MASTER'S THESIS

Layout Design and Cost Model Development for a Composites Manufacturing Company

Jorge Alonso Campo
2013

Master of Science in Engineering Technology
Mechanical Engineering

Luleå University of Technology
Department of Engineering Sciences and Mathematics

LULEÅ UNIVERSITY OF TECHNOLOGY

Preface

This report is the final result of the Master Thesis performed by the author during the academic year 2012-2013 at Luleå University of Technology. The work done and included here is part of an improvement plan for a manufacturing company, complemented by Brandán Villasenín Labandeira's Master Thesis, Layout Design and Short Term Production Scheduling for a Composite Manufacturing Company.

This entire project has been carried out under supervision of Torbjörn Ilar at the Department of Applied Physics and Mechanical Engeneering at Luleå University of Technology, Sweden.
I would like to take the opportunity to thank Torbjörn Ilar for his support and also express gratitude to all the members of Blatraden AB company, specially Tord Gustafsson, John Meiling and Peter Lundmark for their time and commitment with this project, it would not have been possible without them.

Furthermore, I am grateful to Gustavo Peláez, from University of Vigo, for his support and guidance and also for making possible my presence here.

Finally, I would like to send a special thanks to my parents and my family, close to me and always ready to help and support, my friends here in Luleå and there in Vigo, especially Brandán Villasenín Labandeira, for all the hours spent together dedicated to this plan.

Luleå, June 2013.

Jorge Alonso Campo

Abstract

According to a continuous improvement philosophy, the understanding and development of the production system is a basic requirement for every manufacturing company, in order to enhance their professional activity and increase their efficiency.

This understanding should be also one of the first steps for a newly established company, as it is in the case of the collaborating company for this project.

Many different issues belong to the wide area of production within an industrial company like this one and the challenge is to consider all of them with room for improvement.

Related to these many issues to deal with, one of the main decisions is to design the facility layout.

The nature of this subject matter makes that there could be more than one possible solution, being difficult to choose the best one from a theoretical approach. In that way, until the beginning of the activity is not always possible to keep in mind the whole net of relations amongst the system items.

For the reason mentioned above the development of a simulation model as accurate to physical reality as possible could be worth to show a more realistic point of view helping to the decision making process.

Many other information can be drawn from a simulation model and the author have decided to build this model and make it as helpful as possible for the company, being able to predict the system performance running different scenarios of production, changing for instance the number products produced, quantity produced per period, number of workers, working hours, operation times or layout modifications as already mentioned.

Throughout this project two different parts may be recognised. The first one has been developed in collaboration with Brandán Villasenín Labandeira and the second part has been developed by the author on his own.

In the first part mentioned three different layout alternatives will be designed and evaluated with the support of a simulation model in order to decide a new layout for the company. The implementation of the best alternative will be also a part of the objectives for this work.

Going back to the development of the production process, the knowledge of the company global costs and the impact of them in the final product is a powerful tool for the improvement of the activity performance.

According to that, the second part of this project will consist on the development of a costing model, considering all the cost elements present on the company activity. This development will make possible to determinate the real cost of the final product. In addition to that, the model will be helpful for other decision making like establishment of the sale price, control of department costs, study of trends in the costs of raw materials and other supplies and so on.

These two main subject matters will be discussed in depth throughout this project and in the results and conclusions chapters the achievement of the objectives will be analysed.

Table of Contents

1 Introduction

1.1 Background

Companies in the field of composite solutions belong to a highly dynamic market, rather young and full of expectations. Nowadays composite materials can be found on a very wide range of applications being present on many different sectors as transportation, marine, construction, electronic and electrics, aerospace or consumer goods.

The capacity of substitute many other materials, due to its design flexibility in order to achieve a particular balance of properties, offer enormous opportunities to this branch of industry.

Specifically, glass fibers composite manufacturing is dominated by small and medium sized companies like could be Blatraden AB. These companies are seeking out new areas of applications for their products, diversifying their production and internationalising their sales and purchases.

However, to support all this research and innovation, these small companies must not neglect under any circumstance their main production process, the way to keep them afloat.

Regarding that, the aim of this master thesis is to increase the process performance, allowing the company to reduce production costs, increase their quantity produced per period and developing a simulation tool to study different scenarios.

1.2 Present situation

Many different areas must be studied on a newly established company in order to achieve the best way to work on every activity.

At the moment this study is taking place, Blatraden AB must face different challenges that we will try to answer throughout this document. The nature of them is related to the recent start of the production.

Most of Blatraden AB workers are already experienced on composite manufacturing processes. Nevertheless, it is required to get used to new conditions such as new technology and machinery, new process engineering and design, new tasks on the process and so on. In additions to that, company's know how must be reconsidered constantly, even more on the very beginning of the activity. By the time the company established, they considered the current facilities as a temporary solution, until a better place could appear.

This opportunity came up close to these first facilities, in Öjebyn, popularly known as "The Composite Village" due to the location of many companies related to this branch of industry. This new location brings the opportunity to develop a new layout design and it will be studied in depth using different methods that will be described afterwards.

1.3 Purpose and Objectives

The main purpose of this Master Thesis is to improve the production system performance through the study and development of two different issues.

First of all, decide an efficient layout for the new facilities taking into account several considerations based on different methodologies and supported by the experience acquired on the current ones and the nature of the process. This part has been developed in collaboration with Brandán Villasenín Labandeira and it is also included on his Master Thesis *Layout Design and Short Term Production Scheduling for a Composite Manufacturing Company*. The objectives for this first part will be described below.

Related to that, it has been considered to build an accurate simulation model useful for the analysis of the different layout possibilities. It will be also helpful for the analysis of feasible scenarios of production and business activities.

The second point analysed will be the development of a costing model based on the cost accounting theories and studying different cost ascertainment.

In particular, a list of objectives will be settled to each one of these parts.
For the first one, the main goal is to reduce the time dedicated to transport activities during the working day, minimising the distance travelled by the workers on the production activity. To reach this objective, it must be kept in mind the sequence of operations in the process, the critical material handling amongst some workstations, the particular location for some of these workstations, the possibilities of warehousing and so on.

Considering all these factors, it is possible to notice how interesting could be to use a simulation software to display different alternatives easily and
compare the performance of the system for each case. In this way and also related to this first area of study, the goal is to build three different layout alternatives for the new facilities based on several methodologies that will be explained later on and supported by a robust, reliable and useful simulation model.

Once it has been decided to compare the layout alternatives with simulation software, amongst other tools, the objective is to make it as accurate as possible, regarding future possibilities.

The software tool that has been chosen makes possible to build a production system model with different requirements. Choose the number of workstations, change their physical characteristics with files imported from design software such as AutoCAD, define workers and measure the total distance travelled by them.

Regarding the second part of this project, the cost accounting issue, the objective will not be quantitative; its nature is to build a reliable costing model based on purchases, consumptions, labour costs and others to develop different criterion to allocate these costs to the final product.
It will be also part of the objective that this second part is useful for management tasks and decision making.

2 Methodology and Time Schedule

2.1 Methodology

Throughout this second chapter the methodology followed to carry out this project will be described. The aim of the chapter is to introduce the different stages and activities developed by the author in order to achieve the desired goals.

All the stages mentioned down below have happened in different moments and were repeated during the whole project, as it can be noted on the time schedule.
However, a logical order is followed for these activities, to complete the set of chapters that make up this project.

• Briefings and meetings.
Several briefings and meetings have been set up throughout the project amongst the different parties involved on it.
Specifically, academic advisor, members of the company acting as external supervisors and the author have met to discuss the subject matter of the project and come to agreements in all the phases of it, from the main goals to particular decisions.
These meetings and briefings have taken place either at Luleå University of Technology or at Blatraden AB facilities, in Öjebyn next to Piteå. The main topics treated on these meetings are described on the time schedule, at the end of this chapter.

• Visits to the company.
The company facilities, the operating mode of the production process, the main properties of the products manufactured and the auxiliary activities have been introduced and described deeply by the company members during different visits. The first aim of these visits was to get used to the company way to proceed. This step allowed the author to present a list of possibilities for this project, described in chapter number three, where Blatraden features are discussed.
Once the subject matter of the project and the goals were settled, the purpose of the visits changed and focused on data collection and, as it was explained just above, briefings and meetings with the company members to discuss and share different approaches.

• Theoretical information and technical resources retrieval.
After the acknowledgement and agreement about the purpose of this project, the development of these topics has been based on theoretical information and technical solutions related to this theory. Different theoretical sources have been consulted during the development of this project, as can be noted in the References chapter, most of them coming from specialized books or websites, as well as theoretical documentation received during the degree.
This theoretical information research was carried out to get a deeper understanding of the production process and also to be the basis for the solutions presented.
At the same time the information research was going on, some possibilities of applying different technical resources appeared. The techniques finally used will be introduced in chapter number three and following.
Moreover, as it was already discussed, the development of a simulation model was found to be a practical solution, not only to reach the main goals of this project but for future changes in the company.

• Development and adjustment to the company requirements.
The final step to reach the set objectives has been to use the information collected and the technical tools chosen in order to develop the most appropriate solution for the company.
Once the production process and the main properties of the company were presented, the development of a particular solution based on these parameters was the deal to achieve the results required.

2.2 Time Schedule

Id.	Task Description	Start Date	Finish Date	Duration
1	Introduction to academic advisor at LTU	03/09/2012	03/09/2012	1h
2	Theoretical information of composite materials	04/09/2012	18/09/2012	11d
3	Project possibilities discussion with academic advisor and external supervisor	20/09/2012	20/09/2012	2h
4	Study of different project alternatives	21/09/2012	05/10/2012	11d
5	Presentation of alternatives	08/10/2012	08/10/2012	1,5h
6	Final selection of project subject matter	11/10/2012	11/10/2012	1d
7	Discussion with academic advisor to decide the project sequence	26/10/2012	26/10/2012	1h
8	Visit to the company and introduction to the members	30/10/2012	30/10/2012	1d
9	Meeting with academic advisor and presentation of temporary title	05/11/2012	05/11/2012	1h
10	Introduction to Simio Simulation software	05/11/2012	26/11/2012	16d
11	Data collection at the company and visit to the new facilities	20/11/2012	20/11/2012	1d
12	Development of the first simulation model for the company	21/11/2012	07/12/2012	13d
13	Meeting with academic advisor to check first simulation model	10/12/2012	10/12/2012	2h
14	Data collection at the company and presentation of simulation model	13/12/2012	13/12/2012	1d
15	Theoretical information for layout design	14/12/2012	21/12/2012	6d
16	Development of layout alternatives and introduction in simulation model	07/01/2013	25/01/2013	15d
17	Visit to the company and presentation of layout alternatives	28/01/2013	28/01/2013	1d
18	Redesign of layout alternatives due to company requirements	29/01/2013	08/02/2013	9d
19	Visit to the company, selection of layout alternatives and discussion of second part	11/02/2013	11/02/2013	1d
20	Theoretical information for costing model development	12/02/2013	25/02/2013	10d
21	Meeting with academic advisor to show ideas for costing model development	26/02/2013	26/02/2013	2h
22	Development of costing models	27/02/2013	16/05/2013	57d
23	Data collection and presentation of costing model in development	19/03/2013	19/03/2013	1d
24	Report writing	20/03/2013	31/05/2013	53d
25	Data collection at the company	28/03/2013	28/03/2013	1d
26	Data collection at the company	15/04/2013	15/04/2013	1d
27	Introduction of data and costing model review	22/04/2013	22/04/2013	1d
28	Presentation of costing model and discussion about approaches	03/05/2013	03/05/2013	1d
29	Final project presentation to the company	17/05/2013	17/05/2013	1d
30	Corrections and preparation of presentation at LTU	15/05/2013	04/06/2013	15d
31	Presentation at LTU	05/06/2013	05/06/2013	1d

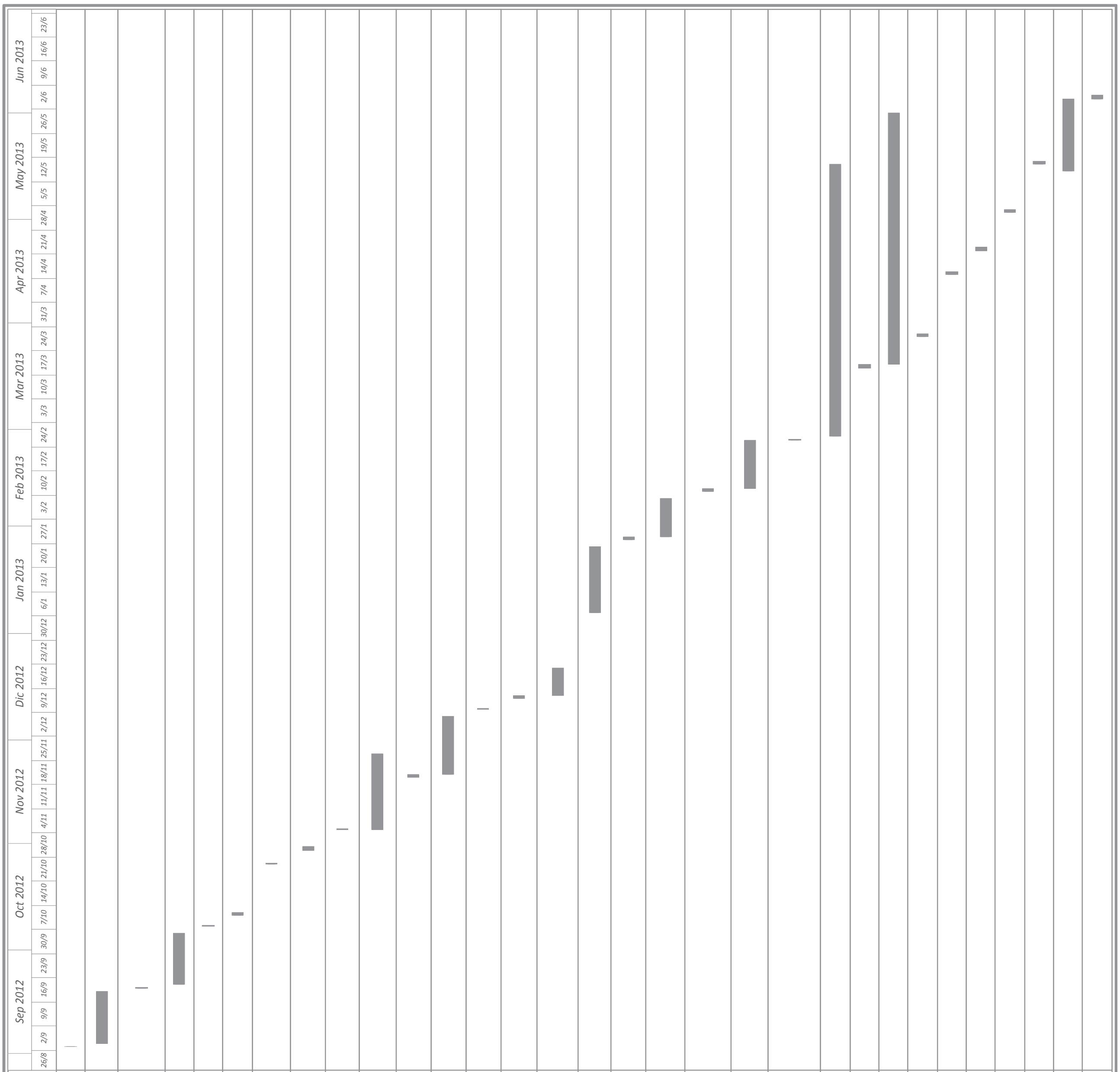

Figure 1. Time Schedule.

3 Theory

3.1 Introduction to Composite Materials. [1] [2] [3]

A composite material can be defined as a solid material composed of more than one component with a recognizable difference between them.

It is possible to think of many examples of materials that could be included on this definition, such as wood which is made of cellulose fibres and a lignin matrix or bones which are made of collagen fibres in a mineral matrix. These are some examples in nature but also human designed composites are very common nowadays: Steel reinforced concrete, asphalt mixed with sand, wind blades with shell of foam and carbon fibres reinforcement.

From these first introduction lines one can have noticed the concepts of matrix and reinforcement. To give a more accurate definition of a composite material from a technical approach it is required to refer to them.

According to that, the matrix is the continuous and homogeneous component. Its principal role is to give shape to the structure and transfer the loads to the reinforcements. Usually it also protects the fibres, reinforcements, from abrasion and environmental attacks like heat, solvents, staining agents, gases, fire, electricity, and light.

Therefore it could be very useful to find materials that can be easily shaped to satisfy product designs as polymers. Nevertheless, for some applications may be necessary to achieve high environment protection and ceramic or metal matrix could be better solutions.

One of the most important classifications on the composite materials science is done in relation to the material nature of its matrix, materials that we have mentioned above. In that case there are three different groups: Organic Matrix Composites (OMC), Ceramic Matrix Composites (CMC) and Metal Matrix Composites (MMC).

Currently the main group is the Organic Matrix Composites, which are present on over 90% of modern composite materials. This chapter will focus on this group because it is also this kind of composite materials that are used on the company processes that will be analysed further on.

Organic matrixes are also called polymers, resins or even plastics. In fact, these three terms used without distinction are slightly different.

Polymer term refers to the molecular structure where many identical units known as monomers are joined together making a chain. According to the number of monomers on the chain, the molecular weight of the polymer will be higher or lower.

The term resin is related to the polymeric material ready to be processed, it is often in liquid state and after a curing process it will be solid.
On the other hand, the term plastic makes reference to the same material but in solid state, after processing.

Within the polymeric materials, it is possible to classify either as thermoset or thermoplastic materials.

This first group are low molecular weight before curing and infusible and insoluble after curing. This group cannot be melted, thermoset become fixed with heat and if the temperature continues increasing it will finally char.
During this curing process, a three dimensions cross-linked structure is made from different chemical reactions driven by heat generation. Crosslinking between the polymeric chains is the result of these reactions and set up many important characteristics of the final state of the composite. This first group is the most common of the polymeric materials within the composites. Resins like polyesters, vinyl esters, epoxies, polyimides or phenolic are examples of these thermoset resins.

The second group, thermoplastics, are high molecular weight and commonly solid at room temperature. They do not require long curing cycle as chemical reactions do not take place and polymers remain as linear chain molecules.
One of the main aspects of thermoplastics is that they can be melted and reprocessed with heat. Some of the common thermoplastic resins include: polyethylene, polypropylene, nylon, polycarbonate, polyethylene terephthalate (PET), polyvinyl chloride (PVC), acrylic and acetal.
In relation to the applications of the final product one or another resin must be chosen, keeping in mind the use-temperature of it.
The glass transition temperature of a polymeric material is considered the maximum use-temperature of it. Although this temperature does not represent a thermodynamic phase transformation like the melting point, it is the temperature where many physical properties change rapidly; expansion coefficient, elastic modulus, viscosity or heat capacity are some of them. At this point the polymer structure is still intact but there will not be crosslinking anymore in the structure and the material may change from a rigid, glassy solid to a semi flexible and softer material.

Polymer materials may present a certain degree of crystallinity, being able to classify them between amorphous or semi crystalline according to the disposition of the molecules, randomly arranged or in orderly arrays respectively. This characteristic depends on the polymer type, molecular weight, and crystallization temperature.
The degree of crystallinity often presents a range from 30% to 90%. It is not easy to attain a hundred per cent degree because the long chain structure of this material. As higher crystallinity degree less possibilities to exhibit glass transition temperature, the physical properties do not change until the melting point.

To summarize the ideas related to the matrix it may be said that it is the bulk material, it dominates some properties of the composites, it is a polymer material in most of the composites and in this case the most important properties are related with thermal transitions. Polymers may be thermoplastics which melt with heat and they have a higher degree of crystallinity or thermoset that char with heat because of the crosslinking.

Once matrix materials and the main characteristics of them were introduced, the next step is the reinforcements of the composite.
As it was written above, the role of the reinforcements is to provide strength, stiffness and other mechanical properties to the composites.
These reinforcements may have many different shapes and can be found in the form of particles, whiskers, flakes, short fibres, long fibres or sheets.
Usually these reinforcements have a fibre shape, which means that are materials with a long axis in comparison to the other dimensions, this relation amongst dimensions is called aspect ratio. The mechanical properties provided are stronger on the direction of orientation of the fibres.
This is a design parameter that has to be considered to achieve the proper requirements, so according to the loads or forces direction fibres should be oriented on the appropriate direction.

This orientation is not only present at a macroscopic level but also the internal molecular structure is often oriented on the same direction. This property depends on the manufacturing process. If the pliable fibre is pulled in the long direction the molecules remains oriented along the length of the fibre.

For the composites manufacturing and design the most important properties are the fibre length and concentration. The higher length increases tensile strength, modulus of elasticity, flexural strength and elongation of the composite. If the fibres length is the same as the component or product, fibres are called continuous. Increasing the fibres concentration one may find the following effects on the composite: increasing of the tensile modulus and flexural strength and decreasing of the elongation. General properties of the fibres like tensile strengths, modulus or elongation are rather higher than other competitor materials like common metals.

Nevertheless there is an important property hidden under these values and it is the weight of each material. Increasingly many applications like aerospace, wind turbine blades, sporting goods need to keep mechanical properties with the lower weight possible. So it is in this area where the reason for using composites is absolutely clear. In Figure 2 we can compare the values of some important mechanical properties

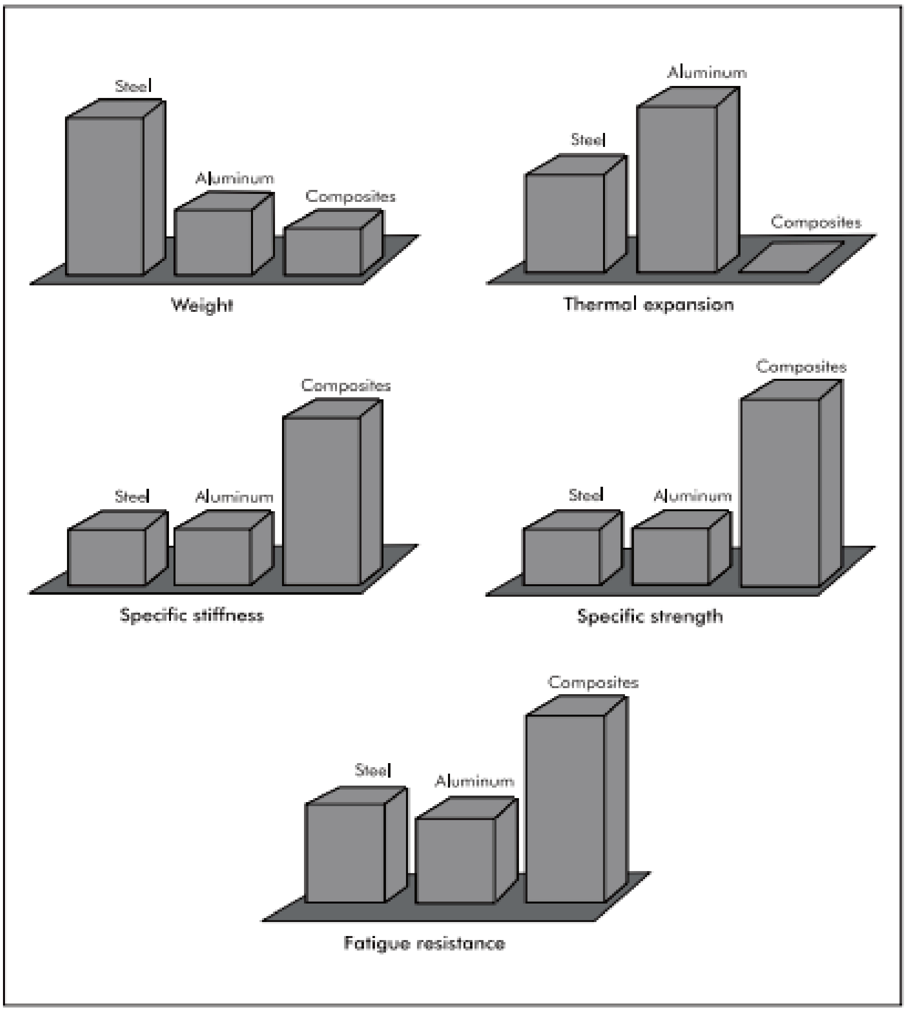

Figure 2. Mechanical properties of metals and composites.

After the general properties explanation, it is necessary to distinguish the main reinforcements used nowadays and highlight their properties.

Glass fibres, carbon fibres and organic fibres are the most important in relation to industrial and commercial applications.

Glass fibres have been used as reinforcements for a long time in History, but their use dramatically increased after World War II. It started to be used to reinforce many consumer goods like recreational boats, automobile bodies or even airplane parts. It is almost always combined with polymeric matrixes and in that way this particular combination became known as Fiberglass Reinforced Plastics (FRP), name that still remains to refer to polyester resins and fiberglass combination for composites. This kind of composite will appear further on in this document because is the type used on the company for their main process.

Fiberglass is the most common reinforcement in the industry and it is due to its low prize and excellent properties. As it was almost the only reinforcement available after WWII, it developed a high volume of use making cheaper this material. Nowadays in the consumer goods industry there is still no reason to change to other kind of fibres. However carbon fibres are used for high performance applications and their price has been dropping last years.

Common fiberglass is mainly composed of silica (SiO_2) in a 50-60% and contains other different oxides making possible to distinguish four principal types of fiberglass: E-glass, S-glass, C-glass and Quartz. E-glass is good electrical insulator, S-glass is high silica contents which allows to withstand higher temperatures, C-glass has better resistance to corrosion and Quartz fibres are made from quartz mineral and are rarely used, just for applications where its superior softening point temperature and/or superior electrical signal transparency are necessary.

As it has been mentioned before, in relation to other materials fiberglass is lighter, but it is also easier to shape, not susceptible to water corrosion and even the manufacturing cost is often less than other materials. On the other hand toughness and elongation properties may be considered by the time of material selection.

Carbon fibres are usually demanded for high performance applications where large levels of strength and stiffness are required being more important than material prizes. Industrial applications for these fibres started on the 1960's.
Originally graphite fibres were made by processing carbon fibres through an extra step of high temperature which increased mechanical properties. Nowadays all the carbon fibres are manufactured including this step so there is no difference between graphite and carbon fibres anymore. Even though, some authors have different point of view and draw a distinction in relation to the carbon contents.

These fibres are a kind of the highest representative of reinforcements; they combine high strength, high stiffness and low weight. As applications of carbon fibres are increasing rapidly, the prize is slowly decreasing, so these fibres probably will be used in many other fields more influenced by economic considerations.

Organic fibres have also an important role in the fibres manufacturing. This kind of reinforcements, based on organic chemistry, reaches high levels of stiffness and strength after manufacturing processes. From a composites manufacturing approach, the most significant results of these processes are aramid and polyethylene fibres.

Aramid fibres are organic fibres with levels of strength and stiffness between glass fibres and carbon fibres.
The name is a generic term that refers to a type of synthetic organic fibres called aromatic polyamide fibres. A famous trade name for these fibres is Kevlar®, a product of DuPont Company, used to bullet proof vests manufacturing among other uses.

Polyethylene fibres used for high performance applications are also known as ultrahigh-molecular-weight polyethylene (UHMWPE). These fibres present a high degree of crystallisation. Polyethylene is used in many ways from supermarket bags to pipes or toys, so for a high performance application different manufacturing processes are required. It is also used for ballistic protection like Kevlar®, sometimes in combination with it.

There are many other fibres in this manufacturing industry that could be named like Boron, Silicon Carbide or natural fibres like spider silk, flax or hemp as well as ceramic fibres but they play a secondary role on the composites dimension so they will not be commented on this document.

To put an end to this point in chapter three it is worth to overview what happens to the interaction between matrix and reinforcement because this bond will be critical for the material performance.
The strength of reinforcements decreases in the presence of moisture absorption and surface defects, so the surface of fibres can be treated with a sizing, finish, or coupling agent to prevent these defects and improve the matrix-reinforcement bound.

3.2 Composites Manufacturing Processes [1]

Throughout this part of the project composites manufacturing processes are going to be introduced. The aim is to explain in depth those methodologies related to the process used by Blatraden AB and the ones commonly used with thermoset matrixes because of the importance of this material over thermoplastics.
Nevertheless before getting started, it is worth to understand the importance of the reinforcements form by the time to set up a composite manufacturing process. The same reinforcements may be found in many different shapes in the fibres market, so these different alternatives will be described to know the properties of each shape and its manufacturing process.
Reinforcements are made as single filaments by a process named spinning. The liquid raw material passes through a metal die with many holes where each hole forms a single filament. This first step is almost the same for all the reinforcements used in composite manufacturing. After that, many different operations take place to produce the wide number of forms existing nowadays.
A fibre is considered to have a high aspect ratio, which is a dimension (length) much larger than the others. Practically, if the length is less than 0.5 cm it is usually called whiskers instead of fibres. If the material has a very low aspect ratio, it can be called particle, but this form is not usually considered as reinforcement in the same way as the rest.
Another possibility for the fibres once the filaments are processed is to be gathered into a group of filaments called roving for the fiberglass or tow for advanced fibres like carbon, aramid or UHMWPE. A general name for both, independently of the kind of fibre, could be strand. Finally if the strand is twisted to keep the fibres in the bundle it is called yarn.

Fibres can also be shaped through a weaving process producing woven or fabrics; they are placed on a loom between two supports and aligned in a particular direction to produce a weave. In general there is a main direction called warp or machine direction and other fibres are interwoven above and below the warp fibres.

This process is usually highly automated and many properties can be achieved changing different manufacturing parameters. This disposition of the reinforcements are often called fabrics like in the textile industry and their properties depend on those manufacturing and material parameters like type of weaves, areal weights, fabric thicknesses, thread counts, variety of fibre diameters, etc.

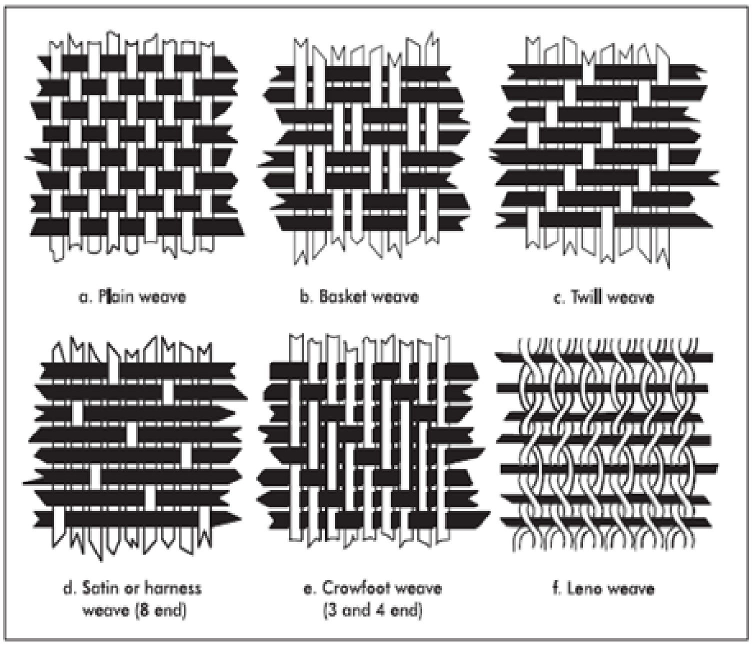

Figure 3. Different woven fabric patterns.

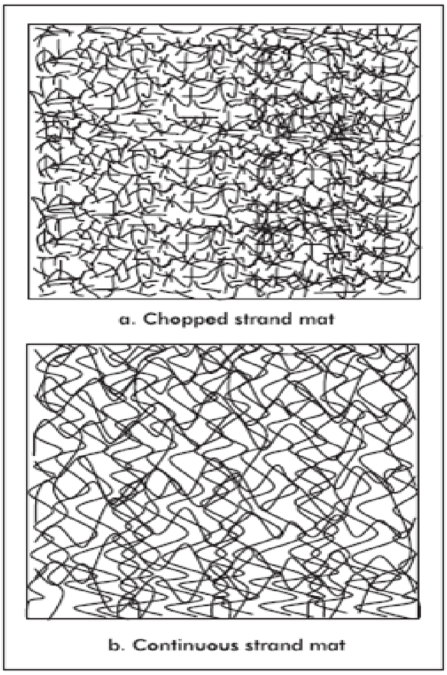

Figure 4. Non-woven fabrics.

Fabrics are not always as sophisticated as the ones commented above, and another solution is called Non-woven fabrics or mats and it consists on applying a light coating of binder to chopped or continuous fibres and dried to create a material that can be handled as a sheet. This solution is cheaper than the woven fabrics and its mechanical properties are still high especially in the continuous strand mat.
It should be noted that both woven and non-woven fabrics are used in the Blatraden AB manufacturing process as it will be discussed further on.

For more specific orientations, related to direction of loads and design requirements, another method has been developed. It consists on the placement of the filaments on the desired direction, coating them with the matrix resin. In this case the composite will be produced by adding the amount desired of these layers with no extra resin needed.
This kind of materials is called prepregs which is fibres pre-impregnated with the matrix resin. Prepregs present a degree of flexibility and stickiness that make them possible to fit to a mould. However, as it will be discussed, specific manufacturing processes are needed for them.

The last possibility of reinforcement shape that will be discussed is called preform. It consists on the manufacturing of the reinforcement with the shape of the final product. Even keeping in mind the cost is higher it makes easier and faster to place the reinforcements and also to satisfy bear of loads and other design requirements. Manufacturing efficiency, quality or economics may be some of the considerations to choose this possibility.

Moreover the manufacturing process must be considered because for some of them, like Resin Transfer Moulding, preforms may be needed to ensure that the layers do not move around in the mould during resin infusion, mould closing or curing.

Once different forms of reinforcements are commented and considering that this form makes a difference not only in the composite properties but also in the methods of manufacturing, it is time to introduce the most important composites manufacturing processes.

It is not the aim of this project to give a detailed description of each process because the purpose and objectives of it are not directly related to this, so the focus will be on the process used in the company giving a brief description for other possibilities.

This part of the chapter will be split in two groups related to the nature of the matrix, so first thermoset processes will be explained and afterwards thermoplastic processes.

The first kind of thermoset processes is called Lay-up process. This process is usually suited for low production volume of medium or large composites. It is probably the simplest solution and the first one used in the composites manufacturing. The process consists on the placement of the fibres on an open mould, wetting them with the resin. It is commonly called wet lay-up because the resin is placed almost at the same time as the fibres.

For these wet lay-up processes there are two different methods: Lay-up moulding and Spray-up moulding.

Lay-up moulding is mostly a manual process, designed for parts with complex shapes or for materials only with a few parts of composites. As it is a manual process it is possible to modify easily the nature of fibres and resins.

Before the fibres are placed in the mould the application of a release material and a gel coat is required. The first one makes possible to release the composite from the mould once the resin is cured and the second one is the outer layer of the part and will replicate the mould surface ensuring a good surface finish.

The Spray-up moulding also starts with the application of the release material and the gel coat. After that, the fibres are chopped and sprayed simultaneously with the resin over the mould.

This method is used for big sizes and simple shapes, because its main advantage is the speed with which both fibres and resin are applied to the mould.

Nevertheless there are disadvantages versus lay-up like the special spraying equipment required, the more limited choice of resins, the inability to control the direction of the fibres, high air pollution because of spraying the resin or the higher skill level needed by the operator.

For both Lay-up methods, curing is usually done at room-temperature, but it is also possible to do it at elevated-temperature. However, during the curing an exothermal chemical reaction take place and it must be considered the optimal ambient temperature.

These processing techniques are not usually applied to advanced or high performance materials; it is not possible to align the fibres in an exactly direction, it is difficult to optimize the amount of fibres and the fibres /resin ratio, essential considerations when high performance materials are chosen.

For these cases, prepregs materials are used manually or automatically depending on the piece size.

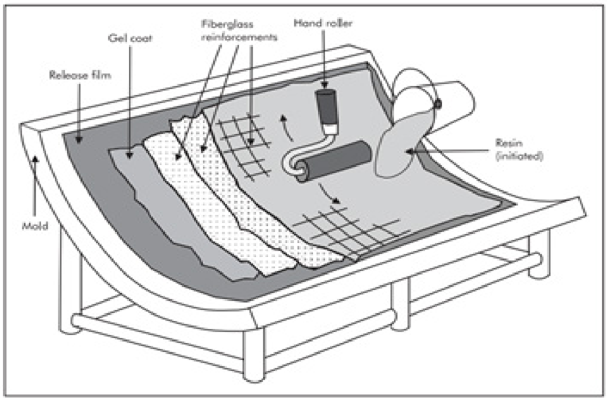

Figure 5. Hand Lay Up.

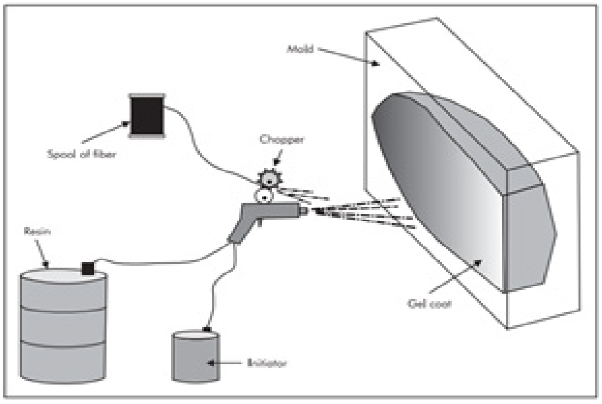

Figure 6. Spray Up.

After they are placed in the mould, the prepregs are bagged and vacuum is applied and the air between layers and volatiles are removed. The cure is mostly done by using an autoclave.

The next kind of thermoset manufacturing processes is usually known as Compression Moulding process.

Bulk Moulding Compound (BMC), Sheet Moulding Compound (SMC), Preform Compression Moulding and Prepreg Compression Moulding belong to this group and all of them use closed moulds for the manufacturing of composite material.

It is also a point in common for these four processes the fact that fibres and resins are placed on the female mould and then the mould is closed and pressure is applied by presses to produce a uniform layer. The material is cured under heating.

Before the description of each of the processes mentioned above, it is a shared property that presses allow fast production cycles and for that reason these processes are commonly used in automotive industry where high volumes of rather small and identical pieces are manufactured.

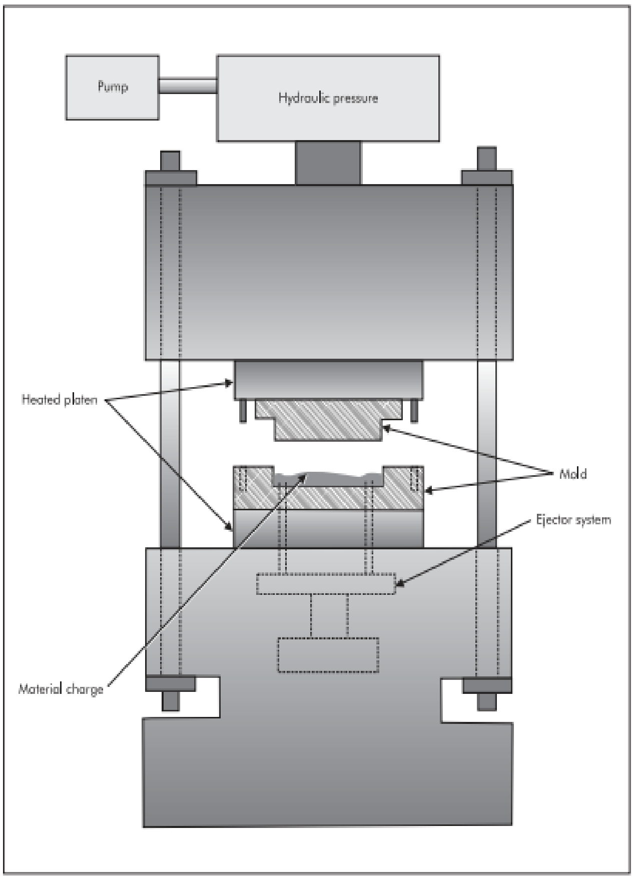

Figure 7. Compression Moulding.

These compression techniques are used in plastics manufacturing as well and even though some work after processing is required it is usually not so expensive because they are mature techniques and the amount of scrap is minimal.

Bulk Moulding Compounds and Sheet Moulding Compounds are materials where resin, reinforcements and other elements like curing agents are mixed before the manufacturing process. Both of them are mostly used for fiberglass and polyethylene composites and the main difference is how the fibres are placed.

In BMC, the fiberglass is chopped and mixed with the resin resulting a paste-like mass which is moulded by placing the male part of the mould and the material is squeezed and cured by heat transfer from the own mould. Viscosity considerations are the most important for this solution.

In SMC, the resin is applied to a carrier film and simultaneously the fiberglass is chopped on the resin. Over these fibres another identical layer of resin and carrier film is placed forming a kind of sandwich so carrier film are the external layers, then the resin and in the middle the fibres.
This compound with sheet shape is moulded by cutting off the amount of sheet required and removing the carrier film. Finally the male mould is placed and the material is cured by applying heat from the mould.

The Preform Compression Moulding is characterized by the shape of the reinforcements. The fibres are manufactured with the mould shape and the resin is added by pouring the mix onto the top of the preform with some minimal effort to evenly distribute it over the surface of the preform. Then the mould is closed, the fibres get wet and the part is cured by the heat from the mould.

Prepregs Compression Moulding is the last possibility analysed in this group. As it was discussed when prepregs were introduced, the orientation of the fibres is controlled even though minimal movements may occur when the mould is closing. This technique is used for advanced materials manufacturing, mostly with small pieces.

Still on the subject of thermoset manufacturing processes is time to analyse the one used in Blatraden AB. This process known as Resin Transfer Moulding (RTM), belongs to the Resin Infusion Processes which also includes Vacuum Infusion Processing and Resin Film Infusion.

The explanation of these processes will start pointing the common properties of all of them, so in that way later on it will be easier to remark the differences. As it happened above on this document, the focus of de description will be on the company process more than on the other ones.

In all these processes the mould is closed with the fibres placed inside but always without resin. Resin is infused into the mould after this step so fibres get wet and the curing process starts. Finally the mould is opened and the piece is removed.

Some of the advantages of this type of processes are their high repeatability of the pieces, the control of the fibres orientation, the smooth finish on both surfaces of the piece, the control over volatile emissions due to the mould is closed, the low pressure needed for the infusion, the low labour needed after the curing or the wide sizes range to produce with these processes.

Nevertheless, some disadvantages are also present, like the costs of moulds and tooling, the high quality design requirements for mould and tooling, the restricted resin choice due to viscosity, the requirement of leak-proof moulds or the difficulty to get a homogeneous wet for the fibres.

To remark the higher relevance of advantages over disadvantages it must be said that these processes have been developed constantly during the last few years showing a high acceleration on the manufacturing possibilities, considering

RTM as the lowest-cost moulding process.
Resin Transfer Moulding is also the most widely employed infusion process and even these infusion processes are often called all together under this name.

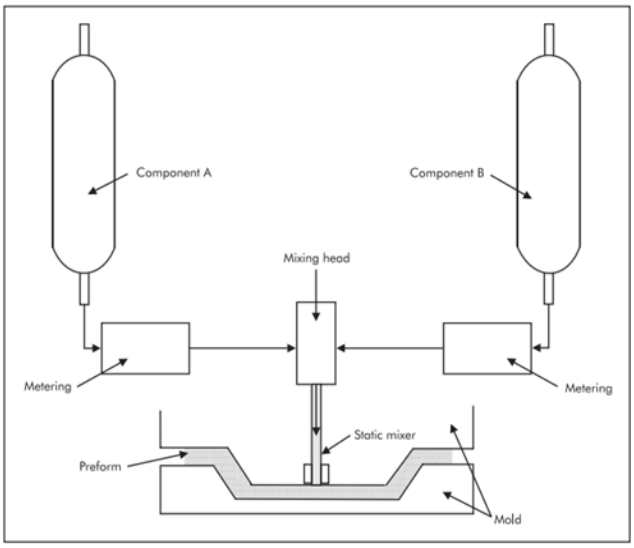

Figure 8. Resin Transfer Moulding.

This methodology was developed from different classical plastic manufacturing processes like transfer moulding and reaction injection moulding.

The principal properties of RTM are the rather moderate pressure required for the infusion, typically around 200 kPa but sometimes could reach 700 kPa. These levels of pressure call for metal moulds in the process and also allow resin to flow through difficult preforms. On the other hand, the pressure may push the fibres and move them inside the mould, defect known as fibre wash, so high quality closure devices are needed for this process. The maximum volume of fibres reaches the 55 or 60% of the piece.

Another methodology that belongs to this group is the Vacuum Infusion Process or Vacuum Assisted RTM. The main property is that vacuum pulls liquid resin into the mould instead of applying pressure to push it inside. It requires lower viscosity of the resins and lower volume of fibres, around 45%.

This solution allows the possibility of using thinner moulds than for RTM, even with composites moulds. Thin moulds cannot withstand with high or moderate pressure, but for vacuum pressures they do it well. This specific kind of Resin Infusion Processes is the one used in Blatraden AB manufacturing process.

Curing cycle times are highly dependent on the piece size and the system to apply the resin.
To control this process and ensure quality in this step, cure control additives are usually mixed with resin, like inhibitors that avoid the premature crosslinking or hardeners also known as curing agents that are chemicals used to start reaction and crosslinking.

Concentration of them in the mix is an essential design parameter for the composite manufacturing.

The last methodology considered is known as Resin Film Infusion and it is used for high viscosity resins.

These resins are usually film-like shape at room temperature, so they are placed in the mould this way and fibres are placed just over them. After that the mould is closed and heat and pressure are applied. As all of these infusion processes, the quality of the piece will be highly dependent on the tool quality.

The next process to be analysed is Filament Winding. It is the process with highest number of users and number of different pieces manufactured.

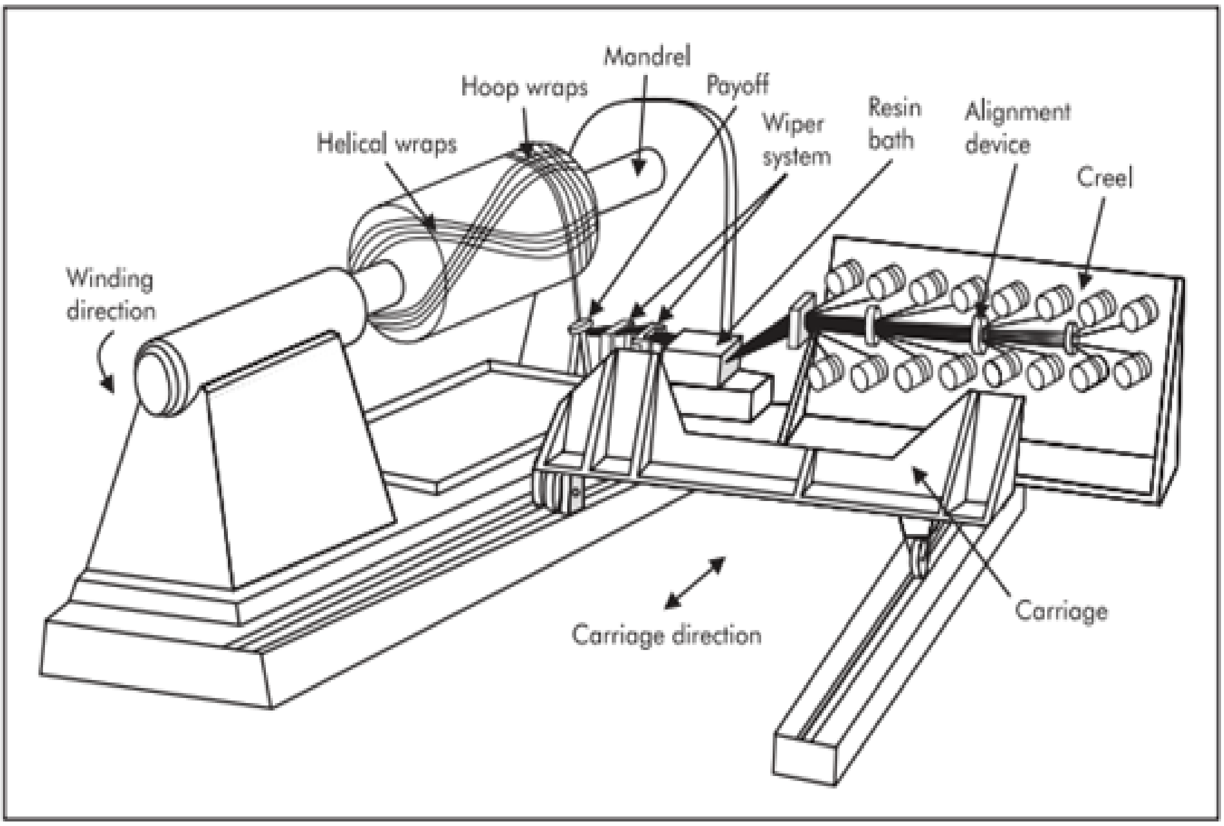

Figure 9. Filament Winding.

It is an automated process where fibres are stored in different coils or spools and mounted on a rack. Strands from all the spools are gathered and aligned with a comb or similar device making a band of fibres. After that, this band of fibres enters a resin bath where the resin was already mixed with an initiator and a hardener, chemicals in liquid state. Once fibres are wet they pass through a wiper to remove the excess of resin and then through a ring or payoff which directs the fibres onto a mandrel. All these devices are usually mounted on a carriage that commonly has one-axis movement. The movement of the carriage, the payoff and the mandrel are synchronised to wrap the wet fibres around a core with the proper pattern.

The directions or wrapping patterns are the main parameter for the process and many properties depend on that. Hoop windings, helical windings or longitudinal windings are the most common winding patterns.

Once the winding is finished, the cure is done at room-temperature, in ovens or autoclaves, with the mandrel in place. After curing the mandrel is removed or it can remain for example for vessels with reinforcement of composites. If the shape of the composite is closed the mandrel can be removed by different ways related to its properties: collapsible mandrels can collapse like an umbrella, melting mandrels can be melted keeping in mind mandrel melting temperature and composite curing temperature, water-soluble material mandrels like those made of sand with polyvinyl alcohol or soluble salts or brittle materials mandrels can also be removed easily.

The mandrel in filament winding plays the role of the mould in the processes explained just before this one. This process is one of the lowest-cost composites manufacturing process because mandrel costs are much lower than moulds. The carriage and other devices can be costly but productivity is very high and almost no labour is needed after the process. Hence, the same part made by filament winding can be half expensive that made by manual lay-up for instance.

This process is intended for making parts that have an axis of rotation and usually a convex cross section, even though different advanced solutions already exist to overcome these limitations. Pipes, tanks, industrial rollers or aircraft structures are typical products manufactured with this methodology.

The last thermoset manufacturing process that will be described on this document is known as Pultrusion which is a continuous process used to make parts of constant cross section and high manufacturing volume.

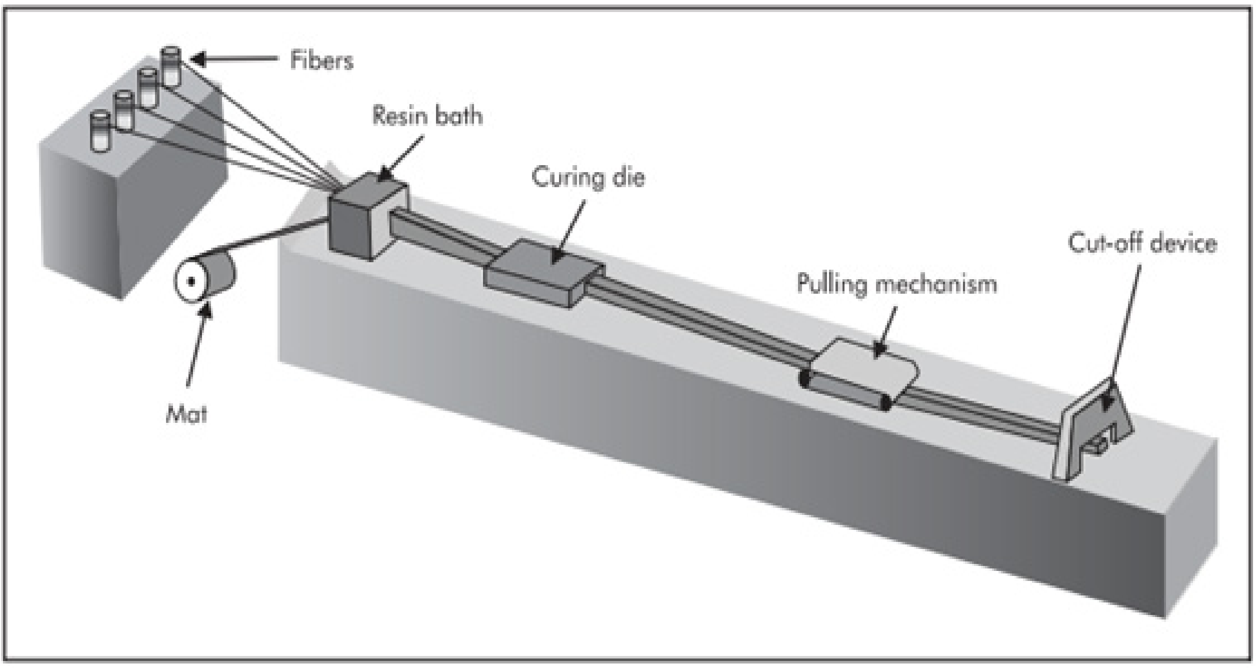

Figure 10. Pultrusion.

It is a similar process to extrusion in plastics manufacturing, except because in Pultrusion materials are pulled instead of pushed through the die. Because of its uniqueness and shape limitations of the pieces, it is not so widely practiced and machinery is still expensive.

This method starts with continuous fibres being placed on reels pulled from them and ordering these fibres to bath them on the resin mix. Secondly, fibres converge towards the die and there they get the final shape and get cured as well by heat transfer from the own die. Next, the pulling system is passed through by the fibres to reach the end of the process to a cutter and trimming station.

Even though its shape limitations and machinery costs, Pultrusion has excellent values in productivity, cycle times and scrap per part terms.

To put an end to this chapter a short overview to the thermoplastic manufacturing processes will be taken.

Thermoplastic composites can either be manufactured as classical thermoplastics when reinforcements are short or like thermoset composites making important adjustments when the reinforcements are long.

The property of being solid at room temperature makes difficult any kind of lay-up, injection or filament winding just because of the difficulties to keep the resin liquid. Prepreg lay-up is actually a consolidated process for thermoplastic and it has the advantage over thermoset that they have infinite shelf life.

Infusion methods are not common for commercial uses in thermoplastics because of the reasons explained but it is not the same for filament winding. For thermoplastic composites, the material used in winding operations is prepreg tow. The prepreg is pressured and heated at the point the winding is taking place to allow the bound of the different layers.

Pultrusion is also used for thermoplastics with some problems to solve as well. However in this method fibres and resin remain well consolidated due to the heat transferred from the die station and a good wet may be achieved.

Some thermoplastic composites moulding processes must be considered separately on this chapter because important differences are present in relation to thermoset composites.

This kind of moulding starts with thermoplastic prepreg sheets, where reinforcements have been oriented on the desired direction.
These sheets are heated in an oven to the point where the resin is softened and it will flow easily under moderate pressure but not to the point where resin melts. After that the sheets are transported to a mould where they are clamped and stretched to the desired shape.

These are the general properties and some different innovations for this process have been done but all of them are based on these main principles.

3.3 Composites Markets and Industry [1] [4] [5]

The impact of composite materials on our everyday life is easy to recognize: They are present showers, washers, dryers, tennis racquets, mountain equipment or golf clubs.

These applications are related to consumer goods, which is one of the composites markets but not the most important at all. Also fiberglass is the most used reinforcement for regular applications but carbon fibre uses are increasing and this trend makes its price lower, working both increasing uses and dropping prices as a loop that will result into a higher market expansion for carbon fibre applications.

Throughout this chapter the composites markets will be discussed as well as the composites industry structure or the influence of external forces.

To put an end to the chapter, future expectations for the different manufacturing processes will be discussed.

The first agents present in the composites industry are the fibres and resins manufacturers. Both of these main products are usually made in large plants with high production rates. Not many companies are dedicated to it due to the high entry barriers as for example the capital investment needed to begin this activity.

After the production of the raw materials, they must be combined to make the composite material. This combining step can be done prior to or during the main manufacturing process.

When this combining is done as a part of the manufacturing process, the raw materials go directly from the start point to these manufacturers.

For some applications combining must be carefully controlled like the ones using compounds or pre-impregnated fibers also known as prepregs. Intermediate companies are dedicated to the manufacturing of these materials, that later will be used by the final product manufacturer.

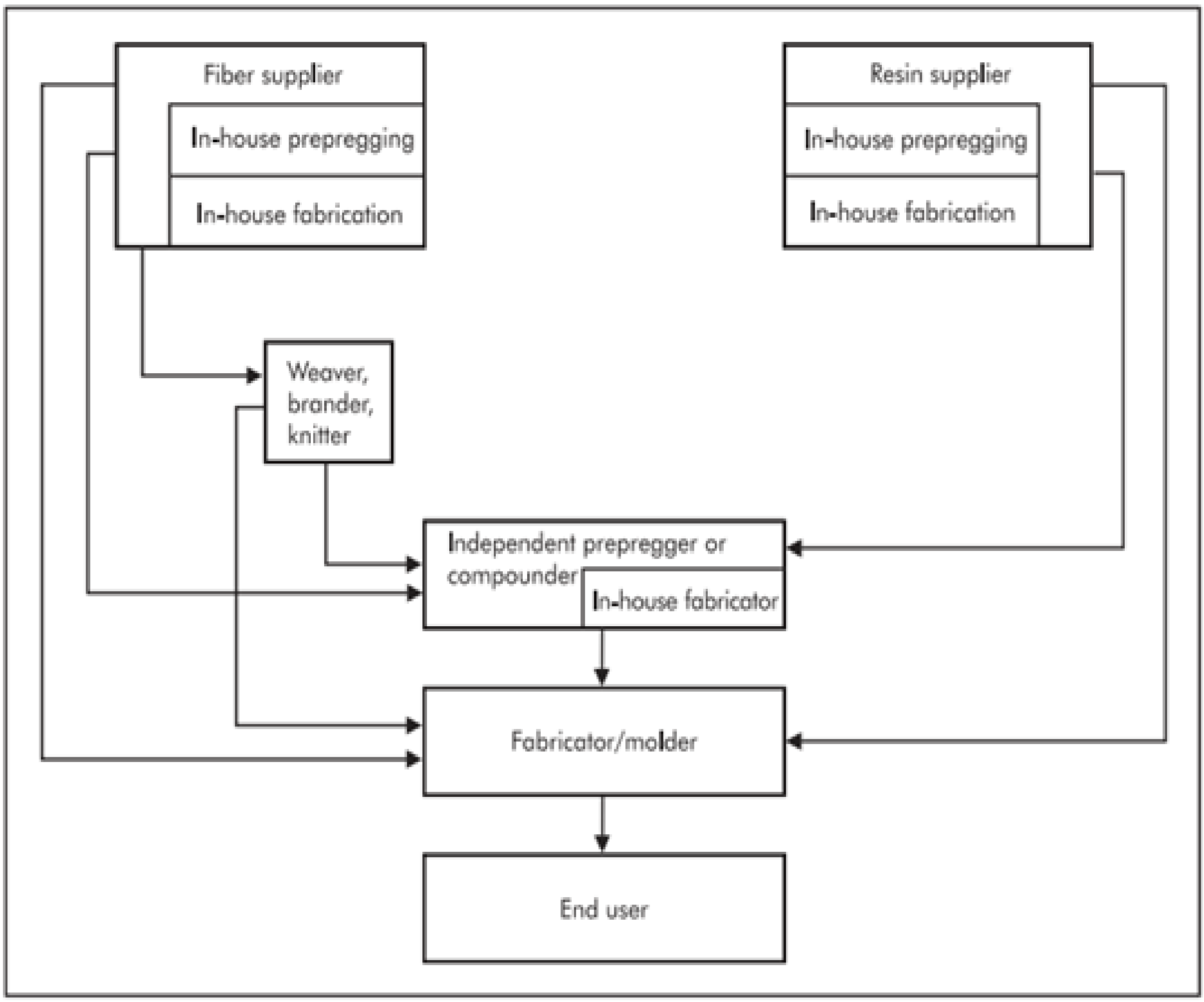

Figure 11. Composites Industry Agents.

The following figure illustrates the relations, external forces, roles and influences present in this particular industry.

Figure 12. Composites Industry Influences.

So far, many composites markets have been mentioned, but now these markets will be described in detail to understand in a better way each market application and further developments.
Transportation will be the first market analysed. This group refers to land transportation instead of marine or aerospace transportation.

The main property of light weight owned by composite materials has been always used as a reason to try to penetrate this market and turn away steel manufacturers. Nevertheless, steel manufacturers have taken actions developing new grades of high-strength steel which make possible to produce thinner parts and lighter consequently.

However not only weight savings are interesting for transportation, also the composites moulding possibilities are an advantage over metals. For highly shaped sections it is real that composites perform better than metals and also for other larger and horizontal surfaces like the trunk or the hood have been produce in carbon fibre. Freedom from rust or corrosion, parts consolidation and lower tooling costs are other interesting advantages of composites.

For these automotive applications the main processes are BMC and SMC, mostly due to the continuously lower cycle time. But also truck tractor and trailer bodies are manufactured with composites using mostly RTM to produce the cabs and pick up boxes. Weight savings and low maintenance requirements are the reasons for this branch of the transportation market.

Also crashworthiness is an important property of the composites, as it was shown in a Formula One MacLaren car for the first time. Initially the weight saving was the main reason for the choice of composites but when a crash test was made and performance was much better than metals, composites started to be the standard in F1. This behaviour is due to the higher energy-absorption potential in comparison to metals, based on the progressive collapse of the laminate layers structure.

The construction market is one of the most important markets. Low costs, light weight and lack of corrosion in addiction to high strength are the advantages over metals. Nevertheless, nowadays only covers, panels, tubs and small structure elements are made of composites.

The lack of composites performance information in big structures is stopping the applications of these materials, but many tests and research are being made to incorporate them to these big structures.

Marine applications are very common for composites as many advantages are really important on this field, like freedom from corrosion, rust, water logging, high strength and durability, minimum maintenance, availability of moulding big parts. Hence, many marine applications are currently manufactured with composites as it could be submersibles, hovercraft, mine-sweepers, sealed pontoons, outboard motor shrouds, canoes, kayaks or for marine industry hulls, decks or other structures.

Usually pipes and tanks manufacturing are so important that they are separated from construction or industrial markets. They are also called as corrosion products and they are rapidly replacing other materials like metals, concrete or fiber-cement.

They are often made of fiberglass and the matrix is dependent on the fluid or product that they are going to be used for. The highest volume-portion of this market is related to water storage or transportation. For this use polyester resins dominate.

New challenges and opportunities related to this field are associated to oil and fuel applications. There, high temperatures, high corrosive environments and abrasion are still an obstacle for regular composites. However the use of composites for oil drilling, especially in offshore wells, is expected to grow tremendously in the near future.

The electrical market uses mostly the non-conductive properties of composites. Some examples are insulators, tools for power line works or circuit boards. These circuit boards are made by bonding a conductive and a substrate material. The most used composite for substrates is glass cloth and epoxy with BMC manufacturing.

In the consumer goods market, the sports applications are the most relevant. Golf clubs, racquets (tennis, racquetball, and squash), pole-vaulting poles, archery bows and arrows, skis and ski poles, water skis, snowboards, tent poles, fishing poles, bobsleds and bobsled tracks, bicycles, baseball and softball bats or rifle barrels and stocks are good examples of the wide range of equipment produced with composites.

Stiffness, strength and weight savings are the advantages considered for these applications, where an accurate design of the loads and forces must be made to reach the required performance.
Also recreational mini-transport carts like golf carts, transporters for elderly people, factory transporters, utility carriers, dune buggies, and even some street mini-cars use composites in many of their parts.

Aerospace market does not play an important role in terms of volume representing around a 1% of the total composites marketplace. Meanwhile, the huge importance of this activity in relation to composites is based on continuous improvement and innovation. Anyhow aerospace industry is still the highest consumer of carbon fibre and applications on this field are almost always related to this reinforcement.
ngs of rocket motors, struts and other support members, decreasing considerably the total weight.

Carbon fibers are used to make the casings of rocket motors, struts and other support members, decreasing considerably the total weight. Composites for these applications must be protected from radiation and other environmental elements, so aggressive in the space.
Some aircraft parts are also made of composites especially military aircraft and helicopter parts like blades.

The second largest carbon fibres market is the industrial market. General industrial products are made with carbon fibres but there is also a place for fiberglass in this market. Wind-turbine blades are a clear example of industrial products where carbon fibres and fiberglass are manufacturing alternatives. As efficiency grows with larger blades, carbon fibre reinforcement has a better specific strength and stiffness so this is a more common solution day to day.

Robot arms or industrial rollers must be also included as important industrial products based on carbon fibres.

Currently there are other markets in ways of development like general appliances or medical applications, even though their importance is not close to the other markets analysed.

After this analysis, a look at the future possibilities will be taken to understand the potential of these different markets in the medium term. Next chart shows the situation of each of the markets in 2010 and the forecasts for 2016.

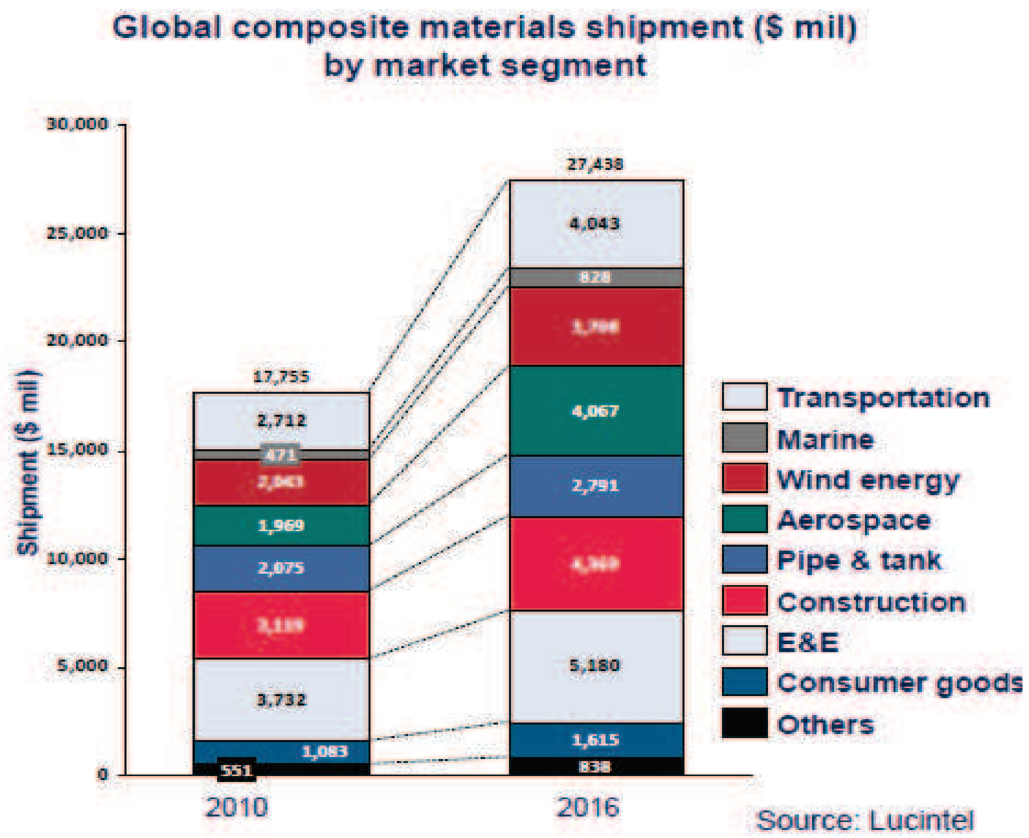

Figure 13. Composites Industry Shipment Expectations.

To highlight some aspects of the chart electronics and electrics market will remain as the most important shipment market, followed by construction. It is remarkable too the expected growth in marine, transportation and industrial markets.

Finally as the end of this point, it is presented an overview of the markets performance in 2012 classifying them by the manufacturing process.

Related to the compounds processes, after the global economic recession the demand in vehicle production fell throughout Europe and this trend was also reflected in the trend for thermoset SMC (sheet moulding compound) parts demand.

In contrast, the electrics and electronics market, with current positive trends in European countries. This is one reason why BMC (bulk moulding compound) production, which is primarily used in this sector, is growing slightly while SMC components have experienced a fall of around 5%.

The demand for parts produced using so-called open processes like hand lay-up or spray-up has generally continued to develop less well than other markets.

These manual processes suffered the greatest relative fall (9%) of any sector in the fiberglass reinforcement global market in 2012.

This particularly affects the many small companies that make individual or small numbers of parts with very little automation. The role played by automation and industrialisation of process is also an influence on this fall.

Related to the market for RTM (resin transfer moulding) and parts manufactured using this process, the substitution of open processes and increased use in automobile production promise a bright future with strong growth potential.

Moreover, improvements and adaptations of the processes subsumed under this category are the focus of a large number of research projects to develop improved and faster production cycles in high volume automobile production.

In contrast, the market for fiberglass pultrusion profiles experienced a fall of 8% last year with production volumes relatively low.

One reason for this is the significant idle capacity in the construction sector in many European countries. Construction and infrastructure are amongst the main areas of application for these products along with isolated applications in the maritime, sport and consumer goods markets.

There is also a clear decline in the manufacture of pipe and tank components using the filament winding process.

Not even strong business in the area of sewer renovation using so-called pipe liners can compensate for the lack of major infrastructure projects especially in Southern Europe.

3.4 Blatraden Company Features

After all the composites background the next step is to get closer to the company, where the main part of this project has been developed.

Blatraden AB pleasantly accepted to collaborate in the course of this project, for what the author is very grateful.

During this point a general description of the company will be done, to carry on with a look in detail at the manufacturing process. Finally some possibilities of improvement will be discussed.

Blatraden AB is a manufacturing company dedicated to the development of products based on composite materials. Keeping in mind the composites properties, they develop these manufactured products with the aim of giving to their customers the added value required.

The story of Blatraden started in 2012, when Tord Gustafsson, Peter Lundmark and John Meiling established the company in the Swedish town of Öjebyn, close to the city of Piteå.

The three of them have experience in the composite field since Gustafsson started and commanded the company APC Composite AB in 1992, Lundmark has a PhD in design methods for fibre composite materials and used to work as a composite researcher at the Swedish research institute SICOMP and Meiling has a PhD in process control, with experience in innovation-driven product development including sandwich laminate design.

The main strength of the company is the development of knowledge. As a company placed in one of the highest standard of living European countries, they will hardly compete in terms of costs in an international marketplace. Hence, what is required is knowledge of fibre composites, their processes and how they may be applied to new products.

This is also a prominent characteristic of Blatraden, their desire of looking for new applications to diversify their markets and open new doors to the composites.

Nowadays the main products manufactured are industrial bathroom equipment, specifically electrical heated bathroom floors manufactured by Vacuum Assisted Resin Transfer Moulding process.

Their one and only customer is the construction company Lindbäcks, placed in Piteå as well and dedicated to prefabricated wooden buildings.

As a new established company they have not developed yet big nets of customers and suppliers but while the production of these bathroom floors is taking place, they are also dedicating time and efforts to research, innovation and implement future solutions in fibre composites.

They have signed an agreement to develop pick up boxes for Scania trucks and also final customer goods related to construction manufactured in composites has been studied as possibilities for short term.

Related to the staff, despite temporary workers, there are currently six people working at Blatraden AB, three full time operators working in the manufacturing process, a Production and Quality Manager, a Research and Development Manager and the CEO.

As can be noted, Blatraden AB is still a small company, but highly dynamic and with many future plans and expectations.

Once the general description has been discussed, the focus will be on the manufacturing process.

Before the beginning of this part it has to be mentioned that at the start of this project only two people were working on the manufacturing process and the first approach of the simulation models were done in this situation.

As this project has been developed for one year, there have been many changes in the company that sometimes have impacted on previous considerations. These changes have been managed as well as possible and final models are completely updated to the current situation. These modifications will be discussed later on in different chapters.

According to the operations sequence, the bathroom floors manufacturing process starts with the reinforcements. Two kinds of reinforcements are used for this product both made of fiberglass. These materials are woven and mats fiberglass. As it was described at the beginning of point 3.2 this class of reinforcement shape can be handled as sheets and have high mechanical properties, specially woven fabrics.

So the reinforcements are stored in rolls from where they are cut in the shape and length needed for the floor size. Two layers of woven and four layers of mat fiberglass are required to each floor.

Once fibres are cut, the next step is to prepare the core of the floor. Actually both processes may be done at the same time, no sequence needed. The core of the floor is made by cutting parts of foam with different thicknesses that will be placed in the mould in the middle of the layers of fibres.

This disposition is called double composite or sandwich structure and the essence of it is to bear the loads present in an upright direction. Fibres layers are placed in horizontal disposition in the mould but this will not be the direction of the main loads when used. Loads will come from the upright direction, like for instance the user weight.

Hence, the core material must be able to withstand these loads but other important characteristics may help to decide the nature of this core. There are four main groups of materials and they are balsa wood, foams, honeycombs, and stitched or compressed materials.

The core used in this process is made of foam and it is covered by fibres layers before sealing the mould. The different thicknesses that have been mentioned above are related to give the floor the desired tilt to drain the water from the shower and others.

Once the cores are cut, they are placed on the robot table. The robot will be used for two different operations: first with a cutting blade draws the path of the heating cable along the core. Second, after the curing time it cuts the remains on the edges improving the surface finish of them. Nowadays this second operation is still made by hand, but in the short term the robot will be used for both.

So after the robot has finished the path, the parts of the core are glued and the heating cable is placed manually on it. After that, the moulding operations start; first the drain shape present in the mould is painted with a special painting that will paint the fibres in contact to it and will release from the mould when dried.

Afterwards layers of fibres are placed all over the mould, then the glued core with the heating cable and finally the second layers of reinforcements.
Each of these reinforcement layers are made of two layers of mat and one of woven making the total of six layers of reinforcement as it has been discussed.

Once this step is finished, the mould is closed and the mixing of the polyester and vinyl ester matrix with hardener and inhibitor products is done. It is important for the process to seal the mould properly and not to allow air going inside while the infusion is taking place. Otherwise, air bubbles will appear in the surface and the floor will have to be repaired.

This kind of matrix belongs to the thermoset matrixes, the most common in the industrial composite manufacturing and also for the VARTM process.

So with the help of a vacuum pump the infusion starts and the matrix fills the mould and wets the fibres. The mixing done triggers an exothermic chemical reaction that makes the matrix dry without any other heat requirements.

By the time the entire resin mix has been infused into the mould, the connections with the pump are closed and the mould remains for two hours of waiting without any other operation. After this time, the sealing presses and the upper part of the mould are removed and the floor is placed on a trolley.

The bathroom floor is almost finished and just the ending operations are left. To finish the product it is needed to polish the edges, make the holes for the pipes and glue the piece to connect these pipes properly.

Finally the process ends with a quality control where electric resistance of the heating cable is measured, the surface finish is analysed and some pressure and load trials are done. Once all these steps are completed, the floor is stored until it is transported to the customer.

At the beginning of the project just two operators worked in this process, with the occasional help of one of the managers. Nowadays, as it was discussed previously, another worker is helping in the process.

After the activity was observed and analysed, some improvement areas were identified. These areas are going to be discussed in two main different groups in relation to common properties.

The first group of improvement areas is related to the production process. Once the process has been introduced, it is needed to explain from the author's point of view some possible actions to develop it and improve the company competitiveness.

The lack of a standardized work in some steps of the process is one of the main aspects related to this first group. Standardized work can be defined as the way used by the worker to organise his or her tasks in a safe and efficient manner. This definition is related to the consideration of a number of organised and unified work steps for each operation in the process.

Even though the process steps are clear for the workers, the operations are not always done in the same way, causing high variability in times and material consumption.

Operations like the mixing of the resin with the inhibitor and hardener, the cutting of the foam core, the crane movement to open and close the mould or the cutting of the fibres for the drain are significantly important due to the material cost involved or for safety reasons.

Some of the benefits of standardizing the work are that it is a safe method for work as the operations are defined and documented in work sheets, potential hazards and required safety steps are clear.

This method also provides a stable and predictable work pace giving security to the operators in knowing how to do each task, it also prevents overproduction and leads to lower costs by the clear definition of the parameters of each operation reducing its wastes and times.

Related to this first improvement area, the second suggestion considered is the lack of a defined sequence of operations. After being clear that two hours of waiting are required for the curing, this would be the bottle neck of the process, it is essential to find a good way to seize this time. It is also important to know which operations can be done in parallel an which ones have to be done in serial.

The improvement in the sequence of operations impacts directly in the efficiency of the production process and many tools have been developed to improve these sequences like Gantt charts, PERT method and some variations.

Nevertheless these tools are helpful for a single process, but when the same process starts for a new product before it is finished the one before these tools become confusing and other methods can be better to get a good enough solution.

This leads to the third possibility that belongs to this first group, all related to the process features. The knowledge of the production costs as accurate as possible is significantly important for a manufacturing company. This knowledge allows to set a competitive sale price and also to focus on the most important costs in order to reduce them.

As it will be discussed afterwards there are many ways to develop a costing model but all of them can bring helpful information to the company.

Hence, a study of the different costs like labour operation times, material used and wasted per product, depreciations, rentals or general services may be done to ensure the knowledge of the right cost of the product , reduce it if needed and fix sale prices.

These two last possibilities cannot be developed without a study of times for each operation, and this study will also be done later on in this project.

To finish this first group of possible actions related to the process it may be discussed the layout modifications. At the beginning of this project, Blatraden AB was placed in a different industrial building that it is now. Once the moving out to the new facilities was confirmed, the study of the new layout was developed in mutual collaboration.

This last action is not only an improvement area like the ones before, but also an extraordinary chance to get because layout modifications, once the process is settled, are difficult to carry through.
This chance is going to be analysed further on in this project with different tools and in direct cooperation with the company. Also the theoretical support used will be discussed in a deeper way.

Also related to the production process, advanced inventory management techniques, key performance indicators systems or make or buy alternatives are other subjects that could be studied.

The second group of improvement areas embraces different aspects more related to a management approach. Anyhow in this group some quality and environmental considerations will be discussed which are obviously also related to the process.

The first subject of this group is to develop an improved marketing approach. Nowadays Blatraden AB sells their products to an only customer. Even though they are developing new products by their own and entering into cooperation agreements to develop more with important companies, it is highly risky to depend on one only customer in the current moment.

Any new competitor, internal modification of the customer process, crisis or just offshoring initiatives of this customer may cause the end of the revenues and the collapse of the company.

According to that, even with agreements signed with the current customer, a market research, market segmentation and marketing planning must be done in order to keep safety in the short term. Even if the productive capacity is not high, it is always much recommended to diversify and to look for new customers.

After these first steps are done in the marketing approach, it must be developed a competitive marketing mix, considering products offered, prices, promotions, points of sale or places, power of influence and public relationships.

This issue could be developed very long and many details must be discussed related to this approach but is not the aim of this project to focus on this part of the company activity.

Going on with this second group and also connected with the relations between the company and the business environment, a suppliers' analysis is highly recommended for a manufacturing company with high costs of raw materials.

The study and management of the purchases is also required, considering different options like websites, guides of companies like Europages or Thomas Register, catalogues, magazines, fair trades or conventions, industrial sector associations, research institutes and so on.

After choosing suppliers, an assessment of them is essential considering for instance reliability of the deliveries, level of prices, economic situation, quality guarantee, technical development, production process, environmental certifications or reaction to rush orders.

Finally in this group but in relation with the whole company, quality and environmental management is also required.

Currently the company is getting ready for ISO 9000 and 14000 certifications which is an important step to set quality and environmental management systems.

3.5 Simulation and Systems Modelling [6] [7]

After the discussion of the main Blatraden AB features, this point in chapter three will introduce the essential concepts related to simulation software and systems modelling.

As it was discussed before, the development of a simulation model for the process would bring many possibilities, not only to study the current issues treated in this project but also for the evaluation of future scenarios.

Hence, the aim of this point is to present the main theoretical bases of general systems simulation while chapter number four will introduce the particular software used to carry out the simulation and its main properties.

A very wide range of activities and applications can be embrace under the simulation term; from weather forecasts to videogames, including also physical models like remote control cars. These examples illustrate the concept of simulation as a different scale representation of a specific system.

Even though simulation is usually described like this, computer based simulation excludes physical models from that definition. Within the computer based simulation, the branch followed to develop the model is related to operation systems, which can be described as a configuration of elements or resources combined for the provision of goods or services.

These operation systems, also known as operating systems, may be considered as dynamic systems due to the importance of their progress through time.

The aim of the simulation model is not to represent the real system fully detailed. It is unlikely that a simulation model could represent the whole complexity, even more if human activity is present on it. Although, even if that were possible, it would not be desirable due to the amount of data collection needed to describe real accurate behaviour.

The real aim of the simulation model is to predict with the required accuracy the performance of the operation system under a specific set of inputs. Thus, simulation provides an experimental approach to modelling; the user enters some variable data and the model developed responds to this situation or scenario according to its parameters.

Therefore simulation models can be defined as "what-if" analysis tools, helpful to evaluate different alternatives or certain scenarios. According to that, simulation must be considered as a part of the decision support system.

Simulation techniques are not the only way to evaluate a system performance. Other modelling approaches like spread sheet models or complex mathematical programming such as linear programming, dynamic programming or genetic algorithms are also possible methods.

Regarding these techniques mentioned just above the main advantages of simulation could be described in three different points:

- Model variability: Analytical methods are not usually designed to deal with variable models and the introduction of variability makes them much more complex. Dynamic properties like equipment failures or variable process times may be difficult to model in these other possibilities.

• Restrictive assumptions: Some modelling approaches require certain assumptions like the Queuing Theory based on specific mathematical distributions for arrival and service times. Simulation instead, only requires the desire to simplify the model and a shortage of data mean.

• Transparency: Simulation is often much more user-friendly than a set of mathematical equations or a large spread sheet. It is also more intuitive and brings the user an animated display of the system.

Speaking from a manager perspective, simulation allows trying new ideas in an environment free of risks, it brings a deeper understanding of the model and it helps to visualize, communicate and choose amongst different approaches within the board of management.

However, disadvantages must also be mentioned and simulation is not an exception. Down below the most frequent disadvantages for simulation are listed:

• Economic costs: Simulation software is not often cheap itself, and the cost of the model development either if it is internal development or made by consultants is also considerably high. Moreover, time consumption does not end in there; running simulations, design new scenarios and update the models are activities required.

• Amount of data: Even though an exactly model is not the goal, a significant amount of data is often required and also difficult to obtain and to put it in a form appropriate for the simulation.

• Expertise required: Simulation modelling requires knowledge in conceptual modelling, validation and statistics, as well as project management and working with people.

However, the benefits of simulation are manifold and its common applications could be manufacturing systems, health care systems, transport systems, construction systems, natural resources, food processing, etc.

After the introduction to simulation and the discussion of the main advantages and disadvantages, the focus will be on the dynamic simulation models, specifically on the discrete-event simulation models.

A way to classify dynamic simulation models is regarding the different approaches to model the progress of time. It is not the aim of this project to describe deeply the background theory of simulation techniques and in that sense only a brief explanation of this point will be carried out. Within this classification there are three main groups:

• Time-slicing approach: Consists on the adoption of a constant interval of time to update the system. This is the simplest approach but it is not the most efficient one because there will be steps without changes and computations will be unnecessary and also the selection of the appropriate interval of time may be difficult.

• Discrete-event simulation approach: Only the points in time at which the state of the system changes are represented. In a classical queuing example, these changes or events could be a customer arrives, a customer starts receiving service or a machine is repaired.

• Continuous simulation approach: For some systems the approach discussed before simply does not represent the essential properties of the model and the state of the system changes almost continuously.

Examples of this could be the movement of fluids in tanks or pipes, chemical plants or oil refineries.
Anyhow this is a relative definition and the difference between discrete and continuous is on the interval of time considered. In the end, digital computers cannot model continuous changes in state and finally the continuous simulation approach approximates continuous change by taking small discrete intervals of time.

Henceforth only discrete-event simulation approach will be considered since it is the one required for the modelling of the company production process.

Most of the simulation software available, as the one that will be used for the development of this project, could be defined as visual interactive modelling system (VIS). This type of simulation software enables the user to develop the simulation from a predefined group of objects through a series of menus. It often provides some form of programming interface that enhances the modelling possibilities.
Other simulation software could be spread sheets or different programming languages as it was discussed before.

Many authors have defined the steps to develop a simulation project and different possibilities have appeared from that. The common points at the end are the following ones:

- Real world problem or current situation: The recognition of a problem or an opportunity existent in the real world is usually the first stage to consider the development of a simulation project to deal with it. Obviously, the nature of the problem may fit to simulation capabilities and may be feasible with the simulation techniques.

- Conceptual model: Design and develop a conceptual model is the next stage and to reach that a conceptual modelling process must be done. It means basically to develop an understanding of the problem situation, determine the model objectives, design the model and collect and analyse the data required. It is often independent from the software used.

- Computer model: Once the conceptual model is developed, the following step is to transfer it to a computer model through the software appropriate. This process called model coding does not strictly mean computer programming; it will depend on the simulation software chosen.

- Understanding and solutions: The last step is to collect the outputs from the model. To get that, experimentation must be done with the computer model, making changes as a "what-if" process. The important properties are obtaining sufficiently accurate results, performing a thorough search of potential solutions and testing the robustness of the solution, via for example sensitivity analysis.

Finally, at the end of this process, implementation must take place. This implementation can be done through three different possibilities. Implementation of the solution, implementation of the model or implementation of the learning extracted from the model.

It might be also recognized that simulation project cycle is not linear. This leads to the last steps that may be repeated making different experiments and obtaining different results and solutions before the process is ended.

Before concluding this first point related to simulation, two more concepts will be defined. Every simulation model must be verified and validated.

Verification is related to a successfully translation of the conceptual model to the software. This term makes reference to the input parameters chosen and the logical structure developed.

Validation is the determination that a model performs as an accurate representation of the real system.

For instance, a simulation model of a manufacturing plant may be verified if the production process with all the workstations, the physical dimensions, the machinery and so on are represented, but it will not be validated if real information regarding processing times, rates of failure or travelling times information is not included.

Hence, validation is usually achieved through the calibration of the model and the accuracy of this calibration will be set by the purpose of the model.

3.6 Layout Design [8] [9]

At the beginning of this project, the cooperating company had already decided to move out to other industrial facilities.

As it was discussed in the first chapter, one of the main purposes of this thesis is to design the new layout in order to improve the process efficiency and fulfill other requirements.

The chance of a new layout implementation is often dramatically difficult to get. The main reasons are related to the industrial activity that has to be stopped due to the transport of workstations, warehouses, transporters, tools, jigs, fixtures, etc.

The plant layout design consists on the physical disposition of the industrial elements that take part on the production process and also the surroundings where warehouses, transports, offices, halls and toilets must be located.

Like for any other decision-making process, it will be worth to follow a sequence of steps that will start collecting all the information possible related to it. For instance it must be clear an overall system perception of the operations and material flow from reception to shipping. It will also be important to keep in mind the specific properties of the industrial elements by the time the design is done.

This concept is related for example to special warehousing conditions like set temperature, safety conditions, noisy and dusty operations or distance to main entrances and exits.

All these considerations are usually included in the basic aims or principles of a plant layout project, which are the following ones:

- Global integration: The best layout will be the one that harmonizes operators from different workstations, materials, machinery, ancillary activities as well as any other aspect related with the ones above, giving an overall approach of the whole system.

- Minimum distance and backtracking: Layout design chases the optimum materials handling and minimum distance traveled by materials and operators. This principle is related to the industrial concept of the added value which is not associated to transport of materials along the facilities.

- Material flow and transformations: Related to the one before, the best layout on equal terms will be the one that places the workstation in the same sequence of the process.

- Cubic space: The aim is the efficient use of the available space both on workstations and on services rooms.

- Operators safety and satisfaction: Between to analogous layouts, it will always be more efficient the one that allows easier, safer and more satisfying working methods.

- Flexibility: It is significantly important the design will be flexible making as easy as possible later adjusts in order to adapt the facility to new situations.

Different situations may cause to carry the layout redesign project through; changes on the production levels, changes on the processes or the technology used on it, changes on the products or their designs or process failures are the more common ones.

Once the need for a new layout is identified, the principal steps to implement the project will be the next ones:

- Introduce the plant layout problem.
- Analyze the current design if it exists.
- Search for different design alternatives.
- Assess the alternatives.
- Select the best alternative.
- Implement the physical location.
- Tracking of the alternative.

After this introduction to a plant layout design project and once the main goals have been discussed, the following lines will explain the most common layout structures, directly related to the manufacturing system.

- Project Shop: This first possibility is characterized by the stationary disposition of the product while raw materials, operators, machinery and other elements are brought to that place. Examples of this could be the building construction, ships manufacturing and also patient surgery, in a non-industrial approach.

- Job Shop: The equipment is arranged by function and the product can follow many different paths among the workstations. The products are usually produced in low volume. Car garages, carpentries or medical laboratories are examples of that.

- Cellular Flow or Batch Flow: Equipment is arranged by process sequence that is common for a set or family of products that are produced in low or medium volume, for instance circuit boards assembly or book printing.

• Flow Shop or Line Flow: Machinery and other equipment are placed one after the other in the process order in such a way the materials follow a linear flow. Examples are automotive assembly lines and bank drive-thru services.

• Continuous Flow: Equipment is arranged by process sequence for continuous product flow. Examples include petrochemical manufacturing and paper mills.

All these different groups are in fact theoretical classifications and not every existing layout has to fit completely into one of them. Often big facilities show a combination of different ones in order to the different manufacturing units. This classification intends to illustrate general possibilities.

So far, the main goals of a plant layout design, the steps to achieve the results required and the most important groups of designs have been discussed. The next part of this chapter point will be to introduce some different tools to support the design and evaluation of the best plant layout.

These tools are often related to the different nature of the goals discussed before, so they will be classified in the following eight groups: Materials, Flow lines and paths, Operators, Machinery, Wait Factor, Build Factor, Change Factor and Service Factor.

Nevertheless and before starting with the first group, it is essential to keep in mind all the considerations that may affect to a specific layout. These tools must support the decision-making process but often they are not so powerful to introduce all the variables that have to be considered and other considerations based on the experience may be helpful as well.

The group of tools related to materials transformation is based on the knowledge of the different production steps needed to the manufacturing of the article, analyzing how the material is transformed from raw material to a final product.

The specific properties of the raw materials, semi-finished products, pieces and final products like shape, weight, volume, total quantity, chemistry properties, etc. will define the equipment needed for storage, transport and manufacturing. After the equipment is decided, an overview to the materials flow in the process is taken and documented in different diagrams or charts.

All the information related to the steps followed by the material throughout its transformation is usually collected in documents and afterwards different diagrams can be developed. ASME symbols are the common way to describe the process considering a different symbol for each of the following possible steps: Operation, Inspection, Transport, Storage and Delay.

Only the operations give added value to the product, so even though the other steps are always present they must be minimized in order to achieve a more efficient production process.

Once introduced these symbols that are used in many tools related to the different groups discussed above, the main diagrams related to material transformations are going to be described. It is important to keep in mind that this first group of tools is more helpful to understand the process sequence than to design a facility layout.

The first tool is the process diagram which is a graphical representation of the sequence of activities using the ASME symbols but without considering real times or distances. On this diagram only the different steps of the process are shown.

The second tool that might be considered for the material transformation is the bill of materials and operations.
Even though it is a production planning tool designed to check the material requirements for the process, it is also a graphical representation of the materials involved and the operations that take place from the start to the end of it.

The third tool is the analytical diagram. This diagram usually shows the path followed by a product pointing all the important activities describing them quantitatively in time or distance.

The last analytical tool in this group is called Travel Matrix, Flow Matrix or From-To Matrix. Here, columns and rows represent the different sections where material may come from or go to. This method is used when many different products are manufactured and they do not follow the same path.

This is the first tool that provides a priority in the relation between the workstations, regarding the material volume that travels from one to another.

The next factor or group of tools is related to the flow lines and paths. It is directly related to the materials transformations and in the end these tools pretend to represent the materials flow throughout the factory. These tools can be also applied to the operators' movements.

The main production flow lines may be described by one of the next configurations:

- Flow in I: It is the simplest flow way, materials are received from one side and the final products are shipped from the opposite one.

- Flow in L: Which is a similar solution considering space constrains.

- Flow in U: Entrance and exit of the process are in the same side. The monitoring is easier and distances are usually smaller from one workstation to the other.

- Flow in S: It is used in long flows where space is not enough.

- Flow in O: It is helpful for revolving systems where pieces go from one step to the other around the circle and at the end they have completed a whole group of operations.

- Comb Flow: Different flows in I end in another perpendicular flow.

All of these flows may be present on a productive system as they were introduced or in combination of them. However more important than the shape of the flow it is to minimize the distance traveled. In this group it has been considered a material movements approach but the same next considerations may be done for the distance traveled by an operator.

The most important tool for this group is the travel chart. It is a graphical representation consisting on the drawing of the movements of the materials throughout the factory or workstation plant. It is usually drawn on a real plan with a proper scale to be able to check the real distances as a complement for the analytical diagram.

It is important to remember that the materials flow between workstations does not add value to the product and as a consequence, as much handling as possible should be eliminated.

The third group is related to Operators or Labor considerations. As a production resource, operators are much more flexible than any material or machine. However, more considerations must be kept in mind by the time the layout design is taking place.

Once the quantity of operators needed for a production period has been defined, some aspects must be considered for the plant layout. Leading with the last point discussed, an operator approach of the distances traveled throughout the production process may be taken, like for the materials handling.

The travel chart for operators works the same way than for materials, considering that operator goes forward and backwards within the facilities not like the materials flow. This is the main reason that for the application of the travel chart to operators it is often used a wire and thumbtacks to track the total distance traveled from the beginning to the end of the process. If the plan scale is known, it is enough to measure the total wire nailed to the plan to know the total distance traveled.

As it will be discussed later on, simulation methods like the ones used in this project are more accurate and available nowadays.

Other considerations related to the operators and even more important for some processes are aspects related to work environment within the facilities. Levels of luminance, ventilation, noise, vibrations or temperature must be measured and not neglected by the time the layout design is developed.

Standards like British OHSAS 18001 focused on occupational health and safety management systems are helpful tools to keep safety and security in the factory bringing and standardized way to plan, do, check and act with these issues.

Machinery factor impacts on the layout design due to the following reasons:

- The number, type and properties of each machine required for the production process has to be considered. Accurate information about size, shape, weight or space needed for everyone is essential. Also the number of machines required for a production level must be studied, although it is not part of the layout design process.

- The balance and coordination among different production lines and workstations will be important by the time the location of each machine must be decided. Searching for delays and bottle necks minimization will include the right location of machines in order to be attended as soon as possible by operators. This points leads with the cellular layout.

In relation to this factor the most important tool is called Systematic Layout Planning. It was developed by the author R. Muther and it is based on three fundamental steps.

The first one is the relationships amongst the operations, considering the Travel Matrix or the Activity Relationship Chart that will be discussed further on, as the proper tools to obtain this net of relations.

The second one is the space requirements that must be measured for each workstation.

And the last one is related to the adjustment of these relations with physical dimensions to the available space.

This procedure will be described in the development chapter since this methodology will be applied for the layout design.

The Activity Chart was designed to fill the information required regarding activities relationship from a qualitative approach, being like a complement for other tools as the From-To Matrix. The Activity Relationship Chart was developed for Muther and it is based on the next steps:

- A list of the different sections is written and numbered, from the office department to the final product warehousing, going through all the process workstations.

- A grid is drawn with all the possible combinations among the sections listed before, so there is a box for each pair of sections.

- Each box is divided in two parts, where the upper part will be filled with the Proximity Rating and the lower part with the Reason Code of the rating discussed.

The Proximity Rating shows the importance of the relation between the two sections linked in this box and it is evaluated with one of the following letters: A, E, I, O, U and X.

The Reason Code is a number code from 1 to 6 where each number represents a possible reason for the Rating assigned. These reasons are standardized, as well as the Proximity Ratings.

An example of this Activity Relationship Chart is shown just below.

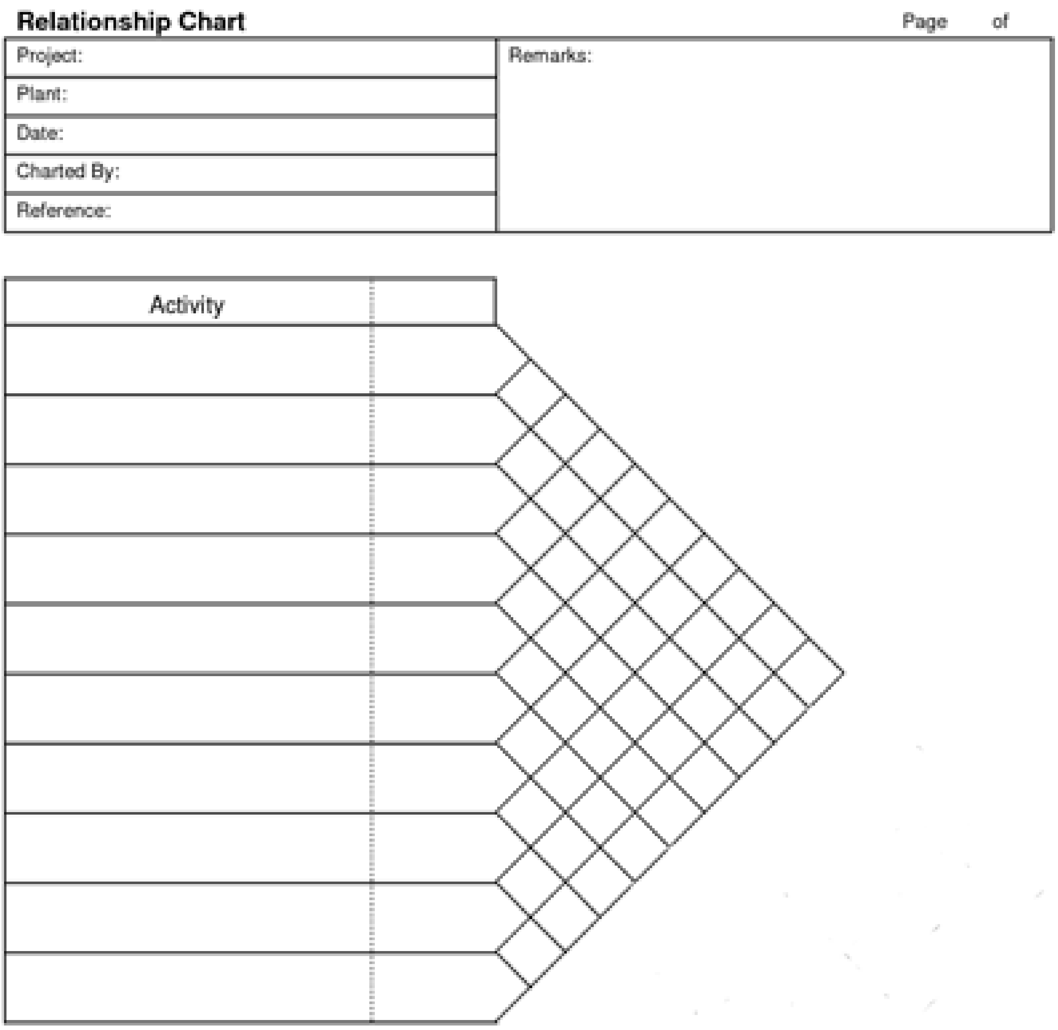

Figure 14. Activity Relationship Chart.

Once the chart is filled the qualitative information about all the relationships and the priority of them may be extracted from it.

The method is completed with the Relationship Diagram, which is the organization of these relations in the priority order. Even though there are many methods to develop this organization, in this project the one followed will be the Francis and White Method using AutoCAD computer program to design the organization of these relations. The Francis and White Method for the Relationships Diagram follows the next steps:

- Start with all the A rating relationships, placing them on a paper and drawing lines among them. Once these relations are placed, they must be reordered to keep the lines as short and straight as possible.
- Add then the E and X relationships and reorder.
- Add the I relationships and reorder.
- Add the O relationships and reorder.

It must be kept in mind that this order is based on the priority amongst the activities, so once the A relationships are ordered, they must be the last ones to be changed to fit the others. This procedure is the same for the other upper ratings over the lower ones.

This method performs properly for a limited number of sections and may bring helpful information to the designer, but it can be noted that for a big list of sections the method will not be fully functional.

Carrying on with the different factors listed, the Wait factor considers three main warehouses in every production system and start the layout design from there.
These warehouses are related to raw materials, work-in-process, and final product. The objective of the Wait factor is to determine the required space in each of the warehouses and is used for companies with a dramatically importance of the warehousing and its capability. As it is not the case for the company where this project is taking place, the tools for this group are not going to be described.

The Service factor is closely related to some aspects of the Operator factor. The first one considers plant services staff like could mainly be quality, logistics or maintenance. Minimum maneuver space for forklift, trucks or other special equipment used in these services is a typical factor. These last considerations will be used in the design but no specific tools will be described to achieve that.

Like the last one, the Building factor brings an important approach that has to be considered but not specific tools will be defined. It focuses on the building properties to choose workstation, warehousing and offices location, like plant shape, the columns, the window situation for ventilation or areas of possible extension. Also current location of cranes is a typical constraint to choose amongst layout alternatives.

Finally, the Change factor observes the adopted solution from a critical point. Future production lines, new processes, different products or material properties are some of the issues that this factor intends to analyze.
In other words, the flexibility of the alternative selected is evaluated from this point of view. As it can be noticed, this last group is a different approach but applied at the end of the design process, with the aim of make possible changes before the final implementation of the solution.

3.7 Cost Accounting and Costs Models [10] [11] [12]

After the layout design based on the methods and tools discussed previously, the second part in this project is related to the development of a costs model for the company.

This point in chapter number three will introduce concepts like cost accounting, cost centre, cost unit and elements of costs.

Also in this point different cost ascertainment methods and techniques will be discussed and a first classification of costs elements will be provided. Finally, an overview of advantages and objections to install a costing system will be done.

Starting from the accounting definition, it may be said that it is a broad meaning term possible to apply to different activities. It is always related to the purpose of providing financial information related to the business performance. This information could be oriented to the different stakeholders of a company and, according to that, three separate types of accounting must be defined: Financial Accounting, Cost Accounting and Management Accounting.

Financial accounting main purpose is to record business transactions in the mandatory books of accounts that must be presented to the tax authorities at the end of the accounting period. These books, Profit and Loss Account and Balance Sheet show the profit or loss of the company in the period considered and the financial position at a point of time respectively.

Obviously, this information may also be used by managers and other employees within the company but some limitations of this accounting activity could show the requirement of other complementary activities.

- Financial accounting shows only aggregate information of the company, it does not give information related to cost by departments, cost of products, cost by processes and so on.

- Financial accounting is related to the past. It shows the business results during a certain accounting period, usually the past year, not giving information related to daily activity.

- No performance assessment, analysis of loss or control of material and labour costs. It is focused on the results and not on the efficiency; its aim is not the improvement of the process.

- Lack of useful information. The classification of costs is often not related to the nature of the manufacturing process and it makes difficult the comparison of performance between periods and the decision making process by managers.

The purpose of cost accounting is to overcome to these limitations and build an internal costing system according to the company properties and requirements of information in order to meet the needs of management.

Cost accounting is related to the ascertainment of past, present and future product costs, considering different parameters and data obtained from the whole company.

The purpose and functions of cost accounting could be described on the following bullet points:

• Cost ascertainment: It is the main purpose and many techniques or systems may be used for this purpose according to the circumstances studied.

• Control of costs: Control the costs in order to reduce them and increase the business performance is essential for the growing competition.

• Guide for decision making: Cost accounting is developed by and for the company so it must be oriented to the management activity, supplying helpful information related to decisions like make or buy, utilisation of idle plant capacity, selling below price and so on.

• Detection of possible activities in which the company losses money.

• Determination of selling price: Cost accounting gathers the global costs of the company, so in that way it is feasible to fix the minimum selling price that covers those costs.

• Efficiency measurement and performance improvement: Classification and analysis of cost data and comparison to other periods may offer actions to keep the business performance on track and also to anticipate to problems evaluating costs elements trends.

Related to this supply information purpose for management activity raises the third accounting group. Management accounting is the concept of accounting as a tool for management. It is a broad term that makes reference to providing accounting information helpful for activities such as planning, controlling and decision making.

This management accounting is not only feed by cost and financial accounting, other sources are used for these activities like could be budgeting, forecasting, statistical tools, tax planning, internal control, internal audit and so on.
Some of the techniques used also in this issue to achieve business goals could be risk analysis, value analysis, cash flow statement, responsibility accounting, learning curve, statistical and graphical techniques, etc.

As it has been discussed, it is not the aim of this project to establish a management accounting system, so these techniques and sources mentioned before will not be explained throughout this document.
After this general accounting explanation, this theoretical point will be focused in the cost accounting. Different definitions will be explained in the following lines.

Starting with the cost concept, its scope is extremely broad and general. It is difficult to give an accurate definition that could fit to all the uses of this term. In general business environment is related to a measurement, in the end in monetary terms, of resources used or expenditure incurred to a certain activity. Anyhow, the cost term must be contextualized to give a more accurate definition related to its use.

Some other terms are used indifferently like expense and loss, but a distinction must be done because in fact these terms are related to different concepts.

Once the main idea of cost has been described, the term expense may be defined. Expense is defined as an expired or committed cost resulting from a productive usage of an asset.

The revenue earning potential of an asset once it is acquired is reduced by its usage and this reduction is the expense quantity. For instance the facilities purchased by a company have their value as an asset by the time the purchase is done, but as the time goes on, these facilities have less value and this periodical depreciation is included as an expense in the Profit and Loss Account.

On the other hand loss concept refers to the expired cost from which the company have not received any revenue, like could be obsolescence or destruction of stock.

Cost centre concept is related to a section of the business to which costs may be charged. This section could be a person, a machine, a workstation made up of a certain number of operators and machinery, an office department and so on.

Regarding that, costs centres are usually classified into personal or impersonal cost centres and also into production or service cost centres. This concept is important due the requirement of the cost accounting to ascertain the costs and control them according the business nature and parameters.

After the classification of costs amongst the costs centres, the cost unit split these costs into smaller pieces helping to ascertain the costs to particular elements. These cost units are usually units to measure material, time or services in relation to which cost may be expressed.

Once these first ascertainment elements have been defined, some different costing methods will be introduced highlighting their main properties. The method used in this project for the collaborating company will be explained in depth afterwards.

The methods of costing are ascertainment techniques or processes designed to achieve different industries requirements and to fit to their manufacturing or service process properties.

All the methods that will be discussed are variations from the two most important, Job costing and Process Costing.

- Job costing: Also known as job order costing is a method used for industries where jobs are particular for each customer. There, the cost unit is the job order. Some industries could be painters, garages, press printing and so on.

- Contract costing: The main different with job costing is the size of the job and when a contract is signed it is usually a bigger one. The general cost unit is the contract although within it many costs are accumulated. Buildings construction, ship-buildings, bridges and so on are example of these jobs.

- Batch costing: It is a method related to job costing in such a way that orders are for an identical batch of products so the cost unit is this batch. Tyres or toys manufacturing, shoes or components fit to this method.

- Process costing: It is the second main method and is used in mass production industries with standard products manufactured in continuous processes. Costs are accumulated for sections, processes or departments and the total cost is divided by the quantity produced. Chemical works, refineries or textile mills are examples of industries that will fit to this method.

- Operation costing: It is a deeper and more detailed variation of the process costing, considering each operation of the process and allocates its costs per product.

• Single costing, output costing or unit costing: It is a variation of process costing useful for industries with few different varieties of the product and produced in the same process. As the unit of output are equal, the unit cost is found by dividing the total cost by the total production of a period. It is applied in mines, steel production, flour mills and so on.

• Operating costing or service costing: It is used for service activities, like transporting or hospitals, cinemas, etc. The cost units could be passenger-kilometre, room per day, seats per show.

• Multiple costing: It is an application of more than one method. Not every company fits perfectly to an only one method and often may be required to apply different methods within the same company. Companies dedicated to both manufacturing and assembly may need different methods for each activity.

It is also important that these theoretical methods should always be adapted to the company requirements and it is essential to keep them in mind but it is also required to be open-minded and not to hesitate using new methods that could fit better. In the end these methods were born out of the first definitions of cost, cost unit and cost centres.

In addition to the costing methods already explained two other methodologies must be included in this point.

These methodologies are more accurate and more used nowadays. The ones explained just above are focused on the production system properties and a method is suggested for each main type of production system.

These methodologies do not deal with the production system but with the activities or departments involved in the process and the characteristics of them are the ways the indirect costs are allocated, since the direct costs are always allocated to the product directly, independently on the methodology.

• Activity Based Costing (ABC).
It is one of the most sophisticated costing methodologies currently developed. It is based on the allocation of the indirect costs or overheads to each activity of an organization and then it assigns the costs of the activities to the products or services caused by the activity. This step is done by identifying the indirect cost and allocating them to the different departments present. Once the overheads are allocated they are split into the activities of each department. After that, to establish a relationship between activity and cost object, cost drivers are identified for each activity. Finally the cost of each activity is identified as well as the cost driver cost. The product cost will be the number of cost drivers multiplied by the cost of each one.

The second method is a simpler version of the Activity Based Costing but also very efficient and sometimes more appropriate regarding the particulars of the system studied. It is related also to the manner allocation of the indirect costs is done.

• Allocation Methods.
This second point is in fact a group of techniques to allocate indirect costs. All of them are based on the allocation of these indirect costs amongst the departments existing in the company assuming a fair way to split each indirect cost into the departments. Once this first step is done the service department costs are split into the manufacturing or main departments considering the influence on each one. Finally a cost driver is defined for each main department.

When the total number of cost drivers is known and also the total cost allocated, the cost of the cost driver can be calculated. Then it is allocated to the product regarding the quantity of cost drivers required on each workstation or department. It is a similar technique to ABC but the cost drivers are associated to departments instead of activities. When departments can be identified to single workstations this methodology may be more appropriated than the ABC.

Major costs, such as newsprint for a newspaper and direct professional labour for a law firm, may each be allocated to departments, jobs, and projects on an item-by-item basis, using obvious cost drivers such as tonnes of newsprint consumed or direct-labour-hours used. Other costs, taken one at a time, are not important enough to justify being allocated individually. These costs are pooled and then allocated together. A cost pool is a group of individual costs that is allocated to cost objectives using a single cost driver.

These allocation methods will be used in the costing model development.

As a complement to these methods explained, some other techniques are commonly used in companies, independently to the type of method chosen or the manufacturing process present in it.

These techniques are used for costing control and to support management accounting. Even though these techniques are not going to be developed in this project, they seem potential issues for further development of it, so in the following lines an overview will be taken to introduce five of the most important ones.

• Standard costing: It is a cost control technique based on the determination of a target of performance, establishing the estimated cost, comparing it to real current cost of this element and considering taking action with intent to reduce it.

• Budgetary control: Another cost control technique based on the comparison between the budget planned and the real total expenditure. In addition to its use in planning, the budget is used to control and coordinate activities.

• Marginal costing: It is a different approach of cost accounting. It is based on the ascertainment of the variable costs and the allocation of them to the products in order to highlight the effects on profit of changes in volume and in type of product produced.

• Total absorption costing: It is the opposite approach based on the allocation of the total costs to the product. More than techniques these to last points are approaches for the cost accounting.

• Target costing: It is the most recent technique presented. It is based on the determination of the target market price for the marketing department and considering the profit margin, the maximum target cost of the product is fixed. This is done before the design and development of the product is decided and then the possibilities of development and manufacturing are evaluated.

At this point it could be noticed the importance of costs study and control within the company activity. Regarding this statement and before starting the explanation of elements of cost that must be considered, some possibilities of classification will be described, to achieve a deeper understanding of the cost impact in the company.

The first classification is the identification between direct or indirect costs.

Direct costs are those directly related to the process or cost unit decided. Wages of the operators involved or costs of raw materials are examples of direct costs. The, indirect costs are those general costs incurred for the benefit of many different processes or cost units. Rentals, lightning, power or managerial salaries are examples of indirect costs.

Nevertheless, this classification is not always that simple and sometimes the same costs could be considered as direct and other times as indirect. In that case it must be kept in mind the accuracy required for the accounting and the definition of a criterion. For instance the power consumption cost of a machine involved in the production of different products could be allocated to the different products considering the processing time for each one.
However if the consumption of this machine is rather low and the cost almost worthless it may be not worth to measure separately and just split it among the products like other indirect costs. So then in this classification, managerial criteria are involved.

This example leads to the costs model methodology that will be developed in this project. As it will be discussed, the basic methodology will be the Output or Single Cost since the products manufactured are slight variations of the same model. However this methodology shows a considerable lack of accuracy and since it gives the same treatment to all the indirect costs.

To deal with that and bring more information to the company from the costs model, these general or indirect costs will be split and allocated to different cost centres or operations being aware of the more expensive activities. These modifications will be explained in the development chapter

The second classification of costs introduces the identification between fixed and variable costs.

Fixed costs are those that remain constant for a certain period of time independently of the manufacturing or service activity rate. Building rent, managerial salaries or insurances are some examples. On the other hand variable costs are those that change with the manufacturing or service activity; material consumption, operator wages or small tools for example. Meanwhile, some costs present both properties at the same time, with a fixed part and a variable part. Examples of this could be telephone expenses, light, power, maintenance, depreciation and so on.

This second classification provides valuable information to the management activity, for instance for the preparation of flexible budgets with different scenarios of activity, the variable cost changes and the acknowledgement of these costs is important. Moreover this identification is important to know the marginal cost and the break-even analysis to set the sales volume to reach profits.

A third classification is an identification of different fixed costs and two groups can be made:

Committed and discretionary fixed costs. Committed costs are those difficult to avoid once they have been accepted like depreciation of machinery acquired or managerial salaries. Discretionary costs are those fixed costs that can be avoided, like advertising, research and development costs, low managerial staff and so on.

Cost may also be classified by period or product costs in relation to the production process or to a certain period of time of activity.

After all these definitions of concepts related to costs and the different classifications of them, the next step in this point is to describe the most common elements of costs present in the companies.

The measurement of the elements present in the following lines in addition to some particular ones will be the basis for the costing model development in chapter number five.

Cost elements may be divided in three main groups: Material, Labour and Expenses. At the same time these three groups may be considered as direct or indirect, so six main groups will be analysed to classify the elements of cost.

Material Costs
It can be defined like the cost of physical elements purchased by the company to carry out its activity.

- Direct materials: Those materials that can be identified and allocated to a cost unit. These materials often are an important part of the final product. Some other materials may become a part of the final product but the value of them is small and it is not worth to measure their quantity treating them as indirect materials. Reinforcements and resins are examples of direct materials for composite manufacturing.

- Indirect materials: The materials used in the manufacturing process that are not easily allocated to a single cost unit and an individual measure for each product is not worth due its small value. Insulation tape buckets or coating spray are examples of indirect materials.

Labour Costs
It is the set of costs related to salaries and wages of members related to the company.

- Direct labour: Costs of operator wages directly related to the manufacturing process. A machine operator is an example of this kind of costs.

- Indirect labour: Wages of company members not identifiable to a certain cost unit or not directly engaged in the manufacturing process. Management salaries, inspectors, supervisors, cleaners or security staff for instance.

Expenses Costs
The other set of costs that are not labour or materials, it is a wide group of cost elements.

- Direct expenses: Also known as chargeable expenses because they are easy to allocate to a certain cost centre. Hire of a special plant for a certain job, special designs, patent rights or experimental costs.

- Indirect expenses: All other costs not directly identifiable to a cost centre. For instance lightning, depreciation of facilities, advertisements, insurances and so on.

The aggregate of the three direct costs is the prime cost while the aggregate of the three indirect costs is the overhead cost.

This concept of overhead cost is used to define other aggregated costs. For instance it is common to distinguish among factory overhead, office and administration overhead and sales and distribution overhead. Each of these three groups would be made up of indirect materials, indirect labour and indirect expenses related to the proper department.

In that way, some aggregated costs may be defined like the following ones:

- Prime Cost = Direct Material Costs + Direct Labour Costs + Direct Expenses

- Factory Costs or Works Costs = Prime costs + Factory overhead

- Costs of Production = Factory Costs + Administration and office overhead

- Total Costs = Cost of Production + Selling and distribution overhead

These groups of costs are often used to obtain information from different ratio analysis that relates them all in order to control costs and present results in an aggregate way.

After the description of the cost elements that are going to be considered during the development of this costing model, the following lines will look at the chosen method in detail and will try to explain its main properties.

As it has been discussed earlier, the cost accounting method decided depends on the industrial features of the company considered and also on the degree of accuracy desired for the allocation of indirect costs.

According to the Blatraden AB manufacturing process, not many different products are currently developed; in fact it is only one model with slight variations on the location of certain elements. According to that the Output or Single Costing seems to be appropriate.

Anyhow this method treats all the indirect costs as an aggregate value and split them equally into the total quantity of final products.
This is an easy way to proceed but helpful information is hidden in this method.

The knowledge of the costs for each section, department or workstation may be useful for the main objectives of cost accounting.

Keeping all this in mind the development of the costing model will be based on the classification of the elements of cost by importance. The indirect costs with higher values will be studied separately and the origin of these costs will be analysed and the lower indirect costs will be treated as a whole and allocated equally to the total quantity of products.

The model developed will be explained in chapter number five, but it will be composed by a Cost Sheet where all the cost elements with their values mentioned before will be included and updated periodically and an Elements of Cost Sheet where all these elements will appear and will be classified.

The analysis intervals to upload the information of these sheets must be decided by the company according to new cost information obtained. The inclusion of past values on the cost sheet may also be appropriate to an easier assessment of the business progress.

Once all these costs for the period defined have been measured, they are classified on the different groups described previously and three main columns are placed in the sheet: The first one with the cost element name, the second one with the value for the period considered and the third one for that value divided by the quantity of final product produced in that period considered to obtain the cost per unit.

The purpose of the Cost Sheet is to reveal the total cost of the period and the cost per unit manufactured. At the same time it also discloses the total costs into different elements of cost and acts as a guide to fix selling prices and quotations of tenders.

To put an end to this point and also to the theoretical chapter some considerations and practical difficulties for the installation of a costing system will be discussed.

In order to meet the special needs of a business, it is required a thorough study and understanding of the elements involved and the properties of the manufacturing system for the development of the costing system. For that reason it has to be clear that benefits obtained from the model must exceed the amount spent on it.

Anyhow practical difficulties may be commonly found during the installation, the following list shows a few typical ones:

- Lack of support from managerial staff: The costing system must be supported by the company managers and commitment with the development of it is required. Otherwise the system will not progress or will be incomplete providing less information than possible.

- Resistance to adoption from the accounting staff: The new accounting system may not be welcomed by the current accounting staff. Benefits from this system and needs of every worker commitment must be highlighted.

- Lack of cooperation of working and supervising staff: Inputs from the production activity are essential for the system and lack of commitment with data collection or its accuracy will damage the system.

- Limitations of trained staff: Staff involved in the system must be trained to maximize benefits of the system and lack of time to do that might impact in the progress of it.

All this difficulties for the system implementation may be overcome and the company may benefits of the costing ascertainment.

In addition to the advantages already mentioned throughout this point some others could be included to underline again the convenience of this model: Reveals profitable and unprofitable activities, checks the accuracy of financial accounts, reveals idle capacity, prevents frauds, manipulations and so on.

4 Technical Resources

4.1 Simio Simulation Software [13]

This point in chapter four will be dedicated to the particular simulation software used for the development of the company production process.

After an overview to different simulation aspects and concepts in chapter number three, this section of the project will be focused on the specific software chosen and its main properties. As many of these properties are common for different commercial simulation software, this point will be an intermediate step between the simulation theory discussed before and the development of the company model that will be explained throughout the next chapter.

This simulation software is based on an object approach to develop the computer model, which leads to the employ of different objects available to build the model. These objects will be described down below but they refer to common items present on general industrial or service systems for instance machines, conveyors, forklifts, workers and so on.

This combination of objects as components of the system allows an easier verification of the model, due to the simple way to develop models.

These objects are placed and manipulated within a simulation workspace, which is an important property. As it was told, general programming languages such as C++ and Java can also be used for simulation as well as other languages oriented to simulation usages, such as OOSimL and Simscript III. The main advantage of these languages is their flexibility and ability to build a completely self-designed model. However expertise is required.

Unlike these programming languages, simulation software with an integrated simulation environment like Arena, FlexSim, Simul8, ProModel or Simio Simulation provide the easiest and simplest way for developing simulation models but at the expense of flexibility and ability to implement fairly large and complex models.

Simio
Forward Thinking

Figure 15. Simio Simulation Logo.

Down below the main features of the software used are going to be described, in order to simplify the comprehension of the model built, explained in chapter number five.

So focusing again on the object oriented approach, these objects are organized in Libraries and they might be customized if it is required.

An object custom behaviour is defined by its properties, states, events, external view and logic.

The properties of an object are input values specified by the user like could be the process time for a workstation.

The states are dynamic values, not input values, which may change during the simulation. For instance, a busy or idle status in a server may change when a customer has arrived or has left the station.

Events are situations or facts that are started or fired if a certain condition is fulfilled. They are useful to inform that something important has happened. For instance a tank object can fire an event every time it is filled or empty.

The external view or symbol, as can be imagined, is the three dimension graphical representation of the object in the simulation environment. This representation can be modified and views can be imported from design software.

Finally the object's logic is an internal process developed to define the behaviour of the object before different events that may occur.

After the main parameters of the objects are defined, a list of the objects available at the Standard Library will be presented. The Standard Library is a general purpose library of objects that is provided with Simio for modelling a wide range of systems.

Anyhow the Entity class of objects must be considered as the key object of a simulation model. This entity refers to the element that moves or travels through the system, the reason why the system performs.

For instance, in an industrial plant it would be the representation of the different stages of the product, with the associated material consumption and operations to transform it from the raw material to the final product. In a service system it would be the customer that comes from one station to another into the system to get some service. This entity object is placed within the user interface in the Project Library, a library of objects corresponding to the current models in the project development.

The following list describes the main objects available for the development of the simulation models.

Object	Description	Main Properties
Source	Generates entity objects of a specified type and arrival pattern.	Entity Arrival Logic, Stopping Conditions, Table Reference Assignments.
Sink	Destroys entities that have completed processing in the model.	Process Logic.
Server	Represents a capacitated process such as a machine or service operation.	Process Logic, Buffer Capacity, Reliability Logic, Secondary Resources.
Workstation	Models a complex workstation with setup, processing, and teardown phases and secondary resource and material requirements.	Process Logic, Buffer Capacity, Reliability Logic, Secondary Resources, Materials and Other Constraints.

Combiner	Combines multiple member entities together with a parent entity (e.g. a pallet).	Matching Logic, Process Logic, Buffer Capacity, Reliability Logic, Secondary Resources.
Separator	Splits a batched group of entities or makes copies of a single entity.	Separation Logic, Process Logic, Buffer Capacity, Reliability Logic, Secondary Resources.
Resource	A generic object that can be seized and released by other objects.	Resource Logic, Reliability Logic.
Vehicle	A transporter that can follow a fixed route or perform on demand transport pickups/drop offs. Additionally, an 'On Demand' routing type vehicle may be used as a moveable resource that is seized and released for non-transport tasks.	Transport Logic, Travel Logic, Routing Logic, Resource Logic, Reliability Logic, Population.
Worker	A moveable resource that may be seized and released for tasks as well as used to transport entities between node locations.	Transport Logic, Travel Logic, Routing Logic, Resource Logic, Reliability Logic, Population.
BasicNode	Models a simple intersection between multiple links.	Crossing Logic, Routing Logic, Tally Statistics.
TransferNode	Models a complex intersection for changing destination and travel mode.	Crossing Logic, Routing Logic, Transport Logic, Tally Statistics.
Connector	A simple zero-time travel link between two nodes.	Routing Logic.
Path	A link over which entities may independently move at their own speeds.	Routing Logic, Travel Logic.
TimePath	A link that has a specified travel time for all entities.	Routing Logic, Travel Logic.
Conveyor	A link that models both accumulating and non-accumulating conveyor devices.	Routing Logic, Travel Logic, Reliability Logic.

Table 1. Simio Simulation Objects.

Moreover the properties included in the table, the following common properties are also present in most of the objects discussed: State assignments, Financials, Add-on Process Triggers, Advanced, General and Animation.

It is not the purpose of this chapter to develop a user guide for Simio Simulation, so these properties will not be described in depth one by one, just will be mentioned as an example of modeling possibilities. These properties are in fact categories that can be expanded and collapsed in the software window, including more detailed properties described in the own software interface.

Anyhow, the names of these properties give the clue of the nature of each group and lead to the specific role of the objects defined.

Actually all the properties listed are options to edit the model and build it almost as accurate to real system as desired. They are means to validate it.

These properties may be defined by different ways like strings, numbers, selections from a list and expressions. For instance, within the Process Logic properties of a Server the property Ranking Rule is selected from a drop down list and the Processing Time is an expression field.

Expression fields are supported by an expression builder that tries to find matching names or numbers as it is typed. Logical expressions, math operators, references to other property names or math distributions and functions can be used to describe behaviors.

After discussing these properties and the set of objects available to develop the simulation model, an explanation of the simulation environment and the user interface will be done, to finish this stage of the project. During chapter number fiver, where the development of the simulation model and their uses will be described, many of these properties will be referenced and discussed in depth.

According to the Simio User Interface, some key areas can be distinguished in the screen; the most important area is the tabbed sections placed in the upper left part of the screen and consisting on the Facility, Process, Definitions, Data, Dashboard and Results tabs.

Each of these tabs has its own tools and areas in the software interface, in such a way that the screen organization changes depending on the tab highlighted. Hence each one of these tabs is going to be introduced and described separately.

The Facility tab is the default screen and is where the physical simulation environment is placed. Within this section the Standard and Project Libraries, already mentioned, are placed on the left, where all the objects listed are available. The Flow Library, a library of objects for modelling flow processing systems, is also present on that side. On the right there is the Browse Panel to move from one model to another within the same simulation project and under this panel the Properties Panel can be found. The simulation workspace is in the middle of the screen and occupying the larger part of it. This is a drawing space for building the object-based model and it is shown whenever the Facility tab is selected. This space is used to create both the object-based logic and the animation for the model in a single step.

It must be mentioned that the objects from the library are placed in this workspace by clicking on the object type in the Library and then in the workspace, dragging the object type to the workspace or double clicking on the object type and then in the workspace. With this last option many objects of the same type can be placed in a row.

Once an object is placed it can be noted that it has its own Input and Output Nodes from which it will be related to the rest of the model. These nodes present similar properties to the Basic or Transfer Node objects, depending on the type of object placed. It is also associated to most of the objects different Buffers, represented in the simulation space as green lines, specifically Input Buffer, Processing Buffer and Output Buffer. These Buffers can be sized in the Properties panel and there will be the place for entities to wait in any step related to this object.

Over the main tabs discussed before, the tools associated to each tab can be found. For this Facility tab, tools are organized in five different groups of actions: Run, Drawing, Animation, View and Visibility regarding simulation run, symbols and decoration, labels and plots, drawing space view or elements visibility respectively.

The second tab mentioned is the Processes tab. This screen allows the designer to build their own logic processes and add them to the objects of the Libraries by selecting on the Add-On Process Property.

This possibility greatly increases the logic behavior alternatives for the model. This custom logic can be used to seize/release resources, make assignments to variables, change travel networks, evaluate alternatives and so on. The processes are created as graphical flowcharts without the need for programming and then added to the objects. Different processes can be inserted in the same object for different properties without any need of object modification.

The process is a sequence of steps that are placed in a graphical flowchart. This process is triggered by some event within the simulation or to a certain state of the associated object. Once the process is triggered, a token executes the different steps of the process changing the state of the objects involved.

This token carries a reference to its parent and associated objects. The associated object is the object that may trigger the event. For instance there could be a logic process to a certain workstation to decide the processing time depending on the class of entity arriving to this workstation. In this example the workstation would be the parent object and the entity the associated object.

These processes could be triggered in three different ways, defining three types of process:

- Standard Process: The process is triggered in general conditions of simulation such as OnRunInitialized, OnRunEnding or OnRunWarmUpEnding.

- Add-On Process: The process is defined for a single object according to an associated property of it such as Entered, Before Processing, After Processing, On Shift and so on.

- Event-Triggered Process: The process is triggered when a particular event has taken place. These triggering events may be combined with the other types of process.

As it was mentioned, to build the processes there are many available steps, that are also defined in the own Processes screen, in the left side of it. In the upper part, the tools related to this screen are placed and the right side is the same as the Facility screen with the Browse and Properties panels.

The Definitions panel is used to define different aspects of the model, such as its external view and the properties, states and events that are associated with the model.

These definitions will be later available to apply to different objects in the Facility or the Processes panels.
Moreover the inherited properties, states and events of a model, the user is able to define new ones, according to variables or possible situations within the simulation model desired. Elements, Properties, States, Events, Lists, Functions or External Views can be defined by the designer. Each one of these classes has its own group of tools in the upper part of the screen while the right side remains the same.

The Data panel is used to define data that may be used by the model and import or export it to external data sources. Tables can be designed in this panel and afterwards called in expression properties of the objects. Repeating the example of the workstation with variable times regarding the entity type, this information can be available in a table with entity types and times, it will be selected the row or column of processing times in this object property and the object will find the associated time to the entity entering. Different kinds of Tables, Schedules and Changeovers are available in this panel that keeps the same organization as the ones before.

The Dashboard panel provides a 2D drawing space for placing buttons, dials, plots, etc., for real time viewing and interactions with the model. These elements can also be placed on the Facility window with the drawing tools, but the purpose of the Dashboard screen is to set the other screens free of these elements and organize them in this one.

The Results panel displays the output from the model after experiments are done. They are displayed in the form of both a pivot grid as well as traditional reports. Multiple model windows can be viewed at the same time by dragging a window tab and dropping it on one of the layout targets.

4.2 Model Possibilities

Once an introduction to the simulation science and to the chosen software has been done, this point of chapter number four will discuss the real applications of the simulation tools for the process studied. It will be discussed as well the limitations of this tool, mostly related to simulate human behaviour.

As mentioned earlier, simulation tools bring the possibility of trying new ideas on a virtual scenario, free of risk, easy to visualize and communicate with the appropriate accuracy. It is a powerful tool for decision making from a management approach.

On chapter number five the properties of the model developed will be described in depth, in order to show the real accuracy of the model built. However in a broader way, the general possibilities for the company could be described at this point, after the introduction to the software and once the manufacturing process has been discussed. To classify these possibilities in a more logical manner, four different groups of possibilities will be presented. These groups are the following ones: Supplying and materials, Production, Workforce and Transport.

Starting with the Supplying and Materials group, relevant information could be gathered from the software. For instance data related to:

- Different delivery frequencies or batch sizes from suppliers and how these terms impact on inventory management decisions.
- Shipping failures delays or defects impact on the production process.
- Tracking inventory quantity progress of all the materials used.
- Definition and modification of bills of materials and material consumption on each workstation, as well as material scrap.

Regarding the Production group some other possibilities are achievable like the following:

- Definition of different set up time, processing time and teardown time for each workstation and for each product manufactured to study the worst case scenario situation.
- Definition of failure types and reliability logic of each process.
- Modification of capacity of the workstation according to improvements in methods.
- Modification of ranking or dynamic rules and their impact on the process.

• Assignation and control of production costs of each workstation clarifying offshoring possibilities.

• Definition of logical processes and times on each workstation for different production steps like Setting Up, Processing Batch or Finished Good Operation, to introduce improvements related to SMED methods or transfer batch size.

• Introduction of new workstations, new production lines or new products in the current model and study of their impact on current production.

• Layout modifications and visualization of production process without any risk and keeping production on track.

According to the Workforce group, several situations could be analysed through the simulation model in order to measure the influence on production schedule:

• Manufacturing with different number of workers available.

• Modification of ranking rules, travel logic and activities assigned for each worker.

• Definition of different work schedules and day patterns and measure of impact on production process.

• Definition of transport requirements and seizing of a limited resource considerations.

The last group, Transport, makes reference to the possibilities available in the software used to describe alternative means of transport and their properties:

• Definition of conveyors, forklifts, cranes or human transport in the system and ride capacity and speed, travel logic or resources requirements to perform.

• Seizing of a limited resource considerations, priorities and financial costs of each vehicle.

All these application examples relevant for the company could be carried out in the simulation software chosen. As it will be discussed in the next chapter, the model of the first manufacturing process used in the old facilities and the different alternatives for the new manufacturing process have been developed in this software. Some of the possibilities mentioned have been already included on them and other will be considered as possible further development.

Anyhow before the end of this point it would be relevant to introduce some limitations found by the time the real model was developed. These limitations concerning the workers behaviour made difficult to match each real worker to a chosen one on the simulation.

In general, workers defined in simulation do the same tasks and operations as the real ones, but in such a manufacturing process, where the same operations are made for different workers along the day it was not achievable to set a dynamic sequence with a good response to approach to real behaviour. For instance, operations like mixing are done twice or three times per day and maybe one operator do it each time. Actually defining a list of possible workers to choose for each operation was feasible. The problem found and not possible to solve was related to combine the production requirements with the transport requirements for the workers defined.

It was not possible to reach an optimisation of distances travelled by the operator and setting at the same time the right processing sequence. The internal logic of workers, defined by the own software, gives priority to processing requirements, so the worker will attend first to production seize requests than to transport requests.

The situation described caused the definition of a set of considerations to carry out the main objectives of the process that will be discussed in depth during the next chapter.

Anyhow, the list of possibilities shown is wide and many other implementations and experiments could be analysed once the user gets used to the software.

Nevertheless, the economic cost must be kept in mind as one of the most important disadvantages of the simulation software according to the high prize of licences. Hence, before deciding a purchase, the company must evaluate the real benefit of it.

4.3 Supplementary Software

To put an end to this chapter dedicated to technical support it will be offered a general overview to some other supplementary software deployed throughout this project.

In addition to general Microsoft Office software, like Microsoft Excel used for the second part of development within this project, it must be mentioned the use of two different computer software as they are SketchUp 8 and AutoCAD 2007.

It is not the purpose of this point to explain in depth the properties and the commands of these programs as it has been done with Simio Simulation. The purpose is to illustrate the way these tools have been used and the benefit obtained from them.

Both of these computer programs have been used for the development of the first part of the project, the layout design of the new facilities.

SketchUp 8 is a 3D design and modelling computer program, acquired by Google from @Last Software and now under Trimble Navigation, Ltd.

SketchUp 8 is a 3D modelling program for a broad range of applications like architectural, civil, mechanical, film as well as video game design. The greatest advantages of the program are its ease of use and an online repository of model assemblies such as windows, doors, automobiles, industrial machinery and so on, known as 3D Warehouse enables designers to locate, download, use and contribute free models.

This program has been used for the development of the workstations within the facilities in order to build them as physically similar as possible to reality, at least in sizes to use them for the layout methods considered.

SketchUp 8 designs are compatible with Simio Simulation, so the models developed on the first one can be imported as symbols or external views of the objects in the simulation workspace.

This possibility gives much more reality to simulation in order to place in the facility model workstations with real sizes and physically similar.

Most of these models have been developed by the own author and others downloaded from the 3D Warehouse mentioned above.

The second computer program mentioned is AutoCAD 2007, a software application for computer-aided design (CAD) and drafting. The software is developed and sold by Autodesk, Inc., used in a wide range of industries, employed by architects, project managers and engineers, amongst other professions.

This computer program was used throughout the project to develop the layout alternatives and to import the facility floor plan to Simio Simulation due its compatibility.

Within this facility floor plan, the different areas occupied by the workstations involved in the process were drawn, organized and modified according to the layout design method used.

The Activity Relationship Chart method, explained in chapter number three, requires the size of the workstations to analyze the alternative plant distributions in such a way that all the workstations in the process must be measured and the relationships amongst them must be evaluated.

All the layout design process developed through this method is explained in diagrams built in AutoCAD 2007.

5 Development

5.1 Simio Simulation Model

The first part of this project starts with the development of a simulation model that will be used for the evaluation of the different layout alternatives. This part of the layout design and simulation model development has been carried out in collaboration with Brandán Villasenín Labandeira.

The explanation of the simulation model developed with Simio Simulation Software will be carried out in this point of chapter number five.

In fact two different simulation models will be explained: The old facilities manufacturing process and the new facilities manufacturing process. As it has been mentioned, the length of this project caused that modifications in the company activity have taken place. These changes of considerably importance make necessary the development of two different computer models in the simulation software.

The changes discussed just above are related to three different aspects:

- The modification of the number of different products manufactured.
- The modification of the number of workstations involved in the process.
- The modification of the facilities used for the company activity.

Even though since the beginning of this project the company had already planned to move out to a new industrial building, the author considered convenient to develop the old facilities simulation model to get a deeper understanding of the process and also to be able to compare the performance between both processes. So these two reasons would be the aspects considered in relation to the first step for the development of a simulation project mentioned in chapter three: the answer to a real world situation or opportunity.

The real world opportunity for the second model built has been mentioned endlessly throughout this project and it is the requirement of a new layout design for these new facilities and the possibility to support the decision with a simulation computer program like the one chosen.

Both models will be described during this point, but as the most important goals are related to the layout design and to the development of a simulation model helpful for future situations, the second model will be explained first and more deeply. The old facilities simulation model will be explained afterwards, highlighting the differences between both, already introduced in the beginning of this point.

In addition to that, three different variations of the second model will be built, related to the three layout alternatives that will be explained in the following point. So the only change amongst these three alternatives is the physical location of the elements involved in the process. In that way throughout this point there will be no distinction and just old process model and new process model will be described.

The description of these two models will be done by following the steps of the simulation project cycle introduced before, that are: Real world problem determination, Conceptual model development, Computer model Development and Understanding or solutions.

The conceptual model may be defined as a model developed not in the simulation software, consisting on the basis for the simulation model that will be developed explaining its objectives, inputs, contents, outputs, assumptions and simplifications of this simulation model.

Nevertheless even though the conceptual model seems to be a previous step to the computer model, adjustments on both take place at the same time since the simulation software sometimes contributes with different constraints and difficulties.

The objectives of the simulation model are the purpose of the model and the simulation project. In other words the simulation model must provide the information desired for the real world problem defined.

The conceptual model may be built in the shape of a component list, process flow diagram, logic flow diagram or activity cycle diagram. Anyhow inputs, contents, outputs, assumptions, and simplifications must be included.

A process flow diagram has been built to illustrate the main steps of the manufacturing process that is going to be developed in the simulation software.

Even though some important inputs, contents, outputs, assumptions, and simplifications are not included, this diagram will be helpful to make clear the essential sequence of the manufacturing process.

The conceptual model will be completed with the description of the required elements for the development of the simulation model.

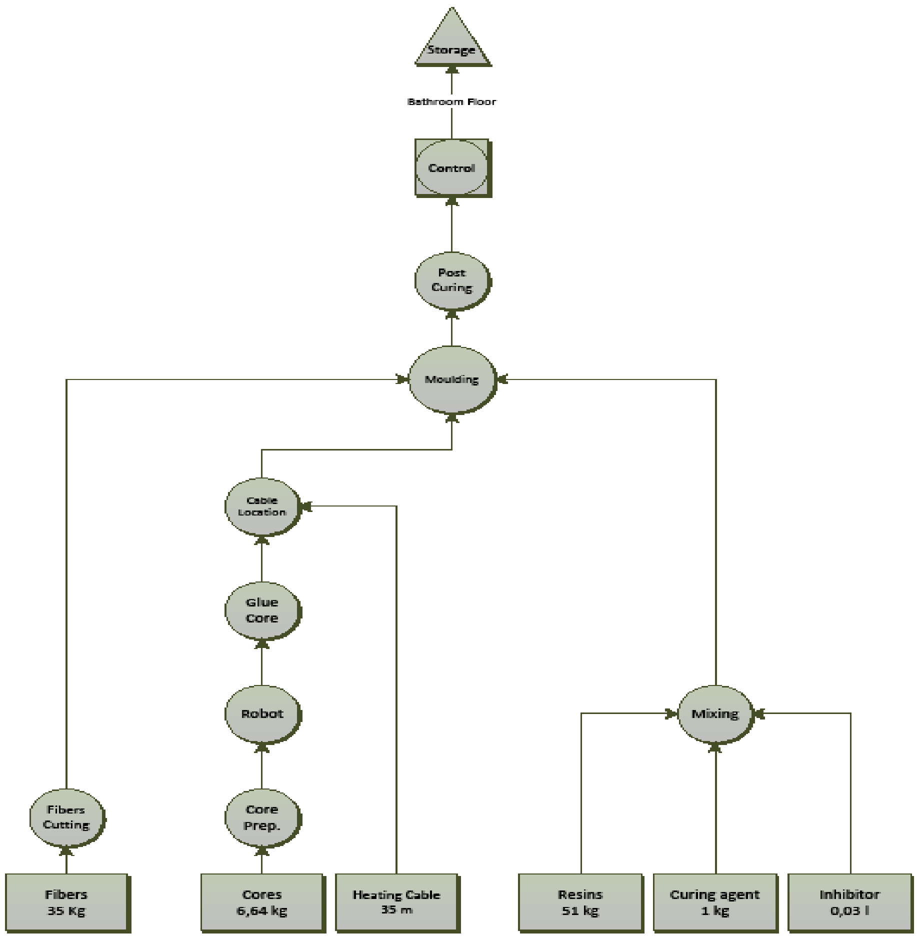

Figure 16. Process Flow Diagram.

The inputs of the conceptual model are the elements that can be variable in the model to make improvements in the real world or get a better understanding of it. In the conceptual model developed in this project the inputs considered will be the following ones:

- Setup, processing and teardown times in the workstations.
- Logic behavior and division of tasks of the workers.
- Distances and sizes of the objects included.
- Production order quantities.

The contents of the model are the components represented in it and their interconnections. In this case the model is composed by the following contents:

- Workstations.
- Operators.
- Transports.
- Machinery.
- Material.
- Facility plan.
- Interconnections and communications.

The outputs are the results chased for the simulation project. In this project the simulation model will support the layout design by measuring the average distance traveled by the operators in the different alternatives.

This measurement will be done for the processing of a unit of the product manufactured. So this could be considered the output seek for this model.

Moreover a deeper understanding will be obtained due to the ability to visualize the system performance in each of the three layout alternatives that will be developed and it must be considered as an output too.

Assumptions are statements accepted to deal with uncertainties or elements difficult to be measured. The following assumptions have been considered:

- Manufacturing performance is independent of operators' mood, tasks allocation, day in the week, month, season, weather conditions and other external factors not directly related to the company.

• Machinery performance is independent of the aggregated processing time, the worker attendant or other external factors like the ones mentioned before.

• Raw material and especially chemicals performs the same independently from environment conditions.

• The elements not considered in the model like replenishment activities, transport of final products, facilities cleaning and so on do not impact considerably in the process performance.

After assumptions have been described, the next step is to explain the simplifications of the model and the justification of them making it clear that these simplifications do not interfere on the achievements of the objectives fixed.

According to that it is essential to keep in mind the current purpose of the simulation model, establishing that if some of the possibilities listed in the previous chapter are going to be studied these simplifications must be reviewed ensuring the verification and validation of the model.

• Limited variability for setup, processing and teardown times: The mentioned workstation times have been measured for the development of the second part of this project, the costing models. Once a time study took place and the data collected was treated, the obtained values were included in this model.

Even though, for a more accurate model a mathematical distribution could be assigned to each operation in order to achieve a more realistic performance. The times, as it will be deeply described in the second part, were measured several times for each operation and then mean and standard deviation was calculated for each workstation and introduced in the simulation model.

• No time distinction between the two final products manufactured: Currently the differences between the models manufactured are futile in terms of manufacturing time since those differences are the side the drain is located and the locations for other connections like the sink or the toilet pipes.

• Regular material consumption and scrap for each workstation: Even though it is not the real situation, for the objectives of this model is not worth to carry out a study of the variability of material consumption and scrap related to each step of the process.

• Permanent division of tasks amongst the workers: This simplification may be the most restrictive of the ones considered. The process sequence is always the same since the products manufactured are almost identical. In that way the division of tasks is present in the real manufacturing process and simulation model responds accurately to this situation.

Nevertheless considering the required waiting times for robot operations or curing, some intermediate tasks are carried out by workers doing some cleaning, helping each other, doing some operations in advance and so on.

This dynamic behavior was completely unable to introduce to the simulation model due to the logical operator constraints. Hence, distance traveled during these waiting times will not be recorded and operators will strictly fit to the production planning.

This simplification is an example of the relation between conceptual and computer model in such a way that in some cases is the own simulation software that may force to take some simplifications.

• Straight movement for operators amongst workstations: The possibility to import symbols from design software allowed a highly accurate external view of the manufacturing process. In that way workstations, transporters, machinery and other elements' sizes are the real. To simulate the transport of material or the operator movement through the facilities different paths have to be included, connecting and communicating the contents of the model. According to that the direction of the paths has been kept as straight as possible in order to connect the considered elements in the shortest way.

• No repair time considered after quality control: As every manufacturing process, failure rates are present and repairing may be required. Nevertheless for this study it does not provide any kind of valuable information and the uncertainty and low frequency of these activities made difficult to carry out a time study like for the other operation times.

• Exclusion of raw material supply and final product delivery processes in the model: Due to the nature of the manufacturing system and the workstations, supply activities from the warehouse to the workstations and from the facility entrance to the warehouse were excluded. As it will be described, fibres, cores and resins have buffers in the workstations where operations related to these materials take place. It means that raw material transport from the warehousing has low frequency and it was not included in the study. Also transport from the storage point to the exit or loads in the transport means were not included.

• Same operation and movement efficiency for the three workers: Not different travel speeds were considered amongst the three workers involved and the operation efficiency is not known for each one of it since it is not a purpose. Anyhow since the division of tasks is accepted, the times measured for each operation are related to the worker involved and while the division is the same the times will be reliable.

Different authors define a list of qualities for the conceptual model to fulfill the requirements and being helpful for the subsequent development of the computer model. To take an overview to some matching qualities found on different authors, some essential ones are described just below.
Validity of the model: Defining a valid conceptual model like the one considered by the modeler as accurate enough for the purpose at hand.
Credibility of the model: It is the same concept of validity by on behalf of the customers.
Utility of the model: A common perception for customer and modeler that the model is useful as an aid to decision making within the specified context.
Feasibility of the model: The perception by customer and modeler that the model can be developed into a computer model.

After the model simplifications it may be required to underline the importance of keeping the model simple to meet the objectives of the simulation project. Simple models can be developed faster, are more flexible, require less data, run faster and it is easier to interpret the results. Sometimes complex models may be required but it is common the tendency to model every aspect of the system when a simpler and more focused model could meet the objectives defined.

Once the conceptual model has been described and illustrated, the next step in this simulation project cycle is the development of the computer model which will be explained in the following lines.

A detailed description of the objects will be done including the logical of each one, the relationship amongst them and the application of the simplifications already justified. This will clarify the behaviour of each object and will allow the verification and validation of the model.

The methodology followed to explain all the objects included in the simulation model will be based on the description of the next fields:

- Type of simulation object.
- Object name in the model.
- Image of the object's external view
- Role in the manufacturing process.
- Properties.

These objects will be explained including their Input and Output Nodes, elements associated to the object used to connect the Paths to it, following the sequence of the manufacturing process and also making groups by type of objects. In other words, the Entities group will be explained entirely then the Sources group and so on.

In addition to that, some of the simulation objects will not be explained individually since their importance in the process is secondary and just their main function is used. For instance there are more than sixty Paths included in the model, most of them just connecting Output Nodes to Input Nodes without any property. It is the same for Connectors and Basic Nodes and only the main ones with special properties will be explained separately.

Regarding the division of tasks amongst workers, it has been done according to the way the tasks are split in the real model allocating them to the three simulation workers as in the real manufacturing process. It has also been discussed in the simplifications of the conceptual model that it would be impossible simulate completely the behaviour of real workers in the simulation model, so keeping the model simple the division is done by following the general real behaviour.

After these considerations and the explanation of the methodology that will be followed, the description of the objects group will start just below.

Entities.
The concept of Entity may be the most difficult one to understand in the simulation model and it is a concept present in most of the simulation computer programs.
The Entity is not related to a specific object or element of the real system. It is associated to what is transferred from one element to another within the system. For instance, an Entity may start being a production order from the production office to the first workstations in the process and once the manufacturing operations start, this same Entity will be an intermediate product, travelling throughout the model. So Entity could be defined as the information or physical element that flows throughout the model from the Source where it is created to the Sink where it is destroyed.

- BigFloor1.
  It is the Entity associated to one of the two bathroom floors currently manufactured by the company. It is created in the Office Source and it represents the different states of its manufacturing process, from the production order to the different steps throughout the process

until the final product. According to that, this Entity has six different external views in relation to the stage of the manufacturing process where it is. To distinguish between the two BigFloors manufactured for logic processes an Initial Priority is assigned to each one giving value one to BigFloor1 and value two to BigFloor2.

- BigFloor2.

It is the Entity associated to the other model manufactured nowadays. As BigFloor1 it is also created in the Office and has six different external views. The difference between both is the side where the sink and other connections of the bathroom floor are placed. As it will be explained later, the arrival frequency is fifty per cent of each. Henceforth BigFloor1 and BigFloor2 will be mentioned as the main Entities. It must be said that the differences between BigFloor1 and BigFloor2 in the real system are the side the sink is located which causes the utilisation of one mould or the other.

- Pipes:

So far Entities represented different elements of the system, from information to different stages of the product, but in the case of the Pipes Entity it represents just a manufactured piece included in the floor to connect it to the housing pipes.
The decision to model this piece as an independent Entity and not as another step of the manufacturing process is due to the real process considerations. As Pipes must be glued and must wait for two hours before they are installed in the floor, this operation is done in a set of four pieces each time it is carried out. So four Pipes are manufactured each time and then this operation has to be done only once of each four production order arrivals.
According to that it is simpler to include a second Source that creates a Pipes Entity and request the manufacturing operation each time four BigFloor are created than including this operation in the general manufacturing process. This Entity does not have different external views and it is included in the BigFloor Entity in a Combiner object that will be explained later on.

- Trolley.

This Entity has a limited importance in the simulation model. It represents the trolleys used to transport the bathroom floors from the mould to the final operations, control and storage. The decision not to model them as transports is that for the objective of this simulation model it is easier to consider them as an infinite resource that is combined to the main Entities than consider them as scarce resources since the number available is enough to transport the production of several days. In that way Trolley Entities are created when the moulding operations are finished and the worker travels to this Source, placed in the simulation model where the real trolley storage is located, which is enough to track the distance travelled, the current objective.

Before carrying on with the description of the objects present in the computer model an essential property of the model will be explained. Since operations are split into the different workers, each one is responsible of a set of workstations. If the production orders were very frequent, Entities would be queuing in the first workstations, requesting always the use of the worker. According to that the worker, if no logic was included, would always be in the first workstations. To solve that a priority system was developed to give a logical behaviour to the worker.

This logical behaviour consists on the selection of the lower priority Entity.

The presence of an Entity in the queue of a workstation is the event that triggers the worker to travel there. At the same time each Entity created has an individual label to recognise it from the other ones of its same Entity Type.

In the priority system developed, each workstation has a priority value regarding its position in the manufacturing process. In that way, Fibres has the lowest priority and Control the highest considering nineteen values for priority due to the nineteen workstations. Once the Entity arrives, the priority value is given to the Entity by the workstation where it is placed. This value given will be the distinction property that will allow the worker to choose which Entity serve. The worker according to this system will always serve to the lowest priority Entity.

The logical behaviour ends adding this quantity of nineteen to each workstation once the Entity was processed. The aim is to put at the end of the priority ranking the operation that has already been done giving priority to finish the current orders before attending the new orders.

So the priority system could be illustrated as follows:

An Entity arrives to the Fibres workstation and the priority value associated to this workstation is assigned to this Entity. In this case the value is one.

After this Entity is processed and exited the workstation, the priority value of the Fibers workstation changes to the initial one plus nineteen, in that case twenty.

When another Entity arrives it will have priority of twenty, so when the worker is forced to decide, he will go first to the Entity that has spent more time in the system, which will have priority of two, three or other value regarding its location but it will never have a priority higher than nineteen throughout the first cycle of the whole process.

This system is the same for all the workstations, so the initial order remains the same since all add this value of nineteen after the processing of one Entity.

Sources.
The Sources are the objects where Entities are created or where they come from. Thus the most important properties of them are the properties Entity Type and Arrival Mode that will be discussed in each one.

- Office.

The Office Source represents the place where the production orders come from in the simulation model. The type of Entity created is defined in the Table1 included in the Data tab where the ratio between BigFloor1 and BigFloor2 production is also fixed. In this Table1 is also included a number associated to each external view of the Entity.

The number of Entities per arrival is set as three since Entity in that step is a production order and there are three different workstations in parallel in the beginning of the process: Fibers, Drain_Painting and Core_Prep. As there are only two workers to perform these operations one of them must wait until the end of another. The Arrival Mode is Interarrival Time which is the time considered between two consecutive production orders. It is not a critical parameter since only one cycle of production will be analysed for this project.

Regarding the Add-On Processes of this Source the InitialPriorities process is included, where the initial priority value is given to the workstations. Add-On Processes have been already discussed and they are the way logical behaviour is included in the objects. In this case the InitialPriorities process is based on the assignation of initial values to the workstations through an Assign step, these values are saved in the State Variable [Workstation Name].prioridad.

The State Variable prioridad is a priority defined by the author to keep these values of priority already explained. When the workstations are described it will be discussed in depth.

Finally, in the Output Node of the Office the Entity Destination is defined to assign each Entity to the proper workstation, one to Fibers, one to Core_Prep and one to Drain_Painting, each time Entities are created. This cyclical destination is achieved changing the property Entity Destination Type, making a list of Destination Nodes in the Definitions tab including the Input Nodes of Fibers, Core_Prep and Drain_Painting and selecting it as Cyclic to send one Entity to each Node.

Also in the Output Node an Add-On Process is defined. This process is related to the Drain_Painting workstation. As there are two types of main Entities and each one goes to one mould, there are two Drain_Painting workstations one in each mould since this operation is done directly in the mould.

So to know which mould to go the initial priority of the Entity must be analysed. This analysis is done in BasicNode1 where there is an Add-On Process that allows passing only through the Path connecting to the right mould and closing the one that connects to the wrong one.

On the other hand to ensure that in the beginning both Paths are opened, the Add-On Process of the Office OutputNode opens again both paths, to decide again in the BasicNode1 which Path to open regarding the Entity Type.

As too many elements have been explained in this point, the details of the processes to open and close Paths will be given further on, in the description of other elements since they are processes commonly used in this model.

• Pipe_Source.
This Source creates the Pipes Entities, already discussed. The Arrival Mode is also On Event, being the event considered the entrance of a main Entity in the Input Node of the Fibers workstation. To satisfy the conditions of the Pipes Entities discussed before, it is included that the event has to be triggered four times, so Pipes are created each four main Entities.

• Trolleys.
The Trolley Entities are created in this Trolleys Source and the Arrival Mode is On Event instead of Interarrival Time like in the Office. The event that triggers this arrival is the entrance of a floor in MyCombiner3, a Combiner object placed after the moulding operations. In that Combiner, Trolley Entity and main Entity are combined and treated as one for the next operations.
In its Output Node it is required a Worker to transport this Trolley Entity each time it is created, achieving the objective of tracking the distance travelled to get a trolley and take it to the moulds.

MyWorkstations.
These are the objects where the manufacturing operations take place. Almost all workstations are related to a workplace or an operation in the real process. According to that, most of the external views have been designed to look like the real workstations and their sizes are the real ones as it has been discussed. Nevertheless, some operations have been considered independently even though they are done in the same place, in that cases they have been considered as different workstations but the external view of them has been minimised. For instance in the moulding operations only the moulds appear and eight different workstations are considered in there. It would have been too much reduction of the process steps to consider as an only workstation and once the times for each operation were measured, the system was more accurate including them separately.

However the objects used to model these real workstations were not the Workstations available in the Standard Library. To achieve the performance of the priorities system already discussed a variable to keep the priority value has to be created modifying the standard properties of the Workstations. This inclusion of new properties can only be done by creating a new object. The new object is called MyWorkstation and it is completely identical to the standard Workstations but with the inclusion of a State Variable defined by the author called prioridad.

The way to create a new object based on a standard one is right click on the Standard Library Object that will be the basis and selecting Subclass. This new object will appear in the Navigation part of the screen and it can be selected and the Facility, Processes, Definitions, Data and Dashboard tabs may be modified. Some other new objects were created like MyCombiner and MyWorker to include new State Variables, all of them with the same procedure.

Going back to MyWorkstations, Setup, Processing and Teardown Time as well as Secondary Resources are the most important properties. Regarding these times it must be mentioned that a methodical time study have been developed to measure these values, analyse their variability and define a standard time for each operation. This time study will be explained in depth in point 5.3 and it must be considered as one of the tools to validate this computer model.

Before the beginning of the individual description of the workstations it must be discussed the priority logical processes included in all of them. As it has been explained every workstation has a variable priority that is given to an Entity each time it arrives and changes its value each time the Entity processing is finished. The workstation priority value is given to the Entity while it travels through the Path just before the MyWorkstation or in the Before Exiting State Variables of the MyWorkstation before. As it is a property of each MyWorkstation even within one MyWorkstation is possible to make reference to the value of another.

The priority value for each MyWorkstation is changed in the State Assignments Properties, Before Exiting conditions of the workstation adding nineteen units to the current value. This is the general methodology and the exceptions will be discussed on each case. To make easier and faster the explanation all the following objects are MyWorkstations even though they are mentioned as general workstations regarding its real role.

- Drain_Painting.

  It is not a workstation in the real process although in the model is simulated as one for efficiency reasons. This MyWorkstation makes reference to the drain painting operation that takes place in the own mould. Even though operations in the mould do not start until the processing is advanced, it must be done first of all because the painting must dry before placing fibres and core there. This workstation is included in the priority system and is performed by the Worker1. In fact this workstation appears twice in the simulation model, once for each mould. According to the mould that is going to be used, the Entity will go to one or another. This situation is the same for all moulding operations, the workstations are repeated for both moulds and a logical process is applied to decide the destination mould according the Entity Type.

- Fibers.

  The Fibers workstation is one of the three starting workstations. It is the computer simulation of the workstation where the fibres are cut in the real process. The task is made by Worker1 and the Entity symbol changes before exiting the workstation. o choose the worker performing this operation it must be selected the Secondary Resources property in the Properties window. There adding one row, it may be selected the Type of Object required as secondary resources.

This could be a specific Worker, Vehicle or another kind of scarce resource, one of them selected from a list or a Parent Object. Then the number of secondary resources and the name of them can also be chosen. Another important property to define is the place where the Secondary Resource will be located and if it is needed the movement of it to a certain point. The definition of this property is done selecting Request Move, To Node and typing the Node Name. Usually as the workstations have the real shape the working node is the OutPut Node, placing it in the real workplace or an associated BasicNode placed also in the typical real location.
This procedure is the same for all the MyWorkstations included in the model.
In the Output Node it is also specified that the same Worker1 must transport the Entity to the following point.

- Core_Prep.

The Core_Prep workstation is the other first point of the manufacturing process. The cutting of the cores in the correct size before they are processed by the robot takes place in that workstation. Worker3 is the one who completes the task and also transports the cores to the next workstation, the Robot. The entity changes its external view in this workstation too.

- Robot.

The following workstation is the Robot. Only for the setup the Worker3 is required and then to transport the core parts to the following stations. Two different times are then included a Setup Time and Processing Time.

- Glue_Core.

After the operations performed in the robot, the next step in the process is to glue the core parts to have the total surface of the bathroom floor as one core piece. This operation is done in the same place that the heating cable location so both share the external view. Worker3 completes this operation and the following one.

- Heating_Cable.

It is the workstation associated to the location of the heating cable in the core foam. This operation and the core of the glue take place in the same location in the real manufacturing system, so they share external view and location in the simulation model. As it has been discussed, also Worker3 is involved in this operation and transports the core to the moulds.

- Mixing.

This operation consists on the mixing of the resin with the curing agent and the inhibitor and it is carried out by Worker3. It takes place where the resin tanks are located and the mix is transported to the mould by the same operator. As there is one mould for each kind of main Entity a logic process called Mixing_Entered is included in the Mixing AddOn Processes to decide which mould to go according to the Entity Type arriving. This process considers the initial priority to difference one Entity from another and then allows the movement only through the Path that connects the Mixing station with the proper mould. The Entity External View changes at the exit of this workstation.

- Dress_Fiber_A.

This operation is the one associated to the location of the first layer of fibres in the male part of the mould. It is developed by the Worker1 and the external view is the male part of the mould. As there are two moulds, one for each type of main Entity, the following workstations from this one to Mould_Out will be repeated for both models. Also all those workstations will share the external view since they are performed in the same place.

• Core.
After the location of the first layer of fibres, the glued core is placed by Worker1 and Worker3 over this layer.

• Dress_Fiber_B.
The following operation is to place the second layer of fibres on the mould, over the glued core. This task is completed by Worker1. It must be mentioned the difference of processing time between Dress_Fiber_A and Dress_Fiber_B, the reason is that after this second layer is placed both layers are cut again to adjust their size to the mould surface.

• Mould_Closing.
The upper part or female part of the mould is transported with the crane, matching this part with the one where fibres and core are placed. This operation requires Worker2 to move the crane and Worker1 to support the matching of both parts and the adjustment of the final movements. The upper part of the mould is modelled as a vehicle since it is involved in the simulation only for closing and opening movements, so this vehicle is actually the simulation of the mould and crane movement.

• Infusion_Setup.
To seal the mould different presses have to be placed pressing both parts of it. Also the connections to the pump and to the mixing buckets have to be done and these operations are the ones included in this workstation. All these operations are performed by Worker1. Infusion_Setup is done in parallel with the Mixing since the mix cannot wait too much time before infusion starts. Hence a Separator is placed before this workstation to split the Entity in two just when this operation starts. One of these Entities goes to this workstation and the other to the Mixing, operation carried out by Worker3.

• Infusion.
Once the Infusion_Setup and the Mixing are done, the Infusion starts without the requirement of any worker but at least one must check when the mix is finished to close the connections, otherwise air will enter in the mould causing surface defects.

• Curing.
Curing may be considered a waiting time more than an operation. As it is easier to model as another workstation without any secondary resources needed and it does not interferes in the model objectives it has been considered like this and included in the operations taking place in the moulds.

• Mould_Out.
Like Mould_Closing this workstation simulates the crane movement with the upper part of the mould. Worker2 is required to move the mould and Worker1 is required for the adjustments. This is the last of the workstations repeated in both moulds. After this operation, the main Entity is combined with a Trolley and transported by Worker2 to the next workstation.

• Cutting_Edge.
The following operation in the process is to cut the edges of the mould to adjust it to the designed size. This operation is performed by Worker2 and the external view of this workstation is the chamber where the all the operations will take place until the Control workstation.

• PreGlue_Pipe.
This operation consists on the manufacturing of the pipe piece already discussed. It is a task assigned to Worker2 and as it was explained, it is done in a set of four pieces each time, so the operation is done every four production orders.

• Drilling_Hole.
This operation is carried out by Worker2 and consists on the drilling of the hole where the pipe is going to be connected. After the end of this operation a Pipe Entity is combined with the already combined main Entity and transported by Worker2.

• Postcutting.
The Postcutting workstation is where the heating cable is removed from the inside of the floor allowing electrical connections and checking its electrical resistance value to control the performance of it. Also the manufactured Pipe is glued to the floor in this workstation fastening a stopper valve in the Pipe as well. These operations are assigned to Worker2 who is also the one that transports the Entity to the Control.

• Control.
It is the last workstation in the manufacturing process. Like some other ones it may be modelled as another object but since it is not interference for the model objective, it was decided to keep the same objects used and not to include new ones. The Control is assigned to Worker2 who also transports the Entity to the Storage.

MyCombiners and Combiners.
These objects are included in the simulation model to model different parts of the floor being assembled. In the simulation model this is obtained combining different Entities like Pipes with the main Entities or combining again Entities that were split like before Mixing and Infusion_Setup to achieve the parallel performance in these two workstations. The Matching Rules and the Batch Quantity are the most important properties of this object. A MyCombiner was created just in case priorities system had to be expanded to other kind of objects. These objects were finally used even though no extra properties were finally included, so MyCombiners and Combiners perform the same.

• MyCombiner1.
Entities coming from Fibers, Drain_Painting and Heating_Cable are combined in there to treat them as an only Entity in the mould operations even though it is not an exactly real assembly. The Matching Rules defined ensure that those Entities are from the same type of floor. The logical AddOn Processes called MyCombiner1_BeforeProcessing and MyCombiner1_

Processing change the property CurrentTravellerCapacity of the Paths that connect this combiner to the moulds according to the Entity type, deciding which Path is open in relation to the initial priority of the Entity. These opening and closing Paths processes operate with a Decide step and Assign step in the process flow defined in the Processes tab.

The Decide step set the condition to do one action or another and the Assign step applies the action. Specifically the Decide step evaluates if ModelEntity.InitialPriority value is one or two to distinguish between both main Entities. If it is one then the process advances to the Assign step that opens the Path for the BigFloor1 and if ModelEntity.InitialPriority is not one the process advances to the other Assign step. In the Assign step the CurrentTravelerCapacity of the Paths chosen is modified allowing or avoiding the travelling through it.
This procedure is the same for all the process stages where it has to be decided a destination

depending on the type of Entity arriving like in the Mixing workstation or in the BasicNode1 to choose between both Drain_Painting workstations.

- MyCombiner2.

Pipes and main Entities are combined in there and as usually Pipes are already prepared the day before in the waiting times, a logical process is defined to start simulation with four Pipes already manufactured.

- MyCombiner3.

In this combiner the floor is placed in the trolley combining the Entities coming from the mould and from the Trolleys Source. Here also the Entity External View changes, like always adding a row in the State Variable Properties, Before Exiting and changing the property ModelEntity. Picture and selecting the proper symbol column in Table1.

- Combiner1 and Combiner2.

These are the combiners placed in the moulds, where the Entities that had been split in the Separator are combined again. Both combiners have logical process called Combiner1_MemberEntered and Combiner2_ParentEntered that change the traveller capacity of some the Paths that connect the Mixing to each Combiner. One of these was closed in the Mixing to guide the Entity to the right mould and now in these processes both are opened again once the Entity has reached the Combiners.

Separators.
As it has been discussed in chapter number four, the Separator function is to split the arriving Entity in two. This property is used to be able to complete two operations in parallel.

Playing the same role as when in the beginning of the process three Entities were created one for one of the Drain_Painting, another for Fibers and the last one for the Core_Prep, these Separators are used to split the Entity in the moulds guiding one to the Infusion_Setup and the other to the Mixing. No other properties are included in these objects so Separator1 and Separator2 are already explained in group.

Paths.
The Path objects are the most common in the simulation model since they draw a net of connections amongst the objects already discussed. In fact more than sixty Paths are included in the computer model. Regarding that not every Path role is going to be explained and only the ones considered as important due to special properties will be described. Anyhow the most recognizable properties are Type which means if it is Unidirectional or Bidirectional and Traveller Capacity which is related to the number of moveable objects can travel at the same time. This last one is important and has been very useful to guide the Entities through one Path or another in relation to its class.

To track the distance travelled by the operators, some of these paths have been placed only for them and no Entity travels through it. This tracking is actually the main objective to be drawn from the simulation model and it will be explained deeper when the Workers are described. Nevertheless the way to track it is to record in a Real Discrete State Variable the movement of each Worker through the Path before the Worker exits of it. So in every Path the Worker moves around, there will be an order to record the distance of this Path and add it to the total recorded.

This distance travelled is by default recorded in the State Variable Movement and the only extra requirement is to add this value to the total value that is loaded in a new State Variable defined by the author and called TotalDistanceTraveled. Doing this in every Path travelled, the total distance will be known when the process ends.

- Path1, Path2, Path3, Path4, Path6, Path7, Path8, Path11, Path12, Path13, Path14, Path15, Path17, Path18, Path20, Path21, Path22, Path23, Path24, Path26, Path27, Path28, Path29, Path30, Path31, Path33, Path34, Path36, Path37, Path39, Path41, Path42, Path43, Path44, Path45, Path51, Path53, Path55, Path62.
These are the Paths included to track and record the Workers movements. Thus all of them have the order to record the distance travelled in the property MyWorker.TotalDistanceTraveled ordering this from the State Assignments Properties window, Before Exiting and adding a row there.

- Path9, Path9_1, Path32, Path49.
These Paths are included in logical processes to modify their CurrentTravellerCapacity Property. As it has been explained, this is the method chosen to guide the Entities to the right mould and these are the Paths involved on it. This system is based on the logical processes explained.

- Path36, Path39, Path42, Path44, Path57, Path58.
This group of Paths are the ones related to the movement of the mould. They are also included in different logical processes to model that movement. The simulation of this movement is modelled by the movement of Worker2 to a certain BasicNode where the crane remote control is supposed to be. Once he reaches that Node a thirty seconds Delay step takes place and then the Path for the upper part is opened and the movement starts as it was controlled by the operator. Once the mould reaches the final position the operator is released and the Path is closed again. To remove the mould the same process has to be done.

Connectors.
This kind of objects is similar to the Paths but do not have physical dimensions. They are used in the simulation model to connect objects placed in the same location like for the workstations in the mould.

Nodes.
The importance of the Nodes is they are destination or departure points for Entities, Workers or Vehicles. Hence the guide of these objects is often referred to a certain Node. As for the Paths, there are a lot of BasicNodes, InputNodes and OutputNodes. Some of them have already been discussed in relation to the object associated and others will not be mentioned since they do not provide special properties to the model.

- BasicNode1.
It is the Node where the logical decision process to choose between the two Drain_Painting workstations take place. It has already been described how the opening and closing Paths logical operates.

- BasicNode2.
It is the Node where the Workers start the simulation. It has been considered the starting point since it is a close point to the entrance to the facilities from the dressing rooms, even though these ones are not included in the model. It has been considered that every working day starts from this point and the three operators arrive at the same time.

• BasicNode3.
It is the working destination place for the Mixing operation. Worker3 moves to this Node to carry out the mixing operation. It has been decided to choose another Node to make easier the distinction of Paths since Paths will come to the InputNode of the Mixing from the two moulds and other two Paths are required for the Worker movement.

• BasicNode12 and BasicNode16.
These Nodes are the places where the Workers go to complete the operations in the moulds, BasicNode12 for the left mould where BigFloor1 is moulded and BasicNode16 for the right mould, for BigFloor2.

• MandoGruaMO1, MandoGruaMO2, MandoGruaMC1, MandoGruaMC2.
These are the destination Nodes each time Worker2 travels to get to the crane remote control. Even though there are all the Nodes placed in the same location, there is one for the opening and closing operation for each mould to ensure no interferences between both moulds logical processes.

• NodoInicioM1, NodoInicioM2, BasicNode27, BasicNode28.
These nodes are the start and end of the Paths for each upper part of the moulds. Some processes are referenced to them to control the mould movement.

MyWorkers.
All the three workers have been considered equal in terms of efficiency and behaviour as it was discussed in the simplifications paragraph. In that way, Worker1, Worker2 and Worker3 are going to be defined together since the only difference amongst them is the division of tasks.

To achieve the purpose of this computer model it has been required to define a new State Variable for the Workers to record the distance travelled. As it is not possible for the default Workers included in the Standard Library a new kind of Worker called MyWorker was developed. The value of this property called TotalDistanceTravelled is shown in a label associated to each MyWorker as it could be seen in the simulation file and it operates the way it was explained in the Paths description.

In addition to that, the MyWorkers are defined to choose amongst different requests through the Smallest Value of the variable ModelEntity.order. This variable makes reference to the priorities system also discussed previously. Dynamic Selection Rules consider new requests each time the Worker is released and Ranking Rules does not consider new requests until the current ones in queue are completed.

One Add-On Process is included in all of them, related to the load tasks. When an Entity is transported by a Worker it is able to record the Worker that has transported it. This is a useful property to assign the same Worker to production and transport tasks in each workstation and it is the purpose of the processes Worker1_Loaded, Worker2_Loaded and Worker3_Loaded.

Vehicles.
As it has been mentioned before the movement of the moulds with the crane is modelled as an only vehicle for each mould. Each one of these Vehicles move through an only Path between two BasicNodes already described. The opening and closing parameters for each Path consider that both moulds cannot be moved at the same time keeping the crane as a scarce resource. Vehicle1 and Vehicle 2 do not have more defined properties than the InitialNode and their behaviour is controlled by the logical processes already discussed in the Paths and Nodes explanations.

Sink.
The end of the process is reached when the many times processed and combined Entities end in the Storage. The Storage is the Sink of this process and it simulates the real storage without considering later transports or material handling. It is connected to the Control workstation and a Transfer-In Time can be defined to keep the Entity in queue before it is destroyed.

After these explanations all the objects included in the Facility tab have been described as well as logical processes and data tables trying to clarify the computer model built. The next step is to go back to the verification and validation concepts explained in chapter three for the simulation model and try to ensure that this model satisfies the proper requirements.

As it was defined previously, verification is related to a successfully translation of the conceptual model to the software. This term makes reference to the input parameters chosen and the logical structure developed. Validation is the determination that a model is sufficiently accurate for the purpose defined.

According to that verification is only applied to the step from the conceptual model to the computer model and it can be accepted once conceptual model elements and simulation model elements and properties have been deeply described matching both parameters.

On the other hand, validation includes more fields like conceptual model validation, data validation, comparison with the real system or visual checks, keeping in mind the purpose of the model.

Considering the conceptual model as the first approach to the transformation of the real system into a simulation model, this conceptual model must be developed in the way it is possible between the author and the company members. According to that the conceptual model was developed and accepted by the company members, showing it in the meetings of 13th December 2012 and misunderstandings and simplifications were clarified.

The data validation relies on the accuracy of it. For this simulation model the purpose is to be accurate tracking the distance travelled by the operators. This total distance is influenced by the length of the paths travelled, and this length is influenced by the size of the workstations, the size of the facilities and the division of tasks, processing sequence and processing times.

As the real path followed by the worker cannot be measured it has been decided that the paths must be as straight as possible in the simplifications paragraph.

Regarding other data inputs the size of the facilities, workstations and other objects were given in facility plans by the company and checked measuring them personally.

The division of tasks was observed and discussed with the managers of the company according to the personal skills of each worker. Even though, as it was already mentioned, in the waiting times helps amongst workers are common and difficult to simulate since it is a highly dynamic and improvised behaviour.

The process sequence accuracy was checked in two different ways: The validation of the conceptual model and the visual comparison of the computer model with reality. Both tasks have been done in collaboration with the company members throughout the different meetings to discuss the simulation model and the layout possibilities.

Finally, the processing times are important in order to combine operations of different floors. As the tasks are divided amongst the workers, for one floor is not essential an accurate processing time since each worker will do the same tour. However, when production orders are more frequent, the tour may be affected by the processing times. So these times have been measured with a time study procedure which also will be used for the labour costs quantification in the cost accounting development.

To complete the validation, visual check of the general simulation system and comparison amongst the three layout alternatives imported to the simulation and the ones developed by other means were done and accepted by members of the company and so the author.

To put an end to this point of simulation development the model of the old facilities will be compared with the one described, pointing the differences.
It must be mentioned that the performance of the old facilities simulation model is very similar in operating terms. The methodology to compare them will be to discuss the new objects included, once an introduction of the similarities is done.

The old facilities conceptual model is rather similar to the new one since it is almost the same manufacturing process. Hence the considerations included in the new one are valid for this model.
In relation to the main parameters of this computer model of the old facilities it must be mentioned that the priorities system for the Workers behaviour, the concept of Entity, the way to simulate the movement of the upper moulds, the way to record the distance travelled and so on are exactly the same explained for the model described before.

The main differences that will be discussed in depth down below are related to the number of different bathroom floors produced, the number of different workstations considered, the number of operators working in there and the size of the old facilities. Obviously the name of some Paths and some Nodes does not match between both models because the number is completely different but the role is still the same.

So in relation to the Entities included it has to be mentioned that when this project started and during the first stages of it the company manufactured four different models of bathroom floors instead of the current two models. The other two, that already are not produced, were almost the same models but with different size and other moulds were used. Anyhow it must be clear that the process is exactly the same. In that way four different bathroom floors are considered for the old facilities production and then four different main Entities are created in the Office Source. This Source also considers the Table1 to check the Entities to create and the proportion amongst them.

According to that, different symbols are created for the four Entities and there are also four different moulding stations instead of two, where different workstations are included and also where the moulds move to.

In relation to the workstations included in the old facilities model it must be explained that for the whole length of this project different improvements where applied to the manufacturing process studied. Regarding that some operations were firstly done in particular workstations and then these ones were removed or included in other ones.

For instance in this model, there is the workstation called Drains specifically included for the drains manufacturing, operation that nowadays is done in combination to the Dress_Fiber_A and Dress_Fiber_B. This Drains workstation is placed to do in parallel to the fibres cutting operation and the core preparation since it does not need previous operations.

In this model the moulding operations take place in four different locations, one for each model. Anyhow as they have the same role, the other two moulding stations will not be considered as a key difference between both models and no extra explanations will be done.

Carrying on with the manufacturing process differences the second and last important one is the Postcuring workstation. When the process was introduced for the first time and during most of the time the production was carried out in the old facilities another step was done just after the floor was removed from the mould.

This floor was introduced in a heated chamber for a half an hour post curing operation to strengthen the composite material. Afterwards it was considered that this effect could also be obtained leaving the floor in the storage for some hours before it was delivered so this operation was removed and the post curing chamber also was eliminated from the manufacturing process.

No other differences related to the process were present between both computer models. The differences remaining are related to the number of workers and the size of the facilities. As the initial number of workers was two the division of tasks is different as well as the production rate. The size of the old facilities was obtained from a building plan provided by the company and it was included in the computer model.

Finally it must be said that for the objectives of this project the old facilities computer model has a limited use since the distances and production rates cannot be compared with the new ones. The reason of that is a new operator is working nowadays and the tasks and total manufacturing times are different. Only for a deeper understanding of the process and to check the progress of the process efficiency in global term could be helpful this model.

The current facilities were modelled accurately and the different layout designs developed were included successfully in the computer model saving three different files, one for each layout design. These files actually were helpful for the layout design decision and the results obtained from them are explained in the following chapter.

5.2 Layout Design

The layout design of the new facilities for the manufacturing process is one of the main purposes for this master thesis. To achieve a robust design the study and development of this issue have been based on different information sources and methodologies.

As it has been described in point 3.6, the process to reach this design must be developed from a methodological approach by following a set of different steps. The steps that also were described in point 3.6 are the ones that are going to be followed: Introduction to the plant layout problem, Analysis of the old design, Development of alternatives, Evaluation of alternatives, Selection, Implementation and Tracking.

The first four steps are going to build up this current point of the project while the Selection and Implementation steps will be discussed as results of this project. The Tracking step is a step that must be done in the daily activity, considering limitations and improvements for the design. This task will be left to the company members to control the progress of the activity with the design chosen in order to decide modifications of it.

Starting with the introduction step it must be mentioned that at the beginning of this project the company had already started the manufacturing activity. In that time a temporary layout was designed in order to start production as soon as possible, being aware that sooner or later a study of it should be done. Anyhow this first approach to the process layout was useful to get experience in the process relationships and understanding details often difficult to realize from a theoretical approach. According to that the main properties of the old facilities layout and the building plan will be discussed afterwards.

By the time the company decided to move out from the old facilities, this project had recently started and the opportunity to develop a layout design project was considered very interesting for both. Also because some of the tools suggested were helpful for other studies, specifically simulation tools.

Drilling down a bit more in the reasons for the move out of the old facilities it must be said that it was decided due mostly to economic and strategic reasons like the factor that the new facilities are placed close to the SICOMP Institute, already mentioned, or the rental agreement that allow them to pay just for the surface used in the new big facilities, being able to expand easily their manufacturing process if it is required.

Carrying on with the old facilities layout, the manufacturing process has already been explained in the simulation model description, highlighting the main differences between the old manufacturing process and the current one.

These differences brought difficulties and misunderstandings to the development of the new layout alternatives as it was mentioned in the Time Schedule, specifically in the meeting of 28th January, when most of the manufacturing modifications were explained by the company members. For instance, as it was discussed in the previous point, workstations for the drains manufacturing or elements like the post curing chamber were removed from the process affecting to all the other elements and the organization of space.

Even though the layout alternatives were developed completely considering old manufacturing elements they will not be included in this point since they are no longer helpful for the company.

On the other hand, the layout of the old facilities will be included to analyze it and show the most important points as the step two of the methodology followed: Analysis of the old design. It must be said that a deeper understanding of the process was obtained from the study of the old layout and its development in the simulation software.

To carry out this analysis a general description of the building properties and the flow type will be done and afterwards a pros and cons valuation will be done. As this one is the analysis of a past situation already ruled out, a deep study of its properties and how it could be improved seems to have limited value. According to that this description will overview the main aspects since it is not a valid base for the design of the new layout due to some of the elements present are no longer part of the manufacturing process.

Even though the plan of the facilities is included and is clear, it is not easy to obtain useful information and develop improvements from it. The opportunity to visit the old facilities many different times and observe the manufacturing process personally was the real fact to understand the critical points of the process and the priorities in the relations amongst the elements of this manufacturing process.

The manufacturing process steps and the sequence of operations was already described in chapter number three and also can be understood from the simulation model explanation, so in this part of the project the discussion will be focused in the key points of it considered by the author and also other ones highlighted by the company members.

Regarding that and analysing the process in perspective three different flows may be observed on it. These flows are defined by the type of operations and the sequence of them:

- Flow number 1. The Composite Basis.
  This first flow considered involves the operations related to the fibres cutting and the resin mixing. It also includes the transport of these materials to the moulding station. These activities are not in sequence but both are raw materials that need just one operation to be ready for the moulding tasks. Both go from the raw materials to the key point of the process in just one step so both could be treated in the same group. Anyhow it must be noted that both workstations are independent and do not have to be close. They are grouped in the same flow since they share properties regarding the Moulding station. This is important for further steps when the layout design is done. These stations will have to be close to the Moulding but is not specially required to be close between them.

- Flow number 2. The Core Preparation.
  The third main raw material involved in the process is the core included in the composite to develop the sandwich structure. Opposite to the operations of the first flow for this preparation a sequence of operations has to be done. Starting with the cutting of the core from the sizes these materials are delivered to the size required for the floor. These cutting must be done for cores of different thicknesses as it was discussed to get the proper tilt of the floor. The second step in this flow is the robot operation to draw the path for the heating cable in the core. This operation is done putting the different cut parts of the cores in the robot table and setting up the robot to start the operations. Once the robot has finished the core parts are transported to another workstation to glue them and place the heating cable on it. This flow ends with the transport of the core to the moulding station.

- Flow number 3. The Post-Moulding Operations.
  Once the floor is removed from the mould the last operations of the process have to be done. These operations are the cutting of the edges, the location of the pipes, the extraction of the heating cable and the control to get to the storage and end the process. These operations are done in sequence and the relation amongst them is close since they are done in a row until the end of the manufacturing once the floor is out of the mould.

These three flows meet in the most important point of the process:

- Meeting point. The Moulding Operations.
  The moulding operations include the dressing of the mould with the both layers of fibres, the core location, the mould closing, the infusion setup, the curing and the mould opening. These operations are done in the same physical place that has been told moulding station. This place is the meeting point of the three flows described just above: Fibres, resins and core come to this point before the moulding operations are done and the post-operations flow departs from this point to the final steps of the process.

This process approach was obtained from the observation of the activity, the theoretical analysis of the components flow and from several discussions with the company members. The importance of this process structure is related to the need to clarify relations amongst workstations and being aware of the main branches of this process. According to that this classification will bring information for future designs and the application of different layout development methodologies.

In addition to this flow analysis, some particular transport activities must be highlighted since they are especially critical for the process due to different reasons that will be explained down below. These activities will also be considered by the time the new designs are developed.

- Upper mould transportation.

The closing of the mould once fibres and core are placed in the proper disposition is a highly sensitive operation. Two workers are usually required to place it in the right place with the help of the crane. It also brings security risks since the mould has to be lifted more than one and a half meters from the ground and moved in that height.
This operation requires a considerably amount of time also because the speed to move the mould cannot be high. Regarding that, upper moulds will be placed as close as possible to the lower parts.

- Mixing transportation.

The mixing of the resin with the curing agent and the inhibitor is made in different buckets, usually two of them, regarding their volume. Then these buckets are transported by the operator to the moulding station. The mixing operation is done once the mould is closed and the infusion setup is almost finished. This transport activity is also highly risky and sensitive since there are more than sixty litres of mix to transport from the mixing station to the moulding station. This transport is done with the help of a small trolley but the risk to pour the mixing in the travelling is still real. Thus the mixing station should be as close as possible to the moulding stations.

- Core transportation.

Once the Core Preparation flow finishes, the core is ready to be transported to the moulding station. This activity is done by one or two operators without any help of external means of transport. Regarding that, the risk of breaking the glued core is real since many pieces are stuck together making a quite brittle whole core until it is completely glued. This situation causes that the end of flow number two should also be as close as possible to the moulding station, to minimize the required distance travelled to transport this core to the stations.

Finally, apart from that, some considerations shared by the company members for some elements of the manufacturing process will be explained because they will be kept in mind in the development of the new alternatives.

- Variable facility rental costs.

One of the most important considerations for the layout design is related to the rental costs of the facilities. The agreement signed for this rental established that Blatraden AB will pay to the owner a variable price according to the space occupied. In that way, the building plant is divided in three different parts that can be used. The reduction of the space used for the activity performance will bring lower costs to the company. So in that way one of the key points of the design is to adjust the total area used. This objective is aligned with the Lean Philosophy that will be surrounding this project. Regarding the 7 Mudas of Taiichi Ohno the waste of transport and motion do not add value and bigger facilities bring longer distances to travel causing excesses of transport.

- Office location already defined.

The new facilities were already in use before the company decided to establish there. In that way the last company that used these facilities had built the office room in one side of the facilities as it will be observed in the plan showed afterwards. Regarding that the location of the office will be seized and therefore it will be a fixed location in the layout design.

• Mixing station affected by temperature changes.
This fact avoids the mixing station to be placed close to the entrances and exits of the facilities and also should be far from windows or other outside exits. The reason is the chemicals' properties may be affected by the temperature and curing reactions may be influenced causing failures in the process.

• Robot located in a corner of the facilities.
For security and safety reasons, the robot should be surrounded by protections to avoid accidents at work. Fences or other elements like motion sensors may be installed to keep safety avoiding the operators to go in if the robot is working. Nevertheless considering this fact, the easiest and most economical solution could be the location of the robot in a corner of the facilities and complete security with fences in the other two sides if considering the workstation as a rectangle.

All these understandings, special activities and restrictions will be used for the design of the new facilities and considered in the application of different tools as it will be discussed afterwards.

Before introducing the design tools used and start with the Development of alternatives step, a brief analysis of the advantages and objections of the old facilities layout will be done, according to the factors discussed just above. Also the old facilities size will be discussed and considered in this analysis.

It also must be mentioned that the flow in the old facilities is rather different because there are other workstations involved. The differences would be that the drains workstations would be included in the Flow number one and the curing chamber in Flow number three.

The most important advantage in the old layout seems to be the location of Flow number three. This set of workstations is placed in line almost like a perfect I flow from the curing chamber, cutting operations, control and to the storage. In addition to that the storage is placed close to the entrance and exit of the facility which makes easier the delivery of final products.

Once the upper part of the facilities is the place for the Flow number three, it seems the right place for the moulding station the centre of these facilities being the flows close to it. This is already the distribution chosen and the location of the fibres station, the drains station and the moulding station may be considered as appropriate.

In relation to the objections it is needed to start with the size of the facilities. It may be noted the amount of free space in the facilities even though some other elements are not included in the plan like forklifts, trolleys or tooling location.

Often big facilities are a disadvantage for manufacturing processes. Distance travelled increases, the control of operations is more complex, the transport activities increase, the possibility to combine a set of operations for an only worker decrease, the cleaning and maintenance requirements are higher, the overhead costs like lightning or heating are also higher and so on.

Sometimes these objections may be overcome or it may be possible to deal with, for instance if rental costs are lower or for other strategic aspects, but in general the excess of space will only cause extra costs.

Anyhow, the distribution of a set of workstations in a facility plant much bigger than required does not mean that the elements have to be dispersing throughout the whole space available. According to that, it is often much recommended to concentrate the items in what is considered minimum required space than placing them all around the facility. This approach is developed in the Seven Wastes or Mudas included in the Lean Management approach where extra transportation or extra movement are considered as two of the most important wastes in a company.

Applying this concept to the old facilities it must be mentioned that the other two flows involved in the manufacturing process should be placed closely to the moulding station and to the third flow which it is accurately located. This should be done even if it means to let a big place in the facilities without use, because this fact also brings the clear view that there is a waste of space and the company is paying for it.

So summarizing the objections so far discussed, the general locations of flow number one and number two may be improved regarding distances.

Carrying on with objections, the mixing location is neither appropriate since it is place far from the moulding station and close to the walls of the facility exposed to temperature changes. The distance to the other workstations included in flow number one and the long distance required for the transport of a huge amount of liquid causes that the location must be considered as not appropriate.

Another objection that must be mentioned is the location of the robot and the organization of flow number two composed of the Workshop workstation and the Robot workstation in the plan. First the robot should be placed in a corner to save extra protections. Anyhow it was already surrounded by wooden fences and placed far from other workstations avoiding the unintended entrance.

What it is not so suitable is the distance between the two elements included in flow two. Workshop and Robot must be as close as possible to cut the cores, place them in the robot, remove them from the robot, glue them, place the heating cable and transport it to the moulding station. This leads with the required proximity of the flow two to the moulding station for the transportation of the core. In the case analysed the Workshop is not close to the Robot and neither close to the moulding station, so this situation must be improved somehow.

Finally to end the objections part of the analysis the location of the upper part of the moulds has to be discussed. As it was explained before, the movement of them is a complex and risky task which takes a certainly high amount of time. These mould have to be lifted and transported with the crane and because of the reasons discussed, they must be placed as close to the moulding stations as possible, even though it means these parts are in the ground in the middle of the facilities because finally for the lifting and transporting the interferences will be much lower than keeping them far.

This analysis of the different flows involved in the process, the study of the key points of the process and the implementation of this old design in the simulation model brought the global understanding to the author to develop the different layout alternatives that will be explained down below.

This development was supported by a group of tools and methodologies that were introduced in the theoretical point related to this subject matter. Anyhow the tools used and the benefits of them are going to be explained before the proper development starts.

Regarding the theoretical research done for this chapter, eight different approaches were mentioned as possible points of view to carry out the layout design. These approaches were the following ones:

Materials, Flow Lines, Operators, Machinery, Wait Factor, Build Factor, Change Factor and Service Factor.

Also different tools were introduced for each group and the profit of each one for the development of this layout design is going to be evaluated down below.

According to the Material approach, the main objective of this point of view was to know in depth the properties of the materials and operations sequence to define this process. The tools suggested were for instance the process diagram, the bill of materials, the analytical diagram or the travel matrix. The aim of these tools is to get a deeper understanding of the process by a graphical representation of it or measuring the frequency of travels between pairs of workstations.

All these tools have been considered and some of them were used to develop the simulation model. For instance the conceptual model development was based in a process flow diagram and for the computer model a bill of materials and operations was described by the company members.

Regarding the analytical diagram it must be explained that the purpose of this methodology is to measure the time spent for operations, inspections or delay activities and the distance travelled for transport activities. The times for operations, inspections or control and delay or wait activities were measured as it has been described carrying out a time study and including them in the computer model. Actually this is one of the most complete tools and usually is complemented with the travel chart to add a visual representation of the information collected with this tool. This combination will be described in depth afterwards.

Related to the Flow Lines approach, the purpose is to minimize the distance travelled for the materials involved in the process. This approach also leads to the Lean Management approach of the Seven Wastes or Mudas included in the Kaizen Philosophy. The travel chart for materials that was explained in the theoretical is the most important tool related to the analysis of flows in the plant. This graphical representation of the materials movement can also be applied to track the movement of operators as it was discussed in the theoretical chapter.

That last implementation discussed just above leads to the Operators considerations, where the main ideas are connected to minimize the number of travels and the distance travelled. As it was explained the travel chart for operators considers movement forward and backwards within the facilities and it is measured in a facilities plan with a wire and thumbtacks to track the total distance.

Some other considerations are required regarding operators approach like safety and security aspects.

Anyhow from experience and theoretical analysis it just has been considered the constraints already discussed for the layout design and other particular actions that might be required for the safety and security within the different workstations are not the subject of this study.

At this juncture, it can be noted the value of the combination of the analytical diagram with the travel chart. These two tools may be the ones able to provide the most useful information for a layout design in these three groups already analysed.

Keeping in mind the origin of the data for each one of these tools and the main purpose of them it can be noted that the objectives of them match with the possible answers obtained from the simulation model.

In fact the analytical diagram considers the sequence of activities, the time of each one and the distance travelled for the transport activities. This tool provides quantitative information regarding these activities obtaining it from the measurement of these times and distances.

On the other hand the travel chart for material and operators provides quantitative and graphical information regarding circuits travelled by those elements.

So once the computer model of the manufacturing process is fed by the time study, the size of the facilities obtained from the real plan in AutoCAD format, the size of the workstations measured and designed in SketchUp and the inclusion of the sequence of the operations and logical of the process, it is possible to assert that with the verified and validated computer model the benefit of these tools is obtained from the simulation support developed.

This explanation just above is the role defined for the simulation model to support the decision making of the layout design in addition to other methodologies that will be explained afterwards.

Going on through the considerations defined for the layout design, the next approach to be analysed is the Machinery factor. This factor studies the relations amongst workstations as it was described in the theoretical part. The Systematic Layout Planning tool, also described in the theoretical part, is going to be used as the main tool in collaboration with the simulation model to develop the layout alternatives. Hence this tool will be explained at the end of this general overview of the different groups.

So leaving this machinery factor and the use of the SLP for the main part of this development the following group is the Wait factor. As it was discussed in the theoretical part it does not apply to this situation since it is developed for companies where the space required for warehousing determines the location of the other elements and this is not the case.

In relation to the Building factor it is focused on the building properties, like plant shape, exits and entrances, office locations, walls, windows, equipment already installed like cranes and so on. These properties are considered in the constraints defined and also will be kept in mind by the time the location of the workstations is done. There is no special tool considered for this approach, the objective of it is to be aware of the particularities of the real building instead of considering just as a homogeneous available surface.

Regarding the Change factor, it brings a critical approach evaluating the objections of the alternatives in relation to possible future changes. This approach will be considered in the evaluation part of the layout development.

Finally, the Service factor considers the activity of ancillary staff like maintenance, quality or logistics and also if it exists the activity of means of transport like movement of trucks, forklifts or other elements. This approach will be one of the evaluation considerations to choose among the alternatives defined. The ability to reach the different workstations with means of transport and the ease to move around the workstations will be considered for the assessment.

Once all the factors have been considered and the explanation of how they are going to be used is done, the next step in this part is to develop the main method to achieve the design of the new facilities.

The Systematic Layout Planning is the method that is going to be used to develop the three layout alternatives. The alternatives designed will be later evaluated in the results chapter with the help of the other tools and approaches described. In that point the most suitable alternative will be pointed after an analysis of pros and cons of each one. Once the three alternatives are evaluated and the best one is chosen the objectives of the first part of the project will be fulfilled.

The Systematic Layout Planning is meant to be a successful tool for a limited number of workstations or sections since it is based on the manual adjustment of these sections to the facility plan according to qualitative priorities. These priorities set the proper proximity for the sections considered and often this organization may be conflictive or difficult to satisfy.

As it was discussed in the theoretical paragraph three different steps must be followed to implement the method. The purpose of the first one is to establish the importance of proximity for each pair of sections. This requirement will be done using the Activity Relationship Chart.

In this chart all the activities that will be considered for the layout are listed drawing a grid with all the possible combinations as it will be shown down below. The activities considered for this first step are the ones that will become a part of the new facilities manufacturing process as well as the office and the storage of final product.

The Activity Relationship Chart ready to fill in for Blatraden AB manufacturing process is the following one.

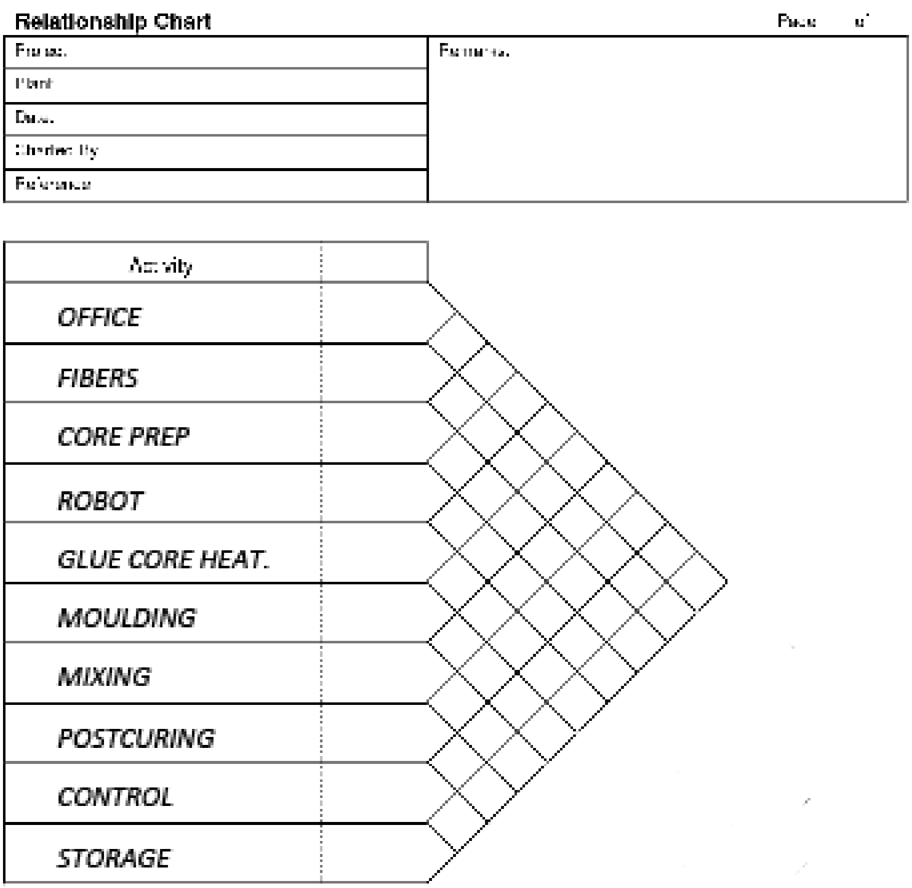

Figure 17. Activity Relationship Chart with Departments Considered.

The first table in the upper part of the image is general information related to the development of the project and does not belong to the proper Activity Relationships Chart. The chart drew down below this table responds to the Activity Relationships Chart shape, where all the activities, sections or workstations are listed and a square is ready for each pair of activities. The activities included are related to the different workstations and for these activities that take place in the same workstation just one element has been considered. For instance the gluing of the core and the placement of the heating cable are included in the same activity. It is the same for the moulding operations, including in that activity also the transport of the upper moulds.

The squares drawn are going to be filled in with the Proximity Rating in its upper part and with the Reason Code in the lower part.

As it was explained, the Proximity Rating shows the importance of the relation between the two sections linked in each square and it is evaluated with one of the following letters: A, E, I, O, U and X. The Reason Code is a number code from 1 to 6 where each number represents a possible reason for the Rating assigned. These reasons are standardized, as well as the Proximity Ratings.
These standard codes are shown down below.

Proximity Rating

VALUE	CLOSENESS
A	Absolutely Necessary
E	Especially Important
I	Important
O	Ordinary Closeness
U	Unnecessary
X	Not Desirable

Table 2. Proximity Rating.

Reason Code

GENERAL REASON	CODE
Flow of material	1
Ease of supervision	2
Convenience	3
Production control	4
Dust and fumes	5
Material control	6

Table 3. Reason Code.

It must be noted that both Closeness definitions and General Reason definitions are rather ambiguous, repetitive and opened to the author interpretation.

The reason of that is the standard qualification. As these Proximity Ratings and Reason codes are developed to fit to every layout design project independently from the process properties, the type of industry, the number of elements involved, the properties of these elements and so on, these considerations are remarkably ambiguous and subjective.

For instance regarding the Proximity Ratings, where is the border amongst "Absolutely Necessary", "Especially Important" or "Important"? Or in relation to the Reason Code what is the meaning of "Convenience"?

To answer these questions properly, the author decided to develop a set of criteria in order to assign the Values and Codes in a more objective way.

According to that the justification for the Values assignment is based on the next reasons.

- A Value.
It has been considered as Absolutely Necessary closeness activities those ones where there are explicit risks of damage for the operators or for main materials involved in the process. The first consideration is related to a safety and security approach and it will mostly be applied to the mould transportation. The second consideration is related to economic costs for the process and risk reduction in the process and it is related to the other two transport activities highlighted amongst the critical transport activities in the process. It will be applied to the core transportation and the mixing transportation.
These reasons also respond to the title of the value considering that the Absolutely Necessary label may involve few special situations.

- E Value.
Considering the three flows included in the manufacturing process it has been decided to consider Especially Important closeness to these consecutive activities in the process sequence that belong to the same flow i.e. Flow number one, Flow number two or Flow number three.
Also included in this value these consecutive activities where the floor is transported in the trolley once it was removed from the mould. The main reason is that still exists a certain risk in this kind of transportation and the intermediate product value is almost the highest in the whole process since almost all the operations have been done.

- I Value.
It has been considered to assign the Important closeness value to these activities that belong to the same flow even though these ones are not consecutive. This will cause that each flow tend to a cell shape instead of a line shape since activities in the beginning and the end of the flow will be required to be close as well. This decision leads to a concentrate organization instead of a disperse location.

- O Value.
This Ordinary closeness value has been assign to the starting and ending activities in the process regarding a proper information flow from the office to the first workstations and from the control and storage to the office.
The priority assigned justification is that the frequency of this information flow with the office is not high and only once or twice per day the information flows in one or other direction.

- U Value.
This value has been defined regarding that what is not necessary to be close it is due to lack of direct relations.

- X Value.
Some of the activities may be required not to be close one from another due to special working conditions, risks or hazardous materials.

According to that the final Proximity Ratings table that will be used is the following one:

VALUE	CLOSENESS	JUSTIFICATION
A	Absolutely Necessary	•Dangerous or risky transport of materials.
E	Especially Important	•Consecutive activities belonging to the same Flow •Floor transport in the trolley
I	Important	•Non-consecutive activities belonging to the same Flow.
O	Ordinary Closeness	•Information flow
U	Unnecessary	•Not direct relations
X	Not Desirable	•Working conditions

Table 4. Proximity Rating and Justification.

Regarding these new Values and being aware of the process particularities a specific Reason Code has also been developed trying to suit these code numbers to the properties of the process.

GENERAL REASON	CODE
Process flow	1
Travel reduction	2
Damages, dangers	3
Same workers	4
Information flow	5

Table 5. Reason Codes Modified.

In this new Reason Code it has been attempted to fit the justifications and the statements considered for the priority classification to the general reasons assigned to the codes. It must be mentioned that this Reason Code is just a simple explanation for the priority given and the development of the method is based on the Proximity Rating described above. Therefore the modification of the codes or the name of the General Reason does not impact in the final solution.

Once these new Proximity Rating and Reason Code have been introduced and described it is time to start the priority assignments to each pair of activities.

The pairs with A, E, I or O priority assigned are going to be described down below, to provide a brief explanation. The pairs with U priority will not be discussed since it may be guessed why there are no proximity requirements. In addition to the rating give for each pair it will be included the code assigned to summarize the main reason.

- **A Priority.**

  o **Glue Core Heating Cable – Moulding:** As it was explained the transport of the core is critical and then proximity is absolutely necessary. The code given is number 2.

  o **Mixing – Moulding:** For similar reasons the previous pair, the transport of the mixing to the mould was considered as a difficult and critical task where proximity is essential. Also number 2 is given.

- **E Priority.**

o **Fibers – Moulding:** According to the criteria described, the consecutive operations in the process sequence that do not have higher priority are considered as especially important proximity. Since in this case it is more influent the process flow than the transport difficulty this pair has been coded as 1.

o **Core Prep – Robot:** Two consecutive operations in Flow number two. This pair is also coded as number 1.

o **Robot – Glue Core Heating Cable:** Also two consecutive operations in Flow number two that are developed in different workstations. This pair is also numbered as 1.

o **Moulding – PostCuring:** After the moulding operations the following activity is postcuring, which has been considered as an only workstation for the different operations done like cutting the edges, gluing the pipe, drill the hole for that pipe and so on since all these activities are done in the same place. Also number 1 is the code assigned.

o **PostCuring – Control:** Another pair of consecutive activities in the process flow. It has been coded as number 2 since the control activity is not a real operation in the manufacturing process. This decision could be discussed but the importance of this codification is limited so it is not worth to analyse both possibilities in depth.

o **Control – Storage:** The final step of the process. Like for the pair described just above these activities are considered as steps of the process but not real operations so it has been coded with number 2.

- **I Priority.**

o **Core Prep – Glue Core Heating Cable:** Both activities are included in Flow number two and are not consecutive so this pair responds to the justification for I priority assignment. It has been coded with number 1 since their relation come from the process flow.

o **PostCuring – Storage:** Activities from Flow number three and not consecutive as it was defined in the I priority justification. Due to process flow reasons number 1 has been assigned.

- **O Priority.**

o **Office – Fibers:** Ordinary closeness priority has been defined for the starting and ending points of the process where communication with the office is mandatory. This pair has been coded with number five.

o **Office – Core Prep:** As the other main initial station for the process and assigned to another worker the communication with the office is required. It is also coded with number five.

o **Office – Control:** The communication between control station and office is needed when some repair works are required and shipments may be affected by delays. It is also coded with number five.

o Office – Storage: It is the communication that the product is ready for delivery. It is also coded with number five.

So after the description of the priority pairs, the Activity Relationship Chart must be filled in to carry on with the method. It has to be mentioned that these priority assignments are going to be standard for the three alternatives designed. Only different location decisions for the workstations affected will differentiate the layout alternatives.

So transferring this information to the Activity Relationship Chart, the final state would be the following one.

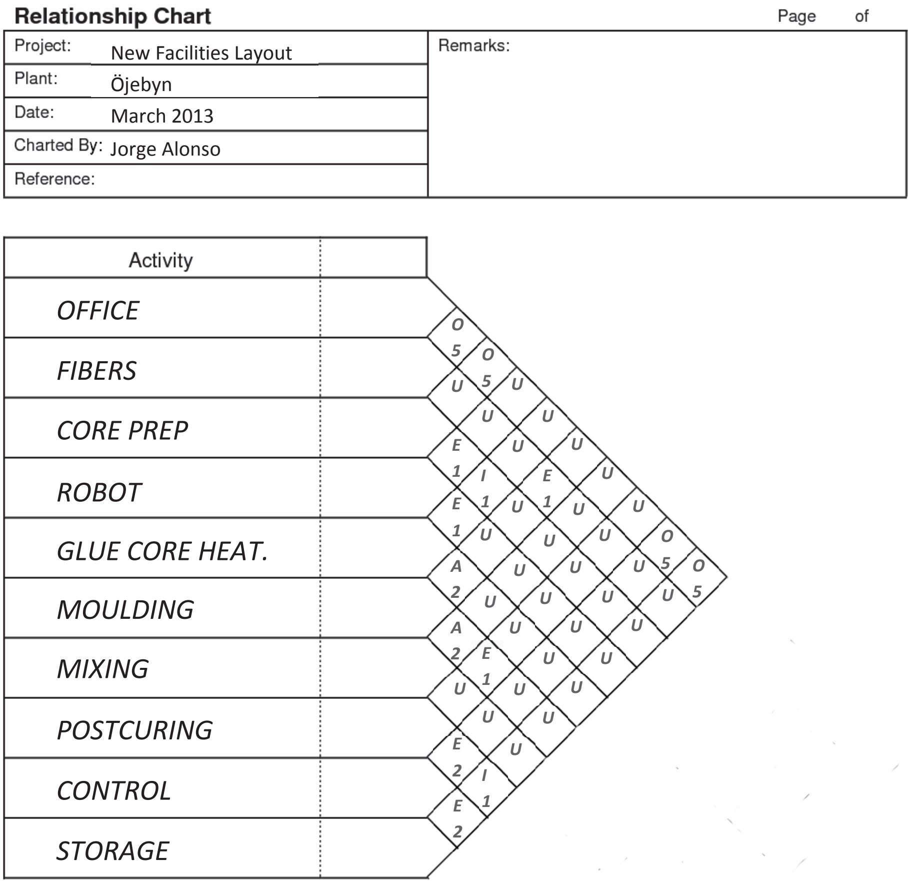

Figure 18. Activity Relationship Chart Filled In.

To show the procedure to fill the chart and illustrate the position of the squares that relate each pair this chart is again included as Figure 19 with a colour code highlighting the relations previously described.

For that an example of relation for each group of priority will be coloured. The squares coloured make reference to the pairs coloured with the same colour. Obviously each activity has relation with all the other ones and not only with the one with the same colour.

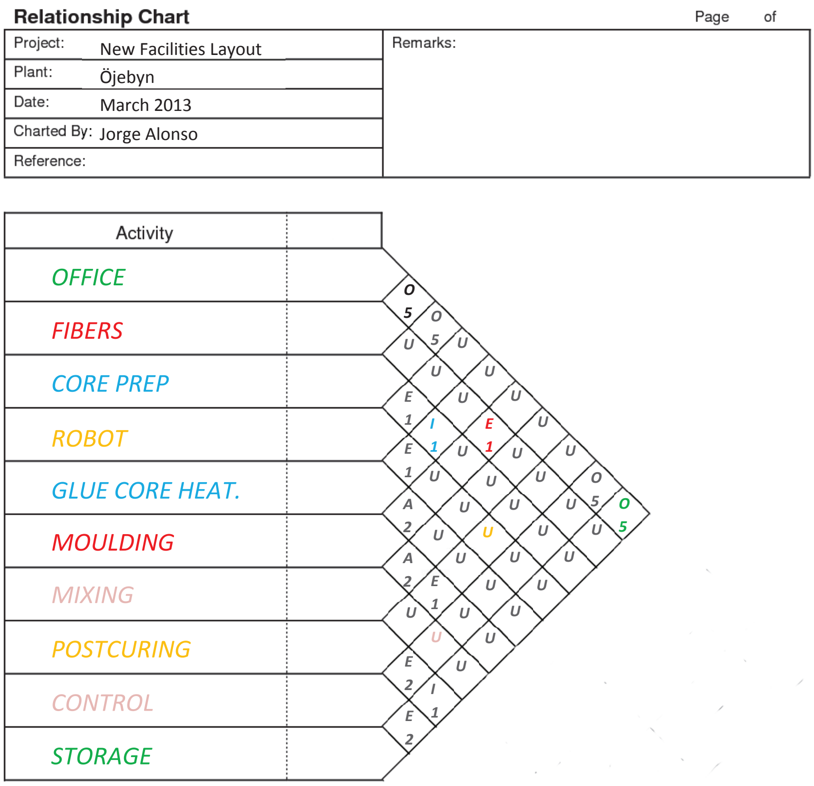

Figure 19. Activity Relationship Chart with Colour Code.

After filling in the Activity Relationship Chart the next step of the Systematic Layout Planning is to measure the space required for each activity to organize them later in the facility plan.

This step has been done measuring the different workstations used in the old facilities since these workstations are going to be moved out to the new facilities. This information is also required for the development of an accurate simulation model as it has been discussed.

The Relationship Diagram can be developed once all the information regarding workstation sizes is collected. As it has been explained this step of the method consists on the organization of these priority relations within the facility plan. The method followed in this project is the Francis and White Method that was also described in the theoretical chapter.

As this step requires modifications of locations and reorganization of the elements it has been decided to develop it using AutoCAD computer program making easier any change and movement of the workstations involved.

In the rental agreement it was signed the cost of the new facilities is related to the amount of surface occupied, so this is an extra motivation for the application of Lean concepts of reduction of required space.

Regarding that the new facilities are divided in two big areas and the office is placed in the left one so one of the common objectives for all the alternatives will be to place all the workstations considered in the method in this left side of the plant.

The procedure followed to design the layout alternatives based on this method will be the next one:

- Start with the A rating relationships, placing them on the AutoCAD file of the facility plan and drawing lines among them. Once these relations are placed, they must be reordered to keep the lines as short and straight as possible.

- Add then the E relationships and reorder.

- Add the I relationships and reorder.

- Add the O relationships and reorder.

As it was told this order is based on the priority amongst the activities, so once the A relationships are ordered, they must be the last ones to be changed to fit the others. This procedure is the same for the other upper ratings over the lower ones.

Without further ado the first alternative is going to be developed following this procedure in fourteen different steps. The purpose is to explain this first alternative in depth to get used to the method operating and then the following alternatives will be explained briefly.

Alternative 1.

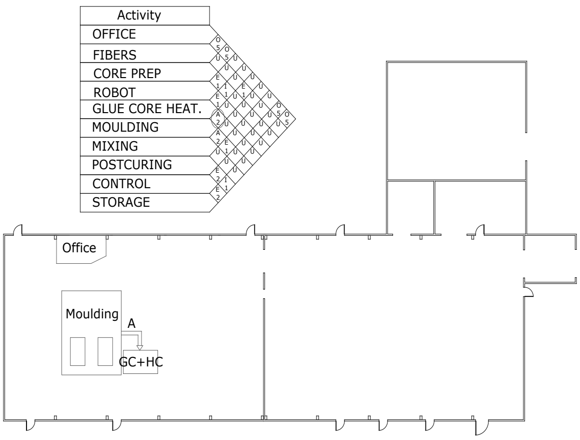

Figure 20. Alternative 1 Step 1.

Step 1.

Location of the Moulding station in the middle of the left side of the facilities since this workstation is the meeting point of the three Flows.

Then, the location of the Glue Core and Heating Cable workstations, close to the Moulding on its right side. This step makes reference to the A priority between Moulding and Glue Core Heating Cable workstations.

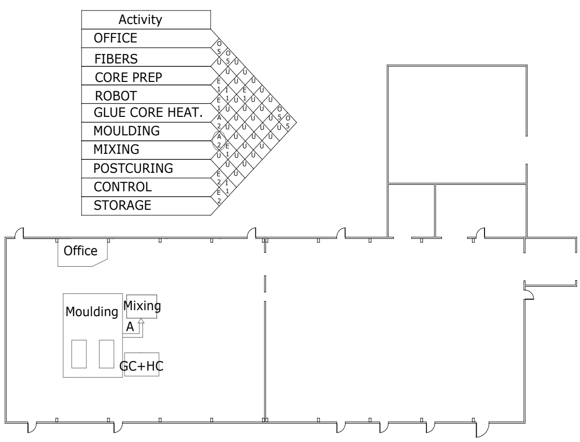

Figure 21. Alternative 1 Step 2.

Step 2.

Location of the Mixing station close to the Moulding also according to the other A priority pair. Moulding and Mixing

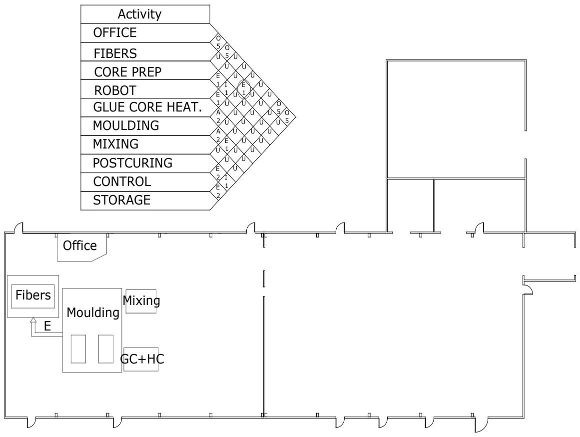

Figure 22. Alternative 1 Step 3.

Step 3.

Starting with the E priority activities the first one that will be placed is the Fibers workstation, regarding its relation to the Moulding.

Due to its size, this workstation is placed on the left side of the Moulding.

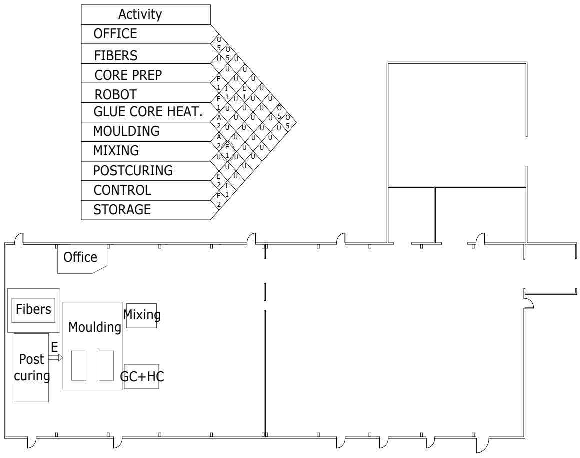

Figure 23. Alternative 1 Step 4.

Step 4.

The pair Postcuring and Moulding also is assigned an E priority. Regarding that and the size of the Postcuring workstation, this one is placed in the left side as well.

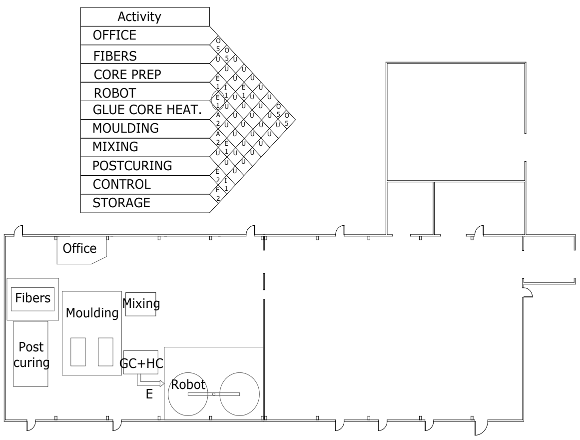

Figure 24. Alternative 1 Step 5.

Step 5.

Robot and Glue Core Heating Cable pair. Analysing the facility plan it can be noted that the robot just can be placed in one corner due to the presence of entrances or exits and the office walls in the other corners. This will also be a constraint for all the alternatives being able only to change its orientation.

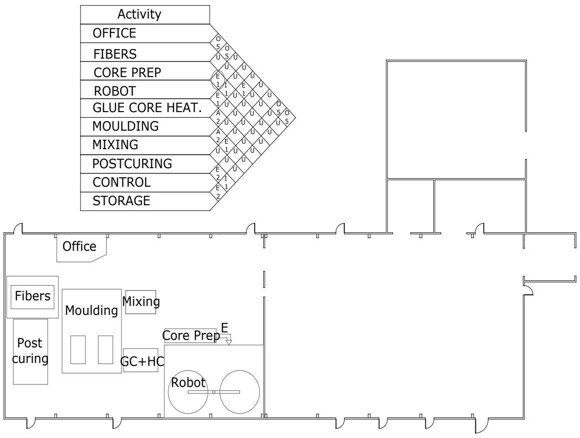

Figure 25. Alternative 1 Step 6.

Step 6.

Location of the Core Prep workstation close to the Robot workstation also with an E priority. No problems of space are present for this distribution.

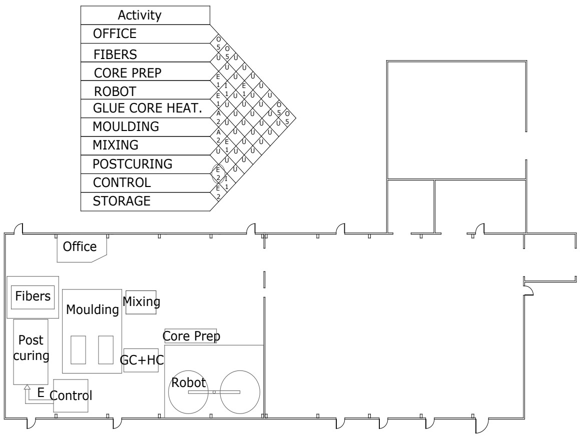

Figure 26. Alternative 1 Step 7.

Step 7.

Control station and Postcuring share an E priority so once the Postcuring is placed it is required to place the Control as close as possible.

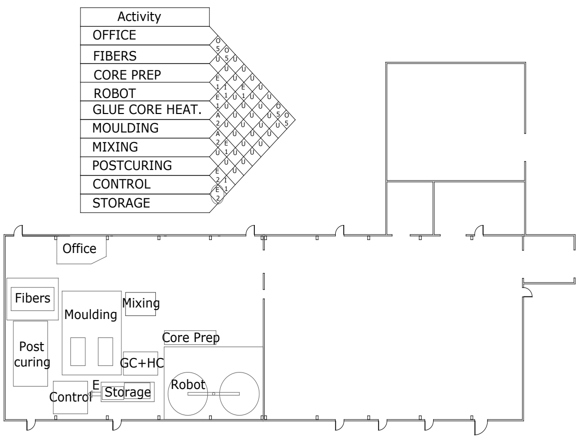

Figure 27. Alternative 1 Step 8.

Step 8

Control station also has an E priority with the Storage so Flow number three is completed with the location of the Storage. It can be noted that reorganization is starting to be required since Control and Storage are far from the exits and entrances of the facility.

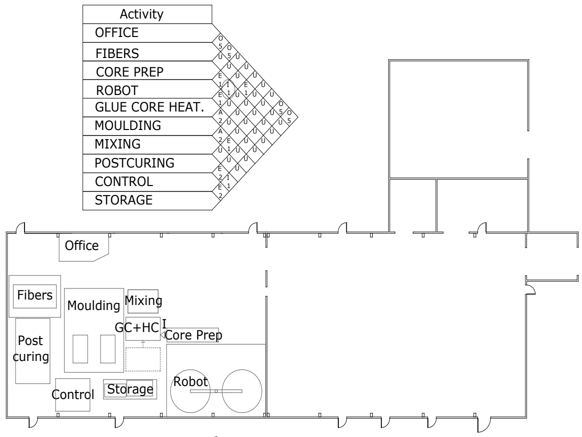

Figure 28. Alternative 1 Step 9.

Step 9.

It is the first step associated to the I priorities. The Glue Core Heating Cable and Core Prep workstations share this priority so the Glue Core Heating Cable is placed closer to Core Prep in order to satisfy this assignment.

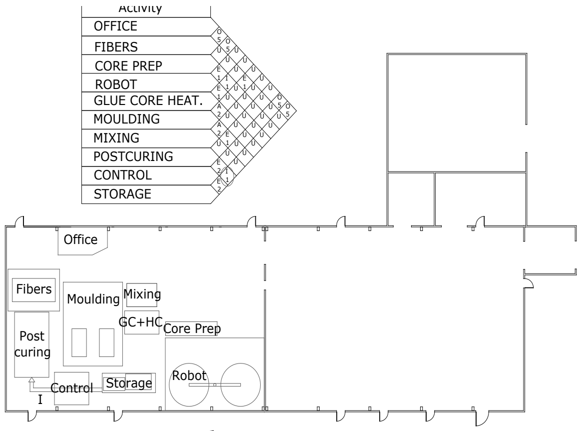

Figure 29. Alternative 1 Step 10.

Step 10.

Storage and Postcuring pair has assigned also an I priority, but the movement of anyone of these workstations is physically limited without moving others with higher priorities. The requirement is considered but the location of both remains the same.

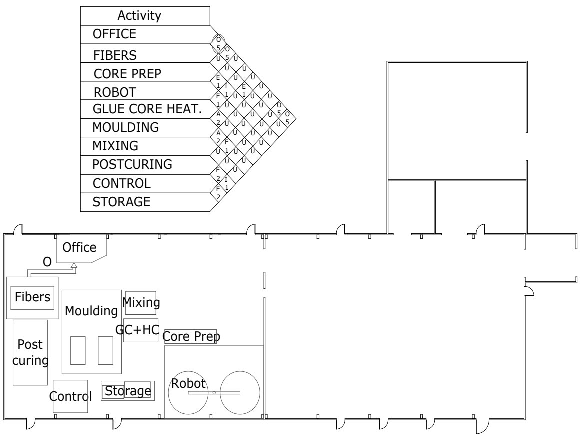

Figure 30. Alternative 1 Step 11.

Step 11.

The Ordinary closeness pairs start with the Fibers and Office stations. This rating value may be considered as satisfied in the current position of both stations since Fibers has higher priority shared with Moulding and move it closer to the Office means to move it away from Moulding.

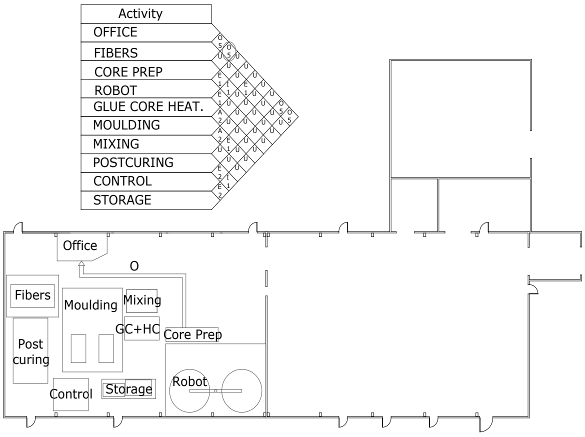

Figure 31. Alternative 1 Step 12.

Step 12.

The same case is present for the relation between Core Prep and Office. If this workstation is moved closer to the Office, higher priorities will not be respected as well as they are from the current position. Then Core Prep is not moved closer. A bigger reorganization may be done but the location of the Robot is a strong constraint and from that point Core Prep and also Glue Core Heating Cable workstations must be in that area.

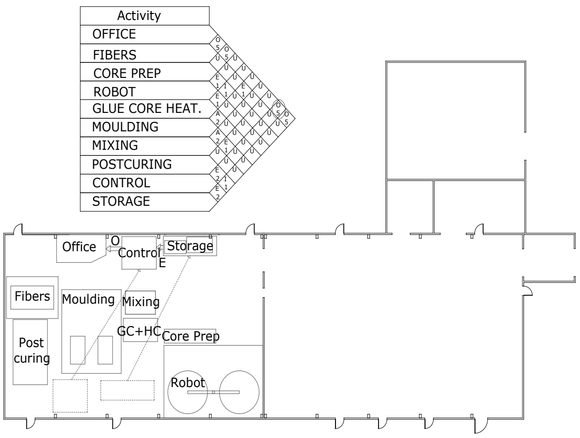

Figure 32. Alternative 1 Step 13.

Step 13.

According to the relation between Control and Office and also Storage and Office these workstations should be closer to the mentioned Office. This situation would also bring the possibility to move these stations closer to the exit of the facilities, on the right side of the plan. On the other hand the movement of these stations would affect to their relation to the Postcuring workstation, with higher priority.

Step 14.

If a general overview is taken it is possible to assess that Flow number two is in an adequate and reasonable location as well as Fibers and Moulding.

At the same time it is considered that should be favourable that Flow number three was placed closer to the exit since the storage of final product belongs to this Flow.

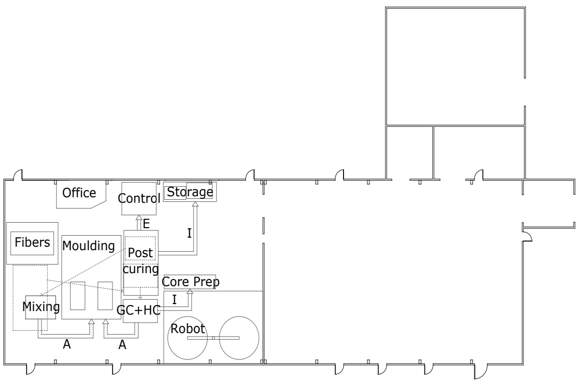

Figure 33. Alternative 1 Step 14.

According to that the movement of the Postcuring workstation to the other side of the Moulding workstation would satisfy the relations of Flow three. Analysing the elements left it can be noted that the location of mixing can be change to the other side leaving free space for the Postcuring, since the mixing relations are only with the Moulding workstation.

So after this process the Systematic Layout planning method is finished and the first alternative of layout design is completed as it can be observed in Figure 34. In the next lines the development of the other two alternatives is going to be explained not so in detail since the procedure is the same, the only difference is the initial location of the higher priorities and the subsequent reorganization to achieve the accomplishment of the whole set of restrictions.

Regarding the AutoCAD images it must be mentioned that the external rectangles of the workstations symbolize working space that is not really occupied by the workstation. This detail is considerably important in relation to the transport of raw materials from the entrance of the facilities to the different workstations where these materials are stored.
According to that the movement with forklifts or other transport means designed for the travelling within the facilities is allowed and all the workstations are suitable to be delivered their raw material when needed.

Moreover, carrying on with the graphical representation of the layout, it must be mentioned that the size for the Moulding station includes the location for the upper parts of the moulds. The orientation of this station will change in the different alternatives developed, but as it was discussed previously, the transport of the upper moulds has been considered so critical that these parts were included in the own Moulding workstation.

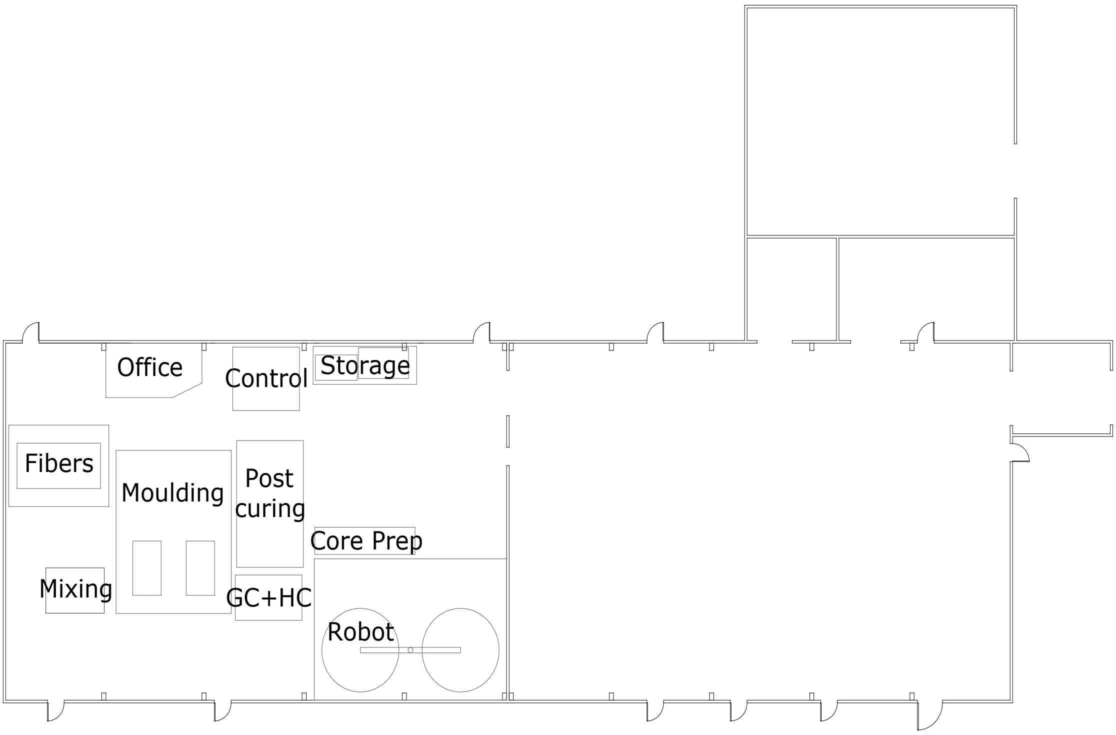

Figure 34. Alternative 1 Finished.

Alternative 2.

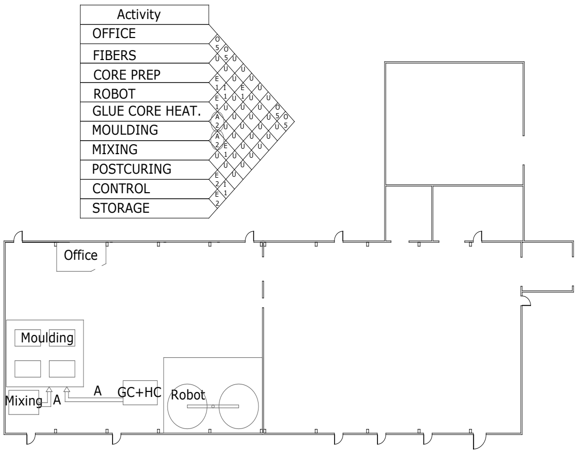

Figure 35. Alternative 2 Step 1.

Step 1.

As it was described before, the explanation for these other two alternatives is going to be shorter since the operating is the same and only the particular locations change. In this first step for alternative two, the location of the Moulding station, the A priority pairs and the Robot is going to be discussed.

Regarding the location of the moulds it has been decided to change the orientation in this alternative to check the how other workstations fit this way. It is also placed in the centre of the facilities plant because it is considered that proximity to the Flows is better from this position.

In relation to the A priority activities, Mixing and Glue Core Heating Cable have been placed close to the Moulding workstation.

It must be noted that also the Robot is in the same place since the alternatives for it are really limited as it has been discussed. So according to that Glue Core Heating Cable also considered the location of Flow two. This location will be recurrent due to the Robot limitations.

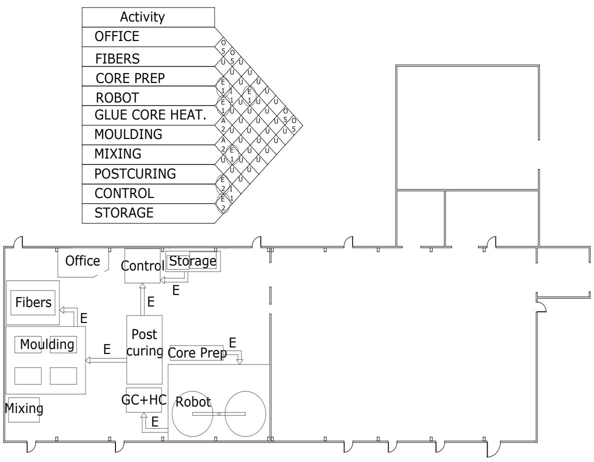

Figure 36. Alternative 2 Step 2.

Step 2.

In this step the location of the E priority pairs will be analysed. Starting from the beginning of the process, the Fibers workstation is placed close to the Moulding station keeping almost the same position as in Alternative 1.

Flow number two is also defined around the Robot location, considering both E priorities and also the A priority of Glue Core Heating Cable with Moulding.

In relation to Flow number three it has been mentioned the convenience to keep it close to the main exit for loading of final products. So regarding that and the E relations of Postcuring with Moulding and amongst the activities of Flow three, the location of this Flow is also defined.

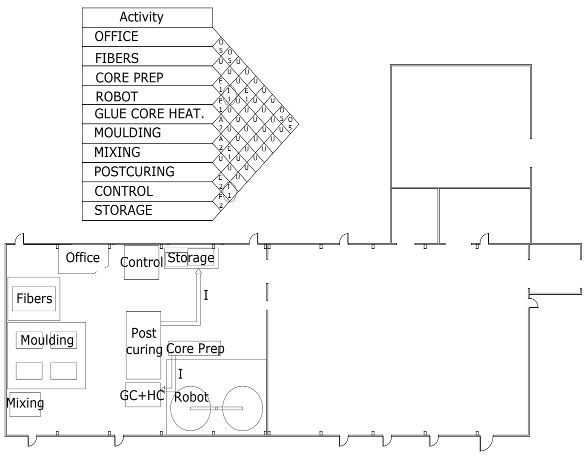

Figure 37. Alternative 2 Step 3.

Step 3.

After step two all the activities involved are already located. It is then required to check the accomplishment of the lower priorities with this organization considering general overviews like for Alternative 1.

In relation to the I priorities, it must be mentioned that the Postcuring relation to Storage is not easy to modify since the location of Storage seems to be adequate and the priority of Postcuring limits the movement of this workstation. So it can be considered that I priorities are properly fulfilled.

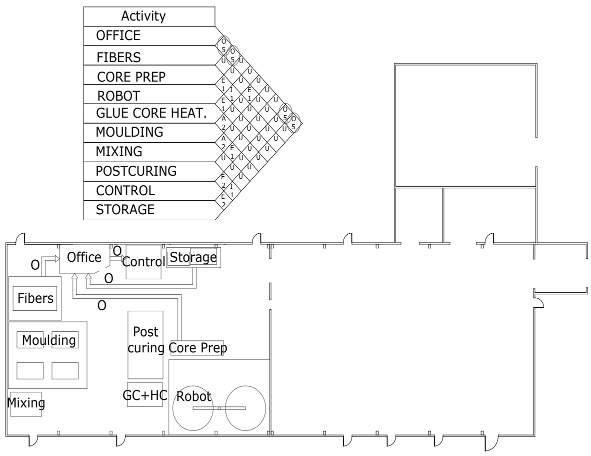

Figure 38. Alternative 2 Step 4.

Step 4.

The Ordinary closeness priorities are going to be analysed in this step to check if the location of the pairs affected is good enough or changes are required.

The closeness between Fibers and Office must be considered as adequate. Also Control is in a proper location for the information flow. Regarding Core Prep and Storage, these workstations are further but it is considered that it is not worth to move their location due to the weight of the other relationships.

Figure 39 shows Alternative 2 completed and the organization of the workstations may be considered as acceptable pending the general evaluation that will be done in the results chapter.

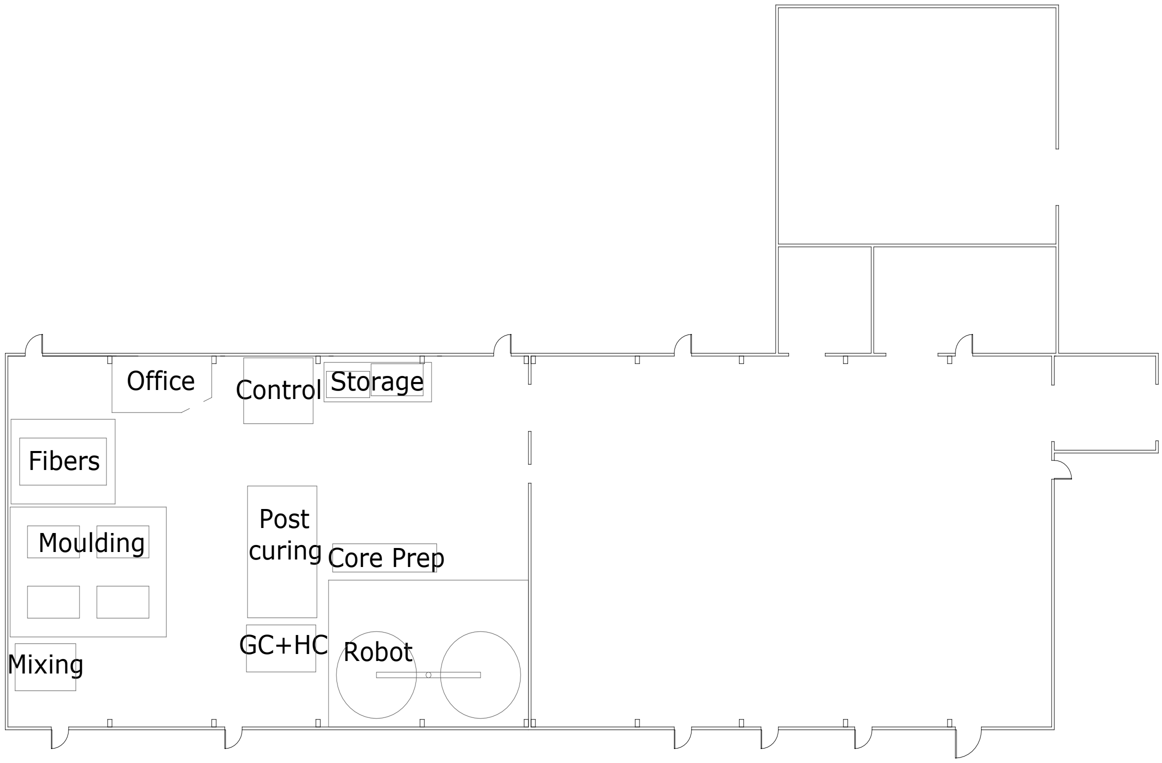

Figure 39. Alternative 2 Finished.

Alternative 3.

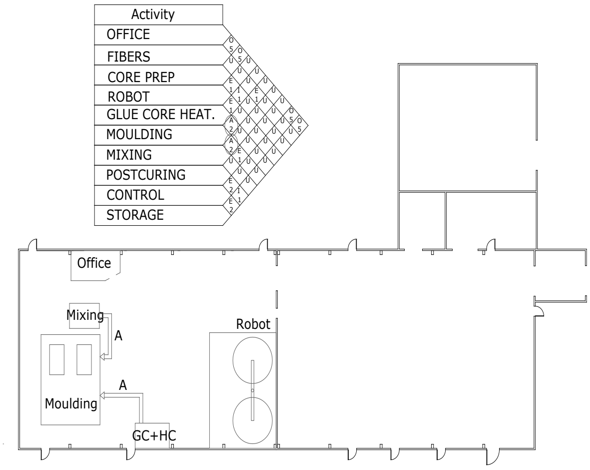

Figure 40. Alternative 3 Step 1.

Step 1.

The procedure for the description of the third alternative designed will be the same as the previous one. Regarding the hierarchy of priorities the first workstations placed are Moulding, Mixing and Glue Core Heating Cable. The location of this last one has been decided considering also the optimal location of Flow number two. Even though priorities are priorities, the global interaction must be also kept in mind.

In relation to the Moulding station, its orientation has been changed again and slightly moved to the left side in the plan. The Mixing workstation has been placed in the upper part of the plan, also close to the Moulding station.

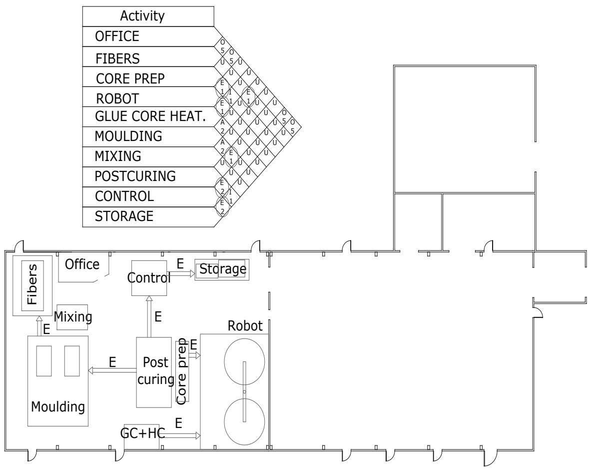

Figure 41. Alternative 3 Step 2.

Step 2.

The location of the E value pairs will be described in this step. Once two alternatives have been designed, the optimal location for the workstations becomes clearer as well as the plant distribution.

In that way, the location for Fibers is defined in the upper left area, Control and Storage in the upper area of the plan, Core Prep close to Robot and Postcuring near Moulding and also near Control. These considerations define the location of all the elements for this third alternative.

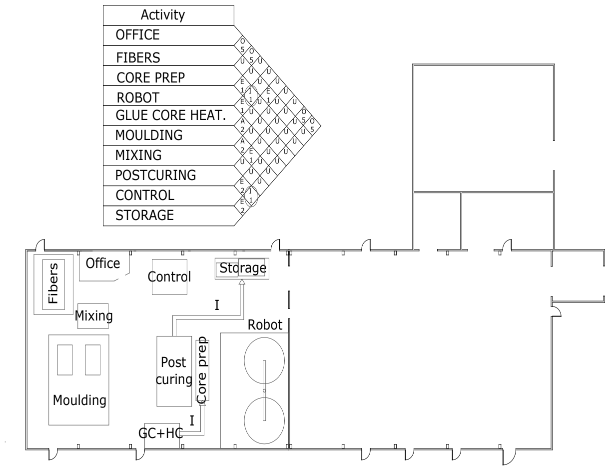

Figure 42. Alternative 3 Step 3.

Step 3.

The I priorities involving Postcuring with Storage and Core Prep with Glue Core Heating Cable are evaluated in this step since all the workstations have been already located.

According to this current location of the workstations, the accomplishment of the I priorities may be acceptable considering that the movement of Postcuring to be closer to Storage without moving further from Moulding is limited and for Glue Core Heating Cable to be closer than Core Prep without being further from Moulding as well.

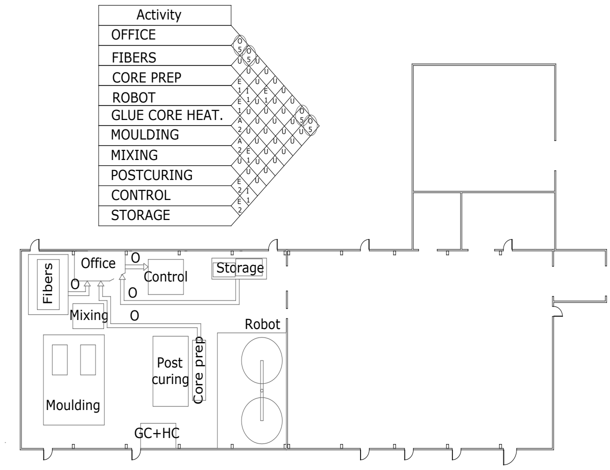

Figure 43. Alternative 3 Step 4.

Step 4.

Regarding the O priorities it may be mentioned that Fibers, Control and Storage satisfy the location from the Office. Core Prep is rather further but as in other cases discussed the weight of the higher priorities limits the movement of this workstation

After the design of the locations for all the elements involved in the method the Alternative three has been already complete.

As it was mentioned previously, the development of the alternatives may be considered as finished at this point since a structured and justified design of three different alternatives has been achieved. Further on in this project, in the following chapter, these three alternatives are going to be evaluated considering the advantages and objections of each one.

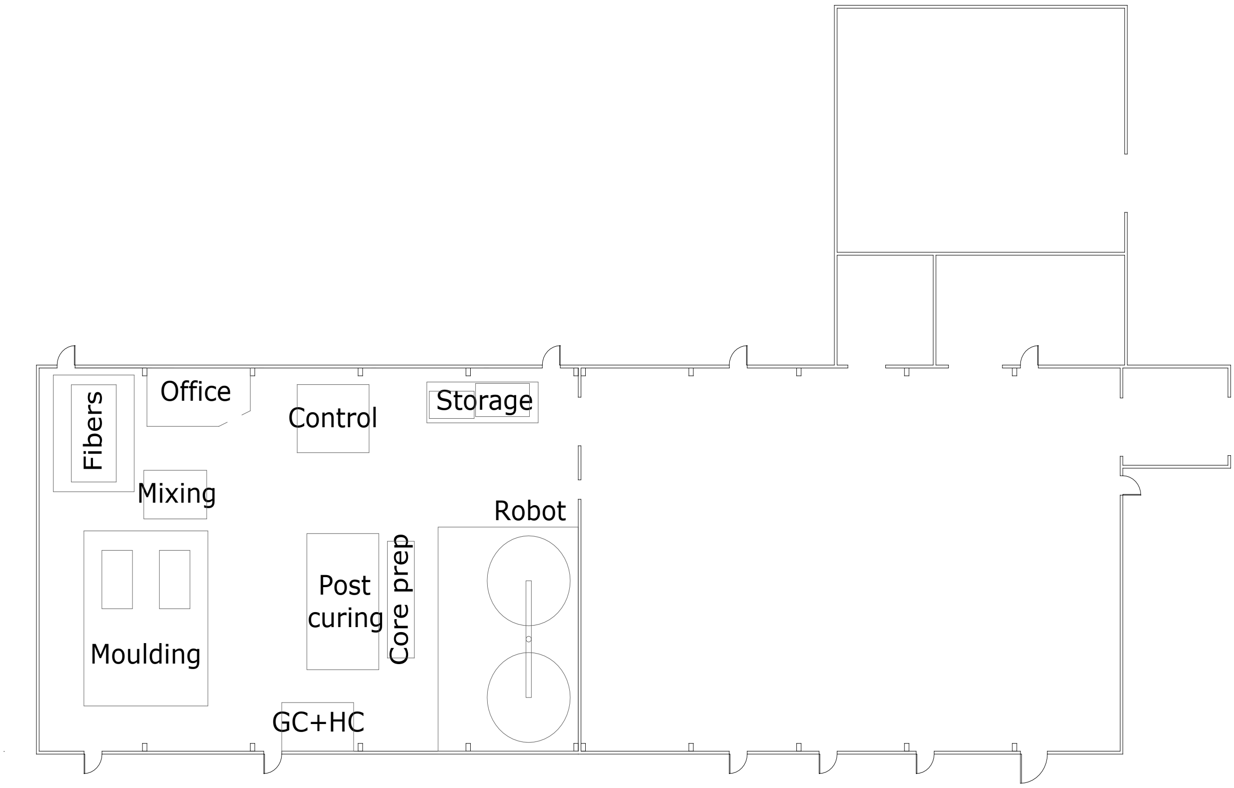

Figure 44. Alternative 3 Finished.

Moreover, in chapter number six, the evaluation of these alternatives is going to be complemented with the information provided by the simulation model. As it will be described in that chapter, all these three alternatives are going to be included in the simulation model with the right position for each workstation being able to check distance travelled and activity performance.

According to that, the development part of the layout alternatives is concluded at this point, pending the interpretation of results in the following chapter.

5.3 Costing Model

The second main part of this master thesis is the development of a costing model for the company in order to implement the cost accounting activity and get a deeper understanding of the costs sharing.

As it was described in the theoretical point in chapter number three, the cost accounting activity provides helpful information to the company, mostly related to the control of costs, the determination of selling prices, the detection of non-profitable activities, the control of efficiency and manufacturing performance over time and so on.

Also in the theoretical chapter, different terms were defined like cost centre, cost element and cost unit, terms that will be used throughout this chapter.

Moreover, different methodologies for the development of costing models were explained, highlighting the most important properties of them and suggesting each one to a certain type of industry.
Amongst the list of methods for costs ascertainment described, the most appropriate solution considered by the author is the development of a particular method for this company.

This method will be based on the Allocation Methods and also on the general principles of the Cost Accounting methodologies.

In that way, direct costs will be directly assigned to the product as in all the costing techniques. According to that, mainly raw materials and direct labour quantity requirements will be assigned to the final product.

Regarding the allocation of indirect costs, this point is where the costing methodologies differ and the objectives and requirements of the model have to be analysed, as well as the properties of the company manufacturing process.

For Blatraden AB process seems to be adequate to study the costs incurred by the main production departments since it is useful for the development and improvement of them taking control of the costs.

According to that, an allocation of the indirect costs by departments will be required. On the Elements of Cost Sheet, all the elements considered will be included, with the cost of them for the period of analysis.

To allocate the indirect costs the methodology followed will be the next one:

- Identification of all indirect elements of cost involved in the manufacturing process.
- Identification of the departments considered for the model.
- Analysis of the contribution of each department to cause the amount each indirect element of cost.
- Split of this amount in percentage according to the contribution considered to each department.
- Split the costs of the service departments into the production departments.

- Definition of a cost driver for each production department and calculation of the total amount of cost drivers in a period and the quantity required per product.

- Calculation of the cost driver cost and application to the product.

So first of all, every indirect cost would be split into the departments. But considering the number of indirect elements of cost it have been decided to apply this methodology to the major costs and split the lower costs equally and directly amongst the quantity of products developed. Lower values contribution split first into departments and then into production departments will be futile and the model will still be accurate.

These individual costs must be analysed before the allocation of the indirect costs to evaluate the importance of each one doing some class of ABC classification of indirect costs.
Further on if it is required the cost of each section could be more detailed to get some specific information. Therefore the flexibility of this model is one of the main aspects to highlight.

According to this implementation, the procedure to achieve the costing model is based on the development of an Elements of Cost Sheet and a final Cost Sheet as it was mentioned in the theoretical part.

The level of detail included on the Cost Sheet is decided by the developer being able to show the aggregate value of these main groups or including each one of the cost elements value separately.
After this description of the methodology that will be used and the criteria required for the ascertainment of special costs, the next step in this point is to describe the groups considered for the Cost Sheet, the way the data was collected for each group and the elements of cost contained in each group.

So regarding the theoretical basis explained in chapter number three, there will be considered three main groups of cost elements: Material, Labour and Expenses.

At the same time these costs will be composed by several cost elements that will be described individually later on.

It will also be essential to split these costs between direct and indirect costs to apply different allocation methods. All these properties will be summarized in an Elements Sheet that will be included in this document before the Cost Sheet.

So in the following lines these three main groups and the role of each element of cost in the process will be described.

Material.

Within this group all the materials directly or indirectly involved in the manufacturing process are going to be quantified. The importance of this group in manufacturing companies is high since in most of them, the material cost represents more than fifty per cent of the total product cost.

This Material group can be classified in different subgroups.

- Direct Material: It is the group composed by the materials that will be a representative part of the final product. These materials must be properly identified and allocated to cost units.

• Indirect Material: It is the group of materials present in the final product with ancillary role being minor in importance. These materials could be small and relatively cheap parts or items that do not compose the own product but are required in the process like lubrication, gel paper and so on.

• Supplies: It is a group of materials minor in importance and used in the process but not directly in the product. These materials could be for instance lubrication for machinery, cleaning products, protection items for workers and so on.

All the elements considered in the Material group have been included either due to direct observation of the process or due to the explanation of members of the company. At the same time the cost of these material elements has been communicated by the company in reference to different purchase invoices and it will be included in the final cost elements table.

In addition to each direct material considered for the costing model, the cost unit associated to it will be mentioned. The concept of cost unit represents the unit of product in relation to which cost must be ascertained. These cost units have been provided by the company since they have an initial control of quantities required for the model. According to that, the cost units remain the same and the material requirements are based on the data provided by the company with no added quantifications. This data includes the average scrap quantity for each material involved in the process.

Direct Material.

In the following lines a list of the Direct Material involved in the process is going to be described. The quantity required for the product and the average scrap will be described later on in the Element table. This group will be composed by cost elements considered as variable costs since the consumption of these elements is directly related to the production activity. At the same time these materials are considered as the most important ones in the manufacturing process since they give the floor the properties that define the final product.

• Fibres.
Cost unit: Kilogram.
Two different kinds of fibres are involved in the manufacturing process as it was explained when the process was described. Mats and woven layers of fibres are placed alternatively on the mould. This operation is repeated twice, one before the location of the core and another after this location. These two kinds of fibres will be called Woven Fibres and Mat Fibres and the quantities and prices will be different for each one.

• Cores.
Cost unit: Kilogram.
According to the double composite structure, a foam panel is placed in the middle layer of the bathroom floor. The process to obtain this panel has already been described and as it was explained cores of different thickness are required to achieve the desired tilt to guide the water to the sink. Three different models of core are used with three different thicknesses. These models are going to be analysed separately since their price and quantity is not equal.

• Resin.
Cost Unit: Kilogram
The manufacturing of composite materials requires the matrix element to surround the fibres

and provide other complementary properties. The matrix used in this process is a mix of polyester and vinyl ester chemicals with the commercial name of Polylite.

- Inhibitor.

Cost unit: Kilogram.
The role of inhibitor was already discussed in this document but it could be described as a chemical regulator of the solidification speed for the matrix. Even though the quantity of inhibitor is very low compared to the quantity of resin, this compound is essential for the process.

- Hardener or Curing Agent.

Cost unit: Kilogram.
This element is also added in low quantity but it is still very important for the process. The role of it is to reduce the curing cycle speeding up the chemical reaction to solidify the resin.

- Heating Cable.

Cost unit: Unit.
The heating cable provides the heating to the floor through the Joule effect. This cable is placed in the core before the moulding operations and the connections are removed from the floor once it is cured through a hole in the back side. A whole package of 35 meters is used per floor so the cost per package will be the one used.

- Pipe.

Cost unit: Unit.
The floor is connected to the housing pipes through a pipe already included on it. This pipe is bought and glued to a woven support. Finally this piece is glued to the floor.

- Woven Piece.

Cost unit: Unit.
It is the support for the pipe. This piece will be glued to the floor in one of the last operations of the process, to allow the connection of the housing pipes to the floor.
These pieces are purchased and installed without any modification so the cost is expressed per unit.

- Stopper.

Cost unit: Unit.
This element is a tape deck placed in the pipe connection to install the flap valve. This valve is not included in the floor. The cost unit is the own piece since it is purchased and installed directly in the floor.

Indirect Material.

Once the main raw material required for the manufacturing process has been described, the following cost elements reference to secondary material, used in the process with limited importance or cost.

These elements will also be variable cost elements. Moreover, these materials cannot be conveniently identified with cost units since the amount of them used per product is variable and their prices are rather low. In that way it is not worth to analyse the consumption per product and then there is no point in defining a cost unit. The total cost will be split amongst the products manufactured.

- Drain painting.

As it was discussed in the description of the process, the drain is painted with a specific painting that will release from the mould covering at the same time the fibres placed in the drain shape of the mould.

- Release Agent.

This material is applied to the mould before the fibres are placed on it. The purpose is to make easier the removal of the floor from the mould.

- Glue.

Two different glues are used in the process, one for the cores and the other for the pipes. These two glues will be considered differently since their costs and quantities are not the same.

Supplies.

This last group of Materials involves those materials or elements consumed in the manufacturing activity but not directly applied to the product. These materials will have a wide range of costs but also a wide range of cycle life since from buckets to robot blades will be analysed in this group. At the same time all of them are variable cost elements. As well as Indirect Materials, these materials are not identified with cost units since their cost is limited or the use of them per product is difficult to calculate.

- Buckets.

The mixing of the resin with the inhibitor and the hardener is made manually in different buckets. These buckets are not reusable since leftovers of dry mixing remain on them and this could impact in future mixings.

- Infusion pipes.

The infusion of the resin into the mould is done through plastic pipes connecting the buckets to the mould holes. These pipes are not reusable for the same reason as the buckets. Two different pipes are used for the connection: One from the mixing buckets to the mould and other from the mould to the vacuum pump.

- Robot blades.

The robot activity is based on the polish of the cores to achieve the tilt required and the drawing of the heating cable path. The tools used are subject to wear and they have to be replaced from time to time.

- Insulation tape.

The infusion pipes already discussed are connected to the mould holes. Nevertheless is extremely important not to leave gaps or eases in this holes because they will cause air leaks and the product quality will be affected. To avoid that, the connection of the pipes to the holes is reinforced with insulation tape.

- Tools.

The tools used for the cores cutting, the cores gluing, the edge cutting of the floor, the drill of the holes and other operations are exposed to wear and rust and they must be replaced as well.

It must be mentioned that some other materials are consumed in the company activity, like office material, but as this consumption is not related to the process it has been decided to include them in the group of general expenses.

After the explanation of this last subgroup, all the material elements of cost have been introduced. The following main group that will be described is the Labour Costs group.

Labour Costs.

This group represent the human contribution to production and it is often the second most important group in the product costs. Hence, this group must not be underestimated.
Labour group can be divided in Direct Labour costs and Indirect Labour costs.

- Direct Labour costs.
  It is the cost of the labour expended in the manufacturing tasks in the process. These costs can be easily identified and attributed to a certain manufacturing activity. Wages of operators are the ones involved in this paragraph.

- Indirect Labour costs.
  These are the wages and associated costs of the company members not directly related to the transformation of the raw material into the final products. Managers, supervisors, CEO and so on are general examples of this.

According to this explanation it can be noted the importance of Labour costs in the cost structure of the product. Related to that, the organisation chart must be analysed in order to obtain the required details for the Direct and Indirect Labour costs and quantify them.

In that way as it was discussed previously, the company is composed by three operators assigned to the manufacturing process, one Production and Quality Manager, one Research and Development Manager and the CEO of the company.

Direct Labour Costs.

Starting with the Direct Labour costs, the structure of these costs must be studied to control the costs and modify behaviours if it is required. To achieve this, it is worth the recording of workers time.

This recording of time will improve the outputs of the costing model and also may help for wage and attendance control purposes.

Therefore, a time study will be carried out being an important part of the labour costs calculations done. The objective of this study is to record worker's times spent on different workstations, allowing as well the calculation of the cost per section. This recording also known as time-booking will be carried out for the ascertainment of the labour costs.

These recordings in addition to the arrival and departure times, known as time-keeping, could help to the preparation of payrolls, attendance records to satisfy statutory requirements, computing labour and overhead costs of a job or develop statistical analysis of labour records to feed different productive indicators.

So in relation to that, in the next lines the methodology followed to develop the time study will be described. The main structure of this methodology is the one explained down below:

- Description of the required process times for the costing model.
- Support for the time study.
- Time Study and Data treatment.

Before the explanation of each one of this bullet points, it must be mentioned that the aim of the time study is to obtain standard times to apply to the direct labour costs ascertainment and in that way calculate the cost for each section or department.

The development of an accurate time study can be the subject for a whole project, since the procedure to carry it out is large and requires considerable amount of time.

On the other hand, the way the Standard Times are calculated in the time study seems to be more accurate than a simple average calculation for a certain amount of samples for each operation.

As it will be described in the third point, for the Standard Time calculation is required to establish the number of samples needed for each kind of task, the evaluation of the worker rate of performance for each sample observed and includes allowances for the worker with the opportunity to recover from physiological and psychological effects.

It has been considered appropriate to include these allowances in the operation times for the labour costs since workers require recovering from carrying out specified work under specified conditions allowing also attention to personal needs. These times will not be considered as unproductive so in that way it is correct to include these values in the operation times.

It must be mentioned that these times are going to be included in the simulation models for the different workstations since it is a very accurate way to determine the labour time required for each operation.

Description of the required process times for the costing model.

Throughout the manufacturing process there are many times related to different activities like transports, waiting times, operations, setup times and so on. All these activities take place during the working day and the higher weight of the operation times the better efficiency of the process.

From a cost accounting approach, the wages and associated costs of operators are allocated to the operation activities since these are the activities that bring added value to the product and will transform it from the raw material to the final product.

According to that, for a more efficient process all the other activities must be reduced as much as possible as it was discussed previously. The layout designs developed attempted to contribute to it reducing distances and movements.

The way how other activities can reduce their times is not the purpose of this master thesis and for the costing models the time recording will be focused in the operations activities.

From a global point of view as less time spent in activities that do not add value more time for operation activities. This increase of available time for operations will make these operations cheaper since workers will be more productive and their wages will be the same.

According to that thinking, the time recording pretends to know how much of the working day is dedicated to operations, how much operation time is required for the manufacturing of a product, how much is the cost for each operation regarding its duration and other aspects that will be discussed further on.

Some other operation times like the robot tasks are not included and the cost of it will be determined by the power consumption and the amortization of it.

Regarding the operators activity, it could be helpful to know the total time spent in the factory but the relevant information for the cost accounting is the time required for each operation assuming workers accomplish the working day duration.

The total productive time could be compared to the time-keeping to be aware of the working day structure but as it was discussed, this time-keeping is more focused on the accomplishment of the statutory requirements than on the development of a costing model.

Regarding the time-booking, the recording of these times is required to satisfy the following objectives:

- Ensure that the operator working day is balanced and the time for which a worker is paid is properly utilised.
- Ascertain the labour cost of each operation in the process.
- Ascertain the idle times, control it and act to reduce it if needed.
- Provide a basis for apportionment of overheads.

As any other repetitive activity, the operation times are exposed to variability and the ascertainment of the real operation time for each task of the manufacturing process is a challenge to deal with.
Therefore, it has been decided that the development of a time study could decrease this variability and provide reliable values to use for the costing model.

Support for the time recording.

For the recording of these times the author monitored the different operations of the process and recorded the times with the help of a stopwatch and a Daily Time Sheet developed by the own author.

The Daily Time Sheet is a document where all the operations of the manufacturing process are included and there are blank spaces to fill in with the different operation times observed. This Daily Time Sheet is shown in the appendix chapter as well as the ones with the real times.

Time Study and Data treatment.

The time recording process has been carried out with the help of the Daily Time Sheet and a stopwatch mentioned. This control of the operation times or time-booking was approved by the company managers and also by the workers involved on it.

The goals of the time study are the measurement of work, the calculation of the time invested by the operators to carry out a specific task and the definition of the standard time for this task.

Once these times are known it is possible to analyse the operations and develop new procedures to carry out them. For this project it is not the objective to improve the way operations are done, even though the benefits of standardized work were discussed in the theoretical chapter.

According to that, for this process the purpose of the time recording is to define the current Standard Time for each operation and set this time as the one required for the ascertainment of each operation cost.

The calculation of the Standard Time for each operation will be done following the steps of a typical time study:

1. Recording of initial time and calculation of mean and standard deviation.

2. Determination of the sample size for each operation and corrections.

3. Recording of the number of samples determined previously estimating the worker rate of performance for each sample.

4. Calculation of the Basic Time.

5. Estimation of allowances.

6. Calculation of the Standard Time.

As it was described the recording of times was carried out with the help of the Daily Time Sheet and a stopwatch.

The values of the initial times were recorded in different days of activity avoiding possible special conditions if the sample is recorded only in one working day.

Once the initial observations have been done it is possible to estimate the size of the sample to achieve reliable results. This estimation of the sample size may be done in different ways:

- Statistical Method.

- Conventional Method.

Statistical Method.

It is based on the definition of the confidence level for the observations and the margin of error allowed for these observations.

The confidence level makes reference to the confidence percentage that the value obtained is correct and the error allowed is the possible deviation of this value. In general Time Studies, the values used are 95.45% for confidence level and 5% of error allowed. Then we must be able to say that for this values we are confident that for 95,45% of the time this observation is correct within 5% of error.

The forn

$$n = \left(40 \frac{\sqrt{n'\Sigma x^2 - (\Sigma x)^2}}{\Sigma x}\right)^2$$

Figure 45. Sample Size Formula.

Where

n = Sample size we wish to determine.

n' = Number of initial observations taken in the preliminary study.

x = Values of the initial observations.

Conventional Method.

Some other authors and companies such as General Electrics have adopted another method based on the total number of minutes for the cycle or operation studied. The size recommended for the sample is then associated to the duration of the cycle. The table of values generally used is shown down below.

Minutes per cycle	To 0.10	To 0.25	To 0.50	To 0.75	To 1.0	To 2.0	To 5.0	To 10.0	To 20.0	To 40.0	Over 40
Number of cycles recommended	**200**	**100**	**60**	**40**	**30**	**20**	**15**	**10**	**8**	**5**	**3**

Source: A. E. Shaw: "Stop-watch time study", in H. B. Maynard (ed.): *Industrial engineering handbook* (New York and London, McGraw-Hill, 3rd ed., 1971). Reproduced by kind permision of the McGraw-Hill Book Company.

Table 6. Number of Recommended Cycles for Time Study.

For this project the statistical method was chosen with the confidence levels and error allowed described previously. According to this calculation, the tables with the sample size for each operation are included in the appendix.
So once the sample size calculation is finished the following step is to record the proper times observed and estimate the worker rating performance for each sample.

To estimate the worker rating performance the definition of qualified worker and his abilities must be understood, to ensure certain objectivity by the time the rates are estimated.
A qualified worker is one who has acquired the skill, knowledge and other attributes to carry out the work in hand to satisfactory standards of quantity, quality and safety.

In relation to that the rating activity consists on the assessment of the worker's rate of working relative to the observer's concept of the rate corresponding to standard performance, which is the rate of output that qualified workers will naturally achieve.

To compare accurately the observed rate of working with the theoretical standard only experience can help. The purpose is to determine from the observed time, the standard time which can be maintained by the average qualified worker and which can be considered as reliable for planning, control and incentives activities.

According to this comparison between the observed rate of working and the standard rate, a numerical scale to support the assessment is required.

There are several scales like 60-80, 100-133, 75-100. The lower figure defines the normal rating or the rate of working of an operative on time rates of pay. The higher value is the called standard rate and identifies the rate of qualified workers that are suitably motivated to apply themselves to their work, as for instance by an incentive scheme.

The British Standard Scale 0-100 represents with 0 the zero activity and 100 the standard rate.
These two values of the scales set two fixed points to compare the observed rate with. Also to complete these key points some other values are defined for the scales:

The scale used for this study is the British Standard Scale 0-100. So once the number of samples required is defined and the Rating Scale is also selected, the sampling process can be carried out.

This process was developed for several days and information related to it will be included with the basic times down below.

After the collection of all the samples for the different operations considered, the next step is to calculate the Basic Time.

If the analyst's ratings were always impeccable, then however many times an element were rated and timed the result will be constant as the following expression:

$$\text{observed time x observed rating} = \text{a constant}$$

Ac[illegible] the operative we[illegible]

$$\text{observed time x } \frac{\text{observed rating}}{\text{standard rating}} = \text{basic time}$$

As the first equation will not be satisfied hundred per cent, it is required to calculate the mean basic time for the sample size This is calculated aggregating all the basic times of the sample and dividing the[illegible]

$$\text{Average Basic Time} = \frac{\Sigma \text{ basic time}}{n}$$

Scales				Description	Comparable walking speed[1]	
60-80	75-100	100-133	0-100 Standard		(mi/h)	(km/h)
0	0	0	0	No activity		
40	50	67	**50**	Very slow; clumsy, fumbling movements; operative appears half asleep, with no interest in the job	2	3.2
60	75	100	**75**	Steady, deliberate, unhurried performance, as of a worker not on piece work but under proper supervision; looks slow, but time is not being intentionally wasted while under observation	3	4.8
80	100	133	**100 (Standard rating)**	Brisk, business-like performance, as of an average qualified worker on piece work; necessary standard of quality and accuracy achieved with confidence	4	6.4
100	125	167	**125**	Very fast; operative exhibits a high degree of assurance, dexterity and coordination of movement, well above that of an average trained worker	5	8.0
120	150	200	**150**	Exceptionally fast; requires intense effort and concentration, and is unlikely to be kept up for long periods; a "virtuoso" performance achieved only by a few outstanding workers	6	9.6

[1] Assuming an operative of average height and physique, unladen, walking in a straight line on a smooth level surface without obstructions.
Source: Freely adapted from a table issued by the Engineering and Allied Employers (West of England) Association, Department of Work Study.

The newer 0-100 scale has, however, certain important advantages which have led to its adoption as the British Standard. It is commended to readers of this book and is used in all the examples which follow. In the 0-100 scale, 0 represents zero activity and 100 the normal rate of working of the motivated qualified worker — that is, the standard rate.

Table 7. Examples of Various Rates of Working on the Principal Rating Scales

The Average Basic Times for the operations considered are also shown in the appendix.

The last step of the time study in order to calculate the Standard Time of each operation is the determination of allowances for recovery from fatigue, for relaxation, to attend to personal needs or other contingency allowances.

These allowances will be expressed as a corrector coefficient for each average basic time calculated.

The Standard Time for these operations will be the result of this multiplication.

The determination of required allowances is a difficult task in the time study due mostly to the individual differences amongst the workers involved in the process, the factors related to the nature of the work itself and the factors related to the environment.

The study of these allowances is often based on the following figure.

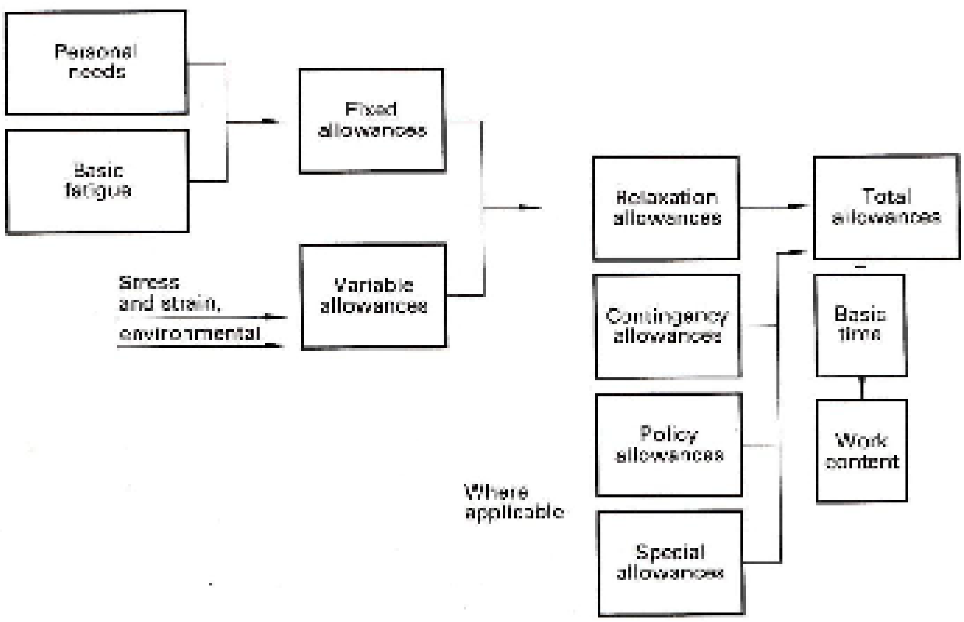

Figure 46. Allowances Groups.

In this figure the relaxation allowances are the essential part since they are considered for recovery from fatigue, personal needs and other variable reasons. These relaxation allowances are then classified into fixed allowances and variable allowances as it is shown in the picture.

Fixed allowances usually have values from 5 to 7% for personal needs and 4% for personal needs. These values are present for all the Standard Times. Variable allowances are defined for special conditions like stress and strain in performing the job in question or poor environmental conditions. For this study two values have been considered regarding abnormal working positions: 2% for tasks with bending positions and 7% for tasks where lying or stretching is required.

Contingency allowances are related to add time to the standard value to meet legitimate and expected items of works or delays. These values are not included in the study.

Operation		Sample Day	Sample nº	Time (mm:ss)	Time (s)
Fibres		20/11/2012	1		
		20/11/2012	2		
n'	6	20/11/2012	3		
Σx	2988	20/11/2012	4		
Σx^2	1491072	13/12/2012	5		
$(\Sigma x)^2$	8928144	13/12/2012	6		
n	4				
Drain Painting		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	665	13/12/2012	4		
Σx^2	111253				
$(\Sigma x)^2$	442225				
n	11				
Core Prep		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	1803	13/12/2012	4		
Σx^2	813357				
$(\Sigma x)^2$	3250809				
n	2				
Robot setup		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	942	13/12/2012	4		
Σx^2	221934				
$(\Sigma x)^2$	887364				
n	1				
Glue Core		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	1392	13/12/2012	4		
Σx^2	486106				
$(\Sigma x)^2$	1937664				
n	6				

Table 8. Example of Initial Observations Obtained and Sample Size.

Once the Standard Times have been obtained it must be mentioned some considerations regarding the allowances. It has been decided to assign the same factor of fatigue to all of them since it is a standard value globally accepted. In the case of personal needs an average value between the values found in the tables has been chosen.

Regarding the variable value, all the activities that take place standing have this 2% value and for the activities where stretching or mental strain is required the 7% and 4% values have been assigned respectively. Finally it must be mentioned that the total value is the addition of these coefficients plus one to increase the value of the Average Basic Time.

With these Standard Times it will be possible to calculate the costs of each section considering the labour and the indirect costs of each one. This will be explained later on.

Indirect Labour Costs.

As it was explained at the beginning of this group of costs, Indirect Labour Costs are the wages and associated costs of members of the company, not directly related to the transformation of the raw material into the final products.
In this case three members of the company are related to managing tasks: The CEO, the Research and Development Manager and the Production and Quality Manager.
These costs treated as indirect costs will be included in the Costs Sheet split into the secondary sections of the company that will be explained once the cost elements are discussed.

Expenses.

All the costs incurred by the company that are not material or labour costs are called expenses. It is in general the third group in importance for the calculation of costs but this situation depends on the properties of the cost elements involved.

As well as the previous two groups, expenses costs may be divided into Direct Expenses Costs and Indirect Expenses Costs.

- Direct Expenses Costs: This subgroup covers those expenses that are specifically connected to a particular job. These expenses are also called chargeable expenses. Examples of this group could be patents rights, experimental costs, hire of a special workstation for a particular job and so on. It must be mentioned that often this subgroup is not present on the general activity of the companies and these costs just appear in particular situations.

- Indirect Expenses Costs: This subgroup covers the expenses not directly connected to a particular job. Rent and rates, depreciations, lightning, insurances, advertisement and so on are examples of this subgroup.
  Once it has been discussed the two main subgroups of expenses costs, the elements of costs that are present on each one will be described.

Direct Expenses Costs.

As it was explained just above, this subgroup makes reference to costs possible to allocate directly to a job, work order or product and are not labour or material costs. These costs are more common for some kinds of industries where patent rights are obtained frequently, where the manufacturing process can be modified for the customer requirements developing particular solutions or when special services are required for a specific work order.

In this case no elements are going to be considered as direct expenses costs.

Indirect Expenses Costs.

This subgroup includes general expenses incurred by the company to be able to carry out its activity. These costs are not material or labour and it is not possible to allocate them directly to a particular job or work order.

This subgroup will be rather extensive; therefore it will be structured in more subsections. The subsections considered will be the following ones:

- Depreciations.
- Rental.
- General supplies.
- Office material.
- Services.

All the elements included on the subsections mentioned will be described down below.

Depreciations.
The periodical cost of depreciations for certain elements involved in the manufacturing process must be included here.
It is not the aim of this cost model development to discuss the depreciations rates used for each element and the values of them have been provided by the company.
These elements are the following ones:

- Robot.
  It is used in the manufacturing process to mark the path for the heating cable in the pieces of core.

- Crane.
  It is used to move up and down the upper parts of the mould.

- Mould.
  It is the main element of the manufacturing process, where the shape of the final product is given to the double structure composite.

- Forklift.
  It is used in transport activities mostly related to transport of raw material to the workstations when it is received.

- Drying chamber.

  This is a special case that will be discussed in the cost model development. The drying chamber is not used in the process so the allocation of its depreciation cost to floors that do not use the chamber has to be discussed.

- Computer equipment.

Rental.
The rental of the facilities is the main cost included in this subsection. As it was discussed previously this rental is variable in relation to the number of areas used in the whole building. There are three main areas and nowadays Blatraden AB is going to use just one. So the element of cost in this group is just Facilities rental.

General supplies.
This paragraph will discuss costs of supplies provided to the company not included in the material group. These supplies are consumed in different departments of the company and according to that it is not possible to allocate directly to a particular job or work order.

- Lightning and power.

  The consumption of lightning and power will take place in the different workstations of the manufacturing process, especially in relation to the robot and crane activity but also in the secondary departments regarding computer equipment consumption. Also the vacuum pump and the forklift will use electric energy. Even though, the offices and the whole building will have lightning and power consumption.

- Telephone and internet.

Office Material.
This subsection was considered separately since the cost elements included in it are related only to office activities. According to that it will be easier to allocate them to just a part of the whole company activity.

- Paper

- Printer cartridges

- Others

Services.
This subsection makes reference to services hired by the company for general use. These services are going to be considered in just one cost element since the nature of them could be very wide. This subsection will include costs of external maintenance and set up for the robot equipment, consulting services, catering services and so on.

At this juncture, all the elements of cost involved in the costing model have been defined. The summary of them with the respective cost and the cost unit or the period considered for the data obtained is shown in the following table.

It must be mentioned that the value of these cost elements is not the real one due to confidentiality reasons. Anyhow the proportion amongst them is the same and the data included is valid for the explanation of the model. The real values and final results have been made available for the company.

Cost group	Cost type	Cost Element	price (kr/unit)	unit
MATERIAL	DIRECT	Fibres (Woven)		Kg
		Fibres (Mat)		Kg
		Cores 20 mm		Kg
		Cores 30 mm		Kg
		Cores 40 mm		Kg
		Resin		Kg
		Curing agent		Kg
		Inhibitor		L
		Heating Cable		unit
		Pipes		unit
		Wooden piece		unit
		Stopper		unit
	INDIRECT	Drain Painting		month
		Glue Pipe		month
		Glue Core		month
		Release Agent		month
	SUPPLIES	Buckets		year
		Insulation tape		year
		Tools		year
		Robot blades		year
		Infusion Pipes Vacuum Pump		month
		Infusion Pipes Mixing		month
LABOUR	DIRECT	Operators		h
	INDIRECT	Managers		h
EXPENSES	DEPRECIATIONS	Robot		year
		Crane		year
		Mould		year
		Forklift		year
		Drying chamber		year
		Computer equipment		year
	RENTAL	Facilities		month
	SUPPLIES	Electric energy		year
		Telephone		month
		Internet		month
	OFFICE MATERIAL	Paper		year
		Printer cartridges		year
		Others		year
	SERVICES	General expense		year

Table 9. Cost Elements.

So once the costs have been defined and the value of them is known, the next step in the model development is to define the calculation period to set the same unit of time for the non-direct costs.

This definition of the time interval considered for the cost model will also establish the quantity of final products to allocate the costs to. In the end the aim of the model is to clarify the cost of the bathroom floors produced considering as much real elements of cost as possible to obtain an accurate and reliable value.

According to that and discussing the interval with the company, the interval of time decided was a month since production per week is more subject to changes and the aggregation of the production will finally balance the quantities. At the same time more than a month seemed to be excessive for future updates of the model.

Time Interval= 1 month

Average floor production rate=50 floors per month

These definitions are essential to be able to allocate the appropriate value of costs to the associated production and obtain a reliable output from the model.

So once this time interval is defined and the average production rate is known, the development of the cost model can be carried out.

The costing model will be organised as it is described down below.

- Direct allocation of direct material costs to each floor.
- Definition of the departments or workstations present in the company dividing them into manufacturing and service departments.
- Allocation of the direct labour to the manufacturing departments.
- Distribution of the remaining cost elements amongst all the departments involved.
- Distribution of the service department costs to the manufacturing department.
- Division of the manufacturing department costs by the average floor production rate.
- Aggregation of all the costs per floor to achieve the unit total cost.

All these steps will be described in depth one at a time since some more explanations are required for the completely understanding of the model developed.

The first step in the model development is the direct allocation of the direct material costs to each floor.

The purpose of the model is to calculate the total cost for each floor. Many techniques of allocation are developed and explained, but the allocation of direct costs is the same for all.
In Table 10 the quantity required and the scrap rate for each raw material is shown.

Cost Element	Quantity	Unit	Scrap rate	Final Quantity	Price (kr/unit)	Cost
Fibres (Woven)		Kg	5%			
Fibres (Mat)		Kg	10%			
Cores 20 mm		Kg	20%			
Cores 30 mm		Kg	20%			
Cores 40 mm		Kg	20%			
Resin		Kg	10%			
Curing agent		unit	0%			
Inhibitor		L	0%			
Heating Cable		Kg	0%			
Pipes		unit	0%			
Wooden piece		unit	0%			
Stopper		unit	0%			
			Direct Material Cost (kr/floor)			

Table 10. Direct Material Costs.

As it was discussed previously, the information regarding consumptions, scraps and prices was provided by the company for the development of this project.

The only thing required for the calculation of this cost was to ascertain the quantity for each core which was carried out studying the surface of the floor and considering the volume and density of each core type. The details of this calculation are included in the appendix of this project.

So once the direct material costs have been allocated to the product, a possibility for this model could be to calculate the quantity per month of the remaining costs considered and divide them by the number of floors produced. After that and adding this value to the one calculated just above we could have a simple cost model for the product manufactured.

According to the aim of development an accurate cost model, the method selected is based on the allocation of the indirect costs to the departments involved.

Once the cost per month for each department is known the cost per floor can be also determined.
The second step in the model development is the definition of the sections or departments present in the company.

This definition is based on the nature of the different management and service tasks, as well as the already discussed Flows present in the process. In that way the departments considered are the following ones:

Department or Manufacturing Section	Type Considered
Administration	Service
Commercial	Service
Research and Development	Service
Engineering and Production Management	Service
Fibres	Manufacturing
Core Preparation	Manufacturing
Robot	Manufacturing
Glue Core	Manufacturing
Heating Cable	Manufacturing
Moulding	Manufacturing
Mixing	Manufacturing
Postcutting	Manufacturing
Control	Manufacturing

Table 11. Departments Type.

The allocation of the service departments' costs to the operating departments is related to the thinking that all costs must somehow be fully allocated to the revenue-producing (operating) parts of the organization. This allocation from the service departments to the operating or manufacturing departments will be done once each department has its costs allocated.

The next step is to allocate the direct labour to the different manufacturing departments in order to calculate the cost of the main stages of the manufacturing process.

The allocation of the direct labour will be based on the Standard Times for each workstation. As the workstations considered do not match with the total operations studied in the time study, some of these workstations will include more than one operation.

Specifically, Moulding will include the times regarding the operations Drain Painting, Dress Fiber A, Core, Dress Fiber B, Mould Closing and Infusion Setup.
Postcutting will include the times for the Preglue Pipe and Postcutting operations. The other sections are directly related to one Standard Time.

According to that the Standard Time for one floor will be the starting point for this allocation.

However it must be noticed that the Standard Time related to the operations time is not the same as the man-hours time. This is because some operations in the Moulding station are carried out by two workers.

Workstation	Standard Operation Time (min)	Standard Man-Minute Time	Standard Man-Minute Time (50 floors)
Fibres			
Core Prep			
Robot			
Glue Core			
Heating Cable			
Moulding			
Moulding two operators.			
Mixing			
Postcutting			
Control			
		TOTAL Man-Minute	
		TOTAL Man-Hour	

Table 12. Total Standard Time.

These total man-hour calculated reveal the total productive time used from the workers throughout one month for the development of the bathroom floors.

Anyhow the labour costs that have to be allocated are not only these productive hours, but all the hours that constitute the working days within a month for the three operators.

According to that the total man-hour available are the following ones.

$$\text{Total man} - \text{hour available} = \frac{8h}{day} \times \frac{20day}{month} \times 3 \text{ workers} = 480 \text{ man} - \text{hour}$$

This difference does not mean that workers do not have the appropriate working rate or they are wasting time on purpose. This difference is caused by the bottle necks of the process, with high waiting times where some operations may be done but with the resources available is not easy to improve the production rate.

This situation causes different approaches for the allocation of these non-productive man-hours. According to that three different final models will be developed considering three approaches for this location. These approaches will not impact for the allocation of the remaining cost elements.

Approach 1.

The first possibility for the allocation of the man-hours not used for operation tasks is to allocate these hours proportionally to the operations the workers do.

Regarding that the workers will do the operations required for the fifty bathroom floors per month but the cost of these operation will be the Standard Time and a proportion of the non-productive time equal to the proportion between the Standard Time of this operation and the Total Standard Tme or total productive time.

According to this approach the difference will be the cost of the productive hours. Each workstation will have the cost of its operation time and the same percentage of idle time as the percentage of the operation time regarding the total.

Workstation	Standard Operation Time (min)	Operation Time Percentage
Fibres		5,84%
Core Prep		5,15%
Robot		2,66%
Glue Core		4,08%
Heating Cable		11,93%
Moulding		39,81%
Mixing		7,79%
Postcutting		20,73%
Control		2,00%
Total Operation Time		

Table 13. Standard Operation Time and Operation Time Percentage.

The aim of this approach is to allocate to the workstations the cost of the operation required. As the required time for the development of all these operations is much smaller than the available worker times, the cost of these operations will not be only the cost of its time but also a proportion of the idle time regarding these Standard Times calculated previously.

Workstation	Standard Man-Hour Time (50 floors)	Idle Man-Hour Allocation Time	Total Man-Hour per month
Fibres			
Core Prep			
Robot			
Glue Core			
Heating Cable			
Moulding			
Mixing			
Postcutting			
Control			
Total Productive Man-Hour		TOTAL Man-Hour	480 h

Table 14. Standard Man-Hour Time and Idle Man-Hour Time.

Workstation	Total Man-Hour per month	Total Labour Cost per month (kr)
Fibres		
Core Prep		
Robot		
Glue Core		
Heating Cable		
Moulding Total		
Mixing		
Postcutting		
Control		
Total Man-Hour per month	480	Total Labour Costs

Table 15. Labour Costs.

This is the final table for the allocation of the direct labour costs to the manufacturing workstations considered for this process.

Approach 2.

The second possibility for the allocation of the idle working times, instead of splitting them proportionally amongst the operation times and increasing the cost of the operation time, is to allocate all these costs to the bottle neck department of the process: The Moulding station.

This approach is based on this statement since after the operation times for this workstation, two hours of curing are required without any worker needed.

This situation causes waiting times in the process and it is the main reason of the workers idle time. The workers can do all the previous operations during this two hours waiting and there will still be waiting time in the process.

It is true that not all the idle times are caused by this curing process but from a bottle neck approach and regarding an improvement in the production line balancing it could be appropriate to point to that workstation as the reason there are so much idle time for the workers.

Workstation	Standard Man-Hour Time (50 floors)	Idle Man-Hour Allocation Time	Total Man-Hour per month
Fibres			
Core Prep			
Robot			
Glue Core			
Heating Cable			
Moulding			
Mixing			
Postcutting			
Control			
Total Productive Man-Hour		TOTAL Man-Hour	480 h

Table 16. Standard Man-Hour Time and Idle Man-Hour Time.

Workstation	Total Man-Hour per month	Total Labour Cost per month (kr)	
Fibres			
Core Prep			
Robot			
Glue Core			
Heating Cable			
Moulding Total			
Mixing			
Postcutting			
Control			
Total Man-Hour per month	480	Total Labour Costs	

Table 17. Labour Costs.

Approach 3.

The third possibility considered for the allocation of the idle time labour costs is based on the statement that in the current moment the distribution of the idle time amongst the workstations is not known.

From that point all the approaches that will try to distribute them will not be completely accurate and the measurement of the idle times must be required.

Since this measurement has not been done it could be better to allocate the costs directly to the bathroom floors like a separate element of cost instead of the allocation to the workstations.

In that case the workstations will only bear the cost of the man-hours times required for the operations to reach the production rate and the remaining labour costs will be assigned to the final product in the absence of a study of the idle times for workers.

Workstation	Standard Man-Hour Time (50 floors)	Idle Man-Hour Allocation Time	Total Man-Hour per month
Fibres			
Core Prep			
Robot			
Glue Core			
Heating Cable			
Moulding			
Mixing			
Postcutting			
Control			
Total Productive Man-Hour		TOTAL Man-Hour	480 h

Table 18. Standard Man-Hour Time and Idle Man-Hour Time.

Workstation	Total Man-Hour per month	Total Labour Cost per month (kr)	
Fibres			
Core Prep			
Robot			
Glue Core			
Heating Cable			
Moulding Total			
Mixing			
Postcutting			
Control			
Total Man-Hour per month		Total Labour Costs	

Table 19. Labour Costs.

As it was mentioned the cost of the remaining labour hours, not used for operation tasks will be allocated in the third Cost Sheet as another element of cost. The amount of these Idle Labour Costs is 143526,25 kr.

The cost model goes on with the allocation of the remaining cost elements amongst the workstations and service departments. As it was discussed previously the approach chosen for the allocation of idle times do not affect to these allocations, only to the final result, included in the following chapter. These are the remaining cost elements.

Cost Element	Amount per month (kr)
CEO wage	
P&Q Manager wage	
R&D Manager wage	
Robot Dep	
Facilities Rental	
Electric energy	
Telephone	
Mould Dep	
Tools	
Computer equipment Dep	
Release Agent	
Infusion Pipes Vacuum Pump	
Forklift Dep	
Internet	
Drying chamber	
Services	
Infusion Pipes Mixing	
Crane Dep	
Other Office Mat	
Insulation tape	
Robot blades	
Glue Core	
Printer cartridges	
Paper	
Buckets	
Drain Painting	
Glue Pipe	

Table 20. Remaining Cost Elements.

An allocation in percentage of these elements amongst the departments will be done. Some of these elements will require explanations in relation to the allocation method and it will be done down below.

Allocation Criteria.

• The wages of the managers are not completely assigned to their departments since they do other tasks and share works because this is a rather small company and all of them work in tasks of different nature. Anyhow it has been considered that the CEO is also the main responsible of the administration and commercial tasks, taking place in his office.

• The facility rental cost is split considering the surface of each department in relation to the total available.

• Electric energy has been split considering the consumption of six main elements:

- Crane
- Robot
- Forklift
- Vacuum pump
- Computer equipment
- Lightning

As the company did not have these consumptions separately, some assumptions have been done to split the cost into the departments. These assumptions are explained in the appendix but are based on the power of the elements and an estimation of the total usage time.

• Computer equipment, internet and other office materials have been split fairly amongst the three physical offices instead of the four service departments considered.

After the application of these percentages to the cost elements values, the cost of the allocated to each department will be obtained.

Cost Element	Administration	R&D	P&Q	Commercial	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
CEO wage	30,00	15,00	25,00	30,00									
P&Q Manager wage	10,00	20,00	50,00	20,00									
R&D Manager wage	10,00	50,00	15,00	25,00									
Robot Dep							100,00						
Facilities Rental	8,99	17,97	17,97	8,99	4,98	1,66	16,59	0,92	0,92	11,61	1,66	5,16	2,58
Electric energy	5,18	10,36	10,36	5,18	6,54	6,74	20,93	1,47	1,47	23,06	4,59	3,61	0,52
Telephone	25,00	15,00	10,00	50,00									
Mould Dep										100,00			
Tools					10,00	20,00		10,00	10,00	10,00	5,00	35,00	
Computer equipment Dep	16,67	33,33	33,33	16,67									
Release Agent										100,00			
Infusion Pipes Vacuum										100,00			
Forklift Dep					33,30	33,30					33,30		
Internet	16,67	33,33	33,33	16,67									
Services	12,50	12,50	12,50	12,50			35,00			15,00			
Infusion Pipes Mixing										100,00			
Crane Dep										100,00			
Other Office Mat	16,67	33,33	33,33	16,67									
Insulation tape										100,00			
Robot blades							100,00						
Glue Core								100,00					
Printer cartridges	25,00	25,00	25,00	25,00									
Paper	25,00	25,00	25,00	25,00									
Buckets										40,00	60,00		
Drain Painting										100,00			
Glue Pipe												100,00	

Table21. Allocation Percentages.

Cost Element	Administration	R&D	P&Q	Commercial	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
CEO wage													
P&Q Manager wage													
R&D Manager wage													
Robot Dep													
Facilities Rental													
Electric energy													
Telephone													
Mould Dep													
Tools													
Computer equipment Dep													
Release Agent													
Infusion Pipes													
Vacuum													
Forklift Dep													
Internet													
Services													
Infusion Pipes Mixing													
Crane Dep													
Other Office Mat													
Insulation tape													
Robot blades													
Glue Core													
Printer cartridges													
Paper													
Buckets													
Drain Painting													
Glue Pipe													
TOTAL													

Table 21. Department Costs.

The last step to obtain the monthly cost of the manufacturing departments, and from that the cost of the floors is to allocate the costs of the departments defined as service departments into the manufacturing departments.

This will also be done considering different percentages of the service departments' costs to the manufacturing departments.

In relation to that, the costs of Administration and Commercial departments will be allocated fairly with the same percentage for each manufacturing process since it does not seem to be any special reason to consider different importance according to that.

On the other hand Production & Quality and also Research & Development departments will be allocated amongst the manufacturing departments considering the nature of each workstation and the improvement possibilities from the approaches of these two service departments.
Regarding that the final allocation of the service departments' costs to the manufacturing departments is the following one:

	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
Admon	11,11	11,11	11,11	11,11	11,11	11,11	11,11	11,11	11,11
R&D	15	15	5	5	5	25	15	10	5
P&Q	15	15	15	5	2,5	20	15	10	2,5
Commcial	11,11	11,11	11,11	11,11	11,11	11,11	11,11	11,11	11,11

Table 22. Department Allocation Percentages.

	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
Admon									
R&D									
P&Q									
Commcial									
Total Allocation									

Table 23. Manufacturing Departments Cost.

6 Results

6.1 Layout Design and Simulation Model

Throughout this chapter number six the results obtained from the development chapter are going to be discussed. As it was mentioned before, the three layout alternatives are going to be evaluated considering advantages and disadvantages for all these alternatives and complementing this analysis with the simulation model information. After this evaluation the author will suggest the best alternative from his perspective.

The simulation model has been developed to predict accurately the distance travelled for the workers in the production of one bathroom floor. The specifics of this model and how this purpose can be reliable were discussed in the previous chapter.

The role played by this simulation model is to support the decision in place of other layout analysis tools like analytical diagram and travel chart, tracking times, distances and sequence for the manufacturing process. As the times assigned to the simulation model are real, the waiting times during this process may last two hours long, specifically the curing time. In this time operators perform other activities which movements are not included since these activities are absolutely diverse and not programmed so in that way these distances will not count in the distance recorded.

Carrying on with the simulation considerations, it has been discussed the kind of objects included to model the real process. According to that, the workstations were modelled with simulation objects called MyWorkstations. These objects may require the presence of an operator as it was discussed specifying the destination point to work. This destination point has been considered the same on each workstation for the three alternatives allowing a fair comparison. On the other hand the Paths followed for the workers to move around the facilities are influenced by the layout design of each alternative since the destination nodes and the sizes of the workstations are the same but the location of them is different.

These considerations are explained to contextualize the results obtained from the simulation model. Specifically the results that are going to be compared are the total distance travelled, the distance travelled per worker, the distance travelled per Flow and the total lead time for the production of a bathroom floor.

In relation to the advantages and objections evaluation, other factors are going to be analysed.

During the design process of the layout alternatives some specific considerations were taken into account regarding the Building Factor and the Service Factor like the variable rental costs, the special location for the robot and the mixing workstation or the current office location. According to that, all the alternatives developed satisfy these special requirements established and no one has advantage from the others in relation to these terms.

Also the Change Factor was discussed previously and regarding that it must be mentioned that all alternatives show a considerable capability of change since the whole facilities are allowed to be used because the rental cost is paid by areas and just one of the three areas is being used currently.

Therefore, the qualitative considerations for the advantages and objections evaluation will be related to a visual analysis of the alternatives according to different aspects like the closeness of the flows amongst themselves, the accessibility to the initial workstations for replenishment of raw materials, the manoeuvrability within the facilities for forklifts movement and secondary activities and so on.

So the evaluation of each alternative will be made up of a summary table of the simulation data obtained and a qualitative analysis considering the aspects discussed just above.

After the description of each alternative a final comparison of the results obtained will be done and the best alternative from the author point of view will be chosen.

Without further ado, the analysis of each alternative is done down below.

Alternative 1.

Simio Simulation results.

Alternative 1	Worker 1	Worker 2	Worker 3	Total
Distance Travelled	57,27 m	73,32 m	64,39 m	194,98 m

Table 24. Distances Travelled Alternative 1.

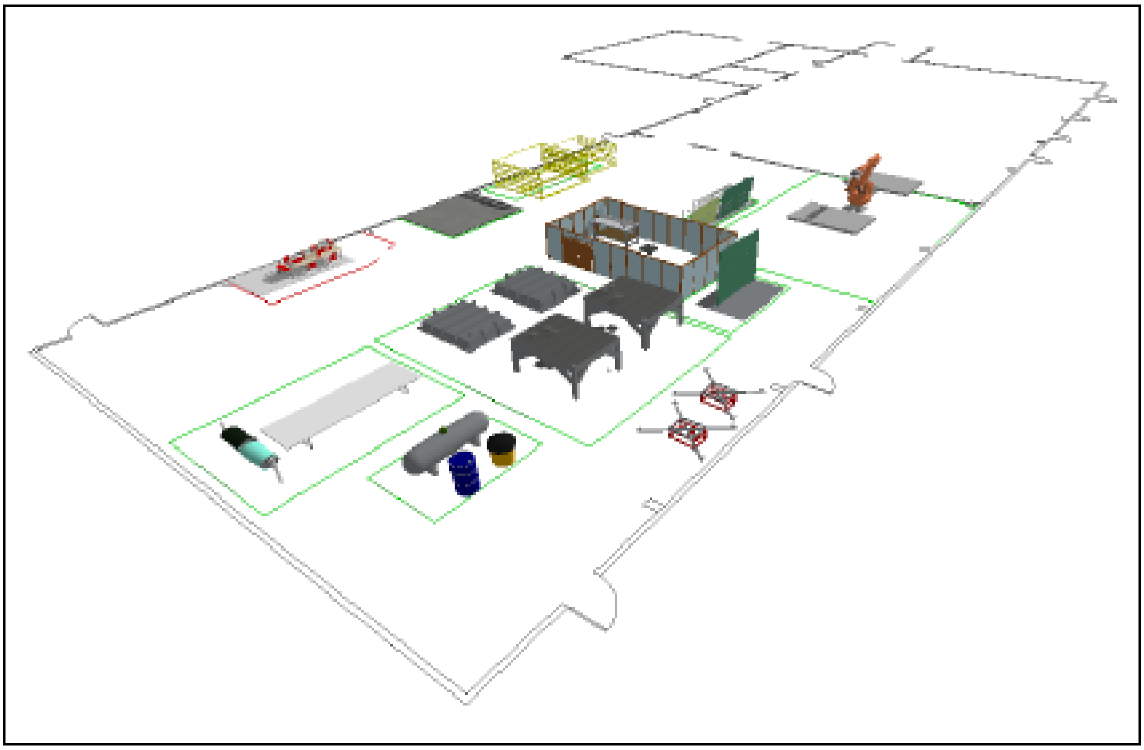

Figure 47. Alternative 1 in Simio Simulation (3D).

Advantages:

- Highest degree of accomplishment for A and E priorities.
- High concentration of workstations in a smaller space.
- Flows closer ones from others and global integration of the process.

Objections:

- Difficult access to some points of the facilities from the main loading and unloading points, specifically mixing workstation.
- More impact of future layout changes since the workstations are next one to others and there is little room for manoeuvre.

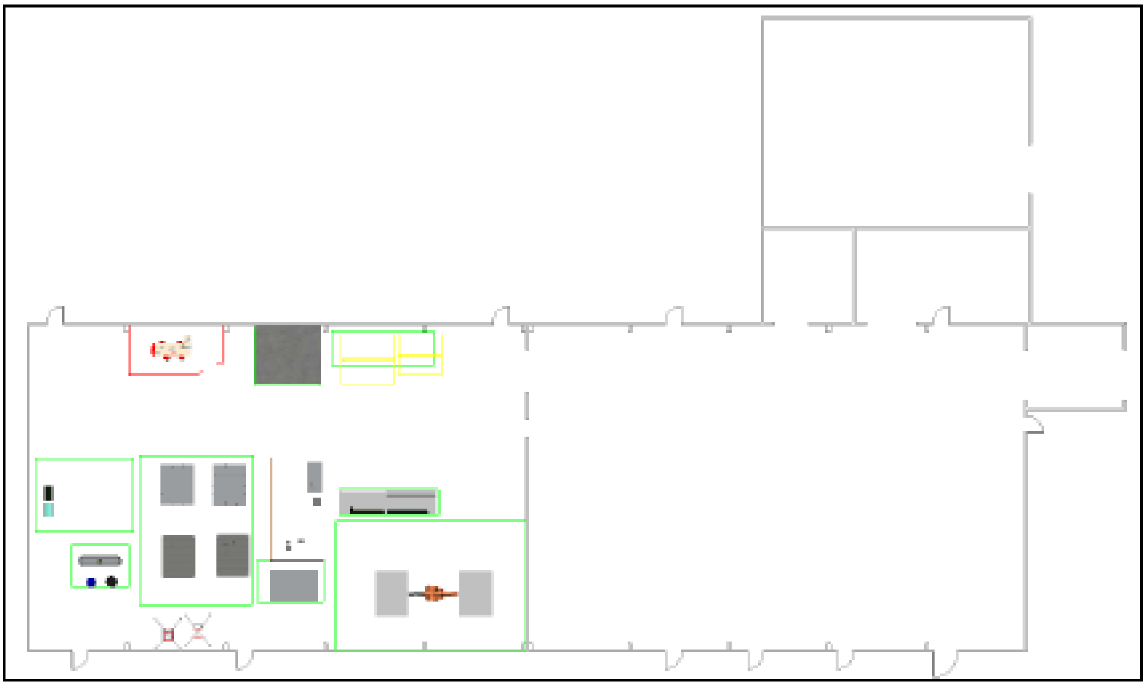

Figure 48. Alternative 1 in Simio Simulation (2D).

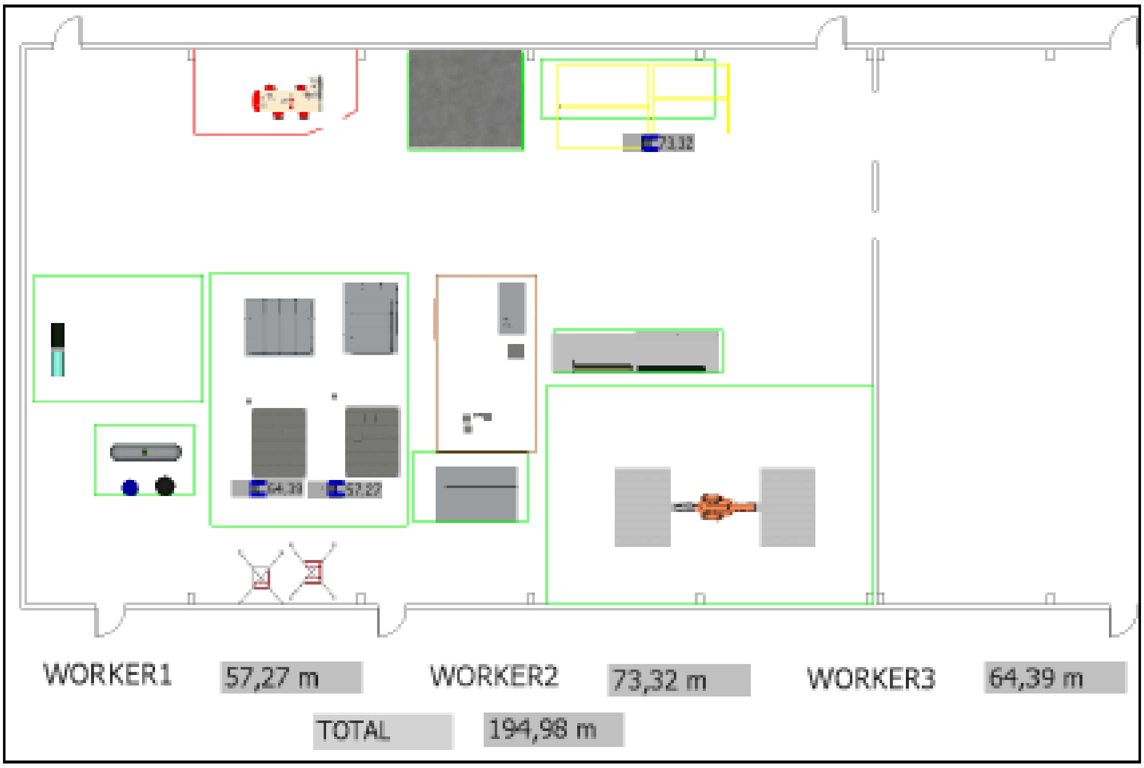

Figure 49. Alternative 1 in Simio Simulation with Distances Recorded.

Alternative 2.

Simio Simulation results.

Alternative 2	Worker 1	Worker 2	Worker 3	Total
Distance Travelled	64,41 m	71,67 m	70,14 m	206,22 m

Table 25. Distances Travelled Alternative 2.

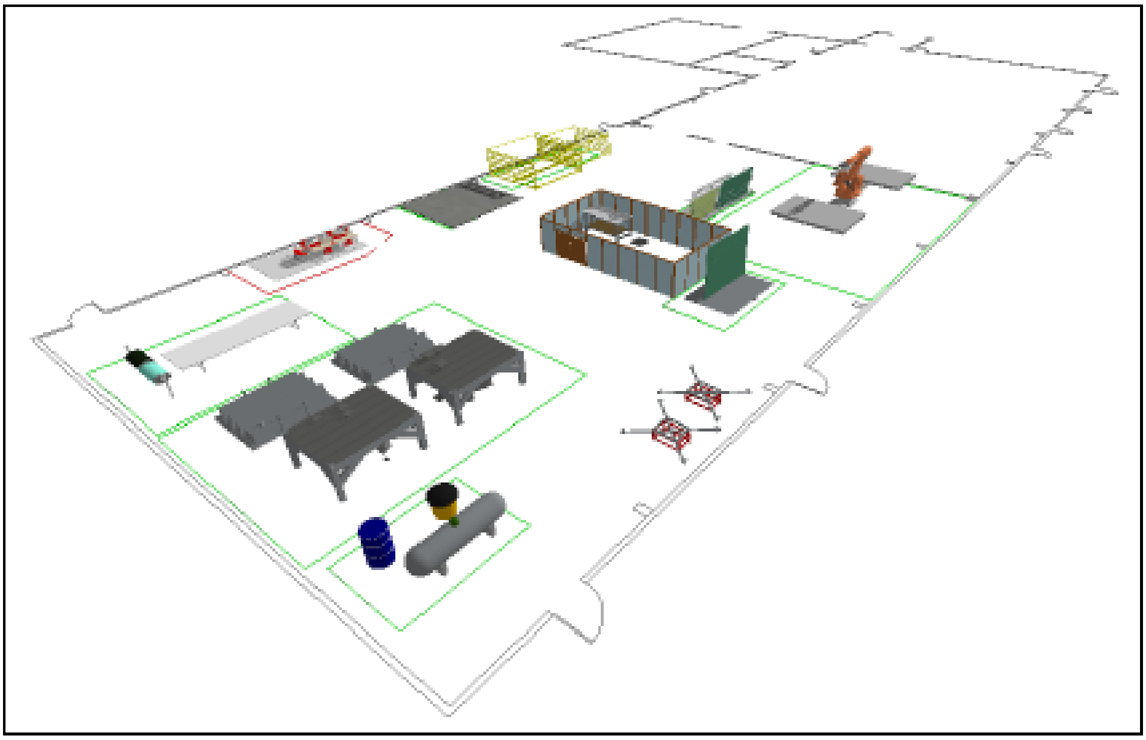

Figure 50. Alternative 2 in Simio Simulation (3D).

Advantages:

- Easy accessibility to all workstations and points of the facilities due to the location of moulding stations.
- Clearness amongst the different flows.
- Ability for future layout changes without impacting the whole system.

Objections:

- Lowest degree of accomplishment for A and E priorities due to the increase of distances to the moulding station.
- Distance between Flows two and three and moulding station.

Figure 51. Alternative 2 in Simio Simulation (2D).

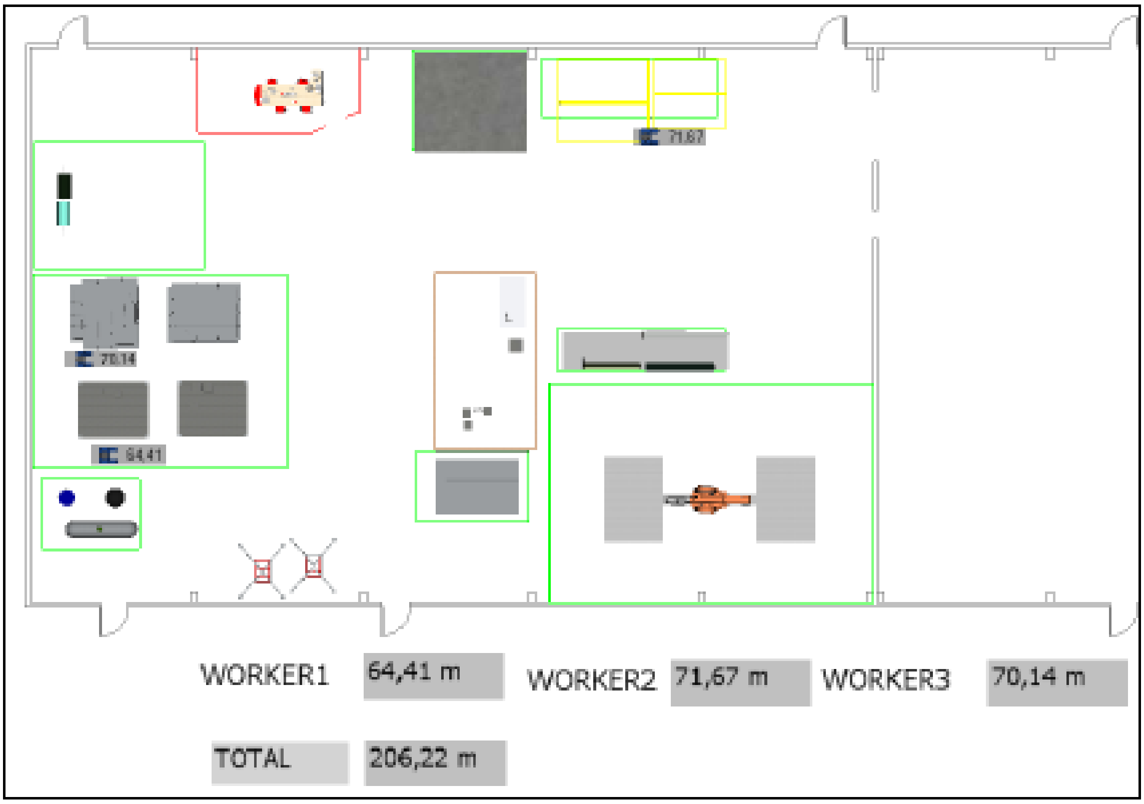

Figure 52. Alternative 2 in Simio Simulation with Distances Recorded.

Alternative 3.

Simio Simulation results.

Alternative 3	Worker 1	Worker 2	Worker 3	Total
Distance Travelled	48,67 m	68,02 m	63,69 m	180,38 m

Table 26. Distances Travelled Alternative 3.

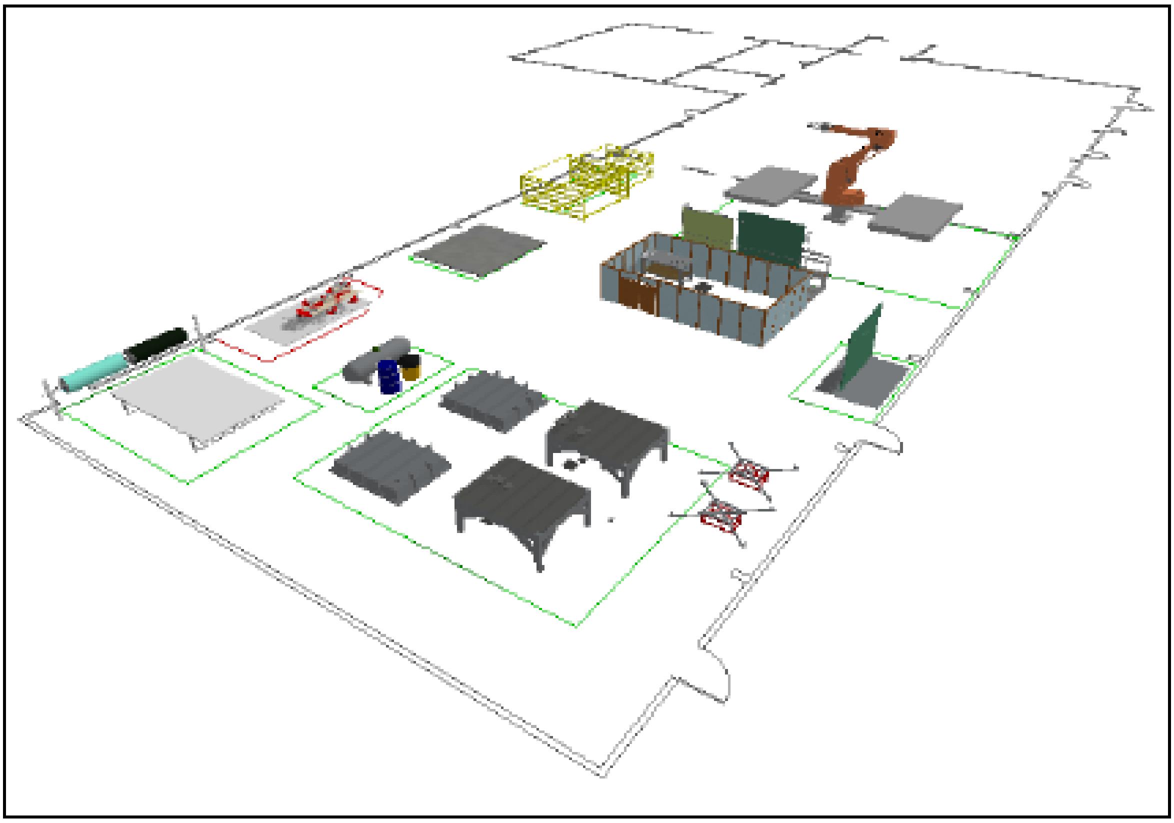

Figure 53. Alternative 3 in Simio Simulation (3D).

Advantages:

- Easy accessibility to all workstations and points of the facilities due to the robot orientation.
- Clearness amongst different Flows with high closeness amongst the workstations within the flows.
- Ability for future layout changes without impacting the whole system.

Objections:

- Distance amongst Flows decreases global integration.

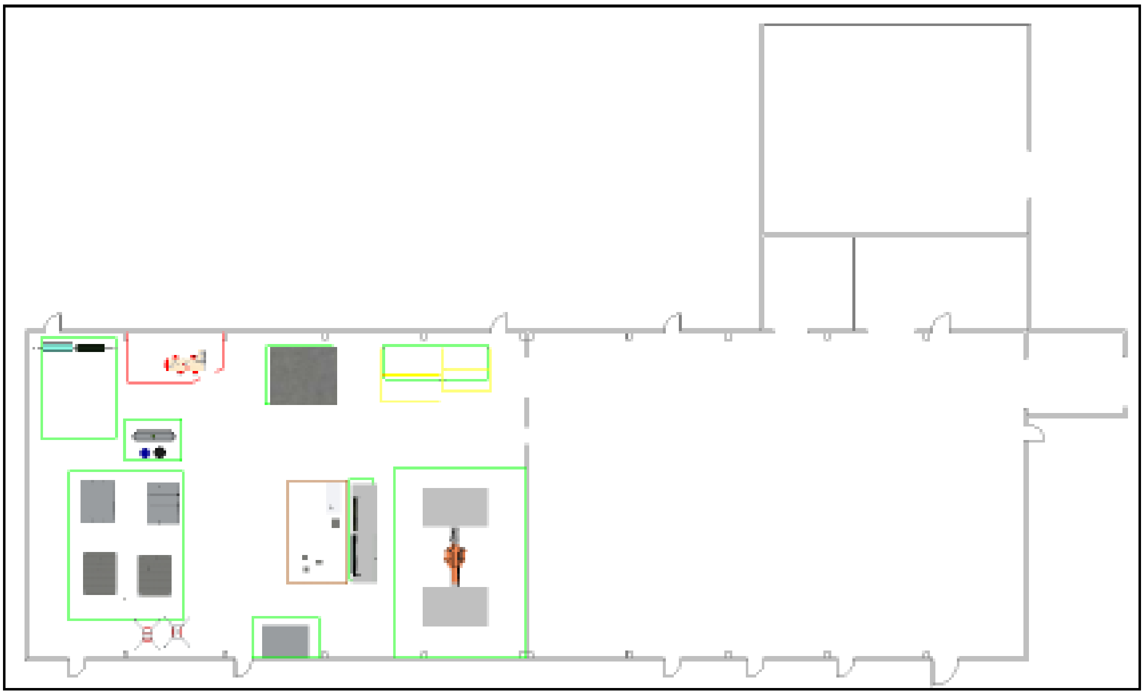

Figure 54. Alternative 3 in Simio Simulation (2D).

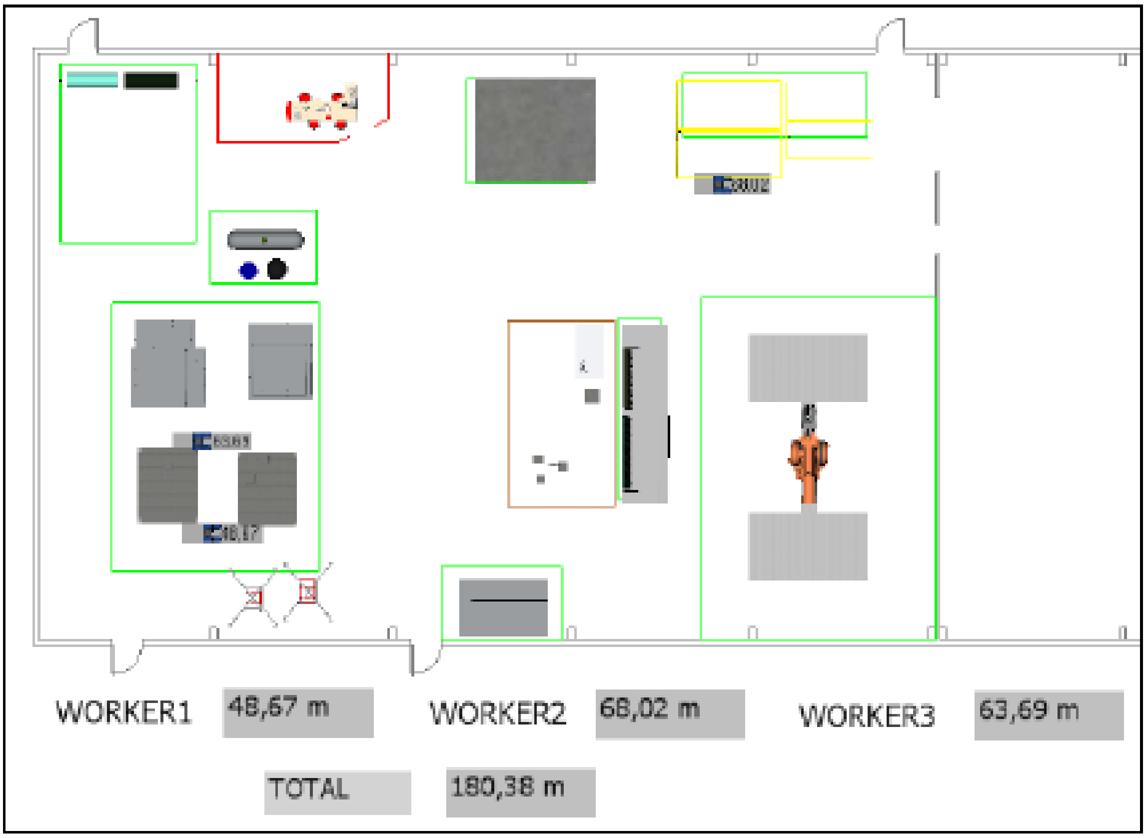

Figure 55. Alternative 3 in Simio Simulation with Distances Recorded.

Decision.

The final alternative suggested will be chosen based on the evaluation of the advantages and objections discussed and the interpretation of the simulation results.

According to the visual evaluation it must be highlighted that Alternative 1 is the one that best fits the Systematic Layout Planning Priorities but at the same time this degree of concentration for the workstations avoid the easy replenishment of raw material and also possible modifications of the layout.

In relation to these last statements, Alternative 2 is the one that best accomplish these aspects but the accomplishment of the SLP priorities is not so successful.

Alternative 3 seems to be an intermediate solution between the accomplishment of priorities and ease for replenishment and layout modification.

Paying attention to the Simio Simulation results, in the table shown down below are collected all the distances for the three alternatives.

Simio Simulation results.

1 Floor	Worker 1	Worker 2	Worker 3	Total	% Difference
Alternative 1	57,27 m	73,32 m	64,39 m	194,98 m	+8,09%
Alternative 2	64,41 m	71,67 m	70,14 m	206,22 m	+14,34%
Alternative 3	48,67 m	68,02 m	63,69 m	180,38 m	

Table 27. Distances Travelled for One Floor.

As it can be observed in Table 27, for the production of one floor Alternative 3 is the one with less distance travelled. Alternative 1 shows an 8,09% more distance and Alternative 2 shows a 14,34% more distance.

This information also points as the best option the Alternative 3 since the reduction of distance is one of the main objectives of the layout design.

These data may be complemented with the study of an average working day production. Assuming that the average production is three floors per day, the final distances at the end of the day for the three alternatives would be the following:

3 Floors	Worker 1	Worker 2	Worker 3	Total	% Difference
Alternative 1	169,00 m	283,93 m	178,98 m	631,91 m	+1,76%
Alternative 2	188,68 m	300,94 m	200,47 m	690,09 m	+11,14%
Alternative 3	154,67 m	281,59 m	184,66 m	620,92 m	

Table 28. Distances Travelled for Three Floors.

It can be noted that the differences are smaller for the manufacturing of three bathroom floors as it is shown in the percentage difference column. The interpretation of this information is that flows are more globally integrated in Alternative 1 and 2 since as much production more advantage in relation to Alternative 3.

Nevertheless this data was obtained simulating a production rate of three bathroom floors per day, which is an objective not reached yet for the company and according to that Alternative 3 is still the most appropriate for the current activity.

Anyhow this information points that for higher production rates, other layouts could be more profitable.

This data may be expressed in a monthly horizon and in monetary units to show better the impact of this decision.
Considering that this scenario of three floors per day is repeated every day of the month (actually the production rate is smaller and the differences would be bigger in favour of Alternative 3) the following table shows the distance travelled in twenty working days and the estimated time associated.

1 month of production	Worker 1	Worker 2	Worker 3	Total	% Difference
Alternative 1	3380,0 m	5678,6 m	3579,6 m	12638,2	+1,76%
Alternative 2	3773,6 m	6018,8 m	4009,4 m	13801,8	+11,14%
Alternative 3	3093,4 m	5631,8 m	3693,2 m	12418,4	

Table 29. Distances Travelled for One Month of Production.

1 month of production	Distance Difference	Extra Time Travelled (mm:ss)	Cost of Extra Time Travelled (kr)
Alternative 1	219,8 m	06:32	27,17
Alternative 2	1383,4 m	41:02	171,00
Alternative 3			

Table 30. Cost of Times Expent in Extra Travelling.

This calculation has been done with the information of the labour cost per hour which is 250kr/h and the estimation of the speed as the Standard Walking Speed of 6.4km/h.

Even though the money savings are not high, the extra time travelled is rather considerable if it is seen from the approach that it is time that could be used for operations. Also it must be mentioned this savings come from the location of the workstations without any other consideration regarding the manufacturing process. So regarding the whole aspects treated throughout this chapter the author suggestion for the company layout is the Alternative 3.

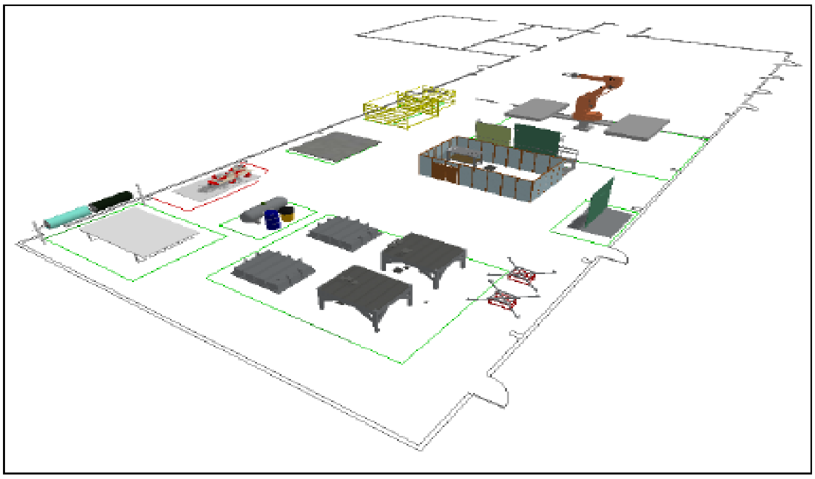

Figure 56. Alternative Chosen.

6.2 Costing Models

Throughout this point of the project the main results of the costing model development will be included and discussed.

The model developed was based on the allocation of the direct material costs directly to the product, then the direct labour costs were allocated to the manufacturing departments or workstations considering the operation time of each workstation. These direct labour costs included idle times that were allocated in three different ways arising three different alternatives of final Cost Sheet: amongst the workstations proportionally to each operation time, directly to the bottle neck of the process or directly to the product as another element of cost.

It must be mentioned that these three alternatives respond to different conceptual visions of the idle labour costs' allocation and the final result of the Cost Sheets is the same for each three alternatives.

According to that, what makes the difference is the cost of the workstations per month and per product consequently, but not the product cost. These visions will not affect to the allocation of the direct material costs or to the remaining indirect costs and they are equal for the three alternatives.

The cost model chosen amongst these three alternatives will be based on the approach desired by the company in relation to all this idle labour time paid.

Approach 1

- From the first approach, the output of this cost model regarding the workstations is that the cost of them is directly related to the operation time required on each one. The workstations with more operation times are more expensive.
    - o Advantage: It is a logical allocation since the company pays the workers for the operations they carry out and the workstations with more operation times should be more expensive.
    - o Disadvantage: There is no clarity in the final results regarding the idle times quantity and its cause throughout the process.

	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
Labour Costs									
Own Indirect Costs									
Allocated Service Costs									
Total monthly costs									

Table 31. Manufacturing Department Costs Approach 1.

COSTS SHEET 1			
Cost Element		Monthly Cost	Cost per Floor
MATERIAL	Fibres (Woven)		
	Fibres (Mat)		
	Cores 20 mm		
	Cores 30 mm		
	Cores 40 mm		
	Resin		
	Curing agent		
	Inhibitor		
	Heating Cable		
	Pipes		
	Wooden piece		
	Stopper		
MANUFACTURING DEPARTMENTS	Fibres		
	Core Prep		
	Robot		
	Glue Core		
	Heating Cable		
	Moulding		
	Mixing		
	Postcutting		
	Control		
	TOTAL COST	kr	kr

Table 32. Costs Sheet Approach 1.

Approach 2.

• From the second approach, the idle times are allocated completely to the moulding workstation. This is the bottle neck of the process since it has the highest waiting time in the process due to the curing time required.

o Advantage: This approach points out to the main cause of the idle times in the process which is related to the moulding station and shows clearly the stage of the process which is required to be improved looking for a balance production process.

o Disadvantage: This moulding station is the main cause but not the only one. Idle times are also related to other activities like set ups, tearing downs, transports of raw materials, travelling from one workstation to another and so on.
Even though some of these aspects were included in the Standard Times, the moulding station is not hundred per cent guilty of this huge idle time.

	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
Labour Costs									
Own Indirect Costs									
Allocated Service Costs									
Total monthly costs									

Table 33. Manufacturing Department Costs Approach 2.

COSTS SHEET 2			
Cost Element		Monthly Cost	Cost per Floor
MATERIAL	Fibres (Woven)		
	Fibres (Mat)		
	Cores 20 mm		
	Cores 30 mm		
	Cores 40 mm		
	Resin		
	Curing agent		
	Inhibitor		
	Heating Cable		
	Pipes		
	Wooden piece		
	Stopper		
MANUFACTURING DEPARTMENTS	Fibres		
	Core Prep		
	Robot		
	Glue Core		
	Heating Cable		
	Moulding		
	Mixing		
	Postcutting		
	Control		
	TOTAL COST	kr	kr

Table 34. Costs Sheet Approach 2.

Approach 3.

- From the third approach, the purpose was to show the idle labour time computed as a particular element of cost without the allocation of this quantity to any workstation.

  o Advantage: This idle labour time may not be a problem of the own workstation if the process is how it is. A lack of balance amongst the workforce available and required for the properties of the process or a lack of short term scheduling of the production process may also be the causes.
  This cost shows that something has to be done with all this time since it represents more than the 68% of the paid time.

  o Disadvantage: It is not a workers' fault themselves and it looks this approach points directly to them. This cost has to be considered by the company as the opportunity to give the workers other tasks or allow them to contribute in other activities not related to manufacturing in order to take more profit of them.
  The results show that the properties of the process show and the workforce are not balanced so other activities may be done to fill these idle times.

	Fibres	Core Prep	Robot	Glue Core	Heating Cable	Moulding	Mixing	Postcutting	Control
Labour Costs									
Own Indirect Costs									
Allocated Service Costs									
Total monthly costs									

Table 35. Manufacturing Department Costs Approach 3.

COSTS SHEET 3			
Cost Element		*Monthly Cost*	*Cost per Floor*
MATERIAL	*Fibres (Woven)*		
	Fibres (Mat)		
	Cores 20 mm		
	Cores 30 mm		
	Cores 40 mm		
	Resin		
	Curing agent		
	Inhibitor		
	Heating Cable		
	Pipes		
	Wooden piece		
	Stopper		
MANUFACTURING DEPARTMENTS	*Fibres*		
	Core Prep		
	Robot		
	Glue Core		
	Heating Cable		
	Moulding		
	Mixing		
	Postcutting		
	Control		
	Idle Labour Costs	-	-
	TOTAL COST	kr	kr

Table 36. Costs Sheet Approach 3.

Even though, another study could be done to analyse the waiting times and associate them directly to the guilty workstations we could say. But for this first costing model it has been considered accurate enough to use this procedure.

From these three alternatives it is the company the one that might choose the appropriate cost model and the one they think reflects better the costs and gives more information regarding the activity costs.

According to that, from the author's perspective Approach 2 is conceptually right but the allocation is not completely fair since the waiting times in the Moulding station could be programmed for lunch breaks, night or other solutions. In that way Approach 3 seems to be more fair showing the quantity of the idle labour costs and not allocating to any particular workstation since it could be a problem of scheduling more than the specific properties of the bottle neck because in this process the bottle neck is not associated to an operation and these waiting times could be reprogrammed.

From a classical costs model approach, Approach 1 seems to be the best one since the costs of the product are split throughout the process' stations and materials.

In relation to that, the author suggestion is to choose the Approach 1. This Approach would finally be the optimal alternative if a study of the distribution of the idle times according to the reason why they are present were carried out. In that scenario the real cost could be allocated to each department. To put an end to this Costing Model Results point, a study of the profit margin and the minimum sale price will be done.

Sale Alternatives	Price (kr)	Profit Margin
Floor cost [minimum sale price]		0%
Price 1		5,8%
Price 2		11,1%
Price 3		16,37%

Table 37. Sale Price Alternatives.

The price fixed must be verified with the market prices in order to be competitive and if the profit margin is low, a study of cost reduction should be done.

7 Conclusions

7. Conclusions

Throughout the development of this project some conclusions were obtained, regarding the subject matter treated, the possibilities to reach different alternatives and the best way to provide valuable solutions to the company.

The author attempted to be as close as possible to this manufacturing process, considering it as the basic part of the company and the starting point of most of the possible developments.

This study of the process was helpful to understand the key points of it and keep them in mind for the development of the plant layout design.

Currently many theoretical methodologies are suggested, but this design must be mostly influenced by the process features. Considerations like difficulty for material handling in certain steps, division of tasks amongst workers, material and information flows within the manufacturing system, or better location of a particular workstation are factors that may be missed from a theoretical approach.

To overcome these important details, the study of the current layout design and an analysis of it from a critical approach seems to be an essential practice.

Anyhow, this possibility is not always available. If it is not possible, simulation tools may help to get a deeper understanding and being like an intermediate step between the theoretical study and the real system analysis. However, the development of a reliable simulation model involves the investment of a certain amount of time and expertise requirement. Regarding that, the author recommends the clear definition of the simulation model outputs, considering its worthiness, before start the model development to save time and money in many ways.

If no one of these possibilities is available, the theoretical development should be studied in depth trying to include from the author point of view global integration of the system, minimum distance and backtracking, study of the material flow and transformations, operators' safety and satisfaction, and finally flexibility since the first design may be improved soon.

Regarding the accomplishment of the objectives for this part of the project, it may be said the objectives have been achieved since three feasible layout alternatives were designed and evaluated in different and complementary ways. The company members also played an important role on the design and analysis and finally the alternative chosen was approved and implemented.

The solution implemented is the one with the best results obtained considering the evaluation properties that have been chosen.

In relation to the cost model development, the advantages of it have been already discussed. For the author it represents an important element for the company with no more requirements than the collection of reliable data and the establishment of a standard set of criteria to be able to check the results and prevent negative trends.

The model developed seems to achieve the objective it was built for, since the cost of the product was obtained as well as the cost of the manufacturing departments. Furthermore, a brief study of sale prices has been done in order to bring more information to the company.

8 Further Development

8. Further Development

This chapter will discuss further possibilities for the issues developed in this project and also for other ones considered appropriate by the author for the company development. Some of these further developments have already been discussed in the chapters related to their nature and at this point it will be made explicit reference to these previous chapters.

Layout design.

- Three alternatives were designed and the performance of them was related to the production rate of the company. So the tracking of the solution implemented and the study of changes associated to other alternatives may be done controlled by the company.
- The evaluation of the alternatives was supported by the simulation model. This evaluation could be improved if the record of the distances travelled was done considering the material transported associated to each travelling. This could be a new aspect to evaluate.

Simulation model.

Regarding the simulation model itself in point 4.2 of this project, further possibilities for the company have been already described.

Costs model.

The costs model developed has been explained as well as the set of criteria defined and the different approaches considered. Anyhow to improve it different actions may be done.

- A deeper study of the idle times in order to allocate them to the responsible workstations.

- A deeper study of the scrap rates to know the direct material costs more accurately.

- Development of a set of indicators regarding the costs trends, the most important cost centres or a classification of them as fixed or variable to establish the break-even point.

- Development of a management accounting system including techniques as the ones introduced in the theoretical point of the cost accounting.

General suggestions.

Some general suggestions for the company activity improvement were described in the point 3.4. These suggestions were classified in two groups:

- Production process: Suggesting actions related to standardize work, short-term scheduling or KPI systems.

- Management approach: Suggesting actions related to marketing planning, suppliers' analysis or ISO certifications.

9 References

9. References

[1] **Strong, A. Brent**. Fundamentals of Composites Manufacturing - Materials, Methods, and Applications

[2] **F.C. Campbell.** Structural Composite Materials

[3] **Deborah D.L. Chung**. Composite Materials. Science and Applications

[4] **Dr. Elmar Witten (AVK), Bernhard Jahn / Doris Karl.** Composites Market Report 2012. Available at:
http://www.eucia.eu/uploads/959ed1403f32d028700fc8d85665b5d4.pdf

[5] **Lucintel.** Growth Opportunities in the Global Composites Industry

[6] **Robinson, Stewart.** Simulation: The Practice of Model Development and Use

[7] **Bank, Jerry. Carson II, John S. Nelson, Barry L. Nicol, David M.** Discrete-Event System Simulation

[8] **Santos, Javier; Wysk, Richard; Torres, José Manuel.** Improving Production with Lean Thinking

[9] **De la Fuente García, David.** Distribución en Planta.

[10] **Arora, M.N.** Cost and Management Accounting.

[11] **Periasamy, P.** Textbook of Financial Cost and Management Accounting

[12] **Pearson Ed.** Cost Allocation and Activity-Based Costing Systems.
Available at:
http://www.pearsoned.ca/highered/divisions/virtual_tours/horngren/man_acc/Ch05ManAcc.pdf

[13] **Simio LLC.** Simio Reference Guide.

[14] **Kanawaty, George**. Introduction to Work Study

Electronic sources

www.simio.com
www.ltu.se/ltu/lib
www.eucia.eu
www.sme.org
www.hpcinc.com
www.industrialtimestudy.com
www.see.ed.ac.uk/

APPENDIX

TIME STUDY.

Daily Time Sheet for times observed.

BLATRADEN — DAILY TIME SHEET — BLATRADEN

☐ WORKER 1	DATE (dd/mm)	______
☐ WORKER 2	DAY STARTS (hh:mm)	______
☐ WORKER 3	DAY ENDS (hh:mm)	______

	MODEL TYPE				MODEL TYPE			
	LEFT	RIGHT	START TIME	FINISH TIME	LEFT	RIGHT	START TIME	FINISH TIME
FIBER CUTTING	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
DRAIN PAINTING	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
CORE PREP	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
PIPE	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
ROBOT PATH SETUP	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
HEATING CABLE	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
DRESS FIBER A	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
CORE TO MOULD	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
DRESS FIBER B	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
CLOSE MOULD	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
INFUSION SETUP	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
MIXING	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
MOULD OUT	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
CUTTING EDGE	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
POSTCUTTING	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____
CONTROL	☐	☐	1____	1____	☐	☐	3____	3____
	☐	☐	2____	2____	☐	☐	4____	4____

Table 38. Daily Time Sheet Model.

TIME STUDY.

Daily Time Sheet for times observed.

This Daily Time Sheet is designed for the tracking of one worker per sheet. Therefore it is required to tick the worker name in the upper part as well as fill the day date and the arrival time and departure time of this worker. These first rows will make easier the treatment of the information and will also provide information regarding the time-keeping.

After these rows are filled in, the second part of the Daily Time Sheet is a list of all the worker operations required for the manufacturing process, placed on the left column of the sheet. Hence, the same design of Daily Time Sheet is appropriate for all the workers since all the activities are included there.

On the right, four different pairs of start and finish times are drawn for each operation. These pairs are numbered from one to four, to fill as many of them as the operation is repeated in the working day.

It has been considered than the maximum production rate is four floors per day for this Daily Time Sheet but if it was required extra sheets could be filled in. Anyhow this consideration is rather optimistic since it is the current purpose for the company and they are still working to achieve this production rate.

Between the operation name and the pairs of start and finish times a box is placed to tick the model type recorded. It must be kept in mind that currently the manufacturing process is just focused on one product with slight differences, based mainly in the side the drain is placed in the floor.

Regarding that, a cross must be put in the appropriate box to have more information by the time the data is treated.

TIME STUDY.

Daily Time Sheets filled in

BLATRADEN	DAILY TIME SHEET	BLATRADEN
X WORKER 1 X WORKER 2 X WORKER 3	DATE (dd/mm) DAY STARTS (hh:mm) DAY ENDS (hh:mm)	20/11/2012 8:00 16:45

	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME
FIBRES CUTTING	X		1 0		X		3 0	
		X	2 0		X		4 0	
DRAIN PAINTING	X		1 0				3	3
		X	2 0				4	4
CORE PREP	X		1				3	3
		X	2				4	4
PIPE	X		1				3	3
		X	2				4	4
ROBOT PATH SETUP	X		1				3	3
		X	2				4	4
HEATING CABLE	X		1 17:05				3	3
		X	2				4	4
DRESS FIBER A	X		1				3	3
		X	2				4	4
CORE TO MOULD	X		1				3	3
		X	2				4	4
DRESS FIBER B	X		1				3	3
		X	2				4	4
CLOSE MOULD	X		1				3	3
		X	2				4	4
INFUSION SETUP	X		1				3	3
		X	2				4	4
MIXING	X		1				3	3
		X	2				4	4
MOULD OUT	X		1				3	3
		X	2				4	4
~~CUTTING EDGE~~ G. CORE	X		1				3	3
		X	2				4	4
POSTCUTTING	X		1				3	3
		X	2				4	4
CONTROL	X		1				3	3
		X	2				4	4

Table 39. Daily Time Sheet Filled In (20/11/2012).

TIME STUDY.

Daily Time Sheets filled in

BLATRADEN	DAILY TIME SHEET	BLATRADEN
X WORKER 1 X WORKER 2 X WORKER 3	DATE (dd/mm) 13/12/2012 DAY STARTS (hh:mm) 8:00 DAY ENDS (hh:mm) 16:35	

	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME
FIBRES CUTTING	X		1				3	3
		X	2				4	4
DRAIN PAINTING	X		1				3	3
		X	2				4	4
CORE PREP	X		1				3	3
		X	2				4	4
PIPE	X		1				3	3
		X	2				4	4
ROBOT PATH SETUP	X		1				3	3
		X	2				4	4
HEATING CABLE	X		1				3	3
		X	2				4	4
DRESS FIBER A	X		1				3	3
		X	2				4	4
CORE TO MOULD	X		1				3	3
		X	2				4	4
DRESS FIBER B	X		1				3	3
		X	2				4	4
CLOSE MOULD	X		1				3	3
		X	2				4	4
INFUSION SETUP	X		1				3	3
		X	2				4	4
MIXING	X		1				3	3
		X	2				4	4
MOULD OUT	X		1				3	3
		X	2				4	4
~~CUTTING EDGE~~ G. CORE	X		1				3	3
		X	2				4	4
POSTCUTTING	X		1				3	3
		X	2				4	4
CONTROL	X		1				3	3
		X	2				4	4

Table 40. Daily Time Sheet Filled In (13/12/2012).

TIME STUDY.

Daily Time Sheets filled in

BLATRADEN Advanced Composite Solutions — **DAILY TIME SHEET** — BLATRADEN Advanced Composite Solutions

X	WORKER 1	DATE (dd/mm)	19/3/2013
X	WORKER 2	DAY STARTS (hh:mm)	8:00
X	WORKER 3	DAY ENDS (hh:mm)	16:30

	MODEL TYPE LEFT	RIGHT		START TIME	FINISH TIME	MODEL TYPE LEFT	RIGHT		START TIME	FINISH TIME
FIBRES CUTTING		X	1				X	3		
	X		2					4		
DRAIN PAINTING		X	1				X	3		
	X		2					4		
CORE PREP		X	1					3		
	X		2					4		
PIPE		X	1					3		
	X		2					4		
ROBOT PATH SETUP		X	1					3		
			2					4		
HEATING CABLE		X	1					3		
			2					4		
DRESS FIBER A		X	1					3		
	X		2					4		
CORE TO MOULD		X	1				X	3		
	X		2					4		
DRESS FIBER B		X	1					3		
			2					4		
CLOSE MOULD		X	1				X	3		
	X		2	9:17				4		
INFUSION SETUP		X	1					3		
			2					4		
MIXING		X	1					3		
			2					4		
MOULD OUT		X	1				X	3		
	X		2					4		
~~CUTTING EDGE~~ G-CORE		X	1				X	3		
	X		2					4		
POSTCUTTING		X	1					3		
			2					4		
CONTROL		X	1				X	3		
	X		2					4		

Table 41. Daily Time Sheet Filled In (19/03/2013).

TIME STUDY.

Daily Time Sheets filled in

BLATRADEN — DAILY TIME SHEET — BLATRADEN

☒ WORKER 1	DATE (dd/mm) 28/3/2013
☒ WORKER 2	DAY STARTS (hh:mm) 8:00
☒ WORKER 3	DAY ENDS (hh:mm) 16:30

	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME
FIBRES CUTTING	☒	☐	1		☒	☐	3	
	☐	☒	2		☐	☐	4	
DRAIN PAINTING	☒	☐	1		☐	☐	3	
	☐	☒	2		☐	☐	4	
CORE PREP	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
PIPE	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
ROBOT PATH SETUP	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
HEATING CABLE	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
DRESS FIBER A	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
CORE TO MOULD	☒	☐	1		☐	☐	3	
	☐	☒	2		☐	☐	4	
DRESS FIBER B	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
CLOSE MOULD	☒	☐	1		☐	☐	3	
	☐	☒	2		☐	☐	4	
INFUSION SETUP	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
MIXING	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
MOULD OUT	☒	☐	1		☐	☐	3	
	☐	☒	2		☐	☐	4	
~~CUTTING EDGE~~ G. CORE	☒	☐	1		☐	☐	3	
	☐	☒	2		☐	☐	4	
POSTCUTTING	☐	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	
CONTROL	☒	☐	1		☐	☐	3	
	☐	☐	2		☐	☐	4	

Table 42. Daily Time Sheet Filled In (28/03/2013).

TIME STUDY.

Daily Time Sheets filled in

BLATRADEN — DAILY TIME SHEET — BLATRADEN

☒ WORKER 1 (black)	DATE (dd/mm): 15/4/2013
☒ WORKER 2 (blue)	DAY STARTS (hh:mm): 8:00
☒ WORKER 3 (red)	DAY ENDS (hh:mm): 16:55

	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME	MODEL TYPE LEFT	RIGHT	START TIME	FINISH TIME
FIBRES CUTTING			1 / 2				3 / 4	3 / 4
DRAIN PAINTING		X (worker 1)	1 / 2				3 / 4	3 / 4
CORE PREP			1 / 2				3 / 4	3 / 4
PIPE			1 / 2				3 / 4	3 / 4
ROBOT PATH SETUP			1 / 2				3 / 4	3 / 4
HEATING CABLE			1 / 2				3 / 4	3 / 4
DRESS FIBER A			1 / 2				3 / 4	3 / 4
CORE TO MOULD			1 / 2				3 / 4	3 / 4
DRESS FIBER B			1 / 2				3 / 4	3 / 4
CLOSE MOULD		X (worker 2)	1 / 2				3 / 4	3 / 4
INFUSION SETUP			1 / 2				3 / 4	3 / 4
MIXING			1 / 2				3 / 4	3 / 4
MOULD OUT		X (worker 2)	1 / 2				3 / 4	3 / 4
~~CUTTING EDGES~~ G. CORE		X (worker 3)	1 / 2				3 / 4	3 / 4
POSTCUTTING			1 / 2				3 / 4	3 / 4
CONTROL		X (worker 2)	1 / 2				3 / 4	3 / 4

Table 43. Daily Time Sheet Filled In (15/04/2013).

TIME STUDY.

Daily Time Sheets summarized

Operation		Sample Day	Sample nº	Time (mm:ss)	Time (s)
Fibres		20/11/2012	1		
		20/11/2012	2		
n'	6	20/11/2012	3		
Σx	2988	20/11/2012	4		
Σx²	1491072	13/12/2012	5		
(Σx)²	8928144	13/12/2012	6		
n	4				
Drain Painting		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	665	13/12/2012	4		
Σx²	111253				
(Σx)²	442225				
n	11				
Core Prep		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	1803	13/12/2012	4		
Σx²	813357				
(Σx)²	3250809				
n	2				
Robot setup		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	942	13/12/2012	4		
Σx²	221934				
(Σx)²	887364				
n	1				
Glue Core		20/11/2012	1		
		20/11/2012	2		
n'	4	13/12/2012	3		
Σx	1392	13/12/2012	4		
Σx²	496105				
(Σx)²	1937664				
n	6				

Table 44. Daily Time Sheets Summarized (Part 1).

TIME STUDY.

Daily Time Sheets summarized

Heating Cable		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	4205	13/12/2012	4
Σx²	4421653		
(Σx)²	17682025		
n	1		
Operation		Sample Day	Sample nº
PreGlue Pipe		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	3841	13/12/2012	4
Σx²	3692379		
(Σx)²	14753281		
n	2		
Dress Fibre A		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	776	13/12/2012	4
Σx²	150690		
(Σx)²	602176		
n	2		
Core		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	163	13/12/2012	4
Σx²	6661		
(Σx)²	26569		
n	5		
Dress Fibre B		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	2224	13/12/2012	4
Σx²	1236606		
(Σx)²	4946176		
n	1		

Table 45. Daily Time Sheets Summarized (Part 2).

TIME STUDY.

Daily Time Sheets summarized

Mould Closing		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	2813	13/12/2012	4
Σx²	2001321		
(Σx)²	7912969		
n	19		
Mixing		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	2783	13/12/2012	4
Σx²	1936437		
(Σx)²	7745089		
n	1		
Operation		*Sample Day*	*Sample nº*
Inf Setup		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	2928	13/12/2012	4
Σx²	2143498		
(Σx)²	8573184		
n	4		
Mould Out		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	3608	13/12/2012	4
Σx²	2143498		
(Σx)²	8573184		
n	1		
Postcutting		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	3457	13/12/2012	4
Σx²	2988681		
(Σx)²	11950849		
n	1		
Control		20/11/2012	1
		20/11/2012	2
n'	4	13/12/2012	3
Σx	641	13/12/2012	4
Σx²	102993		
(Σx)²	410881		
n	5		

Table 46. Daily Time Sheets Summarized (Part 3).

TIME STUDY.

It must be noted the difficulty to achieve the values for the sample size of some operations, since for each floor operations are only carried out once and the production rate in the company hinder the recording of these amounts of data.

According to that it was decided to limit the size of the sample to six extra observations for each operation.

This decision will cause that for some operations the confidence levels chosen will not be accomplished but the economy of time for the costing model development must be considered. The number of six was chosen as the limit since only three operations of the sixteen considered will not achieve the size required and for other levels this number will increase.

Regarding that from a global approach, it must be considered the time consumption for the recording of all these samples and the specific importance of them. Accuracy is required but also economy of time in the costing model development must be appreciated.

Times observed, Worker rating with British Standard Scale, Basic Times and Average Basic Time.

Operation		Sample Day	Sample nº	Time (ss)	Worker Rating	Basic Time
Fibres		20/11/2012	1		110	
		20/11/2012	2		100	
Samples Required	6	20/11/2012	3		100	
		20/11/2012	4		100	
Samples Obtained	6	13/12/2012	5		75	
		13/12/2012	6		75	
Average Basic Time		19/3/2013	7		100	
		19/3/2013	8		100	
		19/3/2013	9		100	
		28/3/2013	10		75	
		28/3/2013	11		75	
		28/3/2013	12		75	
Drain Painting		20/11/2012	1		110	
		20/11/2012	2		75	
Samples Required	11	13/12/2012	3		75	
		13/12/2012	4		100	
Samples Obtained	6	19/3/2013	5		110	
		19/3/2013	6		75	
Average Basic Time		19/3/2013	7		75	
		28/3/2013	8		100	
		28/3/2013	9		100	
		15/4/2013	10		75	

Table 47. Basic Times (Part 1).

TIME STUDY.

Times observed, Worker rating with British Standard Scale, Basic Times and Average Basic Time.

Core Prep		20/11/2012	1		100	
		20/11/2012	2		110	
Samples Required	2	13/12/2012	3		75	
		13/12/2012	4		100	
Samples Obtained	2	19/3/2013	5		100	
		19/3/2013	6		100	
Average Basic Time						
Robot setup		20/11/2012	1		110	
		20/11/2012	2		90	
Samples Required	1	13/12/2012	3		100	
		13/12/2012	4		110	
Samples Obtained	1	19/3/2013	5		75	
Average Basic Time						
Glue Core		20/11/2012	1		125	
		20/11/2012	2		100	
Samples Required	6	13/12/2012	3		75	
		13/12/2012	4		75	
Samples Obtained	6	19/3/2013	5		125	
		19/3/2013	6		100	
Average Basic Time		19/3/2013	7		75	
		28/3/2013	8		75	
		28/3/2013	9		125	
		15/4/2013	10		125	
Heating Cable		20/11/2012	1		75	
		20/11/2012	2		110	
Samples Required	1	13/12/2012	3		100	
		13/12/2012	4		75	
Samples Obtained	1	19/3/2013	5		110	
Average Basic Time						

Table 48. Basic Times (Part 2).

TIME STUDY.

Times observed, Worker rating with British Standard Scale, Basic Times and Average Basic Time.

PreGlue Pipe		20/11/2012	1		110	
		20/11/2012	2		100	
Samples Required	2	13/12/2012	3		100	
		13/12/2012	4		100	
Samples Obtained	2	19/3/2013	5		100	
		19/3/2013	6		75	
Average Basic Time						
Dress Fibre A		20/11/2012	1		75	
		20/11/2012	2		100	
Samples Required	2	13/12/2012	3		75	
		13/12/2012	4		75	
Samples Obtained	2	19/3/2013	5		75	
		19/3/2013	6		125	
Average Basic Time						
Core		20/11/2012	1		100	
		20/11/2012	2		100	
Samples Required	5	13/12/2012	3		100	
		13/12/2012	4		110	
Samples Obtained	5	19/3/2013	5		100	
		19/3/2013	6		100	
Average Basic Time		19/3/2013	7		110	
		28/3/2013	8		100	
		28/3/2013	9		75	
Dress Fibre B		20/11/2012	1		100	
		20/11/2012	2		75	
Samples Required	1	13/12/2012	3		125	
		13/12/2012	4		75	
Samples Obtained	1	19/3/2013	5		75	
Average Basic Time						

Table 49. Basic Times (Part 3).

TIME STUDY.

Times observed, Worker rating with British Standard Scale, Basic Times and Average Basic Time.

Mould Closing		20/11/2012	1		100	
		20/11/2012	2		125	
Samples Required	19	13/12/2012	3		75	
		13/12/2012	4		125	
Samples Obtained	6	19/3/2013	5		100	
		19/3/2013	6		125	
Average Basic Time		19/3/2013	7		75	
		28/3/2013	8		75	
		28/3/2013	9		75	
		15/4/2013	10		125	
Mixing		20/11/2012	1		100	
		20/11/2012	2		75	
Samples Required	1	13/12/2012	3		100	
		13/12/2012	4		100	
Samples Obtained	1	19/3/2013	5		110	
Average Basic Time						
Inf Setup		20/11/2012	1		75	
		20/11/2012	2		100	
Samples Required	1	13/12/2012	3		110	
		13/12/2012	4		100	
Samples Obtained	1	19/3/2013	5		125	
Average Basic Time						
Mould Out		20/11/2012	1		100	
		20/11/2012	2		75	
Samples Required	85	13/12/2012	3		100	
		13/12/2012	4		125	
Samples Obtained	6	19/3/2013	5		75	
		19/3/2013	6		75	
Average Basic Time		19/3/2013	7		75	
		28/3/2013	8		125	
		28/3/2013	9		75	
		15/4/2013	10		100	

Table 50. Basic Times (Part 4).

TIME STUDY.

Times observed, Worker rating with British Standard Scale, Basic Times and Average Basic Time.

Postcutting		20/11/2012	1		100	
		20/11/2012	2		100	
Samples Required	1	13/12/2012	3		75	
		13/12/2012	4		75	
Samples Obtained	1	19/3/2013	5		110	
Average Basic Time						
Control		20/11/2012	1		100	
		20/11/2012	2		75	
Samples Required	5	13/12/2012	3		100	
		13/12/2012	4		75	
Samples Obtained	5	19/3/2013	5		100	
		19/3/2013	6		75	
Average Basic Time		19/3/2013	7		100	
		28/3/2013	8		100	
		15/4/2013	9		125	

Table 51. Basic Times (Part 5).

INDIRECT COSTS ASSUMPTIONS.

Electric Energy Consumption

	Power(KW)	Usage Time (h)	Consumption/Floor (KWh)	Consumption/Month (KWh)	% Cons.	Cost
Lightning				283,95	0,20	
Crane	**7**	**0,46**	**3,22**	**161**	**0,14**	
V. Pump	4	0,666666667	2,666666667	133,3333333	0,14	
Robot	**10**	**0,5**	**5**	**250**	**0,30**	
Tools	3	0,813333333	2,44	122	0,21	
Forklift	**11**	**0,33**	**3,63**	**181,5**	**0,37**	
Computers	0,6	160		288	0,85	

Table 52. Electric Energy Consumption.