



**Linköpings universitet**  
**TEKNISKA HÖGSKOLAN**

# **Design and Development of a Spray Booth**

Daniel Axelsson

Machine Design

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## Preface

I was very pleased when I got the opportunity to make this trip to Santa Cruz, Bolivia and to combine an interesting project with a fascinating experience in a very exciting country. This thesis is based on a three months field study in Santa Cruz. I would like to thank SIDA (Swedish International Development Cooperation Agency) for their support with a MFS (Minor Field Study) scholarship.

I have a lot of people to thank for making this project possible to carry out in a good way. First I would like to thank my supervisor at Linköping University, Stig Algstrand for your support in the thesis.

I would also like to thank my supervisor Gabriela Pinaya at CADEFOR for your great support during my project. I really appreciate your enthusiasm and your interest in my work. Thanks also to Martín Franco for helping and supporting me. I am also grateful to all other people working at CADEFOR for taking good care of me and helping me during my time in Bolivia.

Many thanks to Tecno Carpintería San Pedro for giving me the opportunity to fulfil my dreams of working in Bolivia. A very special thank you I would like to give to Marcelo Lobo, Production Manager, for your commitment of designing this new finishing line.

Thanks also to Daloc Trädörrar in Töreboda for showing me around in your factory of wooden doors in May 2007.

Finally I would like to thank family Saucedo for letting me stay in there house and be a part of their family for a couple of months.

Daniel Axelsson  
January, Linköping



## **Abstract**

As a part of a more extensive project of developing a new finishing line at the Bolivian door manufacturer Tecno Carpinteria San Pedro this thesis presents the development process for a special designed spray booth. The thesis covers every phase from a product idea to a final concept design.

Working with finishing of furniture and other wooden products can effect the workers health in a negative way and damage the environment. The final result of the manufactured door is also depending on the how well the ventilation system in the working area is. Because of these reasons it is important to use safety equipment and a good ventilation system in the working area. As a part of this new finishing line San Pedro is in need of a special designed spray booth to control the spread of paint particles and other hazard substances that is a result of the finishing process.

Together with the consultant firm CADEFOR a spray booth is designed and a proposal design is presented in this thesis. The result is a design built up with a dry filter solution together with an extractor that creates a cross draft airflow towards the rear part of the spray booth. The result of the project together with some recommendations of increasing the capacity in the finishing line are also presented.



## Sammanfattning

Detta examensarbete ingår i ett större projekt i utvecklingen av en ny efterbehandlingslina och presenterar konstruktionen av en specialanpassad sprutbox vid den bolivianska dörrfabriken Tecno Carpintería San Pedro. Examensarbetet täcker hela utvecklingsprocessen från produktidé till slutligt koncept.

Efterbehandling av möbler och andra träprodukter kan påverka arbetarens hälsa på ett negativt sätt och skada miljön. Även det slutliga resultatet av den tillverkade dörren påverkas av hur bra ventilationssystemet i arbetsområdet är. Beroende av dessa anledningar är det viktigt att använda säkerhetsutrustning och bra ventilationssystem i arbetsområdet. Som en del av den nya efterbehandlingslinan är San Pedro i behov av en specialanpassad sprutbox för att kunna kontrollera spridningen av färgpartiklar och andra giftiga ämnen som uppkommer vid efterbehandlingen.

Tillsammans med konsultfirman CADEFOR har konstruktionen av en sprutbox tagits fram och en föreslagen konstruktion presenteras i detta examensarbete. Resultatet består av en konstruktion uppbyggd av ett torrfilter som samverkar med en utsugsfläkt och skapar ett horisontellt luftflöde mot den bakre delen av sprutboxen. Resultatet av projektet presenteras tillsammans med några rekommendationer för att öka kapaciteten i efterbehandlingslinan.



# Table of Contents

1. Introduction.....	1
1.1 Background.....	1
1.2 Aim.....	1
1.2 Method.....	1
1.3 Outline.....	1
2. Theory.....	3
2.1 Wood Finishing.....	3
2.2 Working With Varnish and Spray Paint.....	3
2.3 Safety in Workstation.....	4
2.4 The Development Process.....	5
2.5 The Concept Development Phase.....	6
2.5.1 Customer Needs.....	6
2.5.2 Target Specifications.....	6
2.5.3 Concept Generation.....	7
2.5.4 Concept Selection.....	7
2.5.5 Test Concept.....	7
2.5.6 Final Specifications.....	7
2.6 The Design Process.....	8
3. San Pedro Factory.....	9
3.1 The Finishing Line.....	9
3.2 The Cabin.....	10
3.3 The Four Processes in the Cabin.....	11
3.4 The Production Flow.....	13
3.5 The Door Cart.....	14
4. Methodology.....	15
4.1 Customer Needs.....	15
4.2 Problem Investigation.....	15
4.3 Function Analysis.....	15
4.4 Concept Generation.....	15
4.5 Concept Selection.....	16
4.6 Develop Concept to Final Design.....	16
5. Customer Needs.....	17
5.1 Design Aspects.....	17
5.1.1 Project Description.....	17
5.1.2 Important Design Aspects.....	17
5.2 Weighting of the Needs.....	18
6. Problem Investigation.....	21
6.1 Technical Solutions.....	21
6.2 Booth.....	21
6.3 Airflow.....	21
6.4 Filter.....	22
6.5 State of the Art.....	23
7. Concept Development.....	25
7.1 Function Analysis.....	25
7.2 Concept Generation.....	26
7.3 Concept Selection.....	31
8. Develop Chosen Concept to Final Design.....	33
8.1 Improving Concept.....	33

8.2 Component Identification.....	33
8.2.1 Framework.....	34
8.2.2 Bars.....	34
8.2.3 Sheet Metal.....	34
8.2.4 Paint.....	34
8.2.5 Filter.....	34
8.2.6 Fastening for Filter.....	35
8.2.7 Lights.....	35
8.2.8 Safety Glass.....	35
8.2.9 Extractor.....	35
8.2.10 Service Door.....	35
8.2.11 Hinge.....	35
8.2.12 Handle/Lock.....	35
8.3 Proposal Design.....	36
8.4 Cost Calculations.....	37
9. Conclusions.....	39
References.....	41
Appendix.....	43
Appendix A – Layout for the Finishing Line.....	43
Appendix B – Scale Models of the Design.....	44
Appendix C – 3-d Models of the Design.....	45
Appendix D – Main Dimensions.....	46
Appendix E – Including Components.....	47

## List of Figures

Figure 2.1. A product development process by Ulrich & Eppinger.....	5
Figure 2.2. Activities in the concept development phase by Ulrich and Eppinger.....	6
Figure 2.3. A simple model of the design process by Nigel Cross.....	8
Figure 3.1. The processes in the finishing line.....	10
Figure 3.2. The distress area.....	11
Figure 3.3. Left door before finishing, right door afterwards.....	12
Figure 3.4. The production flow through the working area.....	13
Figure 3.5. The door cart.....	14
Figure 4.1. The black box model.....	15
Figure 6.1. The principle of an electrostatic air cleaner.....	22
Figure 6.2. Dry Back Mini Booth by Berridge Painting Systems.....	23
Figure 6.3. A RDM Engineering booth with dry filter.....	23
Figure 6.4. Paper filter from RDM Engineering.....	24
Figure 6.5. Booth with water wash system to filter the air by Fuccelli Bruno.....	24
Figure 7.1. Black box model for a spray booth.....	25
Figure 7.2. Transparent box model for a spray booth.....	25
Figure 7.3. Concept 1.....	26
Figure 7.4. Concept 2.....	27
Figure 7.5. Concept 3.....	28
Figure 7.6. Concept 4.....	29
Figure 7.7. Concept 5.....	30
Figure 8.1. A 3-D model of the spray booth.....	34
Figure 8.2. Base module.....	36
Figure 8.3. Front module.....	36



## List of Tables

Table 5.1. Weighting of the needs.....	19
Table 7.1. Advantages and disadvantages in the two concepts.....	31
Table 7.2. Ratings for the concept scoring process.....	32
Table 7.3. Result from the concept scoring.....	32
Table 8.1. Cost calculations.....	37



# **1. Introduction**

*This chapter will give the reader an introduction for this thesis.*

## **1.1 Background**

Tecno Carpintería San Pedro is a company in Santa Cruz, Bolivia, that is manufacturing wooden doors and door frames. It is a family owned company with approximately 160 employees. San Pedro is cooperating with CADEFOR (*sp.* Centro Amazónico de Desarrollo Forestal, *eng.* Amazonic Center for Sustainable Forest Enterprise) which is a USAID (United States Agency for International Development) consultant firm located in Santa Cruz. San Pedro is now in need of a new process that handles the finishing of the wooden doors. Together with CADEFOR they are developing this new finishing line that will contain processes like distress, ink and varnish of the doors.

## **1.2 Aim**

It is of big interest for San Pedro to develop their production to stay competitive in an international perspective. The aim of this thesis work is a part of a more extensive project to develop a new department for finishing of wooden doors at San Pedro factory. Because this is a thesis work in Machine Design this is also going to be the principle aspect for this report. This thesis is therefore going to be delimited to consider first of all the design and development of an equipment to increase the employees safety and to control the air pollution in the spray painting process in the new finishing line. People working with furniture and wood finishing are exposed to health risks if not using good safety equipment. Therefore it is important that companies working with these kind of processes have a good knowledge and understanding about the risks and the methods to decrease the risks.

## **1.2 Method**

The methods that are going to be used for this thesis work are first of all based on the needs from the San Pedro factory. To investigate what the needs are, a meeting with the Production Managers is being held. In the beginning of the project a basic study of wood finishing processes and a market analysis was done. For the development and design process Karl T. Ulrich and Steven D. Eppingers *Product Design and Development* (2004) together with *Engineering and Design Methods* by Nigel Cross (2000) became the fundamental literatures. Computer Aided Design was used to present some simple models and drawings for the project. It is of interest to look into different kinds of solutions and investigate what capacity that is needed to eliminate polluting gases and paint particles from the working area.

## **1.3 Outline**

The structure of the report is divided into a couple of steps. First a presentation of why wood finishing is made and what it is like to work with spray paint. Then some theoretical methodologies that is very often used when working with design problems

## *1. Introduction*

like this are presented. This first part will give the reader a good basis to understand the rest of the report in a more satisfactory way. In chapter 3 the factory is introduced and chapter 5 presents the need from the factory and in the following chapter an investigation of the problem is done. A study of state of the art is also done to analyse what kind of products for similar processes that are on the market. In chapter 7 and 8 the concept development phase is presented together with the selection of a final concept and the detailed design of the chosen concept is then worked out. The conclusions made from this thesis are presented in the end of the report. Most of the chapters start with a short introduction in *italic* that presents the contents for the chapter.

## **2. Theory**

*This chapter will present the background and theoretical knowledge that is needed to understand the thesis. First there is an introduction to wood finishing followed by some information about what it is like to work with varnish and spray paint. Some theories about the safety at the workstation will also be introduced. At the end of this chapter some theories about design and product development are presented.*

### **2.1 Wood Finishing**

According to Noel Johnson Leach wood finishing has been used to protect wooden products and furnitures for thousands of years. Though you can find a huge change of techniques and finishing products that has been used during the change of time. The first documented wood finisher was Noah. The working instructions he received from God can be found in Genesis Ch 6, v 14 “Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch”. Since this time a lot of new techniques and finishing products has shown up on the market. New processes, new machines and new materials always makes the market for this kind of products growing.

The aim of wood finishing is to protect the surface from wet and organism that can destroy the wooden products resulting in worse mechanical properties and negative effects on the appearance. The most common type of finishing for wooden products used in an environment with low risk for fungus disease is a surface coating with chemicals. (Nationalencyklopedin, 2007-10-10)

The finishing process starts with surface preparation treatment by sanding, scarping and planing. Imperfections like nail holes and pores are filled up with wood putty or wood filler. Sometimes changes in colour and tone has to be done and it can be made by staining and bleaching. (Wikipedia, 2007-10-10)

The most common used products when working with furniture and wood finishing is different oil finishes, varnish and shellac. According to Andy Charron oil can be applied without worrying about dust, lint and other particles making the surface unsatisfied. As a result of this oil can be applied in a place where ideal conditions are hard to reach. He continuous that although you should serve for good ventilation when working with all kinds of finishing.

### **2.2 Working With Varnish and Spray Paint**

According to The National Institute for Working Life in Sweden (Arbetslivsinstitutet, ALI) it is getting more common to use spray paint when working with furniture. When people spray paint and breathe the polluted air the chemical particles added for counteract bacteria and mould reaches the bronchus and lungs. People working with spray paint are exposed to risks that can result in irritation and allergic reactions in sensitive mucous membrane. Therefore they have made an investigation with focus on the working area and the workers health. According to ALI the concentration of spray paint particles in the air is high several minutes after the painting is completed. The

## 2. Theory

level of concentration and how long time it takes to air the particles depends on the size of the room and how good the ventilation is. (Arbetslivsinstitutet, 2007-10-12)

According to the article *Chemical Hazards of Woodworking* by Theodore J. Fink, M.D. in *Finishes and Finishing Techniques*, toxic chemicals are to be found in many different products used for wood finishing, such as adhesives, paint and varnish. These products and a lot of other similar products are often used when working with furniture and other wooden products to protect the surface. Therefore companies have to be very careful and know about the negative effects that these kind of products can have on the human body if the right safety equipment is not used when working with finishing. Fink continues that all chemicals can harm the body and produce both acute and chronic effects. If the exposure is low enough the effects are reversible but if a person is exposed to the chemical substances during a longer period without using the right safety equipment the acute exposures can have permanent damages and even death as an effect. Chronic effects usually take longer time to appear and does not show up until weeks, months or even years after repeated exposures.

It is very important to serve for good ventilation when applying varnish for other reasons as well. Poor ventilation will increase the risks for a hazy or flat finish. (Yachtpaint, 2007-10-12)

### **2.3 Safety in Workstation**

According to The Swedish Work Environment Authority (Arbetsmiljöverket) the working area and other spaces for the employees must be organized and have ventilation systems for air circulation and collecting the air pollution in a way that the air quality in the area is satisfied. The air circulation must be organized so the spread of air pollution is delimited. They also says in the same constitution that the best way is to design the ventilation system so it is possible to collect the polluted air close to the source. If the process handles very poisonous and dangerous substances the best and sometimes the only way is to totally isolate the working area. More common is the use of partly isolated processes with some kind of booth. The best is though to totally isolate the process but if so is not possible use of local extractor or booths are good options. (AFS 2000:42)

In the article *Clearing the Air* by David W. Carnell in *Finishes and Finishing Techniques* he says that airborne wood dust and toxic finishing vapours are dangerous to breath. The result of this can be damages in the employees health that may take several years to show. Another aspect that has to be taken into consideration when working with finishing is the risk of explosion.

## 2.4 The Development Process

There are almost as many development processes as there are designers. Even if there are some basic models the designer mostly apply them in their own way. Ulrich and Eppinger describes the developing process as following:

*“A product development process is a sequence of steps or activities which an enterprise employs to conceive, design and commercialize a product. Many of these steps and activities are intellectual and organizational rather than physical.”*

Ulrich and Eppinger have also described the product development process in some basic steps and the model is shown in figure 2.1.

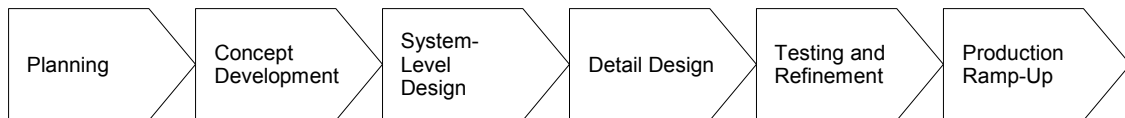


Figure 2.1. A product development process by Ulrich & Eppinger.

- First is the *planning* phase where market segments, business goal and constraints are defined. When a new project is going to start and a new product will be developed it is very important to get a general overview and decide where to start, what has to be done and how much time it will take. The output from this phase is a mission statement.
- One of the most important part of the product development process for a designer is the *concept development* phase. The customer needs are identified, several alternative concepts are generated and further development for one or more of the concepts is done in this phase. Ulrich and Eppinger has set up the most important activities in the concept development phase. These are shown in figure 2.2 and a more specific description of all the activities are presented later in this chapter.
- The *system-level design* is where the architecture and functional specifications of the product are defined. The output of this phase is a geometric layout and a preliminary process flow diagram according to Ulrich and Eppinger.
- *Detail design* is what follows the system-level phase. Type of material, final geometry and a detailed specification of all parts are defined in this phase.
- The *testing and refinement* phase is where tests are made on performance, life and reality. If some changes in the design has to be done this is where those are made.
- In the final phase, *production ramp-up*, the product is going to an early production and the entire production system is started to get operated.

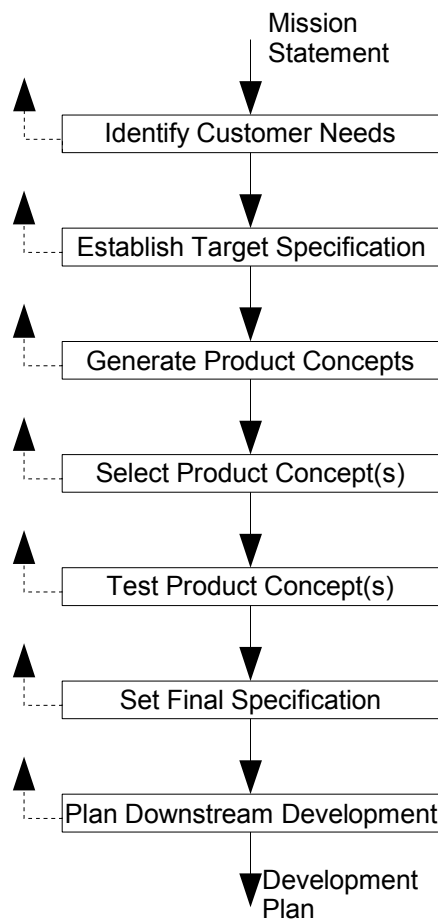


Figure 2.2. Activities in the concept development phase by Ulrich and Eppinger.

## 2.5 The Concept Development Phase

The concept development phase can be divided into a number of activities. Here follows a short description of these activities.

### 2.5.1 Customer Needs

The goal of identifying customer needs is to get a fact base that lives up to the product specifications. It is of great importance to ensure that no critical need is missed or forgotten. Therefore it is very important to build up a good connection between the customers and the designers. It could also be a good idea to make a list with the needs and to weight each one of them in a pairwise comparison.

### 2.5.2 Target Specifications

To get more specific information about what the product specifications, sometimes called product or engineering characteristics, are going to be like one way is to convert the customer needs into more specified metrics. This is sometimes a very important part of the development process and a very useful method to convert the customer needs into

product characteristics is by using the *Quality Function Deployment* method (QFD). One way to set up the QFD-matrix is to first set up a simple matrix that illustrates the relationship between the customer needs and the more specified metrics. This is what Ulrich and Eppinger describe as a needs-metrics matrix.

### **2.5.3 Concept Generation**

The concept generation is an extensive part of the concept development phase and can therefore be very time consuming. This is the activity where the designer has to think with a wide perspective and try to cover a lot of different technical solutions. According to Nigel Cross one way to do this is to first set up a morphological matrix to clarify what kind of means that are possible for each function. The aim of this method is to find solutions that have not earlier been identified.

It is important to make a function analysis to identify the most important and critical functions for the product. This can be made by setting up a black box model followed by a transparent box.

To illustrate possible product solutions one stage of the concept generation phase is to make up some simple sketches and drawings. This will create a good basis for further discussion and concept improvement.

### **2.5.4 Concept Selection**

In the second part of the concept phase it is necessary to select one or a couple of the solutions to develop even more. A very common two stage method for selecting concepts is *concept screening* and *concept scoring*. In the first stage, concept screening, the concepts are estimated relative to a chosen reference solution according to Micael Derelöv. After eliminating a couple of ideas using concept screening the designers can move on to the next stage, concept scoring. In this stage the concepts are not compared in relation to each other but an individual evaluation and a more detailed analysis is performed.

### **2.5.5 Test Concept**

The selected concept or concepts are then tested to see if the customer needs are met. If the response is not as good as expected, some earlier steps in the development process may be repeated or the project may also be terminated.

### **2.5.6 Final Specifications**

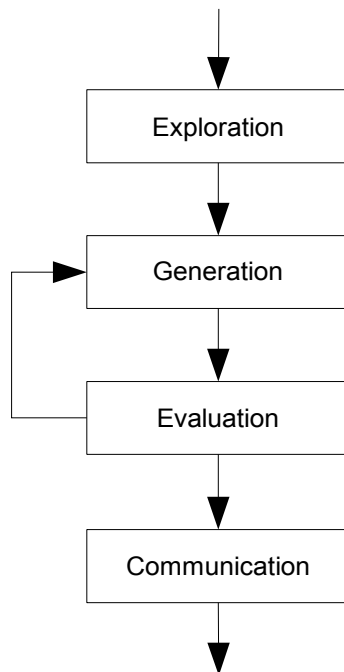
After the testing activity some of the previously set target specifications may need a correction and some changes in the values. A more precise list of specifications where a greater consideration is taken in the relationship between two specifications is set up. According to Ulrich and Eppinger it is very common that trade-offs occur between the technical performance metrics and costs.

## 2.6 The Design Process

The design process is usually a more specific description than the development process and does not include project planning and production ramp-up according to Ulrich and Eppinger. The design process is more focused on concept development, design and testing of the product. Industrial Designers Society of America (IDSA) defines industrial design as following:

*“Industrial Design (ID) is the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer.”*

There are lots of other ways to describe the design process. Nigel Cross shows a simple four-step model in *Engineering Design Methods* that is illustrated in figure 2.3.



*Figure 2.3. A simple model of the design process by Nigel Cross.*

### **3. San Pedro Factory**

*This chapter will give the reader an introduction to the finishing line that is going to be built up in the factory. The processes that will take place in the finishing line will also be presented.*

#### **3.1 The Finishing Line**

As this thesis is a part of a larger project in San Pedro factory a short introduction will be presented for this whole project. This is to get an overview for the whole finishing line and to get a better understanding for the following parts of the report.

San Pedro has together with another company worked out a simple layout for the working area. This layout is shown in appendix A. The finishing line is going to be built up in a building that is not in use right now and therefore it is not going to be any larger disturbance in the present production during the build up process.

The finishing line can be divided into three areas. First a small area (5-10 m<sup>2</sup>) for a *pre-process* where great variations of tone are being decreased. The second area (10-20 m<sup>2</sup>) is the *cabin* where the main processes are going to take place. The third and largest area (50-100 m<sup>2</sup>) is the *drier* where the doors are being dried in between and after the processes.

All the processes in the finishing line are shown in figure 3.1 and the estimated times for each process are based on calculations done at San Pedro.

### 3. San Pedro Factory

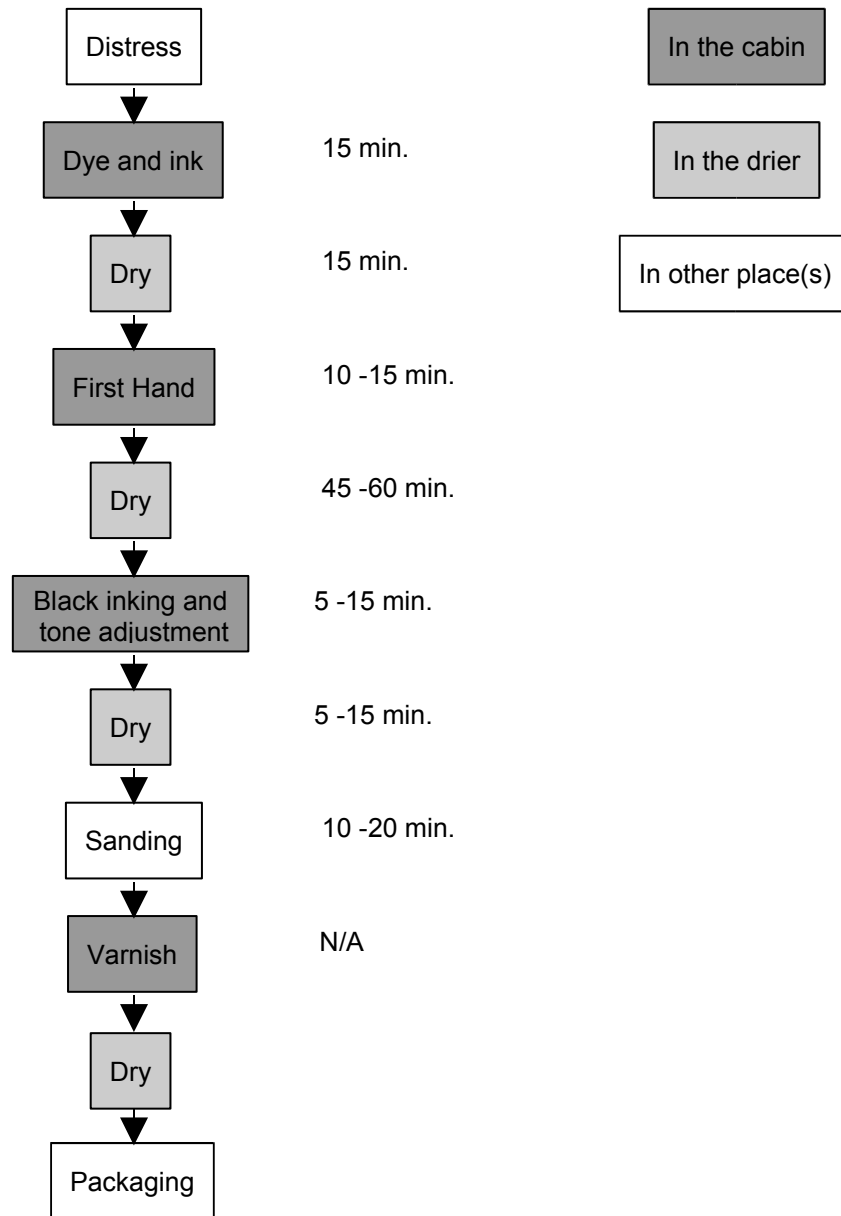


Figure 3.1. The processes in the finishing line.

### 3.2 The Cabin

The cabin is where the main processes will take place. In total there are going to be four processes in this area and in between the doors are going to be transported into the drier. Before the door enter the cabin for the first time it will go through a distress operation. This is made to get an old and used look on the door. Splintering, hitting with chains, brushing and sanding are the main activities at this part of the line. Figure 3.2 shows a preliminary distress area and the left door in figure 3.3 shows what the door looks like before it enter the processes in the cabin.



*Figure 3.2. The distress area.*

### **3.3 The Four Processes in the Cabin**

The first time the door enter the cabin it will get a basic layer of *dye or ink*. This process is going to take approximately 15 minutes and afterwards the door will be transported into the drier for the same amount of time.

The second process will take about 10-15 minutes. It is a *first hand* activity where the door is polished to close pores.

The third time the door enter the cabin it goes through another inking process. This time *black inking and tone adjustment* is being done for about 5-15 minutes.

The *varnish* is the last process to take place in the cabin. This is where the door gets the final look before it goes into the drier for the last time. The result after the finishing process is shown to the right in figure 3.3.

3. San Pedro Factory

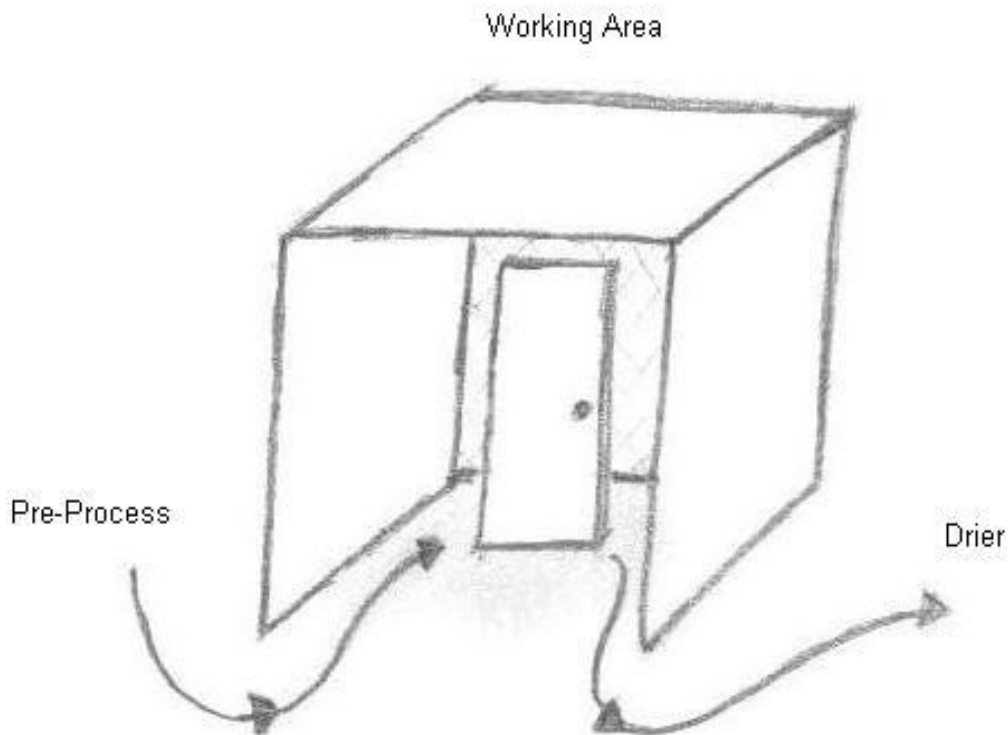


*Figure 3.3. Left door before finishing, right door afterwards.*

### **3.4 The Production Flow**

Two main principles of the production flow through the finishing line has been taken into consideration. An automatic conveyor system that will lower the need of man power. Though this solution will be more expensive to build up and use than the other solution which consists of a manual transportation system with carters.

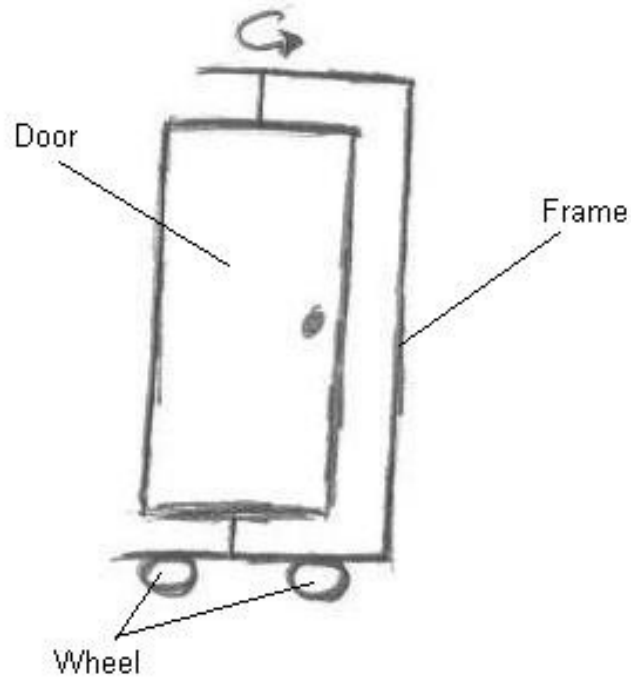
The wishes from San Pedro is in this moment to choose the second option which is easier to build up but will need more employees. The principles for the production flow through the working area is shown in figure 3.4.



*Figure 3.4. The production flow through the working area.*

### 3.5 The Door Cart

San Pedro has designed a prototype of a door cart that is going to be used to transport the doors through the finishing line. During the spray painting processes the door will be set in an upright position in the cart. An easy sketch of the design is shown in figure 3.5 and consists of a frame of wood that will hold the door in the top and in the bottom.



*Figure 3.5. The door cart.*

This design make it possible to rotate the door so all sides can be painted without having to move the carter. Wheels are placed under the frame so the door easily can be moved without having to lift it.

## 4. Methodology

*This chapter will describe the methodology used in this project. It includes all the phases from product idea to final design.*

### 4.1 Customer Needs

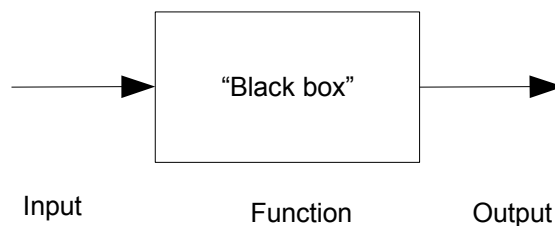
What is it actually that San Pedro need in their new finishing line? This part of the project is to take a first step to discuss what kind of product that is needed in the factory. It is also of great importance to clarify the limitations for the thesis. To get a better understanding for which one of the needs that are of more importance then the others, a weighting of the needs is done in this part of the thesis.

### 4.2 Problem Investigation

When a project like this is going to start an important thing to do is to investigate what has been done in the past. Someone has for sure designed a finishing line like this before. Look up what kind of similar products that are on the market right now. This is what is called a study of *state of the art*.

### 4.3 Function Analysis

It is of great importance to make an analysis for what functions there are for the product. Therefore a *black box* is established and out of this the principle function is identified. The black box model is shown in figure 4.1 and consists of an input, an output and the principle function in between.



*Figure 4.1. The black box model*

From the black box model the main function is divided into more specific sub-functions and different means to solve each of the sub-functions are then worked out.

### 4.4 Concept Generation

The main activity in this part of the development process is to increase the number of ideas. The aim is to generate ideas with different variations and technical solutions. To illustrate the ideas one way is to make up some sketches and easy drawings. These can also be a good basis for further discussions and a easier understanding for the concepts.

### **4.5 Concept Selection**

To select one or maybe a couple of concepts to develop into more specific designs with detailed specifications a discussion is being held with representatives from both San Pedro and CADEFOR. A scoring process is also going to be made to compare the concepts in a more theoretical way.

### **4.6 Develop Concept to Final Design**

To develop a concept that can be produced to a final product a more detailed specification and description is needed. Therefore one chosen concept is developed and all components that the product is going to consist of are designed more detailed. To make each component possible to manufacture dimensions are needed for all including features. All of the components also need to be allotted a material. It can be a good idea to use the same kind of component and material as much as possible to lower the costs and to minimize the complexity in the design.

## **5. Customer Needs**

*This chapter will describe the needs from San Pedro and will also present some important design aspects and a weighting of them.*

### **5.1 Design Aspects**

Working with ink and varnish can have negative effects on the workers health. To decrease the risks of become seriously ill or injured as a consequence of the poisonous gases the working area has to be designed in a correct way and the employees have to use safety equipment. This thesis is going to consider the design of a spray booth for the cabin area and the problem with pollution and risks for the employees health when working inside and around the cabin.

After a meeting with the Production Managers at San Pedro some special needs for the project were identified and put together. Based on these a list of customer needs was set up and the result is presented below. First there is a short project description followed by some other aspects that also has to be taken into consideration during the design process.

#### **5.1.1 Project Description**

Design the cabin area and an equipment to eliminate poisonous gases and polluting particles from the working area.

#### **5.1.2 Important Design Aspects**

There are also some other aspects that has to be taken into consideration when working with this design problem. The most important aspects are presented here and they are going to build up the base for the weighting step. The aspects are followed by a capital letter W or D which shows if the need is a wish (W) or a demand (D) for the final design. To understand which one of the aspects and needs that are of greater importance for the final design a weighting of the needs is presented in the next part of this chapter.

### 5. Customer Needs

SAFE FOR THE USER	D
LOW BUILD UP COSTS	D
LOW OPERATION COSTS	W
EASY TO BUILD UP	W
EASY TO USE	D
FIT INTO AN AREA OF 10-20 M <sup>2</sup>	D
SIMPLE DESIGN	W
ROBUST DESIGN	W
CAPACITY OF 1000 DOORS PER MONTH	W

### 5.2 Weighting of the Needs

To get a better understanding of which of the needs that are more important than the others a weighting of the needs is done. All the needs are set up in a matrix both in a vertical column and a horizontal row and they are then compared to each other. The matrix is shown in table 5.1. The method used consists of a pairwise comparison and every single need is compared to all other needs. In each square except from where the need is compared to itself a number from zero to two is presented. Zero means that the need in the left column is less important than the need in the upper row. Number one means that the two compared needs are of the same importance. And finally if the number two is put into the square the need in the left column is of greater importance than the need in the upper row.

The weighting resulted in a normalized sum for each of the need that is presented in the right column in table 5.1. It shows that the most important aspect to take into consideration is that the design is safe for the user. The weighting also shows that it is not of very big importance, compared to the other needs, that the design is easy to build up.

This weighting of the needs is going to be a useful tool in a later part of the development process when it is time to select a special concept to develop to a final design.

Table 5.1. Weighting of the needs.

	Safe for the user	Cheap to build up	Low operation costs	Easy to build up	Easy to use	Fit into a smaller area	Simple design	Robust design	High capacity	Sum	Normalized sum
Safe for the user	-	1	2	2	2	2	1	2	2	14	0.19
Cheap to build up	1	-	1	2	1	2	1	2	1	11	0.15
Low operation costs	0	1	-	1	1	1	2	1	1	8	0.11
Easy to build up	0	0	1	-	0	1	1	1	0	4	0.06
Easy to use	0	1	1	2	-	2	1	1	1	9	0.13
Fit into a smaller area	0	0	1	1	0	-	1	1	1	5	0.07
Simple design	1	1	0	1	1	1	-	1	1	7	0.10
Robust design	0	0	1	1	1	1	1	-	1	6	0.08
High capacity	0	1	1	2	1	1	1	1	-	8	0.11
									Sum	72	1.00



## **6. Problem Investigation**

*This chapter will investigate the problem and analyse what kind of technical solutions and ideas that are on the market.*

### **6.1 Technical Solutions**

There are many technical solutions for eliminating poisonous particles from the air. Warringah Council in Australia has in a report about spray painting presented the most common ways of this process. They divided this into three main groups, the booth, the airflow and the filter.

### **6.2 Booth**

According to Warringah Council the most common used painting booths are:

- **Open faced booth.** Very simple kind of booth with two or three walls and a roof. The booth has an open front and an extractor together with a filtration system is placed in the rear.
- **Enclosed booth.** This kind of booth is totally sealed and enclosed. The airflow in the room where the painting take place is generally down draft, cross draft or a combination of these.
- **Tunnel or production booth.** Booth with two walls and a roof with openings in both ends. Down draft or cross draft are the most common used methods for airflow in this kind of booth.

### **6.3 Airflow**

An important thing in a spray booth is to make the particles moving towards the filter. Warringah Council also describes some usually used types of airflow through the booth:

- **Cross draft.** The airflow moves parallel to the floor and towards the rear of the booth and the filter system.
- **Down draft.** In this system the air is moving vertically from the ceiling to a filter in the floor. This type of solution is common when working with larger products such as vehicles and allows more than one worker at the same time from different sides.
- **Semi-down draft.** For this kind of system there are two different designs. One is where the air moves from the ceiling in the front of the booth towards the bottom rear part. The other type is when the airflow goes from the centre of the ceiling towards one or two filtered extractors at the bottom of the side walls.

To choose an airflow solution it is important to take into consideration what kind of product that is going to be worked up in the booth. If it is a large product that has to be operated from more than one side it may be better to use a down draft system or a semi-down draft system. If the product, however, can be treated from only one direction a cross draft is more often used.

## 6. Problem Investigation

According to the Swedish manufacturer of spray painting equipment, Greiff Industrimiljö AB, the airflow has two main reasons. First to create a good working environment for the painter and second to extract the paint particles from the working area to avoid that dry particles attach to the painted surface which can cause a granulated surface. The airflow passing the painter needs to be approximately 0.4- 0.5 m/s in a spray booth with cross draft airflow.

The Swedish Work Environment Authority (Arbetmiljöverket) says that the airflow in a spray booth with down draft airflow over the whole cross section has to be at least 0.2 m/s to receive an acceptable working environment (AFS 1986:29).

### 6.4 Filter

According to Warringah Council the choose of filter depends on the spray rate. They say there are mainly two different filter solutions that are used in different ways and combinations. One of the easiest way is to use a dry filter made by paper or cardboard. Another way of separate the paint particles from the air is with a wet filter. It works so that jets of water scrubs the air and the maintaining paint can be collected in a container. If the spray rate is above four litres per hour a water filter should be used, and if the rate is below four litres per hour a dry filter is the best solution.

Camfil Farr is a Swedish manufacturer of filters and clean air solutions. According to them there are two mainly used dry filter principles. First a mechanical solution where the particles are captured when they get into contact with a fibre material. The filter is often made of glass fibres, PTFE or synthetic fibres.

The second way of filter the air stream with a dry filter is by an electrostatic air cleaner. For this kind of solution an external power source is required. Parallel plates are often used to which the particles are collected after that they first get a charge from the power source. In an electrostatic air cleaner it is important that the plates are clean for the best efficiency. The principles for this electrostatic air cleaner is shown in figure 6.1. (Camfil Farr, 2007-11-08)

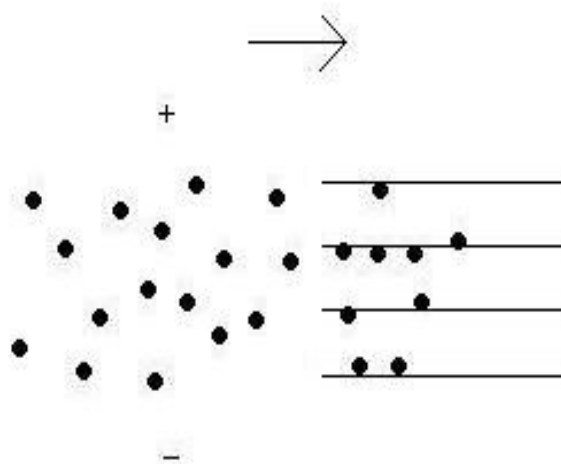


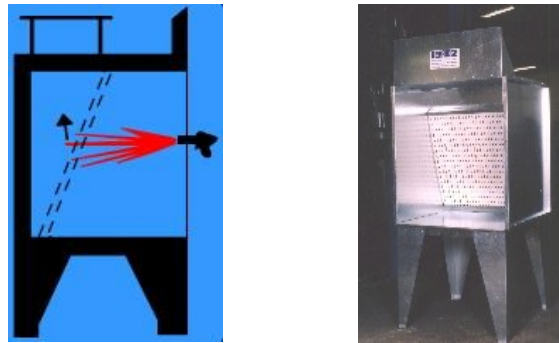
Figure 6.1. The principle of an electrostatic air cleaner.

## **6.5 State of the Art**

To get knowledge of what similar products that are on the market right now a study of state of the art is done. First of all the study consists of research on internet to look at companies that produces equipment for spray painting. During the search some companies where more interesting then others. The chosen ones that are presented in this report are from the following manufacturers: Berridge Painting Systems, RDM Engineering and Fuccelli Bruno. To get a better understanding for what is important for a spray booth, the Swedish company Daloc Trädörrar AB is contacted. They manufactures wooden doors and has got a couple of spray booths for wood finishing.

### **Berridge Painting Systems**

Berridge Painting Systems is a company operating in UK that manufactures different kinds of spray booth systems. One of the solutions is the Dry Back Mini Booth, mostly used for spray painting of smaller products at slow application rates. It is an open front design with the airflow backwards and upwards through the extract filter and output fan. The booth is produced with modular panels from galvanised steel for an easy assembly. The Dry Back Mini Booth is shown in figure 6.2.



*Figure 6.2. Dry Back Mini Booth by Berridge Painting Systems.*

### **RDM Engineering**

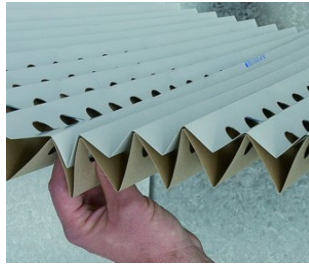
Another UK company that produces spray booths is RDM Engineering. They provide solutions with both dry filter booth as well as water wash booths. One of their products is a dry filter booth with extended height for taller applications. This type of booth is shown in figure 6.3. It is possible to fit the axial extractor fan either on top or at the rear.



*Figure 6.3. A RDM Engineering booth with dry filter.*

## 6. Problem Investigation

RDM Engineering also provides different kind on filter solutions. In figure 6.4 the Standard Andrea Paper Filter is shown. This is an economical filter that forces the air to go a tortuous route and the painting particles get caught in the paper.



*Figure 6.4. Paper filter from RDM Engineering.*

### **Fuccelli Bruno**

Fuccelli Bruno is an Italian company that mainly produces spray booth solutions for hand painted ceramics and clay. One of their solutions is an open front water wash booth with running water in the back panel and an upper aspirator. The water is circulated with a HP 0,16 non-stop pump. The water curtain together with the HP 5,5 extractor and a porous sponge filter cleans the air in a good way. The system also has a sliding tank to recover glazy. This specific spray booth is shown in figure 6.5.



*Figure 6.5. Booth with water wash system to filter the air by Fuccelli Bruno.*

### **Daloc Trädörrar AB**

Daloc Trädörrar AB is a Swedish manufacturer of wooden doors. They are now in a change of production and starting to make their whole production into a more automatic line. Until today they have had three individual spray booths all with dry filter systems. The new automatic system will be a lot different but still the filtration system is going to consist of dry filter solutions.

## 7. Concept Development

This chapter will present the stages where the customer needs are developed into several concepts. The number of concepts are then trimmed and one more specific concept is finally chosen.

### 7.1 Function Analysis

The aim with function analysis is to find different technical solutions for each of the functions and later combine them into different concepts.

To identify what function that is the most important in the design a *black box* model is set up. The first thing to do is to identify what the condition is before the activity and also what the expected result is going to be like. After this is made the main function is set inside the box. The black box model for a spray booth is shown in figure 7.1.

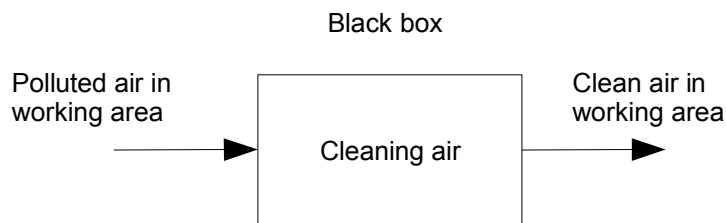


Figure 7.1. Black box model for a spray booth.

There are three main functions for a spray booth. The first thing is to make the maintaining spray particles move towards a filtration system. The second function is to catch all the particles and finally to keep them collected so they do not have negative effect on the workers health or pollute the air. These three sub functions are illustrated in the transparent box in figure 7.2.

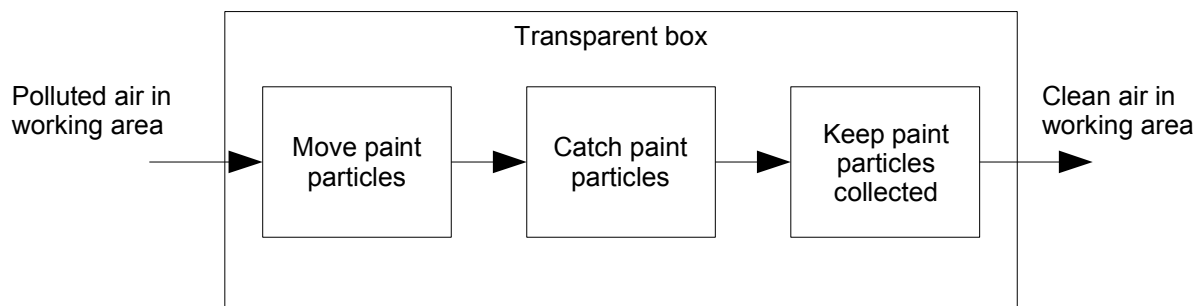


Figure 7.2. Transparent box model for a spray booth.

## 7.2 Concept Generation

With the function analysis as a base the process of generating concepts is taking place. Five concepts are worked out and these are presented here. First are two concepts with dry filter solutions and the following three have wet filters. All concepts are illustrated in simple sketches from a side view.

### Concept 1 – Dry filter booth with cross draft airflow

The booth concept is a simple design built up with three or four walls and a roof. The door that is going to be painted is placed in the front part between the worker and the filter wall. The filter is a dry filter that can be manufactured from for example, paper, cardboard or some other material that have good properties of catching and retaining paint particles. An extractor fan is placed in the rear or possibly in the rear part of the ceiling to create the cross draft airflow. Concept 1 is illustrated in figure 7.3.

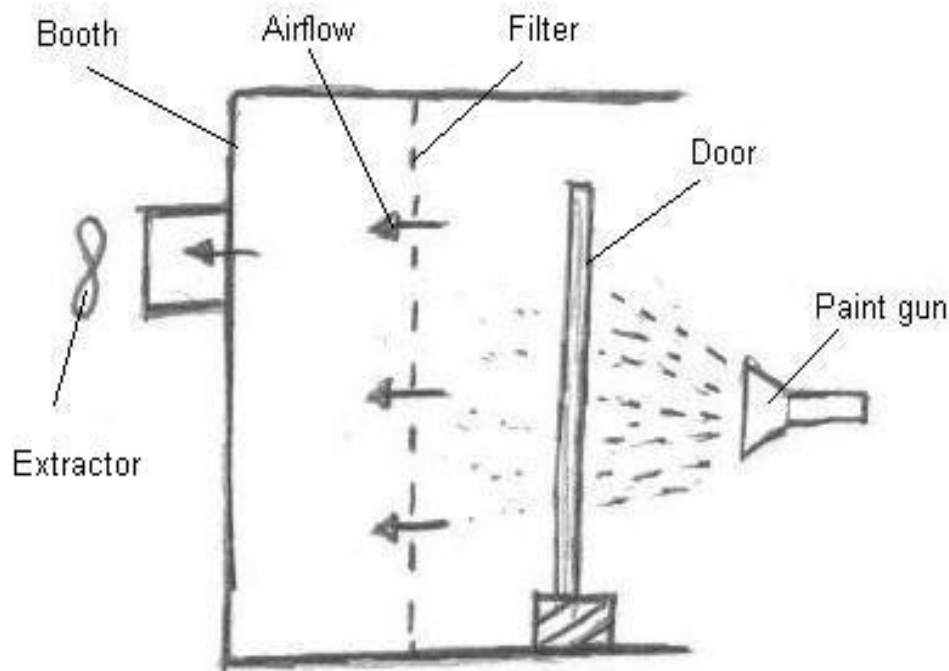
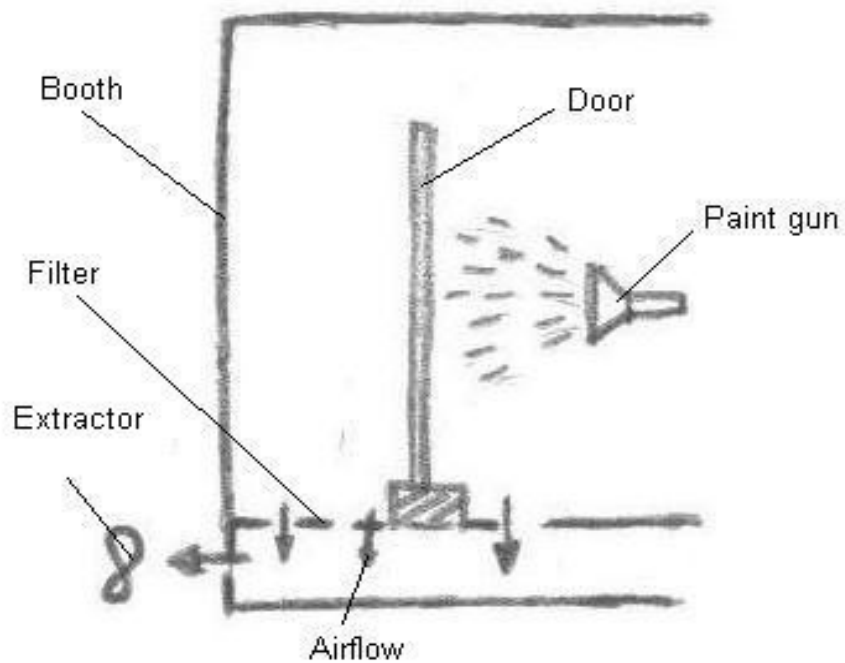


Figure 7.3. Concept 1.

**Concept 2 – Dry filter booth with down draft airflow**

This booth concept is as the previously described concept built up with three or four walls and a roof. Though the airflow in this concept is downwards from the ceiling to the floor. The door can therefore be placed in the middle of the booth. The extractor fan is placed in the floor behind the booth and a dry filter solution is integrated with the floor below the working area. This concept gives the worker the option to paint the door from different sides without turning the object. Concept 2 is illustrated in figure 7.4.

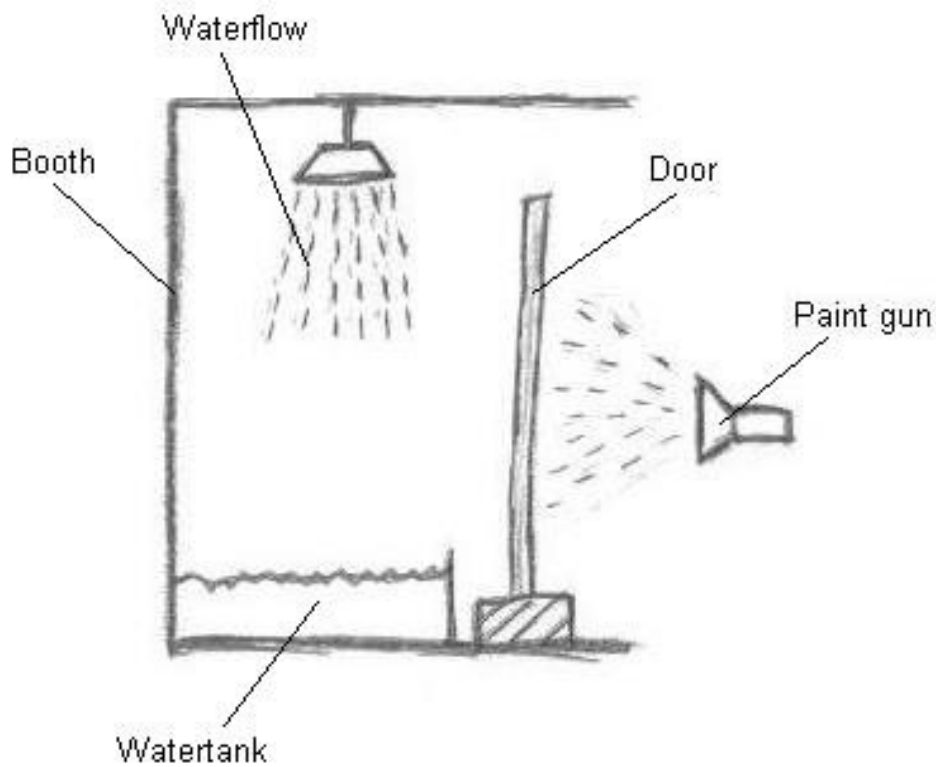


*Figure 7.4. Concept 2.*

7. Concept Development

**Concept 3 – Water wash booth with pump (Shower)**

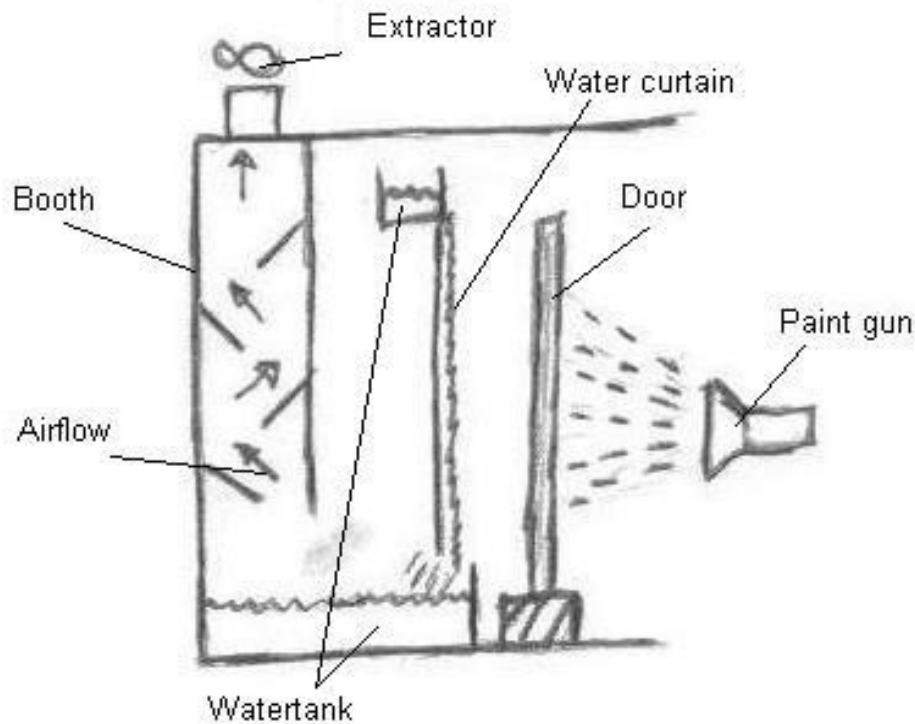
An open booth solution with three or four walls and a roof. The door that is going to be painted is placed in the front of the booth between the worker and the filter. In this case the filter consists of a shower from the ceiling. The waterflow catches the paint particles and a tank on the floor retains them. A pump is used to return the water from the tank up to the ceiling for reusing the water in the enclosed system. A chemical substance will be added to the watertank to separate the paint particles from the water. Concept 3 is illustrated in figure 7.5.



*Figure 7.5. Concept 3.*

**Concept 4 – Water curtain booth with pump**

This kind of water wash booth is as the other concepts built up with three or four walls and a roof. Behind the door that will be painted there is a wall. On this wall a water curtain is running from an upper tank down close to the ceiling towards a lower tank on the floor. Most of the paint particles are caught in the curtain and the rest will be caught up in a scrubbing jet at the lower part of the curtain wall. An extractor is placed in the rear to force the paint to go through the water filter. Barriers are placed in the extract channel to avoid water in the extractor fan. The water is recirculated in the system by a pump. Concept 4 is illustrated in figure 7.6.



*Figure 7.6. Concept 4.*

7. Concept Development

**Concept 5 – Water wash booth without pump**

This booth concept is built up with three or four walls and a roof. The wooden door is placed in a position in between the worker and the extract channel. To clean the air from the paint particles a water filter is used. An airflow is created through the extract channel with an extractor fan in the rear top of the booth. Below the channel a watertank is located. Between the tank and the extract channels front wall there is a small opening. The air is scrubbed when water turbulence is created in the small opening as a result of high speed airflow through the channel. The paint particles are separated from the air, mixed with the the water and collected in the tank. Concept 5 is illustrated in figure 7.7.

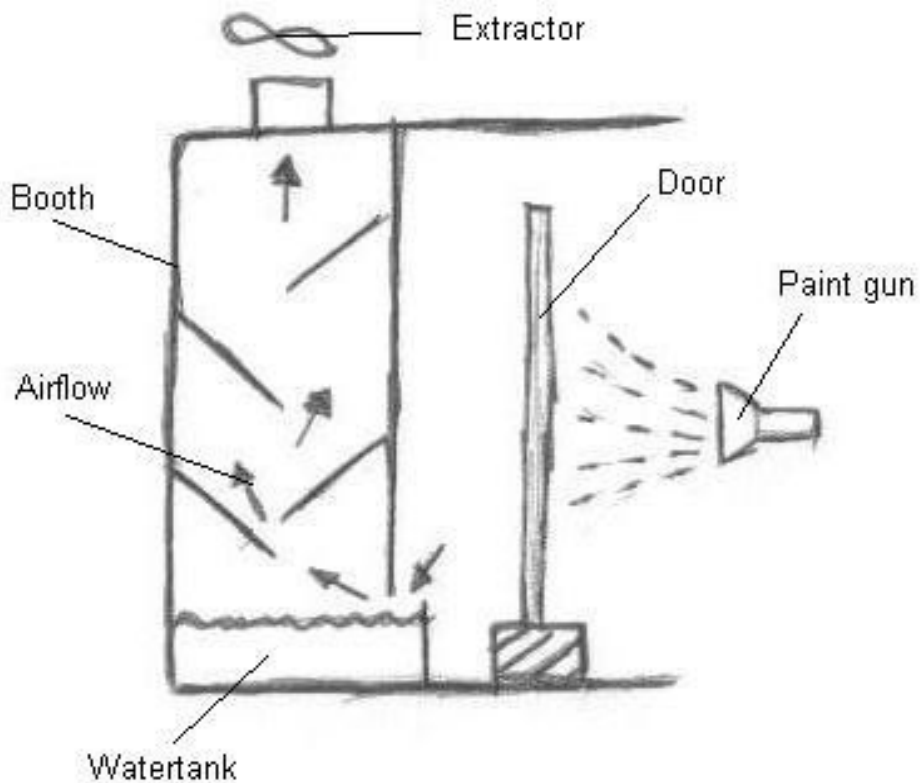


Figure 7.7. Concept 5.

### 7.3 Concept Selection

The five concepts from the generation phase were presented for San Pedro to discuss whether some of the concepts were more interesting than the others. After a review of the concepts two of them were selected for further development before a final selection. This first selection was made together with representatives from San Pedro and CADEFOR and resulted in the two chosen concepts, number 1 and number 4. The first one with a vertical dry filter in the rear behind the paint object. The second one consists of a wet filter with a water curtain that catches the paint particles.

To select only one of these maintaining concepts to develop to a final design a second selection has to be done. This selection will be made based on the advantages, disadvantages and a comparison of the two concepts. The method that is going to be used is based on the concept scoring that Ulrich and Eppinger describes. To get an overview of the two concepts and the advantages and disadvantages they are here presented with plus and minus in table 7.1.

Table 7.1. Advantages and disadvantages in the two concepts.

	Concept 1 (Dry Filter)	Concept 4 (Wet Filter)
	Simple design	No filter change needed
+	Low number of components	Allows high rate of paint
	Easy filter change	Less airflow needed
	Cost of filter change	Complex design
-	Filter change often	High number of components
	High airflow required	High design cost

The choice between the two maintaining concepts will play a decisive role for the further development and the design of the spray booth. It is therefore very important to make a good decision in this part of the design process. Based on table 7.1 with the advantages and disadvantages it is possible to make a decision based on the personal feeling. But to get a better understanding for which concept that fits the needs best a concept scoring method is used. Here the two concepts are rated based on the customer needs that was set up and weighted in an earlier phase and shown in table 5.1. The weighting is multiplied with the rating and the result will be a weighted score. The scale for the rating is based on the method presented by Ulrich and Eppinger and is divided into levels from 1 to 5 as shown in table 7.2. The concept with the highest score is the solution that satisfies the customer needs best and is therefore ranked as number one. In this case the best choice is concept 1 with the dry filter solution. The stage of the concept scoring process is presented in table 7.3.

7. Concept Development

Table 7.2. Ratings for the concept scoring process

Performance	Rating
Very weak	1
Weak	2
Adequate	3
Good	4
Very good	5

Table 7.3. Result from the concept scoring.

	Weight	Concept 1 (Dry Filter)		Concept 4 (Wet Filter)	
		Rating	Weighted score	Rating	Weighted score
Safe for the user	0.19	4	0.76	4	0.76
Cheap to build up	0.15	4	0.6	3	0.45
Low operation costs	0.11	4	0.44	4	0.44
Easy to build up	0.06	4	0.24	3	0.18
Easy to use	0.13	4	0.52	4	0.52
Fit into a smaller area	0.07	5	0.35	5	0.35
Simple design	0.10	5	0.5	3	0.3
Robust design	0.08	3	0.24	3	0.24
High capacity	0.11	3	0.33	4	0.44
<b>Total score</b>			<b>3.98</b>		<b>3.68</b>
<b>Rank</b>			<b>1</b>		<b>2</b>

This selection is the one that suites the presented customer needs the most. Because this selection was made from very basic sketches and ideas the chosen concept has to be developed to a more detailed design before a first evaluation can be made. From the personal feelings and a theoretical point of view the selected concept with the dry filter solution fits the customer needs in a satisfactory way.

## **8. Develop Chosen Concept to Final Design**

*This chapter will present the final design proposal for this project at San Pedro factory. First there is a presentation of the design followed by some economical calculations for the design cost.*

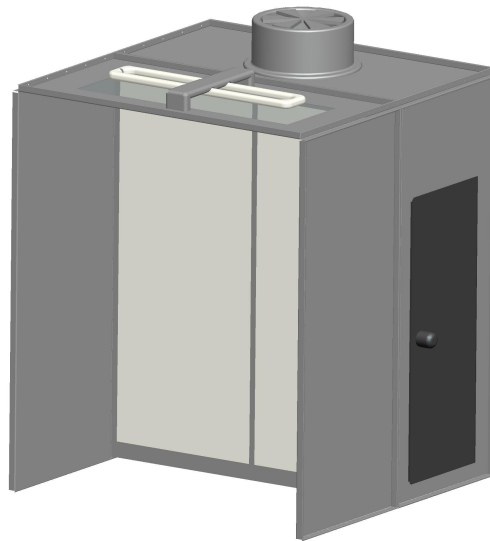
### **8.1 Improving Concept**

Concept number one is the solution that is the most suitable for the San Pedro factory. An early scale model for the spray booth is shown in appendix B. This spray booth consists of an extractor fan in the rear that creates a cross draft airflow through the dry filter that is positioned behind the painting object. Though the concept has to be developed in detail to be able to manufacture a physical product of the idea. The aim of this part is to identify what components that are needed to build up the booth. To set specific dimensions and materials for each of the components is also a main activity in this phase of the development process.

### **8.2 Component Identification**

The spray booth consists of a couple of components that can be designed individually. Though some of the including parts effect each other in one way or another. It is therefore important to identify the relationship between the different components and the features in the design. A model of the design is shown in figure 8.1. An identification of the including components is done and from the early concept generation phase the components can be divided into a couple of groups:

- Framework
  - Bars
  - Sheet metal
  - Paint
- Filter
  - Filter
  - Net/Holding for filter
- Lights
  - Lights
  - Safety glass
- Extractor
- Service door
  - Bars
  - Sheet metal
  - Hinge
  - Handle/Lock



*Figure 8.1. A 3-D model of the spray booth.*

### **8.2.1 Framework**

The first group is the base of the booth and also the components that hold up the rest of the including parts. The group consists of two walls, a roof and a rear part. It is of great importance to design these components in a way that materials and dimensions does not counteract on the booth functionality.

### **8.2.2 Bars**

The bars building up the framework are going to hold up the weight of the roof and the parts on top of it as the light and the extractor. Four bars will form a rectangle and together with a sheet metal they will build up every piece of the walls and the roof.

### **8.2.3 Sheet Metal**

To create a better airflow the walls in the framework are designed with sheet metals. The walls will also keep the construction more robust and make it stronger.

### **8.2.4 Paint**

Because the metal used in the bars and the sheet metal is not produced from materials that are resistant from corrosion the framework is covered with anti-corrosive paint.

### **8.2.5 Filter**

The filter is going to be a dry filter made by fibres or paper. It is of great importance to choose the right filter for the booth. Different filters are good for different kind of spray paint and dust that is in the working area. The filter selection also depends on the

amount of paint.

### **8.2.6 Fastening for Filter**

Since the filter is going to be a dry filter. A component to fasten the filter to the rest of the design is therefore needed. This tool for fastening the filter will be attached to the walls and the roof to force the airflow to go through the filter.

### **8.2.7 Lights**

Because the booth is going to be used in a process where San Pedro will refine the wooden doors with a surface preparation it is very important to use good lights for the booth. With good light in the working area the worker can see the surface much better and the final result after the finishing process will be better.

### **8.2.8 Safety Glass**

One very important aspect for this project is to design a safe product. To protect the employees and the machines in the working area a safety glass will be placed in the roof of the booth below the lights. This is made to keep the paint particles and other inflammable objects away from the hot lights.

### **8.2.9 Extractor**

To create an airflow backwards in the booth and force the paint particles to move through the filter an extractor fan is placed in the back of the booth. The fan will be positioned behind the filter either in the ceiling or in the rear.

### **8.2.10 Service Door**

To be able to clean, service and repair the spray booth more easily a door is placed in the rear part of the booth. The door open up for an easier access to this part of the construction and it will simplify the change of filter as well. The door is designed with a frame that is built up with the same kind of bar and sheet metal as the framework. It also consists of hinges and a lock.

### **8.2.11 Hinge**

To make it easy to open and close the door two hinges are attached to it. One in the lower part and the other one in the upper part on the vertical side.

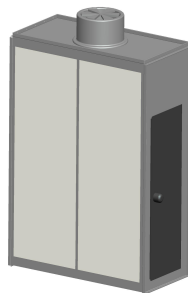
### **8.2.12 Handle/Lock**

A handle and a lock is placed on the opposite vertical side from the hinges to make it possible to close the door and keep the door closed even when the airflow is going through the booth.

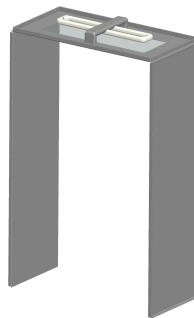
### 8.3 Proposal Design

The framework of the spray booth is built up with modules that are easy to assemble with bolts or by welding. Each of the modules consists of a number of walls and a roof. Both the wall and the roof components are assembled in the same way by four L-profiled bars with the cross section of 1" x 1" x 1/8" and a 1 mm thick sheet metal. Since the materials are not resistant to corrosion a paint with anti-corrosive substances is applied to the exposed areas.

The final product can be divided into two main modules. This proposal of the design presented here is based on a spray booth built up with these two modules. First the base module with walls, roof, extractor and filter, shown in figure 8.2, and then one front module with walls, roof and lights, shown in figure 8.3. The spray booth with the different combinations is also shown in appendix C.



*Figure 8.2. Base module.*



*Figure 8.3. Front module.*

The extractor can be placed either on top or in the back of the base module. This decision depends on the space in the area where the booth is going to be placed. In some cases it may also be a better idea to attach the extractor to one of the sides. The size of the extractor and its performance depends mostly on the cross section in the painting area. This means that if the cross section is large a bigger extractor is needed. In this

case the cross section is 5 m<sup>2</sup> and that results in an extractor with an airflow of 7200 – 9000 m<sup>3</sup>/hour according to the approximation by Greiff Industrimiljö AB in chapter 5.3. A drawing with some basic dimensions for the spray booth is shown in appendix D.

### 8.4 Cost Calculations

The components that the spray booth will be built up with are specified as close to the final product as possible at this stage of the process. Some changes may have to be made when the actual build-up process get started but the components presented here will describe the spray booth in a very good way. All cost calculations are made out of these conditions. As the received prices are both in US\$ and Bs. the Bs. are converted into US\$ before the total sum. The calculations are made with the exchange rate of 1 US\$ = Bs. 7.65. The work costs are estimated to 50 per cent of the total component costs according to information from CADEFOR. The calculated costs for the base module combined with one front module is shown below in table 8.1. All cost calculations are made based on prices for the chosen components that are shown in appendix E. These specific components were chosen to get a better understanding for the costs and they are perhaps not optimal for this spray booth.

Table 8.1. Cost calculations.

	Bs.	US\$	Quantity	Bs.	US\$	Sum (US\$)
Bar (6m)	68		9	612		
Sheet metal (2x1m)	193		10	1930		
Paint	42		1	42		
Filter		80	1		80	
Net/Holding for filter	120		5	600		
Lights	146		1	146		
Safety glass	75		1	75		
Extractor		480	1		480	
Hinge	10		1	10		
Handle/Lock	72		1	72		
Bolt	0.80		200	160		
Other costs					100	
<b>Sum</b>				<b>3647</b>	<b>660</b>	<b>1136.73</b>
<b>Work cost</b>	(50 % of the component costs)					<b>568.37</b>
<b>Total cost</b>						<b>1705.10</b>

Exchange rate US\$ 1 = Bs. 7.65

To find out if the chosen concept is a good product, a testing period is needed before the main production can start. This step of the development process is not going to be part of this thesis but from the theoretical point of view and with the use of common sense this concept will reach the needs from San Pedro factory in a very good way. Both technically and economically.



## **9. Conclusions**

The new finishing line at Tecno Carpinteria San Pedro is going to be built up in a short future from now. Today a pre-production has started and a couple of doors per day is produced in a temporary line. Since the line is not going to be automatic and the finishing line is going to be built up in an area that is not earlier used for manufacturing it is easier to build up one part of the line at a time.

In the beginning of this project one of the needs was to reach a capacity of 1000 doors per month in the finishing line. By using one single spray booth of the proposal design this capacity may not be reach, but by using two or maybe three individually worked booths the wish from the factory can be reached.



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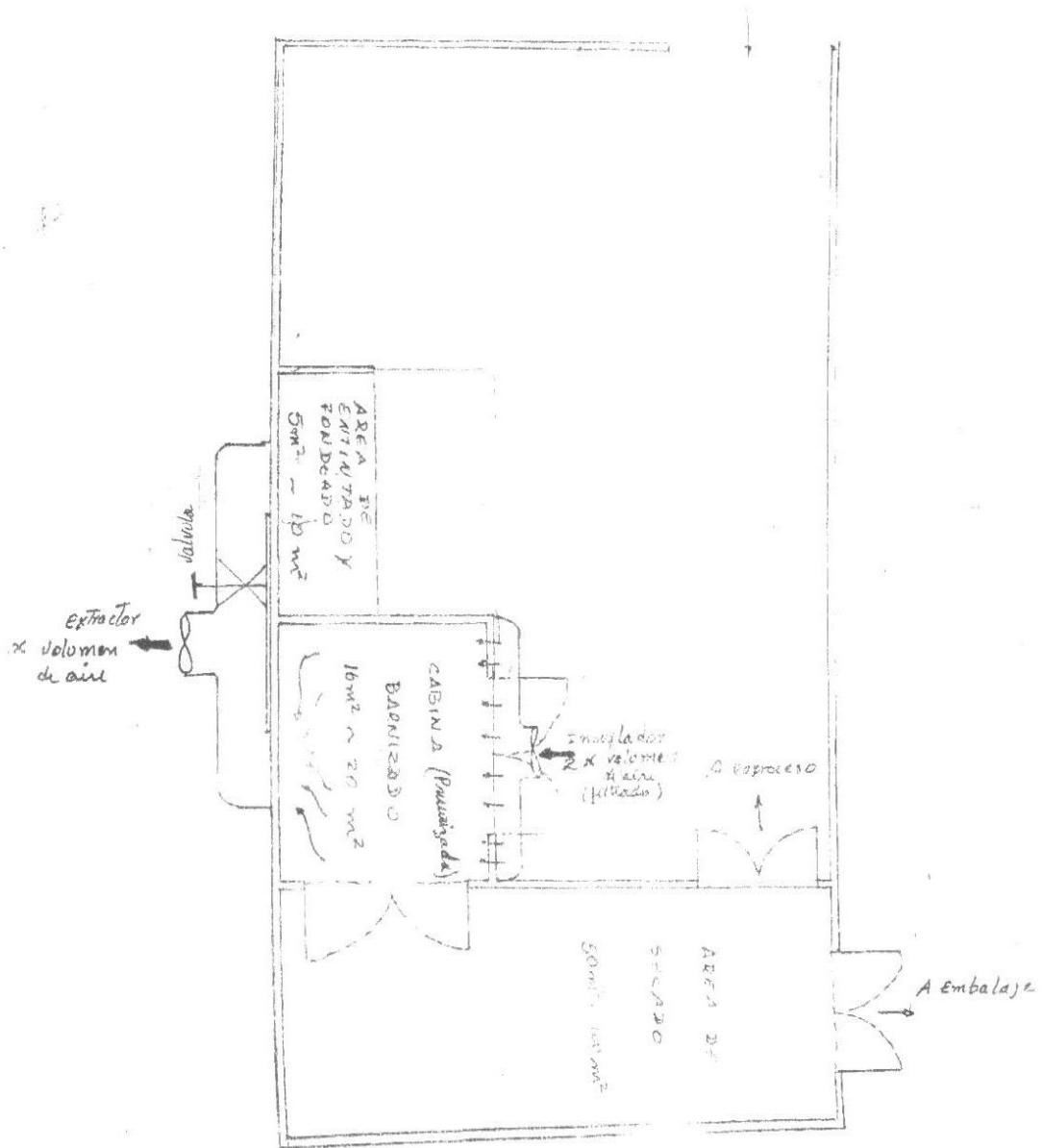
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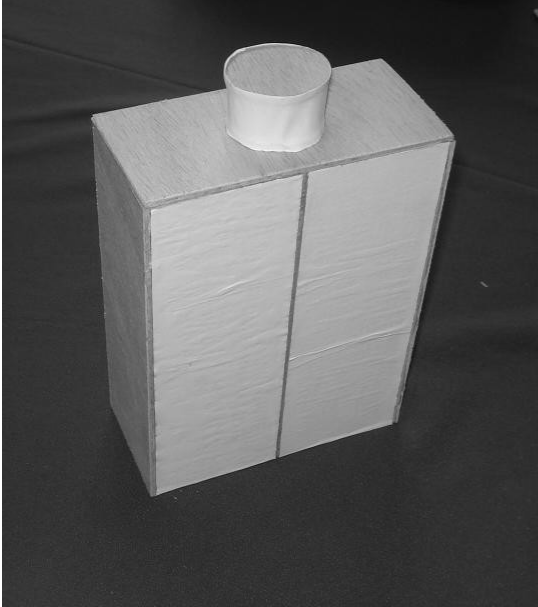
Lars Hasselström, Greiff Industrimiljö AB

# Appendix

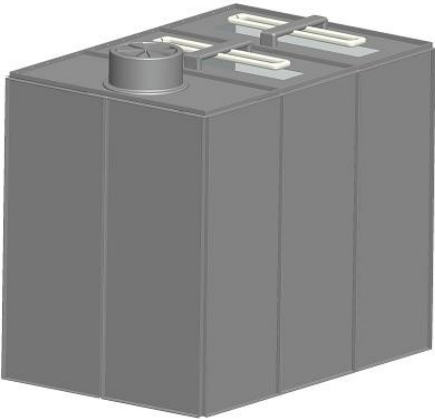
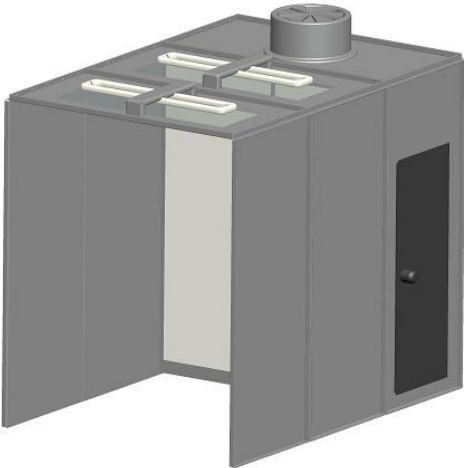
## Appendix A – Layout for the Finishing Line



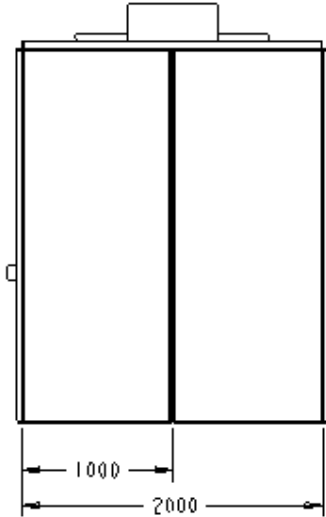
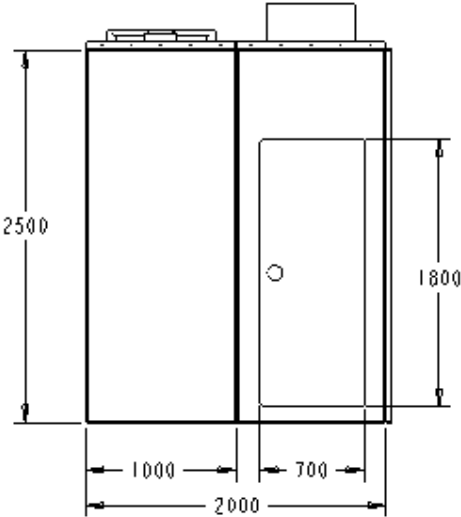
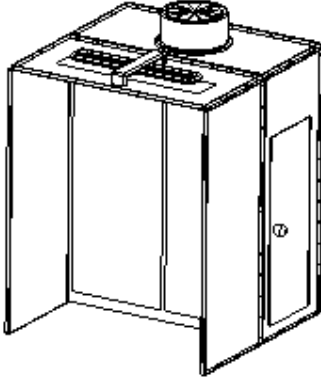
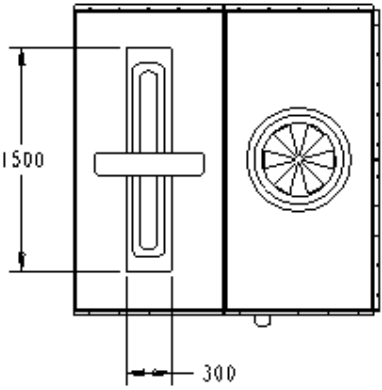
**Appendix B – Scale Models of the Design**



**Appendix C – 3-d Models of the Design**



**Appendix D – Main Dimensions**



## ***Appendix E – Including Components***

Bars	(L-profile, 1"x1"x1/8", 6m)
Sheet metal	(1mm, 2x1m)
Paint	(anti-corrosive aluminium, 1L)
Bolts	(5/16 x 1½)
Filter	(P210, 940mm x 10m)
Net	(½"x14, 1x1m)
Extractor	(AX-60 IP, 11 000m <sup>3</sup> /h)

Calculated required airflow is 7200-9000 m<sup>3</sup>/h

Lights	(2x40W)
Safety glass	(4mm, 1,50x0,30m)
Hinge	(4" double)
Lock	