation of the pallets and the truck volume; (iv) Validate the developed model and prototype system through real–life case studies and expert opinion.

7.2.1 Achievements of the Set Research Objectives

The first objective is to establish the state of the art in areas related to the project. To achieve these objectives many journal and conference papers, theses, books and websites were analysed and discussed. All these documents helped the researcher to identify the research gap. It was observed in this stage that many improvements have been done in the supply chain area. Nowadays, more and more activities are automated in many companies; this is called FMS (Flexible Manufacturing System). This system consists of joining different machines together in the production line and each machine is responsible of making a task. Once the product has been manufactured the companies have other concerns that are: how the product has to be loaded onto the pallet, how the product should be stored in the warehouse or how the product should be delivered.

This research project is focussed on the area of how the product should be loaded onto the pallet and utilisation of transport vehicles. Many companies have established how the set of material should be loaded in terms of the size of the pallet. These companies have a specific fix number of product sizes per pallet. In the corrugated industry sector deciding on the best way of delivering a product is a difficult task due to many factors are involved and the interactions between these factors. These factors include product sizes, material and types and pallet dimensions. For example, the type of material that should be delivered influences the pallet. The way the pallet is loaded into a truck affects to the volume utilisation of the truck. If a little improvement is made in the delivery of the product, a reduction of cost and time for the preparation of the order will be achieved. In this project another handicap should be added, there is a lot of variety in terms of pallet sizes, order (cardboard sheet) sizes and sizes of the trucks. All these diversity makes very difficult to make the best decision about the way the order of the customer should be delivered.

The literature review combined with many visits to the sponsoring company provided the necessary information and knowledge to identify the key variables that the researcher had to take into consideration and how these variables should be linked together. In this stage, the weight of the cardboard sheet was highlighted as an important factor to take into account. The reason was that the material that has been studied in this research was very fragile kind of cardboard. The research study has worked with a cardboard made of microflute.

A gap analysis from the current practise demonstrated in Chapter 4 shows a need for a better technique for addressing the problem of not managing customers´ orders maximising the utilisation of the pallet. The sponsoring company did not load the pallets to their maximum capacity. Consequently, of this there was a waste of space utilisation of the trucks used for the product delivery. In this stage the second objective was achieved that was the identification of the key variables for the development of the system.

The third objective entailed the development of the analytical approach of the decision support system for pallet utilisation in the sheet feeder industry. In this stage "if" and "then" rules were defined in order to link the key variables to get the desired results. As a complement of these rules many questionnaires have been sent to companies that work in the same business area as the sponsor company in order to know how they manage their customers' orders and observe if the system could be useful in companies working in the same business field as the sponsoring company. In these questionnaires, it has been observed that all of them have a shop – floor operator that decides which pallet fits better for each order. This involves decisions by different operators. By the development of this decision support system this decision will be standardized as much as possible, as well as the decision time will be reduced.

Finally, the validation was carried out. In these meetings engineers from the planning department to IT managers discussed the developed system. All their comments were taken by a digital recorder and by notes.

7.2.2 Analytical Approach Development

For the development of the analytical model many data have been captured. For this reason, many visits to the shop-floor have been done in order to gather data about pallet and truck sizes and to have informal interviews with the shop-floor operators. These interviews helped the researcher about how use the data collected in order to develop the model.

Firstly, an analytical model were presented taking into consideration the equations related to the height available into the truck to load the material to estimate the number of sheets per pallet. These cardboard sheets calculated per pallet were used in the shop-floor as a trial and it was observed that in some material these quantities were excessive due to these materials were crashed because of the weight of the stack.

So, weight factor was considered in the analytical model. Consequently, new data were collected. These data included the different kind of papers used for the cardboard manufacturing and their weight regarding the size of the cardboard sheet.

This analytical model combined with the rules developed for making the decision of the best way of managing customers' orders provide as a result the decision support system presented.

7.2.3 Developing a Decision Support System for Pallet Utilisation in the Sheet Feeder Industry

The decision support system for pallet utilisation has the capability to improve the current system of managing customers' orders onto the pallets. The sponsoring company distributes customer's orders equally onto the pallet. Pallets are not loaded to their maximum capacity. This will depend on the space available in the truck, the weight that a pallet can support the type of material that will be loaded and the customer requirements. Some customers are very restricted in terms of the number of cardboard sheets that can be loaded per pallet because they store those pallets into racks.

Another issue that has been addressed in this research project is that the company was normally loading one stack per pallet. However, more than one stack is loaded per pallet the company will employ less number of pallets. Therefore, cost reduction in terms of pallet and truck usage will be achieved.

The developed system assists in selecting the type of pallet that should be employed taking into consideration the size of the cardboard sheet of the order and the customer requirements. Some customers specify the type of pallet that should be used or they provide their own pallets.

7.3. Contribution to Knowledge

The main contribution has been the development of an innovative analytical approach and prototype system to reduce the number of part pallets and select the most suitable pallet for the product delivery. The new approach and system will standardise more the way the customer orders are in the sheet feeder industry. Moreover, a comprehensive survey has shown that the development of this program could be useful within the corrugated industry. Many of them have a shop-floor operator that decides which pallet fist better in terms of the size of the cardboard. The operators use their own knowledge to make these selections. Therefore, decisions will be different from one shop-floor to other operator. The development of such system will provide them a time saving for preparation of the orders and a standardisation in customers' orders management.

7.4. Conclusions

In conclusion, it may be stated that the research study presented has achieved the aim and its objectives of developing a decision support system for pallet utilisation in the sheet feeder industry. Moreover, this thesis has tackled the following main points:

- There is no standard way to choose the most suitable pallet for each order. The studied companies have a shop - floor that makes this decision.
- The weight is a new factor to consider into the business of the sheet feeder industry. The conventional cardboard is a lightweight and strong material but with the new trends of material (microflute) appearing in the sheet feeder industry, the weight plays an important role.
- The developed system has the capability to improve the current practise giving the following benefits: a maximisation of pallet and truck utilisation and reduction in the overall number of pallets used and a time saving. The system provides an improvement of 5% in the way of managing customers' orders.

7.5. Limitations of the Research

Ideally, the findings of this research should have been focussed not only on one case study. Therefore, it is complicated to provide general conclusions. Mainly, this research has been based on the knowledge that has been captured within the sheet feeder industry. Not so much literature review addresses the problems related with customers' orders in the sheet feeder industry. From the responses obtained from the questionnaires and the two cases studies it has been observed that each company has its way of managing customers' orders. So the generalisation is complicated.

All the data and the issues of the company were obtained from informal interviews and meetings. These informal data collection methods generated disagreements in some information collected. Not all the people in the company were fully aware in the way the customers' orders were managed. Consequently, these disagreements generated initial incorrect analytical models. Nevertheless, this research study has developed a system that has improved the way the customers' orders are managed.

7.6. Future Work

The project presented could be approached as a system that enhances the production line and the planning department. After the realisation of this project the researcher considers that there are new paths to follow in the following directions.

A depth study can be carried out in order to automate as much as possible the pallet assignment to each customer order. Instead of a shop-floor operator making this task a robot can do it by the reading of a code bar of the pallet. This code bar will provide information about the type of pallet should be selected. A mobile platform will move the chosen pallet from one part of the warehouse to the point where the order is. The pallets are stored by groups (each group will have pallets with the same dimensions) and a robot will put the selected pallet onto the mobile platform.

A research study is needed during this project a system to choose the most appropriate pallet in terms of the board dimensions have been disclosed. In this selection the weight has been an important factor in the system. The weight restriction considered has been the same for all the materials and for all the pallets. The next step will consist on studying deeper this weight restriction. This weight should be studied more carefully regarding the type of flute and the type of pallet. The maximum weight will be different taking both factors into consideration.

A new system is needed to report how the pallets should be placed into the truck. The way the pallets are loaded into the truck plays an important role for the maximisation of the truck volume.

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Appendices A

COMPANIES QUESTIONNAIRE

1.1. Introduction

The aim of this questionnaire is to research if the decision support system for pallet utilisation, that it will be developed, could be applied in the rest of the sheet feeder industries. In chapter 2 the original questionnaire is shown.

1.2. E-mail Message to Companies

Dear Sir /Madam,

I am conducting a study on behalf of a company that produces sheets of corrugated board in a wide range of paper grades and flutes. The aim of the study is to maximise the pallet utilisation, and thereby maximise the use of the transport vehicles. We are interested in some aspects of other companies working in the same field in order to make an overall evaluation about logistic issues. After the completion of our study a report with the obtained results will be sent to your company.

We would be grateful if you could spare a few minutes to answer the questions in the attached questionnaire.

Many thanks for your assistance in this matter.

Sincerely,

Olatz Celaya

1.3.Questionnaire

Write "X" in the most suitable answer. You can make any comments if you think that it is necessary.	YES	NO
1. As a general rule, when customer makes an order, do they specify the exact number of boards?		
Comments:		
2. Does your company supply exact amounts of boards to your customers?		
Comments:		
3. Does your company supply within +/- tolerance? If so could you specify the tolerance?		
Comments:		
4. As a general rule, if there are part pallets in the order, does your company add to the whole number of board of the order a ±X% of tolerance? ▪ *We called part pallet to a pallet that is filled less than its 90% of capacity.* ▪ *± X % of percentage means that the company could add or rest that percentage to the last part pallet to get as close as possible to a full pallet (this percentage has been previously agreed with the customer).*		
Comments:		
5. Does your company make any size of board, having as a restriction only that the size of board should be between a minimum and a maximum measure?		
Comments:		
6. Does your company only supply board in set sizes as opposed to bespoke sizes, e.g.: 1000mm x 1200mm, 1100mm x 1250mm, etc.?		
Comments:		

7. Select the way you use, as a general rule, to distribute the order onto the pallet: **- Do you load the pallet to its maximum capacity?**		
- Or do you distribute equally the order onto the pallet? ▪ *For example, if a customer makes an order of 1300 sheets of board and the maximum capacity of the pallet is 400 of sheets, instead of loading 3 pallets with 400 sheets and one pallet with 100 of sheets, the company delivers to the customer 4 pallets with 325 sheets each one (1300/4).*		
Comments:		
8. As a general rule, do you have a fixed minimum quantity to load onto the pallet? ▪ *In other words, if the last pallet there is a quantity less or equal than the minimum quantity specified per pallet, the company distributes those sheets from the last pallet on the other pallets, in a way that you remove that last part pallet.*		
Comments:		
9. If in the last part pallet you have less number of sheets than the minimum quantity established to load a pallet, do you remove those lasts sheets? If not, what do you do with them?		
Comments:		
10. When you select the type of pallet for each order, do you allow the board sheet to stick out "X" cm (previously specified) from the pallet, if the customer allows this? What are your palletisation rules on overhang?		
Comments:		
11. In your company, do you allow the board sheet size be smaller than the size of the pallet? What are your palletisation rules on under hang?		
Comments:		
12. As a general rule, in some customer orders do you allow loading more than one stack per pallet? ▪ *For example, if you have a board sheet size smaller than the size of the pallet, you load 2, 3 …stacks if you have the chance to do it.*		

Comments:		
13. Do you have weight restrictions when you load the pallet? Could you tell which the maximum weight that you consider to load onto a pallet?		
Comments:		
14. Do you have a maximum standard quantity that varies regarding the size and the type of cardboard that you load onto the pallet?		
Comments:		
15. Does this maximum quantity vary as well regarding the size of the truck where that order will be loaded onto?		
Comments:		
16. In orders that the board sheet size is too big, do you join two pallets in order to deliver those sheets to the customer?		
Comments:		
17. In your company, do you have a shop floor operator that decides the type of pallet that should be used for each order? Which point in the process does the operator decide?		
Comments:		
18. Or does a system automatically select the type if pallet that should be used?		
Comments:		

THANK YOU FOR YOUR TIME!!!!