RESUM

El present projecte s'ha realitzat a les instal·lacions d'una empresa real que es dedica a la fabricació d’apòsits adhesius amb l'objectiu de millorar els seu procés productiu. Aquesta millora es vol aconseguir mitjançant l’automatització de l'operació de paletitzat en algunes màquines i l'optimització del flux de material dintre la fàbrica.

Inicialment es descriuen els productes i el procés, parant especial atenció a l’operació de paletitzat. Seguidament, s’explica el flux de material dintre la fàbrica, que s’analitza amb l’eina de gestió visual Value Stream Mapping. Per suplir les mancances d’aquesta eina es crea un programa informàtic que permet quantificar l'eficiència del flux de material. A continuació s’inicia un procés de generació, descart i selecció d’alternatives on diferents escenaris s’avaluen en funció d’uns criteris prèviament definits. Per últim s’estudia la viabilitat de l’alternativa seleccionada i se n’extreuen conclusions.

La solució proposada assoleix els objectius proposats, donant resposta al problema de l’automatització del paletitzat i millorant alhora el flux de material. A més, el projecte realitzat es veu com el fruit d’un estudi global que ha tingut en compte tota la fàbrica. En un altre nivell, l’aprenentatge adquirit i la satisfacció de l’empresa i l’autor reforçen l’èxit d’aquest treball.
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1. PREFACE

1.1. Origin of the project

This final thesis begins with the desire to improve of a mass-market company which wants to remain anonymous. This firm is constantly revising its processes, and for some time, was considering eliminating the manual palletizing operation at the end of some of its production lines.

As a result of that, the author of this final thesis received the opportunity to work as a trainee engineer in the facilities that the company has in Spain. During this time, the thesis was carried out with the guidance of two experienced engineers and the collaboration of the other departments, which was required to provide a solution to this real industrial problem.

1.2. Motivation

In order to success and cope with the intense competition that mass-market firms suffer, they have to be highly efficient. For this reason, the company is constantly examining its processes in order to eliminate non-value added activities such as the manual palletizing operation.

1.3. Confidentiality

Due to confidentially reasons, the name of the company will not appear in this thesis and some processes will not be described with precise details. Also related to this issue, the plans presented in Annex N do not have a high degree of detail; and therefore, machines appear as squares or grouped into blocks.

The unique goal of this is to avoid providing information to competitors that might be used against the interests of the corporation. Apart from that, it is important to say that the figures, processes described and reasoning behind decisions are real.
2. INTRODUCTION

2.1. Project objectives

The initial objective of the thesis, stated by the company, was to provide a solution for the automation of the palletizing process. In spite of that, in the early stages of the project it was detected the possibility of combining the automation with improvements in the material flow in order to obtain a solution that considers the whole process.

As a result of that, the main objectives of this final thesis are:
- Provide an accurate photo of the material flow in the plant.
- Provide a solution to the automation of the palletizing process combining this issue with an improvement in the material flow.

2.2. Scope of the project

This final thesis is not a project of detail focused on the characteristics and design of the machines and devices used in the automation process. It is oriented towards the feasibility and convenience of the automation, its effect on the material flow and potential improvements in the layout as a result of the automation.

The study of the material flow is limited inside the plant, not taking into consideration the links between the production plant and the suppliers and customers. Also regarding the material flow, its improvements will not consider changing the production process, materials or machines.
3. GENERAL DESCRIPTION

3.1. The company

This final thesis was carried out in a multinational mass-market corporation leader in the wound care sector. This company has worldwide presence and employs thousands of employees in its administrative buildings, production centres and warehouses. To give an idea of the importance of the corporation, the order of magnitude of its annual sales is in the thousands of millions of Euros.

The company has a production centre located in Spain which manufactures adhesive bandages. This is the factory which has been analysed and studied and the place where this final thesis has been carried out.

3.2. Products

As it has been said previously, the factory manufactures adhesive bandages. An adhesive bandage or sticking plaster is a small medical dressing, used to cover injuries that are not severe enough to require a full-size bandage. The functions of a sticking plaster are:

- Protect the cut from infection and mechanical damage.
- Keep the wound isolated from foreign objects.
- Soak up blood containing it in one place.
- Help to seal the wound to expedite the clotting process.
- Some adhesive bandages have especial substances that provide antiseptic properties or promote the healing of the wound.

Sticking plasters are divided into two main groups called strips and dressing lengths.
3.2.1. Strips

In general, strips consist in a support, which has an adhesive spread on its surface, and an absorbent pad placed on the middle of the support. When the bandage is applied, the pad covers the wound, and the support sticks to the surrounding skin to hold the strip in place and prevent dirt from entering the wound.

![Figure 3.1: Strip, front and back view.](image)

To avoid the adhesive from sticking everywhere before using the strip, there is a silicone paper, also called protector, which covers the support. This protector should be removed before applying the strip on the wound.

![Figure 3.2: Strip, detail of the silicone paper or protector.](image)

3.2.2. Dressing lengths

Dressing lengths have the same components than strips; they also have a support with an adhesive, an absorbent pad and a silicone paper. But, while each strip is an individual element that is applied on a wound, dressings are larger and the user has to cut the necessary part to cover the injury.
3.2.3. Articles

Product differentiation is essential for the company, and for this reason bandages are produced using different supports, pads and glues. Supports can be made from different kinds of fabric or plastic, determining the proprieties of the bandage such as the thickness, the degree of protection, the permeability or the elasticity. Some supports are also presented with different designs to make them more attractive.

Pads don’t have a selection as wider as supports; but apart from the basic one, there are some others with special properties. In addition, bandages are produced in different sizes and shapes.

The bandages are grouped and placed into boxes; in some products all the bandages inside the box are equal; but there are other products called assortments, which consist in a combination of bandages with different shapes and sizes.
The same product is sold in different countries, but the box has written information about the corporation and the bandage. For this reason, countries are grouped and there is one box for each group with the information written in the suitable languages.

As a result of all this possibilities, between strips and dressing lengths, the company produces more than 300 different references that are sold all over the world. This number only considers the finished goods, but becomes much higher if we take into account raw materials and semi-finished products. This gives an idea of the number of different materials that are moved inside the factory and the complexity of the process.

3.3. Description of the production process

The production process has four steps either for the strips or for the dressing lengths. Steps number one, two and four are the same in both cases, but the third step is different. The Figure 3.6 resumes the production process in one page. Apart from this graphic representation, the process is explained with detail in the following paragraphs.

3.3.1. Strips production process

Step 1: Coating

Before starting to produce, raw materials from suppliers must be stored in the warehouse. Two of these raw materials are the support, which arrive at the factory in coils, and the glue, which is received in containers. Note that the support served from the supplier is just a coil of fabric or plastic without adhesive. Consequently, the aim of the first step of the production process, which is called coating, is to obtain a coil of support with a layer of glue on it.

In order to prevent this layer of glue from sticking everywhere, it is covered with a silicone paper. The result of this first process is a semi-finished product called coated coil.

Step 2: Slitting

The second step is an operation called slitting. Here coils are cut into rolls with a certain width depending of the size of the future strip. Three types of coils are slit in this operation, pad coils, silicone paper coils and coated coils. Notice that the first two are raw materials, while the third one is a semi-finished product. The output of this operation is in each case: pad rewind, silicone paper rewind and coated rewind.
Step 3: Strip Formation

The third step is called strip formation and differs from the dressing length process. The aim of this stage is to obtain a roll of strips. The inputs in this process are the followings:

- Coated rewinds.
- Pad rewinds.
- Silicone paper rewinds.
- Cold seal films.

First of all the silicone paper that covers the coated rewind is removed so the adhesive is exposed. Then, a rotary die cut the coated rewinds without silicone paper into portions the size of the strip. Another rotary die cut de pad rewinds into little pieces that are placed on the middle of the coated portions; because the adhesive from the coated portion is uncovered the piece of pad sticks on the surface. Then, the silicone paper rewind is used to cover the coated potion and the piece of pad. This silicone paper has two parts and is folded so the final user can easily remove it before applying the strip on the wound. The last part of this third step is to introduce these strips between two cold seal films providing them protection, consistency and forming a roll of strips.

Figure 3.5: Detail of a strip with its cold seal. Roll of strips.

Step 4: Packaging

Finally, the roll of strips arrives at the last step which is the packaging operation. Here, the roll is cut and a certain number of strips with the cold seal films are introduced inside the primary box. There is more than one roll of strips that are feeding the boxes; so the process can be realized quicker and it enables to introduce strips of different sizes and shapes inside one primary box. Once the box has all its content, it is closed and sealed. After that, a group of primary boxes are grouped and packaged together using the secondary box. The secondary box consists in two parts, the tray and the lid. At the end, secondary boxes full of strips are stacked on pallets and the pallet wrapped using a plastic film, after that it is ready to be shipped.
3.3.2. Dressing length production process

The first two steps are the same than in the strips process; coating and slitting. In many cases, the same material can be used to produce a strip and a dressing length, so coated rewinds, pad rewinds and silicone paper rewinds are produced indistinctly without considering which of the two processes is going to consume them.

The third step however is different and it is called covering. Here the aim is to obtain a long and continuous rewind of dressing length. The inputs in this process are the followings:

- Coated rewinds.
- Pad rewinds.
- Silicone paper rewinds.

As it happens in the strip process, firstly the silicone paper that covers the coated rewind is removed so the adhesive is exposed. Then, the pad from the pad rewind is stuck on the middle of the coated band. Finally, the silicone paper rewind is used to cover the coated band with the pad. As in the other process, this silicone paper has two parts and is folded making it easy to remove before applying the dressing length on the wound.

The last step is the packaging operation and it is equivalent to the strip process. The continuous rewind of dressing length arrives at the packaging machines. There, it is cut into pieces, and a certain number of pieces of dressing length are introduced inside primary box. After that, boxes are closed, sealed and grouped. Then, these groups are packaged together using the lid and the tray of the secondary box. The last step is to put the secondary boxes on pallets and wrap them, after that the dressing lengths are prepared to be shipped.
Figure 3.6: Resume of the production process
3.4. Packaging/palletizing process

3.4.1. Current process

As it has been stated in the objectives, the packaging/palletizing process of the finished goods is one of the main points of this final thesis. Almost all the materials are placed on pallets once they are produced, but the palletizing process of finished goods is more costly than the others. Placing one coated coil on a pallet once it has been manufactured, or 30 rolls of rewind on a pallet once they have been slit is easier than putting 400 secondary boxes of finished goods. Apart from the number of boxes, they are produced at a really high cadence and have to be placed in a certain pattern, in order to obtain a consistent pallet.

Machines related to the packaging process will be introduced here; even though, all the machines are explained in section 4.2. Currently, there are 14 machines that produce finished goods, but five of them are much more important than the others due to the fact that they manufacture the greatest part of the production. These five machines are called PS1, PS2, PS3, PD1 and PD2 (Table 4.1: Table of machines.) and have some common points; all of them need more than one person to work and they produce secondary boxes, with very similar dimensions, at a high cadence.

In these five machines, when secondary boxes are produced, they arrive automatically at a platform. This platform is considered the final part of the machine, and next to it there is a pallet. One worker has to pick these secondary boxes from the platform and place them on the pallet. It is important to remember that these machines produce secondary boxes at a really high cadence (up to 18 per minute) and that they have to be placed on the pallet in a certain pattern. Apart from that, if too many boxes are on the platform waiting to be placed on the pallet, the machine stops working. For these reasons, in these five machines there is one person which its main task is to do the palletizing operation manually.

Figure 3.7: Manual palletizing process
By automating the palletizing process, the company would eliminate this non value-added operation and these machines would be able to work with one fewer person; so cost would be reduced.

### 3.4.2. Automation

The most common solutions to automate the palletizing process in the industry are systems formed by conveyor belts and robots. In these systems, the machines are connected to conveyor belts that carry the boxes to a robot which does the palletizing operation automatically. The most common robots have the capacity to palletize up to four different pallets with boxes from four different machines simultaneously.

![Figure 3.8: Palletizing system from Modu System [5].](image-url)

The following image shows an example of a palletizing system. In that case, the system receives boxes from two different machines and carries them to one central conveyor belt. This central conveyor belt transports all the boxes to a point near the robot where the boxes are sorted into different roller tables according to the machine where they were produced. Then, the robot picks the boxes from these tables and places them on the corresponding pallet.
The previous image shows that apart from the conveyors and the robot, the palletizing system has two other elements:

- Distribution mechanism: this part changes the boxes from one conveyor to another one. It is used to control the access of the boxes to the central conveyor.

- Sorting mechanism: its mission is to sort the boxes that arrive at the robot to its corresponding roller table.
Figure 3.11: Sorting Mechanism from Cisco-Eagle [6].

But installing the palletizing system has other advantages. In the current process, once the boxes have been palletized manually, the pallet is transported to one wrapping machine that wraps the pallet with a plastic film. Then, the transport staff have to go to a computer, print a label which identifies the pallet and indicates the shelf where it has to be stored, and stick it on the it. These operations can also be done in the palletizing system once the robot has finished one pallet. The robot also has the capacity to take empty pallets from a pallet buffer next to it, and place them on the floor each time that one pallet is finished and a new one has to be used.

Figure 3.12: Wrapping machine which can be placed at the end of a palletizing system (from BEMA [7]) and robot taking one pallet (from Cermex [8]).
One important parameter is the cadence at which boxes arrive at the palletizing system. In our case, the maximum cadences at which these five machines produce secondary boxes are:

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>CADENCE [secondary boxes/minute]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS1</td>
<td>18</td>
</tr>
<tr>
<td>PS2</td>
<td>12</td>
</tr>
<tr>
<td>PS3</td>
<td>7</td>
</tr>
<tr>
<td>PD1</td>
<td>15</td>
</tr>
<tr>
<td>PD2</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 3.1: Machines cadences of secondary boxes.

If a hypothetic palletizing system was connected to machines PS1, PS2, PS3 and PD1, it would receive 52 boxes/minute. That means that the robot has to place 52 boxes on the pallets each minute, or what is the same; almost one box every second. If the robot was taking one box in each cycle, it would not have enough time. In the reality, boxes are conveniently arranged in each roller table, so the robot takes a group of them in each cycle using its suction cups.

Figure 3.13: Robot carrying more than one box from Millsom materials handling [9].

Another important issue is the location of the robot. It is advisable to implement compact palletizing systems because the conveyor belts are expensive. So only considering the palletizing process, the robots should be located near the machines, in order to reduce the longitude of the conveyor belts and as a result the cost. But remember that apart from the automation of the palletizing process, this thesis also considers the material flow. For this reason, we will consider the possibility to place the robots further if the material flow improves due this decision.

Even though the conveyor belts of the palletizing system are crossing the factory, they have to allow the normal movement of people and materials without representing an obstacle. To
solve that, conveyor belts are installed at a certain height fixed to a wall or the roof. So in this case, the first part of the conveyor belt is a ramp up which takes the boxes from the machine to a high level. Then, they are transported at this high position allowing the movement of people and transport below it. And finally there is a ramp down which takes the boxes from the high position to the sorting mechanism and the robot.

### 3.5. Material grouping

As it has been said previously the company works with a great number of raw materials, semi-finished products and finished goods; during the period of study there have been recorded movements of more than 2,000 different materials. These materials have been grouped in one classification (material grouping 1) that has been used in the Value Stream Mapping analysis; this tool will be explained in section 0. In order to reduce the number of groups we have created another classification (material grouping 2).

<table>
<thead>
<tr>
<th>MATERIAL GROUPING 1</th>
<th>MATERIAL GROUPING 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coated coils</td>
<td>Coated coils</td>
</tr>
<tr>
<td>Pad coils</td>
<td>Pad coils</td>
</tr>
<tr>
<td>Packaging Material</td>
<td>Packaging Material</td>
</tr>
<tr>
<td>Pad rewind</td>
<td>Rewind</td>
</tr>
<tr>
<td>Coated rewind</td>
<td></td>
</tr>
<tr>
<td>Silicone paper rewind</td>
<td></td>
</tr>
<tr>
<td>Strips rolls</td>
<td>Strips rolls</td>
</tr>
<tr>
<td>Strips FG</td>
<td>Strips FG</td>
</tr>
<tr>
<td>Support coils</td>
<td>Support coils</td>
</tr>
<tr>
<td>Dressing Length rewind</td>
<td>Dressing Length rewind</td>
</tr>
<tr>
<td>Dressing Length FG</td>
<td>Dressing Length FG</td>
</tr>
<tr>
<td>Silicone paper coils</td>
<td>Silicone paper coils</td>
</tr>
<tr>
<td>Cold seal</td>
<td>Raw Material</td>
</tr>
<tr>
<td>Glue</td>
<td></td>
</tr>
<tr>
<td>Supplier pad rewind</td>
<td></td>
</tr>
<tr>
<td>Supplier coated coils</td>
<td></td>
</tr>
<tr>
<td>Supplier strips</td>
<td></td>
</tr>
<tr>
<td>Various</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.2: Groups of materials.

**Material grouping 1:**
- Coated coils: coils of support, glue and silicone paper after the coating operation.
- Pad coils: coils of pad that come from the supplier.
- Packaging material: boxes used to package finished goods.
- Pad rewind: rewind of pad after the slitting operation.
- Coated rewind: rewind of coated after the slitting operation.
- Silicone paper rewind: rewind of silicone paper after the slitting operation.
- Strips rolls: rolls of strips after the operation of strip formation.
- Strips FG: strips as a finished good; ready to ship.
- Support coils: coils of support that come from the supplier.
- Dressing length rewind: rewind of dressing length after the covering operation.
- Dressing length FG: Dressing length as a finished good; ready to ship.
- Silicone paper coils: coils of silicone paper from the supplier.
- Cold seal: cold seal films from the supplier.
- Glue: containers of glue.
- Supplier pad rewind: rewinds of pad that come directly from the supplier; they haven’t been slit in the factory.
- Supplier coated coils: coils of coated that come directly from the supplier with glue and silicone paper: they haven’t been coated in the factory.
- Supplier strips: strips that come directly from the supplier; they haven’t been produced in the operation strip formation in the factory.
- Various: other minor materials like inks used in machines or cardboard.

Material grouping 2 (only two changes from grouping 1):
- Pad rewind, coated rewind and silicone paper rewind have been grouped into one single group called Rewind.
- Some groups of materials that come from the supplier (Cold seal, glue, supplier pad rewind, supplier coated coils, supplier strips and various) have been grouped into a group called Raw material.

3.6. Facilities

Within the facilities of the company there are three buildings related to the production process; two industrial premises and a warehouse. From now on, we are going to use the abbreviations PA and PB for the industrial premises and WH for the warehouse. The following image and plans 1 and 2 from appendix N show the general view of the factory and its buildings and chambers.
Building PA has seven different chambers that receive names from A1 to A7. Chambers A3, A4, A6 and A7 are production chambers, in these areas there are machines that carry out operations from the production process. Chambers A1 and A5 are connection chambers; they have doors to receive and send materials to other buildings and are also used as store points inside the production building. Finally chamber A2 is another storeroom inside the production building used to store semi-finished goods.

Building PB has four chambers and only one of them, B1, is a production chamber. B2 and B3 are the connection chambers of the building, and they are also used as store points. Finally, B4 is not interesting for the study and will not be explained.

At last, the WH building has three chambers W1, W2 and W3. The chamber W1 is an area with rows of shelves where materials are stored. It has three front doors, used to unload trucks of raw materials, load trucks of finished goods and send materials to the PA and PB. Apart from that, materials are also sent to PB through a lateral door. The second chamber, W2, is a big area with rows of shelves and a lateral door, where materials arrive from PA and PB. Finally, chamber W3 is used to load trucks and it is not interesting for the thesis. There are three main zones to store materials in WH: ES.MP to store raw materials and semi-finished goods, ES.MP.EXP for finished goods and BUL to store raw materials which are...
particularly voluminous. The plan 3 in appendix N shows the warehouse with its main parts, the following figure is an image from that plan.

Figure 3.15: Warehouse or building WH and its main store points.
4. MATERIAL FLOW ANALYSIS

4.1. Introduction

Firstly, the company was interested in knowing whether or not it was convenient to automate the palletizing process of the packaging machines, and in that case, receive an appropriate solution. This aim gives the name to the final thesis due to the fact that it was registered at the very beginning of the project.

But after the first steps of the study, we found ourselves facing a dilemma over how to approach the problem. On one hand, there was the option to stick to the first aim of the company, limiting the thesis to the automation of the palletizing process of the packaging machines. This project would have included studies of the cadences of these machines and comparisons of different palletizing robot technologies and suppliers.

On the other hand, there was the option to go further and carry out a study involving the whole process. This second study was defined around three main concepts: automation, layout and quantification. The automation was the first problem that the company wanted to solve and of course has a place in this second study. The concept of layout appears as a result of considering if a new layout in the factory combined with the automation could provide a global solution with higher improvements. And the third concept is related to the desire to discover how costly for the company is the movement of materials, what steps of the process consume more transport resources and to quantify the improvements of the solution.

Finally, the company and myself, decided to conduct the global study due to the following reasons:

- Potential synergy that results from the combination of the automation and the layout study.
- Possibility to obtain a greater knowledge of the process thanks to the quantification.

To develop these concepts is necessary to gather information about the process; this has been obtained using material flow analysis.
4.2. Material flow explanation

The previous sections have been used to define the products, describe the process and introduce the buildings. The next step is to explain the material flow following the normal course of the materials; since they arrive at the factory as raw materials until they left as finished goods.

In order to make the explanation more comprehensive, the following table shows all the machines: giving their name, the operation that they carry out and also if they are used to produce strips, dressing lengths or both. In order to understand the explanation is advisable to consult the plans 1 and 2 of appendix N, because the explanation is constantly referring to buildings and chambers.
TABLE OF MACHINES

<table>
<thead>
<tr>
<th>NAME</th>
<th>OPERATION</th>
<th>PRODUCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Coating</td>
<td>Strips and dressing lengths</td>
</tr>
<tr>
<td>S1</td>
<td>Slitting (support and silicone paper)</td>
<td>Strips and dressing lengths</td>
</tr>
<tr>
<td>S2</td>
<td>Slitting (pad)</td>
<td>Strips and dressing lengths</td>
</tr>
<tr>
<td>S3</td>
<td>Slitting (support)</td>
<td>Strips and dressing lengths</td>
</tr>
<tr>
<td>S4</td>
<td>Slitting (special pad and support)</td>
<td>Strips and dressing lengths</td>
</tr>
<tr>
<td>F1</td>
<td>Strip Formation</td>
<td>Strips</td>
</tr>
<tr>
<td>F2</td>
<td>Strip Formation</td>
<td>Strips</td>
</tr>
<tr>
<td>F3</td>
<td>Strip Formation</td>
<td>Strips</td>
</tr>
<tr>
<td>F4</td>
<td>Strip Formation</td>
<td>Strips</td>
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<tr>
<td>F5</td>
<td>Strip Formation</td>
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<tr>
<td>F6</td>
<td>Strip Formation</td>
<td>Strips</td>
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<tr>
<td>F7</td>
<td>Strip Formation</td>
<td>Strips</td>
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<tr>
<td>F8</td>
<td>Strip Formation</td>
<td>Strips</td>
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<tr>
<td>F9</td>
<td>Strip Formation</td>
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<tr>
<td>F10</td>
<td>Strip Formation</td>
<td>Strips</td>
</tr>
<tr>
<td>F11</td>
<td>Strip Formation</td>
<td>Strips</td>
</tr>
<tr>
<td>F12</td>
<td>Strip Formation &amp; Packaging</td>
<td>Strips</td>
</tr>
<tr>
<td>F13</td>
<td>Strip Formation &amp; Packaging</td>
<td>Strips</td>
</tr>
<tr>
<td>F14</td>
<td>Strip formation special process</td>
<td>Strips</td>
</tr>
<tr>
<td>PS1</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>PS2</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>PS3</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>PS4</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>PS5</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>PS6</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>PS7</td>
<td>Packaging of Strips</td>
<td>Strips</td>
</tr>
<tr>
<td>C1</td>
<td>Covering</td>
<td>Dressing lengths</td>
</tr>
<tr>
<td>C2</td>
<td>Covering</td>
<td>Dressing lengths</td>
</tr>
<tr>
<td>C3</td>
<td>Covering</td>
<td>Dressing lengths</td>
</tr>
<tr>
<td>PD1</td>
<td>Packaging of Dressing lengths</td>
<td>Dressing lengths</td>
</tr>
<tr>
<td>PD2</td>
<td>Packaging of Dressing lengths</td>
<td>Dressing lengths</td>
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<tr>
<td>PD3</td>
<td>Packaging of Dressing lengths</td>
<td>Dressing lengths</td>
</tr>
<tr>
<td>PD4</td>
<td>Packaging of Dressing lengths</td>
<td>Dressing lengths</td>
</tr>
<tr>
<td>PD5</td>
<td>Packaging of Dressing lengths</td>
<td>Dressing lengths</td>
</tr>
</tbody>
</table>

Table 4.1: Table of machines.

From now on, we are going to refer to raw material as every material that comes from the supplier, semi-finished good as a material that has been transformed at least once inside the factory and finished goods as every material that is ready to ship.
4.2.1.1. Strips

Receipt of raw materials

The process begins when raw materials are received and stored in WH.

Step 1: Coating

This is the first step of the process; some raw materials are moved from WH to PA. These materials are: support coils, glue containers and silicone paper coils. Once they arrive at PA, they are temporarily stored in the chamber A1. When they are needed, they are transported to chamber A3 where machine H1 transforms the inputs into coated coils. After that, coated coils are carried to chamber A2 and stored there.

Step 2: Slitting

There are four slitting machines, three of them (S1, S2 and S3) are placed in chamber A4 and are the most important because they are used constantly. Though these machines could slit more than one type of coil, generally S1 slits support and silicone paper coils, S2 pad coils and S3 support coils. Machine S4, installed in chamber B1, is very specialized and dedicated only to cut special materials.

As we said previously, three types of coil are slit independently in this part of the process. Coated coils are brought from the chamber A2 to the slitting machines in the chamber A4. For its part, pad coils are transported from WH to PA and stored temporarily in the chamber A1. When they are required they are carried to the slitting machines in the chamber A4. Silicone paper coils follow the same course than the pad coils.

When the operation is finished, we obtain coated rewind, pad rewind or silicone paper rewind; depending on the coil that we have cut. These rewinds are stored in chambers A2 and A5.

Pad rewind produced in machine S2 has one peculiarity; this material is not transported using pallets as it normally happen in the factory. Once it is produced it is placed on trolleys, which are also used to move and support the material while it is stored.

Step 3: Strip Formation

In this part we are going to talk about the normal strip formation machines, which are the machines with the name from F1 to F11. Machines F12, F13 and F14 are special and will be commented later in a section called special processes.
To form the strips we require the three types of rewind and the cold seal film. For this reason, cold seal film is transported from WH to PA; after that, all the materials are in the same building as the strip formation machines. When it is convenient, these materials are brought to chambers A6 and A7, where in machines from F1 to F11, they are transformed into rolls of strips. These rolls of strips are later carried to WH where they are stored. As we see here, apart from raw materials, in WH there are semi-finished goods as well.

**Step 4: Packaging**

In the last step of the strip process, rolls of strip and packaging material (primary boxes and secondary boxes) are transported from WB to PB where the packaging machines of strips are placed. The most important machines of this section are PS1, PS2 and PS3. There, strips are introduced first inside primary boxes and then groups of primary boxes are put inside secondary boxes. At the end of each machine there is one person who manually puts these secondary boxes on a pallet.

Machines PS4 and PS5 operate in a different way and have lower production volumes than the previous machines. Finally there is the machine PS6, which is smaller and not comparable with PS1, PS2 and PS3.

After this last step, the pallets with the strips packaged are brought and stored on a shelf in WH.

**Shipping of finished goods**

When a pallet of strips has to be shipped, it is removed from its shelf WH and brought to one of the truck loading bays that we found in the same building.

**4.2.1.2. Dressing lengths**

The first stages of the process (receipt of raw materials, coating and slitting) are exactly the same than in the strips process. For this reason we will begin explaining the third step.

**Step 3: Covering**

There are three machines that carry out this operation; two of them (C1 and C2) are in chamber A4 and the other one (C3) in chamber A6. These machines take the coated, pad and silicone paper rewind from chambers A2 and A5 and produce a continuous rewind of dressing length. Once it is produced, dressing length rewind is placed on trolleys, not on pallets, and stored against the wall in chamber A4.
Step 4: Packaging

All the machines of this operation put the dressing length inside primary boxes and then primary boxes into secondary boxes, but there are different types of packaging machines in this operation. Machines PD1 and PD2 are the big packaging machines of dressing length; they are larger than PD3, PD4 and PD5, they need more than one person to work, produce a very high volume and they put several short pieces of dressing length inside one primary box.

On the contrary, machines PD3 and PD4 are smaller, have lower volumes of production and put only one longer band of dressing length inside the primary box. Finally there is PD5, which can be considered similar to PD3 and PD4.

It is important to remark on the fact that in all these machines, secondary boxes are placed on a pallet manually. At last, the pallets with the dressing lengths are transported and stored on a shelf in WH.

Shipping of finished goods

When these pallets of finished dressing length have to be shipped, they are removed from its shelf in WH and brought to one truck loading bay in the same building.

4.2.1.3. Special processes

The processes described until here, cover almost the totality of the production of the factory, but there are other special processes taking place in the plant and involving other machines. Though these special processes have a less important specific weight, it is interesting to comment their main features.

Some of the strips produced in the factory are sold in markets which demand that the strips have to be sterile. These strips follow the same course than the other ones except for one difference. After the strip formation operation, these rolls of strips are sent to another company which makes the sterilization process. Once they are sterile, these rolls of strips return to our plant where they can be packaged in the last step of the process.

Machines F12 and F13 have been put into the strip formation family because they also receive the three types of rewind and the cold seal. But they also receive packaging material and instead of rolls of strip they produce strips as a finished good.

Machine F14 is used to form only one particular type of strip, which is later sent to the WH and finally brought to the packaging machines where it is packaged.
Machine PS7 is very specialized because it also employed to package a certain type of strips which do not pass through the whole process because they arrive at the WH from a supplier. So this machine receives the strips and packaging material from WH and produces the finished good in one step.

4.3. Types of movements and vehicles used

Except for some cases which will be explained, in the plant, materials are stacked on pallets as it generally happens in the factories. Pallets allow the transport of materials easily and in our case these movements are carried out using different vehicles. Due to the fact that the facilities consists in three different buildings, some transports take place inside one building, while others go from one building to another.

4.3.1. Indoor movements

When the origin and the destination of the transport are in the same buildings the following vehicles are employed:

4.3.1.1. Electric trucks

This is by far the most used vehicle in the factory to move materials inside the buildings. We include in this group electric stackers and electric pallet trucks. The difference between these two vehicles is that in the first one, the fork can be moved upwards in order to reach or deposit pallets in high positions like shelves. On the contrary electric pallet trucks can only load and deposit pallets on the floor.

![Electric stacker and electric pallet truck from Jungheinrich](image)

Figure 4.2: Electric stacker and electric pallet truck from Jungheinrich [10].

4.3.1.2. Trilateral stackers

Trilateral stackers are a family of vehicles specifically designed to reach and deposit pallets in very narrow aisles. The principal characteristic of these vehicles is that they can orientate their fork to the front, left or right. As a result, when they operate between rows of shelves which are very close, they can reach or deposit materials in the laterals only moving forwards and backwards. Electric trucks have to manoeuvre to face the shelves frontally; and in
narrow aisles there isn’t enough space to do that. Due to the fact that trilateral stackers are designed to work in warehouses they also have the capacity to reach higher positions than electric stackers.

Figure 4.3: Trilateral truck from Jungheinrich [10].

In the plant these vehicles operates in the narrow aisles between rows of shelves in the WH; where electric trucks haven’t enough space. Electric trucks and trilateral trucks cooperate in the WH. When materials have to be stored there, electric trucks bring them from one of the doors to the beginning of one aisle. Once there, pallets are transferred to trilateral trucks which deposit them on a shelf. The process is the opposite when materials have to be removed from one of these shelves. The following image shows in red colour the areas where electric trucks operate and in green colour the zones where trilateral trucks work. This image is also presented in the plan 4 from the appendix M.

Figure 4.4: Zones where trilateral and electric trucks operate inside the warehouse.
4.3.1.3. Trolleys

Trolleys are vehicles used to transport materials inside buildings and they consist in a metal structure with wheels. To be moved, these vehicles have to be pushed by people because they don’t have any engine or battery.

![Figure 4.5: Trolley from Akro-Mils [11].](image)

Movements using these vehicles have two peculiarities:

- Materials transported with trolleys don’t use pallets; they are placed directly on the metal structure of the vehicle. When these materials are produced, they are placed on a trolley and are not removed from it until they are consumed.
- These vehicles are moved by operation workers not by transport staff (see section 4.3.3).

In the company, the only materials that use trolleys instead of pallets are dressing length rewind and pad rewind produced in the machine S2.

4.3.2. Outdoor movements

Imagine the case presented in Figure 4.6 where one material has to be moved from machine PS2 in building PB to WH, where it has to be stored. First of all an electric truck takes the pallet from its origin in PB to one door in the same building. Then an outdoor vehicle (in this case the diesel forklift truck) brings the pallet from the door of PB to one door of WH. After that, another electric truck carries the material from the door of the WH to the beginning of one aisle; and finally, a trilateral truck deposits the pallet on its destination; one shelf.
Figure 4.6: Example of a transport.

The example shows the complexity of one single movement that involves four different vehicles. The second one is an outdoor vehicle which can be a diesel forklift truck or a train.

4.3.2.1. Diesel forklift truck

It's a forklift truck powered by a diesel engine. It is used to bring materials from the door of one building to the door of another one.

Figure 4.7: Diesel forklift truck from Jungheinrich [10].

4.3.2.2. Train

All the vehicles describe until now transport one single pallet in each movement. Every day loads of pallets have to be carried from the WH to the other buildings and vice versa. Using the train is possible to transport more than one pallet in the same movement. This vehicle consists in a diesel forklift truck that pulls several carts attached behind it. The pallets are placed on these carts.
Figure 4.8: Train from Jungheinrich [10].

Train transports consist in five tasks which are presented below.
- The diesel truck loads the carts with the pallets.
- The driver attaches the carts to the diesel truck; forming the train.
- The train is transported to its destination.
- The driver detaches the diesel truck from the carts.
- The diesel truck unloads the pallets from the carts.

Loading and unloading the pallets from the carts require some time. For this reason the train is only convenient when the distance of the movement is not very small. Due to that in the plant the train is used to bring materials from WH to PA and vice versa, while the diesel forklift truck is used to transport pallets between WH and PB and between PA and PB.

4.3.3. Transport staff

Apart from the operation workers, there are a group of 16 workers which form the transport staff. The job of operation workers is to operate the machines while the transport staff bring materials where they are required (machines, shelves, trucks...). There is only one exception, because in the transports with trolleys, these vehicles are pushed by operation workers. The 16 people from the transport staff are divided into groups; each group works in one particular place and uses one particular vehicle. The number of people working in each group is always the same and for confidential reasons it has been decided not give this information. The groups are presented below.
- Building PA using electric trucks.
- Building PB using electric trucks.
- Building WH using electric trucks.
- Building WH using trilateral trucks.
- Outside using the diesel forklift truck or the train.

It has been said that the job of the transport staff is to bring the materials where they are required. Actually, that’s only one of their tasks. They also have to keep updated the Enterprise Resource Planning system, creating in the software the materials when they are produced and print and stick the labels that describe each pallet. Apart from that, they wrap the finished goods pallets and act as a link between the machines and the planners who
decide which products have to be produced. All these activities are carried by the transport staff, but don't consist in moving materials are called support activities.

4.4. Compilation of information

4.4.1. Handling units

In order to undertake a complete material flow analysis it is necessary to gather information about the movements of materials that take place in the factory. One option is to determine the quantity of materials moved through the process; for example: number of support coils transported, number of metres of rewind moved, number of strips transported etc. But there is one problem; we don't know if moving two coils is more costly than moving 4.000 metres of rewind or less than moving 200.000 strips. That's because there are different materials involved and we need a common unit to measure them.

Literature about this topic suggests tracking the handling units used by the materials instead of the quantity of materials moved. A handling unit is a physical unit consisting of a support and the goods contained on it. In our case handling units are pallets and trolleys. This theory suggests that moving a pallet requires more or less the same effort independently of the material carried on it.

Trolleys are a handling unit and a vehicle as well. We have to take into account that moving a trolley is considered less costly than a pallet because the material is placed on a handling unit that has wheels and can be pushed by the operation worker. For this reason, it doesn't need the transport staff or a powered vehicle.

4.4.2. Temporal period of the study

The number of handling units transported has to be registered during a representative period of time. In order to obtain useful information, this period of time has to be recent and cover the fluctuations in the demand that affect the production. Though people get hurt during the whole year, the demand of adhesive bandages has fluctuations due to marketing campaigns and because people are more likely to get hurt during the warm months of the year; when they do outdoor activities.

For these reasons the temporal period was fixed at one year; from the 01 August 2010 to 31 July 2011.
4.4.3. Sources of information

The information desired is the number of handling units moved during the period of study. Apart from the number of movements we also need the material transported, the origin and the destination of the movement.

Although the company uses an enterprise resource planning software where this information is recorded, obtaining it was not an easy process. The first step was to download large amounts of data from this software, but this data could not be used directly in the material flow analysis and had to be treated previously. Through several meetings with staff from practically all the departments, we acquired the knowledge and the tools required to do the data treatment.

The information obtained consisted in a huge list of movements, with many different materials and a large number of locations (machines, store points etc.). In order to make this information easier to understand, we grouped the materials and machines into groups and we used a tool called Value Stream Mapping or VSM.

![Diagram of Value Stream Mapping](image)

Figure 4.9: Reduction of the complexity process.

Machines have been grouped in section 4.2 and materials in section 3.5; in the following chapter we are going to explain the method called VSM.
4.5. Value Stream Mapping (VSM)

4.5.1. Introduction

The value stream are all the actions (both value added and non-value added) currently required to bring a product from its design to the customer [1]. In this final thesis we are going to cover only one part of this stream; the “door-to-door” production flow inside the plant. This is from the reception of raw materials coming from the suppliers, to the shipment of finished goods.

The VSM is a visual management tool developed by Toyota, which helps companies make the transition to lean manufacturing. Theoretically it represents the current-state production flow and a future ideal state, but because we use VSM as a tool to understand our process, we are going to do only the current-state production flow. It uses icons, which are described in section A.1 of the appendices.

It works on the big picture; so it is a balance between having enough information to describe the process accurately and not having too much or the tool won’t be visual and understandable. It is also very advisable to draw one VSM for each family of products; otherwise the result is normally too complicated.

VSM include the three big flows that a factory has:
- Operations of the production process.
- Materials.
- Information.

Value stream mapping can be applied in more or less detail but it requires time. As we wanted to study the material flow, we decided to focus on two of the flows: operations and materials.

4.5.2. VSM application

As it has been said previously we are going to represent the VSM only for the current-state flows of operations and materials. Apart from that, we are going to do one VSM for each process, strips and dressing lengths. Finally, because it has to be visual, it will show the flow of the most common and important steps; not representing special processes or machines that has very low volumes. The aim of this is to give the big picture but with the processes that appear in both VSM we cover about 95% of all the movements.

VSM for the strip process and for the dressing length process are presented in the following pages.
Study of the automation of the packaging/palletizing process in an adhesive dressing plant

Figure 4.10: VSM strips process.
VALUE STREAM MAPPING DRESSING LENGTHS

NOTES:
- Period of the study: from 01 August 2010 to 31 July 2011 (one year).
- The numbers on the arrows show the number of pallets or trolleys moved during the period of study and also the proportion of the total that this movements represent.

Figure 4.11: VSM dressing lengths process.
In order to see which steps of the processes produce more transports, movements from both VSM have been grouped depending on the step of the process that is directly related to these movements. The results are the Grouped VSMs that are in section A.2 of the appendices. Here it's important to take into account one detail. Steps one and two (coating and slitting) are the same for both processes (strips and dressing length). For this reason these steps are presented in both VSM under the group “Shared transports strips and dressing”.

The following bubble chart is a resume of the Grouped VSMs; it is a scale chart where the area of the bubbles is proportional to the percentage of each group.

![Bubble chart](image)

Figure 4.12: Bubble chart.

The previous chart groups the movements from the VSM’s (about 95% of all the movements) depending on the step of the process, but we considered that it would be interesting to classify the movements according to materials. The next chart shows the percentage of
movements for each material; in this case we have taken all the movements (100%) not only the ones included in the VSMs (95%).

![Figure 4.13: Movements classified according to materials.](image)

### 4.5.3. Interpretation of the VSM

The study of the VSM and the previous charts provide some remarkable points about the process:

As we see in the bubble chart (Figure 4.12), only five of the thirty machines (PD1, PD2, PS1, PS2 and PS3) are directly related to 52% of the movements (blue and orange bubbles).

And as Figure 4.13 shows, the materials that produce more movements are:
- Packaging material (23%).
- Finished goods; strips FG and dressing lengths FG (17% + 9%).
- Rewinds (16%).
- Strips rolls (13%).

In order to reduce the number of movements, efforts have to be specially focused on these materials.
4.5.3.1. Packaging material

Looking at the VSMs there is one important fact related to packaging materials. For the four sections of packaging (STRIP Pack A and B and DRESS Pack A and B) there are two important flows:

- **Supply flow:** From the WH to the machines. When it is received from the supplier, packaging material is initially stored in the WH. Then, when it has to be used in the machines, it is transported to the buildings PA or PB.

- **Return flow:** From the machines to the WH. The packaging material arrives at the machines and the production begins. When the production order is finished (all the strips or dressing lengths of one type have been produced) not all the packaging material has been consumed; one part of the last pallet for each packaging material remains unused. Even though it is inefficient, these last pallets have to be returned to the WH because there isn’t space to store them in the production buildings PA and PB. This happens especially with the primary box and the lid from the secondary box; which are exclusive for each finished good. On the contrary trays from the secondary box are not exclusive for each product, so they will be consumed in one of the following production orders; for this reason trays are not returned to the WH.

The following chart shows the percentage of movements from the total that represents the supply and the return flow for each packaging section.

![Figure 4.14: Supply and return flow of packaging material for each packaging section.](image)

The sum of the percentages represented in the chart is 22% and as we have seen previously in the bubble chart, sections STRIP Pack A and DRESS Pack A are the most important. But
the first movements that should be reduced are the inefficient return transport; if we classify the packaging movements according to supply and return flow, we obtain the next chart.

![Pie chart showing total supply and return flow of packaging material.]

Figure 4.15: Total supply and return flow of packaging material.

28% of the material packaging movements are return transports. This means that approximately one in three pallets moved from WH to PA or PB has to be returned to WH because it has not been completely consumed.

4.5.3.2. Finished goods

Strips' movements are more important than dressing length, but between both products finished goods represent about 26% of the movements. The two important sections, strips pack A and dressing pack A, cause 22.8% of the movements of finished goods with only five machines.

4.5.3.3. Rewinds

Due to the fact that the analysis showed that rewind cause an important number of movements, we decided to study whether this rewind movements are indoor or outdoor movements. That's because rewsinds are produced and consumed in PA and store points in chambers A2 and A5 are designed to store all the rewsinds that are produced; so they don't have to be transported to WH provoking an outdoor transport which is more expensive than an indoor one. The following chart shows the number of indoor (blue) and outdoor (red) movements for each type of rewind (coated, pad and silicone paper).
4.5.3.4. Strips rolls

Related to strips rolls there is one important fact that increases the cost of its movements. Strips are produced in the building PA and consumed in PB, but they are not moved directly from PA to PB. Once the strip is produced in the strip formation machines in PA, they are transported to WH, where they are stored. When they are required in the packaging machines in PB they are carried to the building PB.

4.5.4. Limitation of the VSM

VSM is a very useful tool which helped us to understand the process, but it has one important limitation. It only shows the number and percentage of movements but not how costly they are. The cost of one movement depends on things like: the distance, the vehicle used, the number of vehicles needed to do one movement etc (see example of a transport in Figure 4.6.). In order to tackle this limitation it has been developed a calculation tool called Evaluator.
4.6. Calculation tool: Evaluator

4.6.1. Introduction to the Evaluator

The Evaluator is a programme which calculates the time needed to do all the movements of material for one certain scenario. It calculates the time of each single movement and then it sums them to obtain the total. It has been said in section 4.3.3 that the transport staff have two tasks: transporting materials where they are required and doing support activities. Due to that the transport staff spend their time in three activities:

- Support activities.
- Movement with material. Going to one place to another with some material on its vehicle. Apart from the transport it also includes the stacking time and transfer time if the pallet has to be transferred from one vehicle to another.
- Movement without material. Going to one place to another without any material on its vehicle.

Movements without materials are not useful, but they are impossible to eliminate. Normally, when transport staff have to pick a pallet in one place, they arrive there empty. It is important to understand that the evaluator only calculates the time required to carry out the movement with material (it doesn't consider the movement without materials and the support activities).

In this section we are going to introduce the basics of the tool which is explained with more detail in the appendix M. It is a really complex programme which required a lot of time to develop. The programme has more than 13,500 lines; which gives an idea of the complexity and time spend on it.

It is an algorithm, created in the programming language Visual Basic for Application, and it has three main steps: definition of the scenario, execution of the algorithm and visualization of the results.

4.6.1.1. Definition of the scenario

In this first step the user introduces information in the programme in order to define completely the scenario which has to be evaluated. The basic information that has to be introduced is:

- List of movements, including origin, destination, material moved and vehicle used.
- Physical location of all the machines and store points. Location is defined using Cartesian coordinate system (X ; Y).
- Speed of each type of vehicle.
- Time needed to stack one material and time needed to transfer one pallet from one type of vehicle to another.
4.6.1.2. Execution of the algorithm

Once the scenario is completely defined, the user has to execute the algorithm. It calculates the time needed to do every single movement taking into account three elements.

- **Stacking time**: when one pallet has to be moved from one place to another, the first and the last operation are called stacking operations. These operations are: reaching the pallet from its origin; and stacking the pallet on its destination. We have considered three stacking possibilities, where the time needed for the vehicle to do the stacking operation is different:
  - **Floor**: the pallet is stacked on the floor.
  - **Height**: the pallet is stacked on normal shelves.
  - **Superior height**: the pallet is stacked on shelves of superior height. This happens in the WH where the shelves have more levels than in PA.

- **Distance time**: represents the time needed to cover the distance from the origin to the destination. As it has been explained in the section 4.3.2. Moving one pallet from one place to another may need more than one vehicle. In this case each vehicle is doing one stage of the transport.

- **Transfer time**: when more than one vehicle is needed to do one movement; the pallet has to be transferred from each vehicle to the following one, and this operation requires time.

The algorithm uses the following expression:

\[
Time_{ijm} = ST_i + \sum_{n=1}^{N} \frac{D_{ijn}}{v_{ijn}} + ST_j + TrT_{ijm}
\]

Equation 4.1: Expression used to calculate the time needed to do one transport from “i” (origin) to “j” (destination) for the material “m”.

The time needed to do one transport from location “i” (origin) to location “j” (destination) for the material “m” is the result of the sum of some elements.

- **ST_i**: Stacking time in the origin. Time needed to remove the pallet from the location “i”.
- **ST_j**: Stacking time in the destination. Time needed to stack the pallet in the destination “j”.
- **\(\sum_{n=1}^{N} \frac{D_{ijn}}{v_{ijn}}\)**: Distance time: time needed to move the transport from “i” to “j”. It is a summation because if the movement needs more than one vehicle, it has to be done for each stage of the movement (from stage n=1 to stage n=N). The distance time is calculated dividing the distance of the stage by the velocity of the vehicle used in this stage.
- $TrT_{ijm}$: Transfer time for the movement from location “$i$” to location “$j$” for the material “m”. It depends on the number of transfers needed and also on the vehicles that have to do the transfers.

The velocities and the transfer times depend on the vehicle, and the stacking time depend on the stacking possibility (floor, height and superior height). These values have been obtained observing the factory and are explained in section B.1 of the Appendix B.

The image below shows the example of one transport from machine PS2 to a shelf of finished goods in the WH. This image can be seen more clearly in the plan 5 of the appendix N.

![Figure 4.18: Example of a transport from machine PS2 to one shelf in WH.](image)

The transport time is formed by the following elements.

i. Stacking time in the origin (blue cross near machine PS2).

ii. Distance time of the electric truck in building PB (pink arrow).

iii. Transfer time 1 (between electric truck and diesel forklift truck).

iv. Distance time of the diesel forklift truck (purple arrow).

v. Transfer time 2 (between diesel forklift truck and electric truck).
vi. Distance time of the electric truck in building WH (green arrow).

vii. Transfer time 3 (between electric truck and trilateral truck).

viii. Distance time of the trilateral truck (orange arrow).

ix. Stacking time in the destination (blue cross near the shelves).

4.6.1.3. Visualization of the results

When the algorithm has finished, the user can view the results in the “Results” sheet. There are a lot of different charts, but basically they classify the total time according to groups like materials, machines, buildings or outdoor and indoor movements.

4.6.2. Evaluator applied to the current-state

4.6.2.1. Materials

The total time for the current-state is 4.742 hours; it includes the time needed to stack, transfer and transport all the pallets moved from the 1\textsuperscript{st} of August 2010 to 31\textsuperscript{st} of July 2011. The following chart shows the total time divided into materials. It is important to notice that it is different from Figure 4.13 which shows the number of movements (not the time) divided into materials.

Figure 4.19: Transport time for each material.
The most important materials are: Packaging material, Finished goods (strips and dressing lengths), Rolls of strips and rewind. In section 5 some alternatives or scenarios will be presented with the aim to reduce the time of these materials and to solve the automation problem.

4.6.2.2. Transport staff

In order to check the validity of the Evaluator, its results were compared with the reality. According to the Evaluator the time needed to do all the transports in one year in the current scenario is 4.742 hours. The Evaluator also gives this time depending on the building and the vehicle used.

<table>
<thead>
<tr>
<th>GROUP OF TRANSPORTS</th>
<th>TIME [hours]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside PA using Electric Trucks</td>
<td>722.74</td>
</tr>
<tr>
<td>Inside PA using Trolleys</td>
<td>127.93</td>
</tr>
<tr>
<td>Inside PB using Electric Trucks</td>
<td>622.00</td>
</tr>
<tr>
<td>Inside WH using Electric Trucks</td>
<td>1.237.42</td>
</tr>
<tr>
<td>Inside WH using Trilateral Trucks</td>
<td>1.164.82</td>
</tr>
<tr>
<td>Outside using Diesel Forklift Truck</td>
<td>504.51</td>
</tr>
<tr>
<td>Outside using Train</td>
<td>362.60</td>
</tr>
</tbody>
</table>

Table 4.2: Transport time according to the Evaluator for the current situation.

These results were compared with the number of people from the transport staff working in each group. For this reason the row “Inside PA using Trolleys” is not considered because the movements of materials using trolleys are carried out by operation workers not transport staff.

But these figures cannot be compared directly because they are only one of the activities that the transport staff do. It has been said in section 4.6.1 that transport staff spend their time doing three activities: support activities, movement with material and movements without material. The times that appear in the previous table are the times of the activity movement with material and are considered net times. That’s because they are the ideal times needed to carry the materials from its origin to its destination without finding obstacles on its way, or other setbacks. But in the reality, transport staff have to do additional manoeuvres; for example when they are carrying one pallet to one machine but there isn’t enough place to put it because there are other materials. In that case, they have to move the other pallets a little bit, and then finally deposit the pallet that they were carrying at the beginning. Another example is when the train arrives to one building and begins to deposit twenty pallets at the entrance. In that case, electric tucks take these pallets to one provisional place in order to avoid the saturation of the entrance. But then, these pallets have to be carried to its destination.
For these reasons, we defined the gross time doing the activity “movement with material”. This time includes the net time (ideal and calculated with the Evaluator) plus the additional manoeuvres. Observing the factory, it has been estimated that the net time is the 85% of the gross time.

![Diagram of transport staff activities]

Figure 4.20: Transport staff activities.

The next step was to determine the percentage of time that transport staff dedicate to the three main activities. To do this, we observed the factory doing a work sampling which is detailed in the section B.2 of the appendixes. These percentages depend on the vehicle and also the building.

<table>
<thead>
<tr>
<th></th>
<th>PA &amp; PB Electric Truck</th>
<th>WH Electric Truck</th>
<th>WH Trilateral truck</th>
<th>Train &amp; Diesel Forklift Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mov. with material</td>
<td>23%</td>
<td>34%</td>
<td>47%</td>
<td>46%</td>
</tr>
<tr>
<td>Mov. without material</td>
<td>14%</td>
<td>23%</td>
<td>34%</td>
<td>19%</td>
</tr>
<tr>
<td>Support activity</td>
<td>63%</td>
<td>43%</td>
<td>19%</td>
<td>36%</td>
</tr>
</tbody>
</table>

Table 4.3: Transport staff time distribution.

The Evaluator has provided the net time for the activity “Movement with materials”. If the net time is the 85% of the gross time it’s easy to determine this value. And once that the time of the activity “Movement with material” is known, it is possible to find the total time needed to do the three activities. The total time divided into the number of hours that a person works in the company gives the number of people needed. In fact this number of person is a decimal number which has to be rounded to the upper value. Finally this number is compared with the real number of people that forms the transport staff. The following table shows all this process.
Table 4.4: Transport staff time for each activity, total time and people required.

<table>
<thead>
<tr>
<th>GROUP OF TRANSPORTS</th>
<th>Net time</th>
<th>Gross time</th>
<th>% Mov. with material</th>
<th>Total time</th>
<th>People needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside PA using Electric Trucks</td>
<td>722.74</td>
<td>850.28</td>
<td>23%</td>
<td>3.696,88</td>
<td>2.22 (3)</td>
</tr>
<tr>
<td>Inside PB using Electric Trucks</td>
<td>622.00</td>
<td>731.77</td>
<td>23%</td>
<td>3.181,60</td>
<td>1.91 (2)</td>
</tr>
<tr>
<td>Inside WH using Electric Trucks</td>
<td>1.237.42</td>
<td>1.455,79</td>
<td>34%</td>
<td>4.228,71</td>
<td>2.54 (3)</td>
</tr>
<tr>
<td>Inside WH using Trilateral Trucks</td>
<td>1.164.82</td>
<td>1.370,37</td>
<td>47%</td>
<td>2.905,19</td>
<td>1.75 (2)</td>
</tr>
<tr>
<td>Outside Diesel Fork Truck &amp; Train</td>
<td>867,11</td>
<td>1.010,13</td>
<td>46%</td>
<td>2.217,67</td>
<td>1.33 (2)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

In total the number of people required to undertake the transports according to our study is 12. As it has been said in the reality there are 16 people in the transport staff. There are two reasons that might explain this difference.

- The evaluator doesn't take into account one part of the job of the people working in the warehouse. These tasks, out of the scope of the thesis, are unloading the trucks from the suppliers and loading the trucks with the finished goods. That's because as it has been said, the material flow study is done only inside the plant.

- If the people working in the plant were just the people needed according to the Evaluator, they would be able to complete their jobs if the requirements of movements appear at regular intervals of time. But that is not the case in the reality; during the day there are intervals of time when more materials have to be moved than in others. If the number of people working were just the one given by the Evaluator, during these peak time there would be cues and machines waiting to receive materials because the transport staff is busy serving other machines. For this reason an extra capacity is required.

Taking all this into account we considered applicable the Evaluator and it will be used to analyse other scenarios proposed.
5. SCENARIOS FOR IMPROVEMENT

5.1. Initial discards

5.1.1. Palletizing solution discarded

It has been said previously that initially the company was interested in automating the palletizing process. If we had decided to approach the problem only from this point of view, the solution may have been similar than the one presented in the plan 6 of the appendix M.

In building PA, production from machines PD1 and PD2 are transported on conveyor belts to one robot in chamber A5. In the same way but in building PB, production from machines PS1, PS2 and PS3 are transported on conveyor belts to another palletizing robot in chamber B3. It is important to notice, that in this scenario any machine has been moved and that the palletizing system has been designed quite straightforwardly. Therefore, each robot is installed in the same building than the machines that produce the boxes. For this reason, once that these secondary boxes have been automatically palletized, transport staff have to carry them from PA or PB to WH where they are stored. So in this solution, layout modifications and material flow improvements are not considered.

So this option was discarded because it was considered more interesting to centralize the palletizing robots in WH. By doing this, finished goods are carried automatically on conveyor belts to the WH, where they are stored. In this case transport staff don’t have to do these numerous and costly outdoor transports between the production buildings and WH.

5.1.2. Materials

We have identified the most important materials:

- Packaging material.
- Finished goods (strips and dressing lengths).
- Rolls of strips.
- Rewind.

So apart from the automation of the palletizing process, scenarios for improvement have to be defined focusing on these materials. But in this thesis efforts have been concentrated on finished goods and rolls of strips; discarding packaging material and rewind for the following reasons.
5.1.2.1. Packaging material

As it has been said in section 4.5.3.1, there are two flows of packaging materials: supply flow and return flow. Supply flow is necessary to bring the boxes to the machines, but returning the unused remains of boxes to the WH is inefficient. In order to tackle this problem we considered the option to create a picking operation in WH. In this operation, workers would separate and send to the machines only the quantity of boxes which are required to finish the production order.

But it has one problem; due to waste during the production, which is unpredictable, if we sent to the machine the exact number of boxes required, we are going to run out of packaging material and the order will not be finished. For this reason we should send the exact number of boxes plus a safety margin to absorb the waste. But if we do this, at the end of the order, one part of the safety margin would remain unused and would have to be sent back to WH as it happens now. So we will be in the same situation but assuming an extra cost coming from the picking operation in WH. For this reason we have decided to discard improvements based on packaging material.

5.1.2.2. Rewind

Rewind, with 9% of the total time, is the last of these important materials. As we saw in section 4.5.3.3, chambers A2 and A5 are designed to store these materials, so they don’t have to be carried to the WH. In spite of that, 18% of the rewind transports are outdoor movements. One possible solution to this problem may be reducing the stock of rewind, so less pallets of rewind have to be stored. But this decision has other repercussions which are out of the scope of this thesis.

5.2. First study of scenarios

The process used to find the alternative proposed to the company has two steps. Initially, we have generated a group of possible scenarios which have been evaluated in a first study. After this and with the information gathered in the first study, we have created two other scenarios which have been evaluated in a second and more profound study.

5.2.1. First study criteria

To do the studies, scenarios are compared using the same criteria. For the first study, criteria are: transport time reduction, degree of automation of the packaging process, impact on the current process and investment.
5.2.1.1. Transport time reduction

This criterion measures how efficient is a certain scenario from the point of view of material flow. To do this, we calculate the time that the new scenario needs to carry out all the movements registered from August 2010 to July 2011 using the Evaluator programme. The time that the Evaluator provides is the net time of the activity “Movements with materials” (see Figure 4.20 for more information).

5.2.1.2. Automation of the packaging process

This second criterion measures the degree of automation in the packaging process. To do this, we calculate the percentage of the total production automated. Due to the fact that strips and dressing lengths are different, to calculate the production we will use the number of primary boxes. The following table shows the percentage of the production of finished goods that each machine manufactures.

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>PRODUCTION PERCENTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS1</td>
<td>35,2%</td>
</tr>
<tr>
<td>PD1</td>
<td>18,0%</td>
</tr>
<tr>
<td>PD2</td>
<td>16,4%</td>
</tr>
<tr>
<td>PS2</td>
<td>15,8%</td>
</tr>
<tr>
<td>PS3</td>
<td>8,6%</td>
</tr>
</tbody>
</table>

Table 5.1: Percentage of the production of finished goods of each machine.

5.2.1.3. Impact on the current process

This criterion judges if the implementation of a particular scenario would affect the current production process severely. The process can be affected for example if it is interrupted for a long period of time or new systems are included so the functioning changes. To quantify this criterion we give to each scenario one of the following levels of impact: low, medium, high or very high.

5.2.1.4. Investment

Investment has been selected as the last criterion for the first study. Investments for each scenario are detailed in appendix E.

5.2.2. Scenario 1

5.2.2.1. Definition

This scenario is presented in the plan 7 of appendix N and has been created focusing on the machines PS1, PS2 and PS3. This machines form the group called STRIP Pack A in the
VSM, and are responsible for a great number of movements. In this scenario, the palletizing process of machines PS1, PS2 and PS3 is automated; these machines are connected to conveyor belts which carry the secondary boxes to the WH where a robot do the palletizing operation. Due to the fact that only three machines are automated only one robot is required. Apart from the automation, finished goods from these machines don't have to be sent to WH with pallets because they are automatically carried on conveyor belts. As a result, more than 12,000 pallets that were transported from the machines in PB to shelves in WH now only have to go from the robot to the shelves in the same building.

5.2.2.2. Criteria

5.2.2.2.1 Transport time reduction

This scenario has been introduced in the programme Evaluator and according to it the total time needed to complete all the movements is 4.266 hours. Compared with the current-state time (4.742 h) it means a 10% reduction of the total time.

5.2.2.2.2 Automation of the packaging process

During the period of study, machines PS1, PS2 and PS3 produced 59,7% of the total production of primary boxes. So with this solution, 59,7% of the production is palletized with the automatic palletizing system.

5.2.2.2.3 Impact on the current process

This scenario has only one change from the current situation, which is the implementation of the palletizing system in the packaging machines of strips. For this reason it has been considered that this option has a low impact on the process.

5.2.2.2.4 Investment

The investment calculated for this scenario is €559,949.

5.2.2.3. Evaluation

The main advantage of this scenario is that it achieves a good time reduction with a lower investment than the other scenarios because it acts only in the three strip packaging machines. Another advantage is that the productive process would not be severely affected during the implementation of this scenario because machines are not moved; and apart from the palletizing system there is not any other change.

But its disadvantages are strongly linked to the same reasons that cause the advantages. Due to the fact that it acts only in the three packaging machines, the percentage of the
production palletized automatically is not enough; and it is also necessary to include the dressing length packaging machines in the palletizing system. In addition, because the palletizing system is the only change from the current situation, it seems that the process and the material flow could be improved considering other variables.

5.2.3. Scenario 2

5.2.3.1. Definition

The second scenario, which can be seen in the plan 8 of appendix N, tries to increase the percentage of production that is palletized automatically over scenario 1. For this reason, the palletizing system collects secondary boxes from the five most important machines in the factory (PS1, PS2, PS3, PD1 and PD2). As a result, the transport time will decrease considerably, because this machines produce and important material flow of finished goods to WH (more than 19.000 pallets per year). Now these finished goods will be automatically transported to robots in WH on conveyor belts. In this case the palletizing system is receiving material from five different machines, and because each robot is capable of supporting maximum four machines (see section 3.4.2 more information) two robots are needed.

5.2.3.2. Criteria

5.2.3.2.1 Transport time reduction

According to the programme Evaluator the total time needed to complete all the movements is 3.948 hours. It is a 17% reduction of the total time compared with the current-state time (4.742 h).

5.2.3.2.2 Automation of the packaging process

Machines PS1, PS2, PS3, PD1 and PD2 are responsible of 94,1% of the total production of primary boxes; so this palletizing systems covers the greatest part of the production.

5.2.3.2.3 Impact on the current process

In this case, the palletizing system is connected not only to the three big packaging machines of strips but also to the packaging machines of dressing length PD1 and PD2. Due to that, the level of impact on the process given to this scenario is medium.

5.2.3.2.4 Investment

The investment calculated for this scenario is €1.089.353. It is considerably more expensive than the previous scenario due to the fact that the palletizing system requires many more meters of conveyor belt; which is a costly element.
5.2.3.3. Evaluation

Like in the previous scenario, the process doesn’t change too much, because it is only altered by the palletizing system. But in this case, the proportion of the production that is automatically palletized is considered highly satisfactory because the dressing machines are also connected to the palletizing system. In addition, the transport time has been considerably reduced from the previous scenario. But it is a solution without any other improvement, where almost all the investment is caused by the palletizing system which is really expensive, that’s because it is not compact and the conveyor belts are too long.

5.2.4. Scenario 3

The distribution of this scenario can be consulted in the plan 9 of appendix N. The aim of this scenario is to reduce the investment in the palletizing system from scenario 2 without damaging too much the material flow. To achieve this, we chose a more compact palletizing system that uses less meters of conveyor belt. For this reason, the five machines that are supported by the palletizing system (PS1, PS2, PS3, PD1 and PD2) have been concentrated in the building PB. It is important to remember that machines PD1 and PD2 were originally in PA.

But these movements of machines have more repercussions; the dressing length section is formed by covering machines (C1, C2 and C3) and packaging machines of dressing lengths (PD1, PD2, PD3 and PD4). Covering machines produce dressing length rewind which is stored in chamber A4 and consumed by the packaging machines using a kanban system. So these machines are strongly linked, because the consumption of the packaging machines dictates what have to be produced in the covering machines. This kanban system provides important benefits, such as stock reduction and easier machine planning, so the company wants to keep it working.

For the proper functioning of the kanban system, its machines have to be well connected; in our case, in the same building. So if machines PD1 and PD2 are transported to PB, all the other machines from the dressing length section (C1, C2, C3 and PD3 and PD4) have to be moved to this building as well. But in the building there isn’t enough space to put all these machines, so some machines from PB have to be transported to PA. It has been decided to move machines F14, PS6, PD5 and PS4.

5.2.4.1. Criteria

5.2.4.1.1 Transport time reduction

In this case the total time required to do all the movements is 4.081 hours: compared with the current-state time (4.742 h) it is a 14% reduction of the total time. It is important to notice that
this scenario has worse result in this criterion than scenario 2. That’s mainly because despite scenario 3 has a reduction in packaging material time, it has a higher increase in rewind time. The decrease in the packaging material time is because now, all the big packaging machines are in PB which is closer than PA from the WH; the place where the packaging material is stored. The increase of the rewind time is due to the fact that covering machines are now in PB but they consume pad, silicone paper and coated rewinds which are stored in chambers A2 and A5 of building PA. The following table compares the changes between scenario 2 and 3 for each material. In the column “Time difference” negatives number represent time reduction while positive numbers show time increases.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Scenario 2 TIME [hours]</th>
<th>Scenario 3 TIME [hours]</th>
<th>Time difference Scenario3 - Scenario2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging Material</td>
<td>1.305</td>
<td>1.232</td>
<td>-73</td>
</tr>
<tr>
<td>Strips rolls</td>
<td>689</td>
<td>706</td>
<td>17</td>
</tr>
<tr>
<td>Strips FG</td>
<td>581</td>
<td>587</td>
<td>6</td>
</tr>
<tr>
<td>Rewind</td>
<td>414</td>
<td>579</td>
<td>165</td>
</tr>
<tr>
<td>Dressing Length FG</td>
<td>321</td>
<td>309</td>
<td>-12</td>
</tr>
<tr>
<td>Raw Material</td>
<td>216</td>
<td>223</td>
<td>7</td>
</tr>
<tr>
<td>Pad coils</td>
<td>164</td>
<td>164</td>
<td>0</td>
</tr>
<tr>
<td>Dressing Length rewind</td>
<td>77</td>
<td>101</td>
<td>24</td>
</tr>
<tr>
<td>Support coils</td>
<td>69</td>
<td>69</td>
<td>0</td>
</tr>
<tr>
<td>Silicone paper coils</td>
<td>62</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>Coated coils</td>
<td>50</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3.948</strong></td>
<td><strong>4.081</strong></td>
<td><strong>133</strong></td>
</tr>
</tbody>
</table>

Table 5.2: Time comparison between scenarios 2 and 3.

5.2.4.1.2 Automation of the packaging process

In this situation, the palletizing system is supporting the same machines than in the previous scenario (PS1, PS2, PS3, PD1 and PD2), so the fraction of the total production covered is the same 94.1%.

5.2.4.1.3 Impact on the current process

Apart from the palletizing system, eleven machines have been moved from one building to the other. Three of these machines are big ones and need more time to be transported (see section 5.2.4.2 for explanation) and the whole section of dressing length have been transported from PA to PB. Therefore, the impact on the process is considered high.

5.2.4.1.4 Investment

The total investment of this scenario is €999.731. Remember that the aim of this scenario was to reduce the cost of the palletizing system respect the previous one. It has been
reduced from €1.072.523 to €914.901 by reducing the longitude of conveyor belts. However, scenario 3 has the movements of machines which increase the investment. Due to that the reduction is not so important.

5.2.4.2. Evaluation

Apart from palletizing automatically the 94,1% of the production, this option achieves a reduction in the investment because the palletizing system is much more compact than in scenario 2. But this improvement has some repercussions in other variables. First of all, eleven machines have been moved from one building to another. Moving one machine doesn't mean only the transport to its destination; it has to be dismantled, transported part by part, reassembled and finally it has to be readjusted until it works properly again.

Small machines can be moved much more easily than big ones because they can be transported practically in one block or dismantled in few parts. On the contrary, big machines like PD1, PD2 and PS4 need more time to be dismantled, transported, reassembled and adjusted. Even though machines would be moved in stages, not at once, in this scenario, an important part of the process would be affected by the changes and interrupted during a period of time while the machines are being moved. As a result of that, the company must anticipate the production of this period of time in order to continue serving the demand. This will cause an increase in the stock level, which from an economic point of view is not an investment but a cost. For this reason has not been taken into account in this first study but will be calculated in the second study.

This scenario has another complication related to the rewind material. This material is produced (slitting machines) and stored in PA. But now, because the covering machines have been moved, part of it has to be consumed in PB. This situation is especially inconvenient in the case of pad rewind. Although is more costly than before, pallets of coated and silicone paper rewind could be moved in an outdoor transport from PA to PB. But pad rewind uses trolleys instead of pallets, and theoretically the company doesn’t use trolleys in outdoor transports. The company wants conserve the use of trolleys in this materials because it is part of the pad kanban system. One possible solution could be transferring the pad rewind from trolleys to pallets before sending them to the covering machines in PB. But this is an operation that also supposes a cost.

Other inconvenient is the separation of machines PS4 and PS5 in different buildings. Although PS4 has a higher production, these two machines are very similar and share some materials so it separation is a disadvantage. For the same reason, the movement of the big packaging machines of dressing (PD1 and PD2) near the big packaging machines of strips (PS1,PS2 and PS3) is seen for the company as an advantage. For example, in case of
breakdown, maintenance staff from building PB is more specialized in repairing this family of machines than maintenance staff from building PA.

5.2.5. Scenario 4

5.2.5.1. Definition

The lay-out of this scenario is presented in the plan 10 of appendix N. This is a special scenario which has been created to find out if the time needed to transport rolls of strips can be reduced implementing a kanban of strips in PB. As it has been said previously, the company has already kanban systems in its process and they provide benefits such as stock reduction, flexibility, simpler planning and reduction of movements. In this scenario there isn’t any palletizing system because we wanted to know the effect of the strips kanban alone.

Remember than in the current-state situation, rolls of strips are carried from the strip formation machines in PA (where they are produced), to WH (to store them), and finally from WH to packaging machines in PB (where they are consumed). In this scenario, some strip formation machines are moved to PB, so rolls of strips are produced in this building. These strips are also stored in PB and consumed by packaging machines (that are in the same building) using a kanban system.

There are fourteen strip formation machines (from F1 to F14) but three of them (F12, F13 and F14) have been initially discarded for the kanban system because they do special processes. There isn’t enough space for the remaining eleven machines and the company is not interested in implementing a kanban with all of them. For this reason we have chosen to include in the kanban system six machines with great productions (F1, F2, F3, F5, F6 and F9); these machines produces about 80% of the amount of strips that the eleven normal forming strips machines (F1 to F11) manufacture.

This part of the production of rolls of strips that are included in the kanban are going to be placed and transported using trolleys instead of pallets; as it happens in the dressing length kanban. These trolleys with the rolls of strips will be stored against the superior wall of building PB (see plan 10 of appendix N).

5.2.5.2. Criteria

5.2.5.2.1 Transport time reduction

The total time calculated by the programme Evaluator is 4.491 hours, which is a 5.3% reduction from the current-state time. The following table shows de differences in time between this scenario and the current situation; time used in strips rolls decreases 354 hours thanks to the kanban, but this reduction is affected by the increase of rewind time, because
pad, coated and silicone paper rewind are slit and stored in PA but now has to be moved to strip formation machines in PB.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Current-state TIME [hours]</th>
<th>Scenario 4 TIME [hours]</th>
<th>Time difference Scenario4 – Current-state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging Material</td>
<td>1.306</td>
<td>1.310</td>
<td>5</td>
</tr>
<tr>
<td>Strips FG</td>
<td>1.091</td>
<td>1.091</td>
<td>0</td>
</tr>
<tr>
<td>Strips rolls</td>
<td>689</td>
<td>335</td>
<td>-354</td>
</tr>
<tr>
<td>Dressing Length FG</td>
<td>605</td>
<td>605</td>
<td>0</td>
</tr>
<tr>
<td>Rewind</td>
<td>414</td>
<td>488</td>
<td>74</td>
</tr>
<tr>
<td>Raw Material</td>
<td>216</td>
<td>242</td>
<td>26</td>
</tr>
<tr>
<td>Pad coils</td>
<td>164</td>
<td>164</td>
<td>0</td>
</tr>
<tr>
<td>Dressing Length rewind</td>
<td>77</td>
<td>76</td>
<td>-1</td>
</tr>
<tr>
<td>Support coils</td>
<td>69</td>
<td>69</td>
<td>0</td>
</tr>
<tr>
<td>Silicone paper coils</td>
<td>62</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>Coated coils</td>
<td>50</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4.742</strong></td>
<td><strong>4.491</strong></td>
<td><strong>-251</strong></td>
</tr>
</tbody>
</table>

Table 5.3: Transport time comparison between scenario 4 and current situation.

5.2.5.2.2 Automation of the packaging process

As it has been said previously, this scenario hasn't got a palletizing system because we wanted to see the effect of the kanban of strips working alone.

5.2.5.2.3 Impact on the current process

Here, the only difference in the process from the current situation is the implementation of the kanban of strips. Though it's only one change, it will modify the functioning of this part of the process and it is a complex project so the level of impact given to this option is medium.

5.2.5.2.4 Investment

The investment in this case is €28.080; it is much lower than in the other scenarios because it doesn't have a palletizing system.

5.2.5.3. Evaluation

The aim of this option is to find out if the implementation of a kanban of strips would provide a time reduction. The reduction in time obtained, may not seem very important, but it is only one of the advantages of the kanban of strips. Apart from that, it would reduce the level of stock, increase the flexibility of the production process and make easier the planning of the machines related to the kanban. For these reasons this kanban is seen as a very interesting option for the company.
It is important to point out that implementing a kanban is a complex project which needs a rigorous study. For instance, apart from the number of machines in the kanban, it is crucial to determine the number or products from these machines that are included in this kanban, because this system can’t work properly with too many different products or products with very low productions. In this scenario we have done a first and rough estimation, which will be developed more accurately in future scenarios.

Like scenario 3, this one has the problem of the transport of rewinds between different buildings, and especially the pad rewind because it uses trolleys instead of pallets.

In this case, the movement of the strip formation machines from PA to PB is not a major problem. All the six machines moved are small ones, which can be transported practically in one block; so the out of work period would be short in this case. For this reason it is not necessary to consider an increase of stock.

5.2.6. Scenario 5

5.2.6.1. Definition

The lay-out of the fifth scenario can be seen in the plan 11 of appendix N and it is the result of the combination of scenarios 3 and 4. On one hand, scenario 3 has the advantage of using a compact palletizing system which covers a really big part of the total production (94.1%). On the other hand scenario 4 has a kanban of strips which could provides to the company all the benefits explained in the previous section.

As a result, scenario 5 has the big packaging machines concentrated in PB (PS1, PS2, PS3, PD1 and PD2). These machines are connected to conveyor belts which send their production to WH; where two robots palletize the secondary boxes. As it happens in scenario 3, because packaging machines of dressing length (PD1 and PD2) have been moved to PB the rest of the dressing length section (C1, C2, C3, PD3 and PD4) have to be transported to this building. That’s because this section uses a kanban of dressing length which has to be conserved.

Apart from that, six strip formation machines (F1, F2, F3, F5, F6 and F9) are moved from PA to PB, and a kanban of strips is implemented, as it happens in scenario 4. So in this case, 13 machines from PA have to be installed in PB, where there isn’t enough space; to solve that, 7 machines from PB (S4, F14, PD5, PS4, PS5, PS6 and PS7) are moved to PA. Finally, machines F4 and F12 are moved from chamber A6 to A7, but this movement have minor implications or costs because they are inside the same building and the machines are small.
5.2.6.2. Criteria

5.2.6.2.1 Transport time reduction

After being introduced in the programme Evaluator, the total time calculated has been 3.915 hours. This is a 17.5% time reduction from the current-state time (4.742h). The following table shows the difference in time between this scenario and the current situation.

Packaging material time decreases because now the big packaging machines are in PB which is nearer from WH where this material is stored, so the movements are shorter. The most important decrease is in finished goods (Strips FG and Dressing Length FG) because thanks to the palletizing system secondary boxes are transported automatically to WH. And there is also an important reduction in the Strip rolls time due to the kanban of strips. But apart from these saving, there is a remarkable increase of the rewind time. That’s because coated, pad and silicone paper rewinds are produced in PA by the slitting machines and stored in chambers A2 and A3, but they are consumed by the covering and strip formation machines, which now are placed in PB. This fact will inspire the creation of scenario 6.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Current-state TIME [hours]</th>
<th>Scenario 5 TIME [hours]</th>
<th>Time difference Scenario5 – Current-state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging Material</td>
<td>1.306</td>
<td>1.248</td>
<td>-57</td>
</tr>
<tr>
<td>Strips FG</td>
<td>1.091</td>
<td>595</td>
<td>-496</td>
</tr>
<tr>
<td>Strips rolls</td>
<td>689</td>
<td>381</td>
<td>-308</td>
</tr>
<tr>
<td>Dressing Length FG</td>
<td>605</td>
<td>309</td>
<td>-296</td>
</tr>
<tr>
<td>Rewind</td>
<td>414</td>
<td>665</td>
<td>251</td>
</tr>
<tr>
<td>Raw Material</td>
<td>216</td>
<td>256</td>
<td>39</td>
</tr>
<tr>
<td>Pad coils</td>
<td>164</td>
<td>164</td>
<td>1</td>
</tr>
<tr>
<td>Dressing Length rewind</td>
<td>77</td>
<td>116</td>
<td>39</td>
</tr>
<tr>
<td>Support coils</td>
<td>69</td>
<td>69</td>
<td>0</td>
</tr>
<tr>
<td>Silicone paper coils</td>
<td>62</td>
<td>66</td>
<td>0</td>
</tr>
<tr>
<td>Coated coils</td>
<td>50</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4.742</strong></td>
<td><strong>3.915</strong></td>
<td><strong>-828</strong></td>
</tr>
</tbody>
</table>

Table 5.4: Transport time comparison between scenario 5 and current situation.

5.2.6.2.2 Automation of the packaging process

The palletizing system covers the same machines than in scenario 3 so the part of the production packaged automatically is also the same, 94.1%.

5.2.6.2.3 Impact on the current process

This scenario has several remarkable changes in the process from the current situation. It has the palletizing system that receives the production from five machines. Twenty of the
thirty four machines have been moved from one building to the other and four of them are big ones and more costly to move. In addition, it has a kanban of strips in PB which is a complex project to develop. As a result the level impact on the process is very high.

5.2.6.2.4 Investment

The investment calculated for this scenario is €1.029.481.

5.2.6.3. Evaluation

Like scenarios 2 and 3, this option palletizes automatically great part of the production, but it obtains a higher reduction of the transport time from the current situation (17,5%). In addition, it implements a kanban of strips which is expected to provide other advantages to the company like more flexibility or stock reduction. The family of the big packaging machines (PS1, PS2, PS3, PD1 and PD2) have been concentrated in one building and PS4 and PS5 are again together with the benefits that have been explained in the evaluation of the previous scenarios. However, due to these movements strip formation machines have been separated which may represent an inconvenient.

But this scenario has other and more important downsides. The investment is very high and the production process would be severely affected by the introduction of this scenario. Apart from the palletizing system, the new kanban of strips have to be implemented and 20 of the 34 machines have to be moved from one building to the other. Four of these machines (PD1, PD2, PS4 and PS5) are considered big ones and they need more time to be dismantled, transported reassembled and readjusted. So apart from the coating and the slitting steps, all the other stages in the production process would be interrupted in some way. For this reason, before initiating the changes, the company must increase the level of stock considerably.

Finally, as it happens in scenarios 3 and 4, there is the problem with the rewinds and especially with the pad rewind; produced and stored in PA but largely consumed by the covering machines and strip formation machines which are now in PB.

5.2.7. Scenario 6

5.2.7.1. Definition

Based on scenario 5, this alternative tries to reduce the transport time and give more flexibility to the factory. As it has been said, scenario 5 has only one material with a big increase of time from the current situation; the rewind. That's because in that scenario, rewinds are produced (slitting machines) and stored in PA but consumed (covering and strip formation machines) in PB. This material flow is between different building and for this reason is more costly.
The solution proposed, which is presented in the plan 12 of appendix N, is to connect the two buildings PA and PB with a corridor. Because the products manufactured in the company are bandages that have to be applied on wounds, the corridor must completely separate the indoor ambient from outside.

Other characteristics of the corridor are its position and its width. From the point of view of material flow, the best choice is to connect both buildings in the central part, so all the points in buildings PA and PB are more or less near the corridor. Apart from that, installing the corridor in the central part of PA has another advantage. In the central part there is the chamber A5; this chamber has no machines blocking the way, and is a store point; so materials stored there, like rewinds, can be directly transported on pallets or trolleys to the covering and strip formation machines. Concerning the dimensions of the corridor, its width is five meters, and as it can be seen in the draw, it has been placed just in the outside door that the chamber A5 has.

5.2.7.2. Criteria

5.2.7.2.1 Transport time reduction

In this case the total time is 3.721 hours, which is a 21,5% reduction from the current situation. Remember that this scenario was created with the aim to reduce the time while transporting rewind from the scenario 5. Related to that, scenario 6 needs nearly 200 hours less than scenario 5; and that's mainly because the reduction of 170 hours in the transport of rewinds.

5.2.7.2.2 Automation of the packaging process

The machines automated are the same than in scenarios 3 and 5, so 94,1% of the production is palletized automatically.

5.2.7.2.3 Impact on the current process

The corridor is the unique difference between this scenario and the previous one. But this element doesn’t interrupt the process during its construction and doesn’t change the way of functioning of the process. Due to that the level given to this option is the same than in the scenario 5, very high impact.

5.2.7.2.4 Investment

The investment calculated for this scenario is €1.081.481.
5.2.7.3. Evaluation

As it happens in some of the previous scenarios, this one also palletizes automatically a great part of the production of primary boxes; but it has other advantages. Because it has been created using the information from the previous scenarios, it achieves the biggest reduction in time from the current situation (21.5%). In addition, the kanban of strips reduces the level of stock, provides flexibility and simplifies the planning. The corridor also improves the material flow connecting both productive buildings (PA and PB). It solves the problem from the scenario 5 related to the rewinds; now they can easily be transported on pallets or trolleys from its store points in chambers A2 and A5 to covering and strip formation machines in PB.

But this is a complex scenario that requires a very high investment and represents a radical change in the layout. The construction of the corridor would not affect the normal functioning of the process, but like in scenario 5 we have to consider the implementation of the palletizing system, the kanban of strips and the movements of machines.

There are two final considerations related to the corridor. Firstly, it uses the outside door which was employed to send material from PA to WH. Anyway, these materials can also be sent to WH through the outside door in A1 or through B3 crossing the corridor. Secondly, it blocks the street between buildings PA and PB. From the point of view of transport it is not a major problem because the street is only used by the transport staff to move materials between different buildings and they can use other ways. But as the following image shows, the street, which in this scenario is blocked, conduces to an evacuation point where people have to go in case of emergency. For this reason, if this scenario is implemented the location of the evacuation point must be moved to a new location.

Figure 5.1: Corridor blocking the old evacuation point and possible new location of the point.
5.2.8. Comparison of the first study scenarios

5.2.8.1. Transport time reduction

Figure 5.2: Transport time reduction of the first study scenarios.

5.2.8.2. Automation of the packaging process

Figure 5.3: Degree of automation of the first study scenarios.

5.2.8.3. Impact on the current process

Figure 5.4: Impact on the current process of the first study scenarios.
5.2.8.4. Investment

![Figure 5.5: Investment of the first study scenarios.](image)

5.2.8.5. Resume

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Transport time reduction [%]</th>
<th>Degree of automation [%]</th>
<th>Impact on the process</th>
<th>Investment [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10</td>
<td>59,7</td>
<td>Low</td>
<td>559,949</td>
</tr>
<tr>
<td>S2</td>
<td>16,8</td>
<td>94,1</td>
<td>Medium</td>
<td>1,089,353</td>
</tr>
<tr>
<td>S3</td>
<td>13,9</td>
<td>94,1</td>
<td>High</td>
<td>999,731</td>
</tr>
<tr>
<td>S4</td>
<td>5,3</td>
<td>0</td>
<td>Medium</td>
<td>28,080</td>
</tr>
<tr>
<td>S5</td>
<td>17,5</td>
<td>94,1</td>
<td>Very high</td>
<td>1,029,481</td>
</tr>
<tr>
<td>S6</td>
<td>21,5</td>
<td>94,1</td>
<td>Very high</td>
<td>1,081,481</td>
</tr>
</tbody>
</table>

Table 5.5: First study resume.

This first study has to serve to discard some ideas from these scenarios and to choose others which will be developed more profoundly in the following analysis. Scenario 1 has low impact on the process and low investment but it has been discarded because its palletizing system doesn’t cover enough production.

Scenario 2 has good marks in the first three criteria but the highest investment of all the scenarios. In addition, apart from the palletizing system, which absorbs almost all the investment, it does not have other modifications from the current situation which could introduce improvements to the factory.
Scenario 3 is a balanced option having not outstanding, but acceptable results in every criterion. For this reason this is one of the scenarios which have been selected to analyse in the second study.

As it has been said, scenario 4 is not a final solution and was created to find out the improvement in the material flow and the reduction in time that a kanban of strips could provide to the factory. Time reduction is only one of the advantages a kanban and for that reason the company is very interested in implementing this system.

Scenario 5 has a remarkable time reduction but at an important cost. Apart from a quite high investment, the process is seriously affected by its implementation because the layout changes radically. These changes are due to machines movements and the introduction of the palletizing system and the kanban of strips.

Finally, scenario 6 has some similarities with the previous one. It has even higher time reduction, but also higher investment and the process is very affected as well.

### 5.3. Second study scenarios

#### 5.3.1. Second study criteria

In this case, the first four criteria are the same than in the previous study: Transport time reduction, Automation of the packaging process, Impact on the current process and Investment. There is only one difference with the indicator “Transport time reduction”; in the first study it has been considered the time given by the Evaluator which is the transport time while moving materials. In this more profound study it has been considered the whole time, including moving materials, moving without materials and the support activity time. These times have been calculated for the current situation and for scenario 3b and 7 in the appendix G.

Apart from that, three more criteria have been included in the second study in order to do a more profound analysis.

#### 5.3.1.1. Inventory

A lean process produces what is necessary to give the customer exactly what he wants, in the amount he wants it, just when he wants it and at a competitive price [2]. To achieve this, it is necessary to eliminate the seven wastes or muda that Taiiichi Ohno identified. One of these seven types of waste is inventory, so in this criterion we will determine the effect on the stock level that the implementation of a scenario has. It will be measured by the reduction of stock in Euros from the current situation.
5.3.1.2. Modularity

As it has been seen in the previous study, the implementation of a scenario causes important changes to the factory, high investment and reduction of staff. For this reason, it is useful to know if a project has to be implemented all at once, or it could be carry out in more than one step. To determine the degree of modularity that one scenario has, we will use three levels: low if the entire scenario has to be implemented at the same time, medium if it can be implemented in more than one step and high if the scenario is very modular.

5.3.1.3. Net Present Value (NPV)

This is a common tool used to measure the profitability of a project. First of all it is necessary to know the investment and the costs and savings of each periods of time in order to find the cash flow associated to each period. After that, each cash flow is discounted back to its present value; and finally all the cash flows are summed.

- The period of study that has been considered is 10 years, divided in sub-periods of six months or semesters.
- The value of the rate of return is 7.5% and has been calculated summing the inflation and a risk element.
  - Nowadays, the inflation in Spain is around 2.5%.
  - It has been considered that this is a medium risk project. The value of the risk element for medium risk project is 5%.

5.3.2. Scenario 3b

5.3.2.1. Definition

As its name indicates, this option is based on scenario 3, which as we have seen in the first study was a balanced option but with a quite high investment. The great part of this investment is caused by the palletizing system, so we tried to reduce the cost of this element.

In scenario 3, the palletizing system was designed to cover the flow of finished goods from the most important packaging machines of the factory (PS1, PS2, PS3, PD1 and PD2). Apart from having a greater number of finished goods movements than the other packaging machines, their secondary boxes are very similar; so it is easier for the conveyor belts and the robots to work with them.

As it has been explained, normally each robot has the capacity to palletize boxes coming from maximum four different machines on four different pallets simultaneously. In scenario 3 the palletising system was covering five machines and for that reason two robots were needed.
Remember that the palletizing system, apart from the automation of the palletizing transports automatically the finished goods from the machines to the building WH. In scenario 3b, we wanted to find out if one of these machines has considerably less important flow of finished goods compared with the other. In that case, only one robot and fewer metres of conveyor belts would be required and the investment would become lower. The following table shows the number of finished goods movements from these machines to WH and the time needed to do them. This information has been obtained applying the programme Evaluator to the current situation.

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>MOVEMENTS</th>
<th>TIME [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS1</td>
<td>6.646</td>
<td>488</td>
</tr>
<tr>
<td>PS2</td>
<td>4.550</td>
<td>345</td>
</tr>
<tr>
<td>PD2</td>
<td>3.858</td>
<td>309</td>
</tr>
<tr>
<td>PD1</td>
<td>3.231</td>
<td>261</td>
</tr>
<tr>
<td>PS3</td>
<td>1.135</td>
<td>81</td>
</tr>
</tbody>
</table>

Table 5.6: Comparison of the movements and transport times of the five most important packaging machines.

Apart from the number of movements and the time required, it also important to see what percentage of the production is doing each machine. This information was presented in the Table 5.1.

Now, it is easy to see that machine PS3 is considerably less important than the other ones. All the other machines have productions two times bigger and movements and times more than three times higher than PS3. Due to its production and movements, the inclusion of PS3 in the palletizing system don’t justify having to implement two robots and many more metres of conveyor belt. So excluding this machine from the palletizing system reduces the investment without compromising too much the percentage of the production automatically palletized or the material flow.

The scenario 3b is exactly the same than scenario 3 but with this modification in the palletizing system. The lay-out of this option is presented in the plan 13 of appendix N.

5.3.2.2. Criteria

5.3.2.2.1 Transport time reduction

As it has been said in section 5.3.1, in this second study the transport time considered is not the time while moving materials but the whole transport time, including the activities “Movement with materials”, “Movement without materials” and “Support time”. The calculations used to find these figures are presented in the appendix G.
The time required to do the three activities in the current state is 16.453 hours while in scenario 3b is only 13.965 hours. This is a 13.1% reduction.

5.3.2.2.2 Automation of the packaging process

As it has been explained, the palletizing system is receiving the production from the following machines: PS1, PS2, PD1 and PD2. These four machines produced the 85.4% of the total production of primary boxes during the period of study.

5.3.2.2.3 Impact on the current process

The impact on the current process of this option is more or less the same than in scenario 3; eleven machines moved from one building to the other and the palletizing system. So the level will be considered high.

5.3.2.2.4 Investment

Due to the fact that now, only one robot is required the investment is much lower than in scenario 3. In this option the investment is €698,831. It is an important reduction if we compare this figure with the investment required in scenario 3; €999,731.

5.3.2.2.5 Inventory

This scenario hasn’t got any measure that produces a decrease in the stock level; so the inventory reduction is zero.

5.3.2.2.6 Modularity

This scenario has three stages which can be carried out separately in different periods of time.

- **Year 1 first semester:** palletizing system part 1. Implementation of the first stage of the palletizing system connecting machines PS1 and PS2.

- **Year 1 second semester:** movement of machines. It is important to notice that all the movements have to be done in the same period of time. If machines PD1 and PD2 are transported from PA to PB and covering machines remain in PA, the dressing length section is now separated. Remember that covering machines produced dressing length rewind which is consumed using a kanban system in PD1, PD2, PD3 and PD4. It this section is separated, the kanban system won’t work properly, so all the dressing length section has to be transported at once.

- **Year 2 first semester:** palletizing system part 2. Implementation of the second stage of the palletizing system connecting machines PD1 and PD2.
Due to the fact that not all the changes have to be done at once, the level of modularity considered in this scenario is medium.

5.3.2.2.7 Net Present Value (NPV)

The NPV of this scenario is €1,297,044 and it is presented in the Appendix I.

5.3.2.3. Evaluation

This scenario has been created from scenario 3 with the aim to conserve its advantages and reduce its investment. It is fair to say that this has been achieved. The investment has been significantly reduced, but it has a good transport time reduction and it palletizes great part of the production.

It has a positive value in the NPV and can be implemented in three steps so the level of modularity is medium. Its downsides are that it doesn't achieve a reduction in the inventory and that its implementation has an important impact in the process.

5.3.3. Scenario 7

5.3.3.1. Definition

This option has been created combining the advantages and good ideas from the previous scenarios and is presented in the plan 14 of appendix N. Like in scenario 3, machines PD1 and PD2 have been moved from PA to PB in order to concentrate the big packaging machines in the building which is closer to WH. By doing this, the palletizing system has to use fewer metres of conveyor belt to carry the secondary boxes to WH where they are stored. For the same reason than in scenario 3b, machine PS3 is left out of the palletizing system which is only connected to PS1, PS2, PD1 and PD2. By doing this, only one robot has to be used and the system is more compact and less expensive.

Four other machines have been moved from its original building. Machines F14, PD5 and PS6 have been transported from PB to PA because space was required to fit machines PD1 and PD2. Machine S4 has also been moved from PB to PA because the company was interested in having all the slitting machines concentrated in one place.

As it happens in scenario 6, a corridor connects buildings PA and PB in the central part. This corridor plays an important role allowing the flow of materials, especially dressing length rewind and rolls of strips, between both buildings and avoiding having to move more machines.

It has been said that dressing length section (C1, C2, C3, PD1, PD2, PD3 and PD4) cannot be separated because its machines are connected by the kanban system, and the dressing
length rewind is transported using trolleys instead of pallets. In this case, not all the dressing length section has been moved to building PB like in scenario 3. That’s because even though they are in different buildings, trolleys with dressing length can be transported from one building to the other through the corridor.

In the same manner than scenario 4, this option also has a kanban of strips. In scenario 4 we did a rough estimation in which all the production from six machines was included in the kanban of strips. This production represents about 80% of the amount of strips that the eleven normal forming strips (F1 to F11) produce. In this case, due to the fact that is the second study we will do a more profound analysis.

The design and implementation of a kanban is a complex project which is out of the scope of this final thesis. In spite of that, we have done a preliminary study in order to define and evaluate a realistic scenario and to prepare a piece of information which could be useful and developed if the kanban of strips is implemented. This information is presented in the section C.3 of the appendices.

The most important points from this preliminary kanban study are commented below. There would be ten different strips included in the kanban, which are the most produced products. These references represent 54% of the total production of strips. These strips are manufactured in 7 different machines which are F1, F3, F5, F6, F7, F8 and F9. The “Kanban part” of the production (54%) will be placed on trolleys once the strips are produced in the strip formation machines, and stored in the strips kanban store point (see plan 15 of appendix N). The rest of the production won’t suffer any modification; strips will be placed on pallets once they are produced and sent to the building WH to be stored.

In this scenario, the strips kanban store point has been located in the corridor. This point is in the middle of the way between the strip formation machines and the strips packaging machines. That’s the reason why this time the corridor is wider than in scenario 6. In scenario 6 the only aim of the corridor was to connect both buildings while in this case the scenario has to store the trolleys with the rolls of strips. There is another difference between this corridor and the one presented in scenario 6. In scenario 6, the corridor was placed just in front of the exterior door of chamber A5; in scenario 7 we wanted to conserve this door so the corridor has been moved to the left.

5.3.3.2. Criteria

5.3.3.2.1 Transport time reduction

In this case the total time required to do the three transport activities (movements with materials, without materials and support activity) is 13.574 hours, which is a 17.5% reduction from the current situation.
5.3.3.2.2 Automation of the packaging process

Like in scenario 3b, the palletizing system that this option has receives the production from machines PS1, PS2, PD1 and PD2. These four machines produce the 85.4% of the total production of primary boxes.

5.3.3.2.3 Impact on the current process

The construction of the corridor is not considered to cause major effects on the process. During this time, machines could work properly and because it is not placed in front of any door, materials could be transported normally. The impact due to machines movements is less important than in scenario 3b; because this time six machines instead of eleven have to be moved from one building to the other. But apart from that, the palletizing system has to be implemented and also the kanban of strips which could be a complex project that would require some time to work properly. For these reasons the level of impact considered in this scenario is high.

5.3.3.2.4 Investment

The investment in this scenario is €848.331.

5.3.3.2.5 Inventory

In section 1.4.5 of the appendix it has been stated that the inventory reduction due to the implementation of the kanban of strips is €116.156.

5.3.3.2.6 Modularity

This scenario has four stages that can be implemented in different periods of time:

- **Year 1 first semester**: palletizing system part 1. Implementation of the first stage of the palletizing system connecting machines PS1 and PS2.
- **Year 1 second semester**: construction of the corridor and movement of machines.
- **Year 2 first semester**: palletizing system part 2. Implementation of the second stage of the palletizing system connecting machines PD1 and PD2.
- **Year 2 second semester**: implementation of the kanban of strips.

Because this time the implementation can be done in these steps, the level of modularity is considered high.

5.3.3.2.7 Net Present Value (NPV)

The NPV of this scenario is €1,473,730 and it is presented in the appendix J.
5.3.3.3. Evaluation

This scenario achieves a considerable transport time reduction and palletizes a really important part of the factory production. In addition it reduces the inventory, has a positive NPV and can be implemented in four steps. Its downsides are that its implementation affects significantly the process and that the investment is important.

5.3.4. Comparison of the second study scenarios

The following table resumes the value that scenarios 3b and 7 have in each criterion.

<table>
<thead>
<tr>
<th></th>
<th>Transport time reduction</th>
<th>Degree of automation</th>
<th>Investment [€]</th>
<th>Impact on the process</th>
<th>Inventory reduction [€]</th>
<th>Modularity</th>
<th>NPV [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 3b</td>
<td>13,1%</td>
<td>85,4%</td>
<td>698.831</td>
<td>High</td>
<td>0</td>
<td>Medium</td>
<td>1.297.044</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>17,5%</td>
<td>85,4%</td>
<td>848.331</td>
<td>High</td>
<td>116.156</td>
<td>High</td>
<td>1.473.730</td>
</tr>
</tbody>
</table>

Table 5.7: Second study resume.

This information has been presented in a radar chart. If the scenario has bad results in one criterion, the line placed near centre of the chart. On the contrary if it has good results, the line is near the edge of the chart.
Both scenarios have the same degree of automation and the same level of impact on the process. Even though scenario 7 has higher investment than scenario 3b it also achieves higher net present value. Apart from that it is more modular because it can be implemented in four steps instead of three. Unlike scenario 3b, scenario 7 reduces the inventory due to the kanban of strips and the transport time reduction is also more important in the seventh scenario.

In addition scenario 7 has the corridor and the kanban. They represent a challenge for the company, but once they are implemented would provide important advantages to the factory which are not easy to quantify economically. These are advantages such as flexibility, better connection inside the factory and easier planning.

Taking into account the information provided by this study, scenario 7 has been selected as the final one.
6. FEASIBILITY

6.1. Economic feasibility

The net present value (NPV) of the project, described in the appendix J and also presented in the following page, proves that it is feasible economically. Although the project needs important investments the savings that occur are bigger.

The costs that appear after the implementation are not comparable to investments or the savings, so the project is economically sustainable.

The cost analyses that have been used until this moment have been carried out with the intention to reflect the reality and provide useful information for the company. For this reason they consider that the investment of the element “working staff” is formed by a trainee engineer and hours of senior engineer. This is how the project was developed, but cost analyses of final theses are often done as if the company was contracting the services of a consulting company which does the project. Regarding this issue, appendix K shows the cost analysis following this structure.
<table>
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<td>Year</td>
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<tr>
<td>Semester</td>
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<tr>
<td>S2</td>
<td>S1</td>
<td>S2</td>
<td>S1</td>
<td>S2</td>
<td>S1</td>
<td>S2</td>
<td>S1</td>
<td>S2</td>
<td>S1</td>
<td>S2</td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>Palletizing system</td>
<td>-503.937</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working staff</td>
<td>-16.830</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corridor</td>
<td>-150.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movement machines</td>
<td>-45.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Kanban strips</td>
<td>-22.500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stock Increase</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robot Energy</td>
<td>-400</td>
<td>-400</td>
<td>-513</td>
<td>-513</td>
<td>-525</td>
<td>-525</td>
<td>-538</td>
<td>-538</td>
<td>-552</td>
<td>-552</td>
<td>-566</td>
<td>-566</td>
</tr>
<tr>
<td>Savings operation workers</td>
<td>60.000</td>
<td>60.000</td>
<td>123.000</td>
<td>123.000</td>
<td>126.075</td>
<td>126.075</td>
<td>129.227</td>
<td>129.227</td>
<td>132.459</td>
<td>132.459</td>
<td>135.769</td>
<td>135.769</td>
</tr>
<tr>
<td>Savings transport staff</td>
<td>20.000</td>
<td>20.000</td>
<td>41.000</td>
<td>41.000</td>
<td>42.025</td>
<td>42.025</td>
<td>43.076</td>
<td>43.076</td>
<td>44.153</td>
<td>44.153</td>
<td>45.256</td>
<td>45.256</td>
</tr>
<tr>
<td>Savings Transport</td>
<td>831</td>
<td>831</td>
<td>1.704</td>
<td>1.704</td>
<td>1.746</td>
<td>1.746</td>
<td>1.790</td>
<td>1.790</td>
<td>1.835</td>
<td>1.835</td>
<td>1.881</td>
<td>1.881</td>
</tr>
<tr>
<td>Total Savings</td>
<td>0</td>
<td>80.831</td>
<td>80.831</td>
<td>165.704</td>
<td>169.188</td>
<td>173.331</td>
<td>173.331</td>
<td>177.577</td>
<td>177.577</td>
<td>181.930</td>
<td>181.930</td>
<td>186.391</td>
</tr>
<tr>
<td>Cash flow</td>
<td>-520.767</td>
<td>-117.655</td>
<td>-31.633</td>
<td>140.246</td>
<td>166.231</td>
<td>169.916</td>
<td>169.916</td>
<td>173.704</td>
<td>173.704</td>
<td>177.588</td>
<td>177.588</td>
<td>181.600</td>
</tr>
<tr>
<td>Discounted cash flow</td>
<td>-520.767</td>
<td>-113.402</td>
<td>-29.388</td>
<td>143.469</td>
<td>143.469</td>
<td>136.246</td>
<td>136.246</td>
<td>129.391</td>
<td>129.391</td>
<td>125.582</td>
<td>125.582</td>
<td>121.129</td>
</tr>
<tr>
<td>Cumulative Cash flow</td>
<td>-520.767</td>
<td>-113.402</td>
<td>-29.388</td>
<td>-143.469</td>
<td>-143.469</td>
<td>-136.246</td>
<td>-136.246</td>
<td>-129.391</td>
<td>-129.391</td>
<td>-125.582</td>
<td>-125.582</td>
<td>-121.129</td>
</tr>
</tbody>
</table>

**NPV** €1,473,730

Table 6.1: Net Present Value for the selected scenario.
6.2. Environmental feasibility

6.2.1. General considerations

The respect for the environment is a crucial element which must be considered when a project is developed. Respect for the environment and sustainability are also very important issues for the company being one of the pillars of its strategy.

After the implementation of the project, the process does not produce any waste that wasn’t produced before; so no additional precautions must be taken in this regard. Probably the most significant change is the introduction of the palletizing system. At the end of the life of this equipment, it must be properly dismantled in order to recycle its components.

6.2.2. Energy consumption reduction and its effects

Another issue which have to be studied is the increase or decrease in the energy consumption. As it has been said before, the implementation of the project causes a significant improvement in the material flow. Due to that, the transport of materials is more efficient and there is a reduction in the energy consumption. In spite of that, it is also important to take into account the additional consumption of electricity caused by the palletizing system. The followed to obtain the energy consumption due to the transport is presented in Appendix H. The following table shows the annual electricity consumption due to transport and the palletizing system for the current situation and for the scenario 7.

<table>
<thead>
<tr>
<th>ANNUAL ELECTRICITY CONSUMPTION</th>
<th>CURRENT SITUATION</th>
<th>SCENARIO 7</th>
<th>INCREASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Due to transport</td>
<td>19.288 kWh</td>
<td>15.811 kWh</td>
<td></td>
</tr>
<tr>
<td>Due to the palletizing system</td>
<td>0 kWh</td>
<td>8.333 kWh</td>
<td></td>
</tr>
<tr>
<td>Total Electricity consumption</td>
<td>19.288 kWh</td>
<td>24.145 kWh</td>
<td>4.857 kWh/year</td>
</tr>
</tbody>
</table>

Table 6.2: Electricity consumption comparison between the current situation and scenario 7.

As the previous table shows, after the implantation of the project, there is an increase of 4.857 kWh/year in the electricity consumption. The environmental impact of the electricity consumed depends on the energy sources used in its generation. Currently, the average CO2 emissions per kWh generated in the Spanish electrical grid is 0.24 CO2 kg /kWh.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption increase</td>
<td>4.857 kWh</td>
</tr>
<tr>
<td>Emissions CO2 kg /kWh</td>
<td>0.24 CO2 kg /kWh</td>
</tr>
<tr>
<td>CO2 Emissions Increase in kg/year</td>
<td>1.166 CO2 kg/year</td>
</tr>
</tbody>
</table>

Table 6.3: CO2 Emissions increase calculation due to electricity consumption increase.
But apart from the increase in the electricity consumption the project causes variations in the diesel consumption. Due to the improvements in the material flow, the diesel forklift truck which transports materials from one building to another is used less than before. The following table shows the diesel consumption due to transport for the current situation and for the selected scenario.

<table>
<thead>
<tr>
<th>DIESEL CONSUMPTION</th>
<th>CURRENT SITUATION</th>
<th>SCENARIO 7</th>
<th>REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Diesel consumption</td>
<td>5.006 l</td>
<td>2.862 l</td>
<td>2.144 l/year</td>
</tr>
</tbody>
</table>

Table 6.4: Diesel consumption comparison between the current situation and scenario 7.

In Europe, the density of diesel is typically 0.83 kg/litre and about 87% of this weight is carbon. Each atom of carbon weighs 12 atomic units, and when it combines with two atoms of oxygen in the combustion process it becomes CO2, which weighs 44 atomic units.

The following table takes into account the increase of emissions due to the electricity consumption and the decrease due to the reduction in diesel consumption.

<table>
<thead>
<tr>
<th>VARIATION CO2 EMISSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (Increase)</td>
</tr>
<tr>
<td>Diesel (Reduction)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Table 6.6: Total CO2 Emissions variation due to the implementation of the project.

As a result of the implementation of the project there is a reduction in the emissions of CO2 of 4.511 kg/year.

### 6.3. Social feasibility

The factory is a workplace for a lot of people; as a result, any change introduced in it must meet the legal requirements maintaining the current security conditions. It is necessary to proceed with great care and attention in order to avoid accidents with the robot. The perimeter of the robot has a security fence to prevent collisions with the staff. The
implementation of the palletizing system includes a training phase in which the staff will receive the necessary information to operate the equipment safely.

Another important element is the corridor; it must have fire protection elements to reduce the risk of fire spreading from one building to another. Apart from that, the corridor blocks the street between the two buildings. This street conduces to an evacuation point where people hav to go in case of emergency. As a result, the location of this evacuation point must be moved to a new location. The following image, which comes from plan 16 of appendix M, shows the new location of the evacuation point.

![Figure 6.1: Corridor blocking the old evacuation point and possible new location of the point.](image)

The reduction in the transports due to the improvement in the material flow is seen as an advantage. That’s because vehicles moving materials inside a factory or warehouse, where other people are working, are always a possible cause of accidents.

Vehicles moving materials inside a factory or warehouse, where other people are working, are always a possible cause of accidents. For this reason, is necessary to place mirrors in the intersections and to mark on the ground routes for workers and vehicles. Due to that, the reduction in the transport as a result of the improvement in the material flow is seen as an advantage, also from the point of view of safety.

The last point that should be taken into account is the fact that the implementation of the project includes a reduction in staff of 8 people. Regarding this issue, the schedule and stages of implementation will be adaptable to the policy defined by the human resources department.
7. IMPLEMENTATION

As it has been said the project is modular; its implementation lasts two years because it consists in four main steps which are carried out semi-annually. Technically, the project could be implemented in a shorter period of time, but it is preferable to do so during two years for the following reasons:

- The project needs a high investment which can be divided during the implementation period.
- The project introduces important changes in the production process. By introducing these modifications in stages the company has time to normalize the situation of one change before the next one happens.
- The implementation of the project causes a staff reduction. Dividing its implementation in steps makes it more adaptable to the human resources’ policy.

The four main steps that form the implementation are presented below:

- **First semester 2013**: Implementation of the first part of the palletizing system. Connecting the system to the machines PS1 and PS2.
- **Second semester 2013**: Construction of the corridor, and after that, movement of machines. It is important to understand that the movement of machines have to be done once the corridor is finished. Otherwise, machines PD1 and PD2 would have problems getting the dressing length rewind, which is stored in trolleys in the building PA.
- **First semester 2014**: Implementation of the second part of the palletizing system. Connecting the system to the machines PD1 and PD2.
- **Second semester 2014**: Implementation of the kanban of strips.

This information is presented in a chart in the following page.
### Study of the automation of the packaging/palletizing process in an adhesive dressing plant

![Implementation chart](image)

**Figure 7.1:** Implementation chart
CONCLUSIONS

The objectives of this final thesis were to characterize the material flow of the factory and to provide a solution to the automation of the palletizing process taking into account the material flow. These objectives have been achieved successfully in this final thesis.

The material flow has been thoroughly analysed using Value Stream Mapping and the Evaluator. The information provided increased the knowledge of the company and highlighted the importance of materials such as the packaging and the finished goods; and machines like the five big packaging machines. These facts corroborate the convenience to automate the palletizing process and to place the palletizing robot in the warehouse in order to improve the material flow.

Apart from that, the implementation of the project is supported by other aspects like its modularity, which is interesting because the changes introduced are important, or the flexibility of the new process thanks to the kanban of strips and the connection between both productive buildings. Regarding the kanban, a preliminary study has been carried out in the appendices in order to prepare a piece of information which could be used and developed when the company decides to implement this system in its factory.
BIBLIOGRAPHY

Bibliographic references

As they appear in the report.


As they appear in the Appendices.


Material from the internet as they appear in the report and in the appendices


Complementary bibliography

