Abstract

In an era where most of the human labor is being substituted by an automatic system, there is a high demand in each sector of the business to get the requirements of the situations. This includes providing power sources for the use of machineries in remote areas where there is no other means of accessible power supply. The idea of using an automobile engine for these purposes emerges here. But this also necessitates the use of a Power-take-off mechanism that will help us connect the required machinery with the car engine.

This project is intended to carry out the manufacturing process and its related economical study required in realizing an already designed "Power-take-Off" mechanism from an Industrial Vehicle. As an initial stage a preliminary market analysis is carried out to determine the number of products expected to be sold per year. The second phase is to carry out the manufacturing process of 10 of its parts along with their drawings on the respective machining center. Those manufacturing process sheets will also be used as a guideline for the operator while carrying out the machining operations. As a third step the machining parameters needed to be calculated for each part and each operation are calculated to be used as a tool in selecting the type of machines and the number of workers required for the center. The fourth and the last phase will include the economical study required to set up the machining center so that it will operate in an efficient and profitable conditions.

June 2007
Table of Contents

ABSTRACT__________________________________________________________________________ 1
TABLE OF CONTENTS _______________________________________________________________ 3
1. ABBREVIATIONS ___________________________________________________________________ 5
2. PREFACE __________________________________________________________________________ 7
3. INTRODUCTION ___________________________________________________________________ 9
   3.1. Objective of the project ............................................................................................. 9
   3.2. Scope of the project .................................................................................................. 10
4. PRELIMINARY MARKET ANALYSIS ____________________________________________ 11
5. MANUFACTURING PROCESS ________________________________________________ 17
   5.1. Transmission Plate .................................................................................................... 17
   5.2. Shaft 3 .................................................................................................................... 18
   5.3. Shaft 4 .................................................................................................................... 19
   5.4. Clutch Sleeve ......................................................................................................... 20
   5.5. Washer .................................................................................................................. 21
   5.6. Seal Cover ............................................................................................................... 22
   5.7. Head ........................................................................................................................ 23
   5.8. Arm Bracket ........................................................................................................... 24
   5.9. Gear 3 ..................................................................................................................... 25
   5.10. Gear 4 .................................................................................................................. 26
6. CUTTING PARAMETER CALCULATION __________________________________________ 27
   6.1. Lathe Cutting Parameters Calculation ..................................................................... 28
   6.2. Milling Cutting Parameters Calculation ................................................................. 30
   6.3. Circular Disc Sawing Parameters Calculation ........................................................ 32
   6.4. Cylindrical Grinding Parameters Calculation ........................................................ 32
   6.5. Broaching Parameters Calculation .......................................................................... 33
   6.6. Gear Hobbing Parameters Calculation ................................................................... 35
   6.7. Cycle time Calculation .............................................................................................. 37
   6.8. Selection of machineries, their quantity and number of workers ............................. 38
7. ECONOMICAL STUDY __________________________________________________________ 41
   7.1. Hour-Cost calculation ............................................................................................... 41
7.2. Calculation of Inversion Cost and Product Selling Price ..................... 43
7.3. Verification of Profitability of the Investment ........................................ 45
  7.3.1. 5 Year Forecast ............................................................................. 45
  7.3.2. Cash Flow .................................................................................. 46
  7.3.3. Pay Back Period .......................................................................... 47
  7.3.4. Net Present Value (NPV) .............................................................. 47
  7.3.5. Internal Rate of Return (IRR) ........................................................ 48

8. PLANT LAYOUT AND LOCATION .................................................. 49

CONCLUSION .................................................................................... 53

ANNEX ............................................................................................. 55

ACKNOWLEDGMENT ........................................................................ 57

BIBLIOGRAPHY .................................................................................. 59
1. Abbreviations

PTO – Power take off

DOP – Details of Phases

LOP – List of Phases

CNC – Computer Numerical Control

PB – Pay Back

NPV – Net Present Value

IRR – Internal Rate of Return
2. Preface

One can trace the origins of modern manufacturing management to the advent of agricultural production, which meant that humans didn't constantly have to wander to find new sources of food. Since that time, people have been developing better techniques for producing goods to meet human needs and wants. The early twentieth century, is generally considered to mark the true beginning of a disciplined effort to study and improve manufacturing and operations management practices. Thus, what we know as modern manufacturing began in the final decades of the twentieth century.

The early 21st century has seen a fast and sharp development of the manufacturing technology in such aspects like "computer-integrated manufacturing" (CIM), "flexible manufacturing systems" (FMS), and "factory of the future" (FOF) which can be sited among part of the vocabulary of manufacturing leaders. And the field, thanks to its applications in the day to day activities of human beings, has attracted a lot of professionals who have contributed to its continuous growth.

Those reasons along with the demands of the society have motivated the initiation of this project. However the first and foremost target of the project is to apply the engineering concepts that has been acquired until now in such a way that it could be used to realize a product from its conceptual stage to its reality where it will arrive to the market and eventually to the consumers. The second motivation is, if possible, contributing to that continuous trend of growth in the field of manufacturing technology through the process of developing the intended product.

As can be said to all projects in this case too there have been some constraints of obtaining accurate information on the price of materials, machineries and tools, lack of some experimental data on the time spent by operators for some activities and unavailability of a complete catalog of all the tools and tool holders along with their price required for the machineries. Therefore a further refining of these aspects of the project is recommended so that it will be possible to obtain a more realistic and accurate predictions that will enable to minimize the risks associated with investing on this project.
3. Introduction

3.1. Objective of the project

The objectives of this project can be summarized with the following main points:

- To carry out a preliminary market analysis and estimate the amount of product that could be sold per year.

- To define the manufacturing process and raw material required for the production of each part. This is approached initially by identifying the operations and the respective machineries that are required for each part. Once this has been done for every part, the cutting parameters are calculated for each operation that will help in selecting the type and quantity of machineries and the required number of operators. By passing through those steps the theoretical knowledge that is acquired until now is applied in the transformation of a product which is at the stage of a conceptual design to its realization.

- To provide the potential entrepreneur of the plant with basic and standard guidelines and formats that will help the plant to start its operation smoothly. This includes the development of formats for Details of Phases (DOP) and a summary that puts all the operations and phases together, named List of Phases (LOP).

- To evaluate and select the best machining operation well suited to the manufacture parts which have different geometrical and surface requirements. This requires looking for an operation which will minimize the cost of production, the required effort to machine a particular operation and the time spent on it.

- To familiarize and get acquainted with the ways of calculating the expenses and costs involved in running a machining center and its associated risks using the tools available for the validation of investing on a project like Pay Back Period, Net Present Value and Internal Rate of Return. By those out comes it will be possible to analyze and decide the economical viability of setting up the machining center.
3.2. Scope of the project

This project is expected to deliver a reasonable foresight for a potential entrepreneur on the outcomes of investing on the proposed machining center of the Power-take-off parts.

Using the conceptual design of 10 parts of the PTO that was carried out before, first this project will layout a standard manufacturing procedure that will be used in machining centers with the available machineries. Operation that may require a work that couldn't be done in the center or in the case where the purchase of some of the machineries can not be justified economically, the parts may be machined by an external company. The next step involves the calculation of the cutting parameters that will be required for selecting the type and quantity of machineries and the number of operators. Finally all those information along with existing market price of material, machinery and tools will help us in justifying the economical profitability of the machining center.
4. Preliminary Market Analysis

The primary reason for undertaking this preliminary market study is to determine the quantity of a Power-take-off gear box that will be sold per year and additionally it will provide some supporting ideas that helps us make a decision as to which type of machineries to use for its manufacturing process, i.e. whether to use a conventional or NC type machines.

For this approach, the existing number of industries in Spain can be roughly taken as a starting point. According to the National Institute of Statistics in 2005 there are a total of 157,111 industries in Spain. This total figure includes all sorts off industries available and after looking the detail we can say 40% of this total can be considered as a potential customer for our product.

A further assumption is required as to how many industrial vehicles will these industries are possessing. Out of the total only 15.7% of the industries have more than 20 employees and it is assumed that these industries will have at least 2 industrial vehicles. The rest 84.3% have less than 20 employees and are assumed to own at least 1 industrial vehicle each.

The above figures can be summarized as follows:

Potential Customers (no. of industries) = 157,111 * 40% = 62,844
Industries with >20 employees => 62844*15.7%*2= 19,733 Industrial Vehicles
Industries with <20 employees => 62844*84.3%*1= 52,977 Industrial Vehicles
Total Number of Industrial Vehicles (app.) = 72,710
And finally out of this it is assumed that 15% of these Industrial vehicles will be a yearly customer of the product to give:

\[ 72,710 \times 15\% \approx 10907 \text{ products to be sold each year.} \]

The next step will be to take this final figure in to consideration and decide the type of machining center that best adapts for the manufacture of these amounts of parts and that maximizes the profitability of the industry. But this will not merely depend on the quantity of the products but also on the complexity of the parts that will be produced on this center. The following part will try to discuss those technical and some economical factors that will help to make a decision on which type of machining center to adopt to this specific case.
1) The 5 most important features that a CNC machine offers, which are not available on non-CNC machines can be explained as follows:

- **Consistency of work pieces produced** - Since a CNC machine executes a program, and it will do so in exactly the same fashion time and time again, the consistency of work pieces produced is much better than work pieces run on conventional machine tools.

- **Faster work piece machining** - Since current model CNC machine tools are guarded (splash guards, windows, etc.) in a much better manner than most conventional machine tools, users can apply the most efficient cutting conditions to attain the best cycle times. Manual machinists tend to nurse-along their machining operations to minimize the chips and coolant is constantly thrown from the work area.

- **Lowered skill level of machinist** - Though there are some misconceptions in this area (some people believe that anyone can run CNC machines without training), the level of skill required to run (but not program) a CNC machine is much lower than that required to run a conventional machine tool - especially in a production environment when the same work piece is run over and over again.

- **Complexity of work pieces to be machined** - CNC machines can generate very complex motions, making it possible to machine shapes that cannot be generated (or are extremely difficult to generate) on conventional machine tools.

- **Flexibility, faster turn-around, and smaller lots** - Because they're programmable, a given CNC machine can be used to machine a large variety of different work pieces. Most are also designed to minimize downtime between production runs (setup time). Some conventional machines they're replacing (screw machines and transfer lines, for example) are extremely difficult to setup, making them feasible only for larger lot sizes.

2) Some of the specific skills a CNC machinist needs over a manual machinist.

By "CNC machinist", we mean a person that is responsible for programming, setting up, and running production. Many work piece producing companies (job-shops) and tooling manufacturers employ this kind of CNC person and refer to them as CNC technicians. Note that in many work piece producing companies, the CNC operator is not responsible for programming or setting up. This means they don't need the level of skill a regular machinist possesses. Special skills required of a CNC technician:
Knowledge of computers and application software - While a conventional machinist will have no need for computers, a CNC technician will be using them every day and in almost every facet of their job. Computers are used to create programs, to verify the correctness of programs, and to transfer programs to and from the CNC machine. Even the CNC control has a computer - some of which have Windows operating systems.

3) A few of the most complex functions that a CNC machine can perform, which can not be handled by any other type of machine.

Given unlimited resources, conventional equipment can be designed to do just about anything that CNC machines can do. With CNC, however, many more of these complex functions are feasible.

- Complexity of work pieces machined - Consider, for example, the machining of the core and cavity of an injection mold. These shapes have traditionally been machined on tracer mills. With CNC, a program provides the commands needed to machine these complex shapes.

- Ability to bring work piece closer to completion - The general nature of CNC machines allows them to handle more machining operations in one setup than is commonly possible on conventional machines. Specific features of CNC machines that are designed to allow this include live tooling on turning centers that make it possible to perform machining operations on a lathe that are commonly done on a mill, rotary tables and indexers on machining centers designed to rotate the work piece to expose multiple sides of the part to the spindle for machining, and spindle probes on machining centers that make it possible to accurately (and automatically) locate key location surfaces.

- Feedback to production control - Since CNC machines have a built-in computer, they can relay information about how they're running to other parts of the company using the same network that other computers in the company are using.

- Self diagnostics - Most current model CNC machines include self-checking systems to constantly monitor their own systems. When something goes wrong, they generate an alarm to alert the operator.

4) The automated features that CNC machines offer which alleviate a machinist's workload.

When it comes to actually running production (after programming and setup are completed), just about every major facet of a manual machinist's workload has been alleviated by CNC machine tools. While a manual machinist must be involved with
everything happening on a conventional machine, once a CNC operator loads a work piece and activates the cycle, the CNC machine takes over, completing all tasks a manual machinist normally does. Specific examples include tool changing, speed, feed, and coolant selection, generating the motion needed to machine work pieces (a manual machinist turns hand-wheels to cause motion), and in some cases, even chip removal. Again, just about everything that happens to machine a work piece is under the control of the CNC machine tool.

5) How CNC machines can be cost effective in the long run, even for a small company that handles precision work.

First of all, CNC machines are not nearly as expensive as they once were. Very capable entry-level machining centers and turning centers are selling for under Euro 30,000.00. Comparable manual machines may not be much less than half this price.

Aside from reasonable the price, many small companies, even one-person shops, employ CNC machines even when lot sizes are small and high precision is required. Shop rates for CNC machine tools range from about Euro 30.00 per hour for smaller and less costly machines to well over Euro 200.00 per hour for larger, more expensive machines. At Euro100.00 per hour, a company can potentially generate about Euro 200,000.00 per year if it is working with the machine one shift (Euro100.00 per hour times 40 hours per week times 50 weeks), assuming they can keep the machine busy and that they charge for all hours worked (some companies charge for production time but not programming and/or setup time). They must of course, pay their people and maintain tooling. But depending on the situations, a company can be very profitable with CNC machine tools.

6) The typical life span of a CNC machine and the maintenance a typical machine will require over the years.

At the start, while the technology was advancing so quickly, over the course of five years, the life span of the earlier CNC machines was quite low. But today, CNC machines commonly last much longer than five years. This, of course, is related to the initial quality of the machine, how well the machine is maintained and how hard it is worked. Generally it can be said that average life-span is about ten years. Preventive maintenance tasks including oil changes (hydraulic and spindle oils, for example), air and oil filter changes, regular inspections of key components like ways and bearings, and of course, replacement of worn components when inspections reveal problems.
7) The most popular type of CNC machines and why companies prefer them so much.

The two most popular metal-cutting machines are machining centers and turning centers. These machines are very flexible which lends to their popularity. The conventional machines they replace are milling machines and lathes. Other popular CNC machines include wire EDM machines in tool-rooms, turret punch presses in metal fabrication companies, and CNC routers in woodworking companies. Of course, this just scratches the surface of CNC machine types. Just about every machine tool used to perform a manufacturing operation has a CNC machine counterpart.

8) Limitations and disadvantages that CNC machines may have.

a. Misconceptions - The most important limitations have to do with misapplications due to misconceptions. Many people feel that anyone can run these machines without training. So they hire unskilled people and put them on the CNCs, only to find that CNC machinists still need basic machining practice skills in order to maintain the production. Many managers feel that once a job has been run one time, it should run flawlessly in the future. But if anything changes (work piece raw material hardness or shape, for example), there will be problems the next time the job is run. People unfamiliar with CNC tend to view it as a black art, thinking that anything is possible with the wave of a wand. In reality, a great deal of ingenuity and effort is required of the people working with the CNC machines.

b. False feeling of security - While machines are becoming more fail-safe, mistakes still cause crashes. Nothing tells the operator before he or she presses the cycle activation button that the machine is out of alignment with the program and a crash is going to occur. Operator mistakes can be very costly, causing a great deal of downtime while machines are repaired.

c. Growing pains - Many companies that buy their first CNC machine find it so productive that they go out and buy their second machine very quickly. And then the third, the fourth and so on. Principles and techniques that can be successfully applied to one or two machines don't work well with twenty. For example, if a company has bought one machine, they hire a person to completely handle it. This person programs, sets up, runs production, and even maintains the machine. This method may work well for two machines (having two people that do everything for their respective machines). But it's infeasible to attempt this with a large number of machines, since there will be a great deal of duplicated effort.
5. Manufacturing Process

Manufacturing is the application of tools and a processing medium to the transformation of raw materials into finished goods for sale. This effort includes all intermediate processes required for the production and integration of a product's components.

The power take off (PTO) consists of a complete clutch assembly with shafts, gears and bearings mounted in a cast aluminum housing that provides an easy installation with the gear box of vehicles. PTO's are used as a standard method for transmitting the power of engines in a great variety of industrial applications such as: air compressors, agricultural machinery, pump drives, crushers, road building machinery, cranes and shovels, oil field service, etc.

In this specific project the Power-take-off mechanism is assumed to have ten components, whose manufacturing process will be described in detail in the coming sub sections.

5.1. Transmission Plate

Fig. 5.1 Section View of Transmission Plate 4
Material: Steel F-1142

Tensile Strength ($\sigma_t$) = 600 MPa

Owing to its geometrical shape and economical use of material, the raw material for this part is considered to be obtained from a forging process. Additionally, forged parts show better mechanical properties than raw materials obtained by other means of manufacturing. Firstly, it will undergo different types of turning operations on the lathe machine and then it will be transported to the milling center where the holes and chamfering of them will be carried out. The next operation will be on a Broaching machine where the internal splines will be broached. Finally, the part will go through a heat treatment phase where it will be treated with an induction quenching to obtain a hardness level of 54-56 HRC that will provide the required mechanical properties for its proper working conditions. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.1.

5.2. Shaft 3

![Shaft 3 Diagram](image)

Fig. 5.2 Section View of Shaft 3

Material: Steel 16 Mn Cr 5

Tensile Strength ($\sigma_t$) = 600 MPa

In this case, the raw material is obtained from a solid round steel bar cut on a circular disc sawing machine. Next, it will be turned on a lathe center to obtain the various dimensional and geometrical requirements needed as per the design. Upon completion of the lathe operation, it will be transferred to a milling center where the machining of the spline will take place. This is carried out while the shaft is fixed between centers using the indexing fixture.

Yared T. MAMO
as is explained in the description of operations part. As a third phase there will be a grinding operation to obtain the requirements of the surface texture that are assigned by the designer. Two types of heat treatment process are required for this part. The first will be carburizing of the part to a depth of 1±0.1mm by providing a proper protection to the groove wall by covering it with paint and then quenching and tempering of the part to obtain a hardness level of 60-62 HRC. A pressing operation will finally follow as a means of relieving the residual stresses developed due to the heat treatment process. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.2.

5.3. Shaft 4

![Fig. 5.3 Section View of Shaft 4](image)

Material: Steel 16 Mn Cr 5

Tensile Strength ($\sigma_t$) = 600 MPa

The manufacturing process required for this part is almost similar to the one used for Shaft 3 except in this case that additional milling operation is required for machining the groove at end of the thread and that there are two splines on each side. As in the case for shaft 3 before grinding, heat treatment and pressing operations will be required to obtain the required mechanical and surface texture properties. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.3.
5.4. Clutch Sleeve

Material: Steel 10 S 20

Tensile Strength ($\sigma_t$) = 400 MPa

As in the case of the transmission plate, the raw material for this part is obtained from forging too that will avoid the wastage of a big volume of material that could occur had been a solid round bar that was used instead. Primarily the raw material is processed on a lathe for different types of turning operations and then transferred to a broaching center where the internal sprockets will be machined according to the dimensions provided by the designer. The next process involves machining the entrance of the sprocket teeth with a radius equal to half of the thickness of the tooth on a special machine so as to facilitate the engagement of the clutch. Finally the part will be heat treated in a similar manner to the previously discussed Shaft 3. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.4.
5.5. Washer

Material: Steel C 25

Tensile Strength ($\sigma_t$) = 260 MPa

The raw material for this part will be a round steel bar cut on a circular disc sawing machine. As the part requires a few millimeters of length (8mm) it is advised to cut a bigger length initially (around 500mm) and then support the material inside the headstock just only by leaving the required length plus some millimeters required for the parting and facing operation. This will avoid the possible bending effect due to the length of the part. The required operations for this part are relatively simple as compared to the other parts and can be obtained only on a lathe machine. No heat treatments are required for this part. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.5.
5.6. Seal Cover

Material: Aluminum (UNE 38212 L-212)

Tensile Strength ($\sigma_t$) = 150 MPa

As specified by the designer, the raw material for this part is obtained from casting and then machined to the required dimensions. All the machining operations are carried out on a milling center that comprise plain and pocket milling, machining of the holes to the desired dimension, drilling and chamfering of the holes. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.6.
5.7. Head

Material: Aluminum (UNE 38212 L-212)

Tensile Strength ($\sigma_t$) = 150 MPa

An aluminum cast of the same property that was used for the seal cover is used as a raw material here too. Then the operations required to get the dimensions are carried out on a milling center. This includes plain milling, machining of the holes, drilling, chamfering and threading of the holes. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.7.
5.8. Arm Bracket

Material: Steel C 25

Tensile Strength ($\sigma_t$) = 260 MPa

A square bar cut on a circular disc sawing machine is used as a raw material for this part. Then the bar is machined on a milling center to obtain the desired dimensional requirements. Those include plain and side milling, drilling and threading of the holes. Finally the part is heat treated by quenching and tempering to get a hardness of 365-410 HB. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.8.
5.9. Gear 3

Material: Steel 20 Mn Cr 5

Tensile Strength ($\sigma_t$) = 600 MPa

As was in the earlier cases, the raw material for this part is assumed to be obtained from a forging process. Then turning operations are done on a lathe machine to get the required internal and external dimensions. Then the part is transferred to a Broaching machine where the machining of the internal spline will be carried out according to the standard specified on the design. Upon completion of this, the next machining will be on a Gear Hobbing machine where the machining of the external spur gear will take place. Carburizing the whole part to a depth of $1\pm0.1$mm, quenching and tempering to get a hardness of 60-62 HRC are also the required heat treatments for this part. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.9.
5.10. Gear 4

![Section view of Gear 4](image)

**Material:** Steel 20 Mn Cr 5

**Tensile Strength** \( (\sigma_t) = 600 \text{ MPa} \)

This part is exactly similar with the previous Gear 3 except the dimensional requirements. Therefore as in the earlier case the raw material is obtained from a forging process and will undergo the same machining and heat treatment operations. The detailed manufacturing process along with the respective drawing and dimensions, types of tools used, measuring equipments and required fixtures is shown in Annex 1.10.
6. Cutting Parameter Calculation

The large number of work materials that are commonly machined vary greatly in their basic structure and the ease with which they can be machined. Yet it is possible to group together certain materials having similar machining characteristics, for the purpose of recommending the cutting speed at which they can be cut. Most materials that are machined are metals and it has been found that the most important single factor influencing the ease with which a metal can be cut is its microstructure, followed by any cold work that may have been done to the metal, which increases its hardness. Metals that have a similar, but not necessarily the same microstructure, will tend to have similar machining characteristics.

The cutting conditions that determine the rate of metal removal are the cutting speed, the feed rate, and the depth of cut. These cutting conditions and the nature of the material to be cut determine the power required to take the cut. The cutting conditions must be adjusted to stay within the power available on the machine tool to be used. The cutting conditions must also be considered in relation to the tool life. Tool life is defined as the cutting time to reach a predetermined amount of wear, usually flank wear. Tool life is determined by assessing the time—the tool life—at which a given predetermined flank wear is reached. This amount of wear is called the tool wear criterion, and its size depends on the tool grade used. Usually, a tougher grade can be used with a bigger flank wear, but for finishing operations, where close tolerances are required, the wear criterion is relatively small. Other wear criteria are a predetermined value of the machined surface roughness and the depth of the crater that develops on the rake face of the tool.

Tool life is influenced most by cutting speed, then by the feed rate, and least by the depth of cut. When the depth of cut is increased to about 10 times greater than the feed, a further increase in the depth of cut will have no significant effect on the tool life. This characteristic of the cutting tool performance is very important in determining the operating or cutting conditions for machining metals. Conversely, if the cutting speed or the feed is decreased, the increase in the tool life will be proportionately greater than the decrease in the cutting speed or the feed. Tool life is reduced when either feed or cutting speed is increased. For example, the cutting speed and the feed may be increased if a shorter tool life is accepted; furthermore, the reduction in the tool life will be proportionately greater than the increase in the cutting speed or the feed. However, it is less well understood that a higher feed rate (feed/rev × speed) may result in a longer tool life if a higher feed/rev is used in combination with a lower cutting speed.

The first step in establishing the cutting conditions is to select the depth of cut. The depth of cut will be limited by the amount of metal that is to be machined from the work piece, by the
power available on the machine tool, by the rigidity of the work piece and the cutting tool, and by the rigidity of the setup. The depth of cut has the least effect upon the tool life, so the heaviest possible depth of cut should always be used. The second step is to select the feed (feed/rev for turning, drilling, and reaming, or feed/tooth for milling). The available power must be sufficient to make the required depth of cut at the selected feed. The third step is to select the cutting speed. Although the accompanying tables provide recommended cutting speeds and feeds for many materials, experience in machining a certain material may form the best basis for adjusting the given cutting speeds to a particular job. However, in general, the depth of cut should be selected first, followed by the feed, and last the cutting speed.

Here under all the formulas that are used in the calculation of the cutting parameters in all machining centers will be presented and the calculated tables for each part are presented in Annex 2.

6.1. Lathe Cutting Parameters Calculation

In this section the formulas that are used to calculate the parameters of cutting conditions will be dealt. The figure below shows some of those variables that exist on those formulas.

![Cutting geometry on a lathe machine](image)

**Fig. 6.1 Cutting geometry on a lathe machine**

Most machining operations are conducted on machine tools having a rotating spindle. Cutting speeds are usually given in meters per minute and these speeds must be converted to spindle speeds, in revolutions per minute, to operate the machine. Conversion is accomplished by use of the following formula:
Where: \( n \) is the spindle speed in revolutions per minute (rpm), \( V_c \) is the cutting speed in meters per minute (m/min) obtained from tool catalog and \( D \) is the diameter of the workpiece to be machined.

The feed speed \( V_a \) (mm/min) is calculated by multiplying the spindle speed by the feed rate factor \( a \) which is given in mm/turn. Therefore

\[
V_a = n \times a \quad \text{Eq. 6.1.2}
\]

The selection of feed rate factor value \( a \) depends on the required level of surface texture and the radius of the tool and is given by

\[
a = \sqrt{\frac{R_a \times r_p}{25}} \quad \text{Eq. 6.1.3}
\]

Where \( R_a \) is value of surface texture required in (\( \mu \)m) and \( r_p \) is the radius of the tool.

Usually the feed factor rate for finishing and roughing operations is in the order of 0.1-0.2 and 0.5-0.8 mm/turn respectively.

The time required to turn a part from an initial diameter \( D_o \) to a final diameter \( D_f \) is simply the time to travel across the length of the part. Thus it is given by the formula

\[
t_c = \frac{l}{V_a} \quad \text{Eq. 6.1.4}
\]

Where \( t_c \) is the cutting time in minutes, \( l \) the length that the tool traverses in mm and \( V_a \) the feed speed in mm/min.

The cutting force, \( F_c \), required for any operation on a lathe machine is given by the formula

\[
F_c = k \times a \times p \times \sigma_t \quad \text{Eq. 6.1.5}
\]
Where $\sigma_t$ is the tensile strength of the material to be machined in N/mm$^2$, $a$ for feed factor in mm/turn, $p$ for depth of cut in mm and $k$ is a constant factor whose approximate value is between 3 and 5, the first for elastic materials and the later for material with little or no elasticity like cast part.

The cutting power, $P_c$ in kw can be calculated easily once the cutting force is known and is given by the formula

$$P_c = \frac{F_c \cdot V_c}{60000} \quad \text{Eq. 6.1.6}$$

And the machine power, $P_m$ (kw) required for an operation is calculated by

$$P_m = \frac{P_c}{\eta} \quad \text{Eq. 6.1.7}$$

Where $\eta$ is efficiency of a lathe machine and the value ranges between 0.7-0.8.

### 6.2. Milling Cutting Parameters Calculation

As is developed for a lathe operation, the formulas for a milling machine can be developed in a similar way.

![Milling machine cutting conditions](Fig. 6.2 Milling machine cutting conditions)
Equation 6.1.1 holds true in milling operations too except the only difference that in this case D stands for the tool diameter used for the operation.

The advance per tooth $a_z$ is the thickness of the chip removed by one tooth in the direction of advance. The feed speed $V_a$ in this case can be given by the formula

$$V_a = n \times a_z \times z$$

Eq. 6.2.1

Where $n$ is the spindle speed in rpm, $a_z$ is the advance in mm per turn per tooth and $z$ is the number of tooth of the cutting tool. Once the feed speed $V_a$ is calculated, the cutting time can be calculated in the same manner as a lathe operation by the formula

$$t_c = \frac{L}{V_a}$$

Eq. 6.2.2

Where $t_c$ is the cutting time in minutes, $L$ the length that the tool traverses while cutting the work piece plus the approach distance (usually the diameter of the tool) in mm and $V_a$ the feed speed in mm/min. In some cases where it’s geometrically complicated to calculate the length covered by the tool the material removal rate concept is used. Thus the cutting time can also be calculated by the formula

$$t_c = \frac{V_m}{Q}$$

Eq. 6.2.3

Where $V_m$ is the volume of the material to be removed in mm$^3$ and $Q$ is the material removal rate in mm$^3$/min that can be calculated by multiplying the depth of cut ($p$) by the width of cut ($b$) and the cutting speed ($V_a$).

The cutting force ($F_c$) can be calculated using the same formula as Eq. 6.1.5 and then the cutting power ($P_c$) will be given by the formula

$$P_c = \frac{F_c \times V_a}{60000000}$$

Eq. 6.2.4

The machine power $P_m$ (kw) required for an operation is calculated by dividing the cutting power to the efficiency of a milling machine ($\eta$) whose value ranges between 0.6-0.75.

$$P_m = \frac{P_c}{\eta}$$

Eq. 6.2.5
6.3. Circular Disc Sawing Parameters Calculation

Circular sawing is a multipoint cutting process in which a circular tool is advanced against a stationary work piece to sever parts or produce narrow slots.

![Diagram of Circular Disc Sawing](image)

The operations done on this machine are completely assumed to be similar with the ones done on a milling machine using a disc cutter. Therefore the cutting parameters are calculated in a similar manner to that of the milling operations and all the formulas given above are also valid for this case.

6.4. Cylindrical Grinding Parameters Calculation

Cylindrical grinding is an abrasive machining process in which material is removed from the external surface of a metallic or nonmetallic cylindrical work piece by rotating the grinding wheel and work piece in opposite directions while they are in contact with one another. The work piece is mounted between centers and is rotated by means of a work piece holder (grinding dog or center driver).
Due to its similarity with the turning operations, the calculation of the cutting parameters in this machine is considered to be the same as the case of lathe machine operations. The only difference is that in this case both the work piece and the cutting tool have a rotational speed and is required to calculate two spindle speeds for the grinding wheel and the part using the cutting speed and diameter of the cutting tool for the first and tangential speed and the diameter of the work piece for the later. Otherwise all the equations stated in the section 6.1 hold true for all the operations here too.

6.5. Broaching Parameters Calculation

Broaching is a cutting operation where accurate sizing and finishing of surface or shape is achieved by a single pass of a multipoint cutter (the broach). The stock removal of the broach is built into the tool by having each successive tooth cut deeper into the material. Thus, both roughing and finishing cuts may be built into the same tool.
The term “depth of cut” as applied to broaching machine means the total increase in the diameter of successive teeth and is designated by the symbol \( \Delta r \) whose value ranges from 0.03-0.05mm. The pitch (P) of the broaching tool is given by the formula

\[
P = 1.75 \times \sqrt{L}
\]

Eq. 6.5.1

The land width (f) is given by the formula \((0.2-0.3) \times P\) where P is the pitch of the tooth. The number of working teeth required for a broaching tool is calculated by the formula

\[
z_w = \frac{\Delta \phi / 2}{\Delta r}
\]

Eq. 6.5.2

Where \( \Delta \phi \) is the difference between the initial diameter \( D_o \) and the final diameter \( D_i \) of the part to be machined and \( \Delta r \) is the increase in the diameter of successive teeth.

The total number of teeth required \( (z_i) \) can be found by summing up \( z_w \) and \( z_a \) where \( z_a \) is the number of teeth required for finishing the operation and is assumed to be 4 or 5 teeth. The working length \( (l_w) \) of the tool is found by multiplying the number of working teeth \( z_w \) by the pitch of the tool P. Similarly the total length \( (l_t) \) of the broach is found by multiplying the number of total teeth \( z_i \) by the pitch of the tool P. Once all these parameters are found the cutting time \( t_c \) (min) for the operation is given by

\[
t_c = \frac{l_t}{V_c}
\]

Eq. 6.5.3

And the number of broaches required for the operation is calculated by

\[
N_b = \frac{P \times z_i}{l_{\text{max}} - P \times z_a}
\]

Eq. 6.5.4

Where \( l_{\text{max}} \) is the working stroke of the machine, which in this case equals 750mm.

The next parameter to be calculated is the cutting force \( F_c \) in Newton and is given by the formula

\[
F_c = K \times S \times \sigma_i
\]

Eq. 6.5.5

Where \( K \) is the same constant that was used in the calculation of milling and lathe operations and \( S \) is defined by
In which \( n \) is the number of maximum teeth working simultaneously and can be approximated by \((l_i/P + 1)\) and \( d_i \) is the diameter of those \( n \) numbers of teeth.

The cutting power \( P_c \) and the machine power \( P_m \) required for an operation on a broaching machine are calculated using the same formula as shown in Eq. 6.1.6 and Eq. 6.1.7 respectively.

### 6.6. Gear Hobbing Parameters Calculation

Gear hobbing is a multipoint machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (hob). Both the hob and the workpiece revolve constantly as the hob is fed across the face width of the gear blank.

![Schematic representation of gear hobbing](image)

The calculation of the cutting parameters starts by calculating the spindle speed of the hob as in the same way as it was done for milling operations. Then the spindle speed of the part will be calculated by the formula

\[
  n_p = \frac{n_i}{z_i} \quad \text{Eq. 6.6.1}
\]
Where \( n_p \) and \( n_t \) are the spindle speed of the part and tool respectively and \( z_t \) is the number of teeth of the tool.

To calculate the total cutting length of the hob, it will be necessary to consider the cutting geometry.

![Cutting geometry of gear hob](image)

**Fig. 6.7 Cutting geometry of gear hob**

As can be shown from the geometry above, the length \( l \) can be calculated by

\[
l = R \cos \alpha
\]

Eq. 6.6.2

In the drawing the length \( 2.16m \) represents the depth of a tooth that is 2.16 multiplied by the module of the gear. Therefore the total length \( l_t \) covered by the tool is calculated by summing up \( l \) and the length of the tooth. The cutting time required can then be calculated from the formula

\[
t_c = \frac{l_t}{V_a}
\]

Eq. 6.6.3

Where \( V_a \) is the feed speed in mm/min obtained by multiplying the spindle speed of the part by the feed factor \( a \). The rest of the parameters, i.e. cutting force \( F_c \), cutting power \( P_c \) and machine power required for an operation \( P_m \), are calculated using the same formulas with those that are used for a milling operation.
6.7. Cycle time Calculation

All the cutting parameters calculated above lay out a basic foundation to most of the major variables that need to be considered on the set up of the plant where the parts will be produced. The cycle time is one of the important variables out of them.

Cycle time is the time required to complete a given process. The cycle time required to manufacture a part starts with the introduction of the raw material to the machining center until its final phase of manufacturing. The overall process is made up of many subprocesses called phases.

Once the cutting time \( t_c \) required for each operation is calculated using the above formulas, the total machining time \( t_m \) is calculated by

\[
t_{m} = t_{c} + t_{a} + t_{e}
\]

Eq. 6.7.1

Where \( t_{a} \) and \( t_{e} \) are the tool approach time and the tool exist time respectively. In this specific project the tool approach time is considered to be 2sec while the exit is assumed to be 3 seconds. As well the number of products \( n_p \) that can be produced per part can be calculated from the formula

\[
n_p = \frac{t_{life}}{t_{e}}
\]

Eq. 6.7.2

Where \( t_{life} \) is the life of the specific cutting tool edge used for the operation. If \( t_{ch} \) is the tool changing time for a tool then by dividing this with the number of parts \( n_p \), we can distribute the time of tool changing per part for each operation.

The cycle time is first calculated for operations in the same machine and then summed up to get the cycle time of the part. To calculate the cycle time \( t_{ct} \) the following formula was used

\[
t_{ct} = \left( \sum t_{m} \right) + t_{cd} + \left( t_{co} * n \right)
\]

Eq. 6.7.3

Where \( t_{m} \) is summation of the total machining operations carried out in a same machine, \( t_{cd} \) the time consumed by the operator while charging, discharging and starting of the machine, \( t_{co} \) tool changing time between operations and \( n \) is the number of operation carried out on a machine at a time. After calculating this for all operation on the different types of machining centers the cycle time of the part is obtained by summing up the cycle time found per part.
Then the tool price per operation was calculated by dividing the price of a tool by the number of parts \( n_p \) estimated to be produced by a tool and summing up those prices per operation will give the tool cost per part.

The time calculation for all the parts considered in this project is attached in Annex 3.

### 6.8. Selection of machineries, their quantity and number of workers

The other important output from the calculation of the cutting parameters is the machining power required for each operation. After obtaining the result, this parameter is used to select the type of machineries required for the plant. After gathering the specification of the machineries from a catalog, a price request is sent for the companies and the reply from some of them is used as a means of comparison and selection criteria. Accordingly the machineries listed below are chosen and their detailed specification along with the price responses is attached in Annex 4.

<table>
<thead>
<tr>
<th>Mark/Model</th>
<th>KASTOdisc M7/U7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular Disc Sawing Machine</td>
<td>OKUMA LB200</td>
</tr>
<tr>
<td>Lathe Machine</td>
<td>OKUMA MB-46V</td>
</tr>
<tr>
<td>Milling Machine</td>
<td>UNIVERSAL HOBBING UH-150</td>
</tr>
<tr>
<td>Gear Hobbing Machine</td>
<td>UNIVERSAL SGI 305</td>
</tr>
<tr>
<td>Cylindrical Grinding Machine</td>
<td>CHAN YOW CY-10</td>
</tr>
</tbody>
</table>

**Table 6.1 Selected machinery types for the plant**

The next task involves the determination of the number of machineries required and the amount of direct workers that will operate them. The number of machines required \( n_m \) is calculated by the formula

\[
  n_m = \frac{n_p \cdot t_{ct}}{220 \text{ days/year} \cdot 7.75 \text{ hrs/shift} \cdot 1 \text{ shift/day}} \tag{6.8.1}
\]

Where \( n_p \) is the number of product expected to be sold per year in the preliminary market analysis i.e. 10907 products, \( t_{ct} \) is the cycle time calculated per machine. Then the workload of each machine in % is calculated by dividing the calculated number of machines to the real amount by

\[
  \text{workload(\%)} = \frac{\text{calculated quantity}}{\text{real quantity}} \tag{6.8.2}
\]

\[ Yared T. MAMO \]
Those machineries with a work load of 90% or greater should have one more additional machine so as to prevent the over load of machineries in the center.

<table>
<thead>
<tr>
<th>Number of machines required</th>
<th>Calculated qty</th>
<th>Real qty</th>
<th>Work load (%)</th>
<th>Exact qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td>0.22</td>
<td>1</td>
<td>21.63</td>
<td>1</td>
</tr>
<tr>
<td>Lathe</td>
<td>2.06</td>
<td>3</td>
<td>68.78</td>
<td>3</td>
</tr>
<tr>
<td>Milling</td>
<td>1.78</td>
<td>2</td>
<td>88.95</td>
<td>2</td>
</tr>
<tr>
<td>Broaching</td>
<td>0.15</td>
<td>1</td>
<td>15.08</td>
<td>1</td>
</tr>
<tr>
<td>Grinding</td>
<td>0.30</td>
<td>1</td>
<td>30.42</td>
<td>1</td>
</tr>
<tr>
<td>Hobbing</td>
<td>0.20</td>
<td>1</td>
<td>20.11</td>
<td>1</td>
</tr>
</tbody>
</table>

| Total number of machineries in the center | 9 |

Table 6.2 Number of machineries required for the plant

Similarly the number of direct workers, \( n_{dw} \) required is calculated by the formula

\[
n_{dw} = \frac{n_p \times (t_{ocd} + t_{ovp} + t_p + t_{pc} + t_{ma})}{220 \text{days} / \text{shift} \times 7.75 \text{hrs} / \text{shift} \times 1 \text{shift} / \text{day}}
\]

Eq. 6.8.3

Where \( t_{ocd} \) is the time spent by the operator while charging and discharging the parts (45sec), \( t_{ovp} \) is time spent by operator while verification and placing of machined parts (60sec), \( t_p \) is the preparation time of the machines (1hr per 50 parts per machine), \( t_{pc} \) is the total phase changing time and \( t_{ma} \) is the time required for operations on manual machine.

| Number of direct workers required for the plant | 7 |

The detailed calculation for both the number of machineries and direct workers is enclosed in Annex 4.
7. Economical Study

Manufacturing process planning and its associated economic estimations are the lifeline of a manufacturing business. Those two crucial variables decide the design, production, and financial viability of any project. Accurate estimation optimizes resources, minimizes costs and sets standards for world-class quality. As applied to this specific project the first variable and its related parameters are dealt in the previous chapters and the later will be given due consideration in this chapter.

7.1. Hour-Cost calculation

The hour cost calculation comprises the consideration of four major expenses and these are:

A. Amortization cost: Amortization is the process of decreasing or accounting for an amount over a period of time. In this project there are mainly two capital investments i.e. cost of machineries and cost of building the plant. An amortization period of 5 years is considered for the first and 10 years for the later.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Price</th>
<th>Quantity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lathe</td>
<td>109000.00</td>
<td>3</td>
<td>327000.00</td>
</tr>
<tr>
<td>Milling</td>
<td>124000.00</td>
<td>2</td>
<td>248000.00</td>
</tr>
<tr>
<td>Hobbing</td>
<td>32500.00</td>
<td>1</td>
<td>32500.00</td>
</tr>
<tr>
<td>Circular Saw</td>
<td>25000.00</td>
<td>1</td>
<td>25000.00</td>
</tr>
<tr>
<td>Broaching</td>
<td>30000.00</td>
<td>1</td>
<td>30000.00</td>
</tr>
<tr>
<td>Grinding</td>
<td>25000.00</td>
<td>1</td>
<td>25000.00</td>
</tr>
</tbody>
</table>

Total (euros per year) 687500.00

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>Expected time of utilization</th>
<th>Amortization cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>700000.00</td>
<td>70000.00</td>
</tr>
<tr>
<td>Machineries</td>
<td>687500.00</td>
<td>137500.00</td>
</tr>
</tbody>
</table>

Total (euros per year) 207500.00

Table 7.1 Calculation of Amortization cost

B. Salary: Here additional 5 indirect workers are added for the plant on the 7 direct workers found from the calculation and the total salary cost needed per year is calculated.
B

<table>
<thead>
<tr>
<th></th>
<th>Average Salary per month per person</th>
<th>Salary in euros per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>1200.00</td>
<td>100800.00</td>
</tr>
<tr>
<td>Indirect</td>
<td>2000.00</td>
<td>120000.00</td>
</tr>
<tr>
<td><strong>Total Salary cost (euros/year)</strong></td>
<td></td>
<td><strong>220800.00</strong></td>
</tr>
</tbody>
</table>

Table 7.2 Salary cost per year

C. **Electric Power Cost:** Here the power rate of the selected machineries is considered and multiplied by their quantity. Then the sum of this total power is multiplied by a factor of utilization that ranges from 0.5-0.8, by the electricity price rate (0.1 euro/kwh) and the working hours per year.

<table>
<thead>
<tr>
<th></th>
<th>Circular Saw</th>
<th>Lathe</th>
<th>Milling</th>
<th>Hobbing</th>
<th>Grinding</th>
<th>Broaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of machines</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Power of selected machine (kw)</td>
<td>1.3</td>
<td>7.5</td>
<td>7.5</td>
<td>3</td>
<td>2.2</td>
<td>11.6</td>
</tr>
<tr>
<td>Total power required (kw)</td>
<td>1.30</td>
<td>22.50</td>
<td>15.00</td>
<td>3.00</td>
<td>2.20</td>
<td>11.60</td>
</tr>
<tr>
<td>Sum of power consumed by the machineries (kw)</td>
<td>77.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor of utilization</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity price rate per kwh</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working hrs per year</td>
<td>1705</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electric Power Cost (euros/year)</strong></td>
<td><strong>9290.20</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3 Electric Power cost

D. **General Costs:** In this part general administration cost that will be incurred for the day to day operations of the plant are considered and these include telephone, water, stationary, fuel & gas, marketing, preventive and breakdown maintenance, general consumable products for the center and soon.

<table>
<thead>
<tr>
<th></th>
<th>Telephone</th>
<th>Water</th>
<th>Administration costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Per month (euro)</td>
<td>200.00</td>
<td>200.00</td>
<td>15000.00</td>
</tr>
<tr>
<td>Cost Per year (euro)</td>
<td>2400.00</td>
<td>2400.00</td>
<td>180000.00</td>
</tr>
<tr>
<td><strong>Total (euros/year)</strong></td>
<td><strong>184800.00</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.4 General costs
The hr-cost is calculated by summing up the above 4 major costs and dividing them by the product of working hours per year and the number of direct workers.

<table>
<thead>
<tr>
<th>Sum A+B+C+D (€/year)</th>
<th>622390.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Direct workers</td>
<td>7</td>
</tr>
<tr>
<td>Hours of working per year</td>
<td>1705</td>
</tr>
<tr>
<td>Hour-Cost (€/hour)</td>
<td>52.15</td>
</tr>
</tbody>
</table>

Table 7.5 Hour cost before addition of profit margin

### 7.2. Calculation of Inversion Cost and Product Selling Price

The production cost per gear box $C_p$ is calculated by the formula

$$C_p = (C_{hc} \times t_p) + C_m + C_{oc} + C_{tool}$$  \hspace{1cm} \text{Eq. 7.2.1}

Where $C_{hc}$ is the hour-cost calculated above, $t_p$ is the total time of production, $C_m$ is the cost of material, $C_{oc}$ is the cost of operations done outside the company (heat treatment and pressing) and $C_{tool}$ is the tool cost required per gear box.

<table>
<thead>
<tr>
<th>Cost of raw material per part</th>
<th>Type</th>
<th>Price ($)</th>
<th>Production Time per part (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission plate</td>
<td>Forged</td>
<td>15.00</td>
<td>83.114</td>
</tr>
<tr>
<td>Shaft3</td>
<td>Raw</td>
<td>7.08</td>
<td>340.605</td>
</tr>
<tr>
<td>Shaft4</td>
<td>Raw</td>
<td>7.00</td>
<td>454.407</td>
</tr>
<tr>
<td>Clutch Sleeve</td>
<td>Forged</td>
<td>15.00</td>
<td>113.739</td>
</tr>
<tr>
<td>Washer</td>
<td>Raw</td>
<td>0.39</td>
<td>50.355</td>
</tr>
<tr>
<td>Seal Cover</td>
<td>Cast</td>
<td>12.00</td>
<td>164.038</td>
</tr>
<tr>
<td>Head</td>
<td>Cast</td>
<td>12.00</td>
<td>297.152</td>
</tr>
<tr>
<td>Arm bracket</td>
<td>Raw</td>
<td>3.00</td>
<td>293.815</td>
</tr>
<tr>
<td>Gear 3</td>
<td>Forged</td>
<td>15.00</td>
<td>206.481</td>
</tr>
<tr>
<td>Gear 4</td>
<td>Forged</td>
<td>15.00</td>
<td>139.453</td>
</tr>
<tr>
<td></td>
<td></td>
<td>101.47</td>
<td>2143.159</td>
</tr>
</tbody>
</table>

Table 7.6 Cost of raw material
<table>
<thead>
<tr>
<th>Price</th>
<th>No of parts</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of carburizing per part (€)</td>
<td>10.00</td>
<td>5</td>
</tr>
<tr>
<td>Cost of quenching per part (€)</td>
<td>5.00</td>
<td>7</td>
</tr>
<tr>
<td>Cost of pressing per part (€)</td>
<td>2.00</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.7 Cost of operations done by external company

<table>
<thead>
<tr>
<th>Total tool price per Part (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission plate 0.867</td>
</tr>
<tr>
<td>Shaft3 4.562</td>
</tr>
<tr>
<td>Shaft4 5.415</td>
</tr>
<tr>
<td>Clutch Sleeve 1.125</td>
</tr>
<tr>
<td>Washer 0.238</td>
</tr>
<tr>
<td>Seal Cover 2.513</td>
</tr>
<tr>
<td>Head 4.900</td>
</tr>
<tr>
<td>Arm Bracket 3.564</td>
</tr>
<tr>
<td>Gear 3 5.835</td>
</tr>
<tr>
<td>Gear 4 4.806</td>
</tr>
<tr>
<td><strong>33.826</strong></td>
</tr>
</tbody>
</table>

Table 7.8 Tool Cost

| Production cost per gear box $C_p$ (€) | 255.34 |

The next step involves the calculation of the selling price of the product based on the production cost and the inversion cost of the investment. The inversion cost is calculated based on the expenses that will be needed for the first three months after the plant starts its operation.

<table>
<thead>
<tr>
<th>Calculation of Inversion Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Cost</td>
</tr>
<tr>
<td>Investment on Machineries</td>
</tr>
<tr>
<td>Construction of Production Plant</td>
</tr>
<tr>
<td>General Cost (3 months)</td>
</tr>
<tr>
<td>Salary (3 months)</td>
</tr>
<tr>
<td>Electricity Cost (3 months)</td>
</tr>
<tr>
<td>Study of the Project</td>
</tr>
<tr>
<td>Unexpected Costs</td>
</tr>
<tr>
<td><strong>Inversion Cost $C_{inv}$ (euro)</strong></td>
</tr>
</tbody>
</table>

Table 7.9 Cost of Inversion

Yared T. MAMO
The price at which the product will be sold $C_{sp}$ is given by the formula

$$C_{sp} = C_p + \left[ (C_{inv} \times (i/100))/n_p \right] + (C_p \times r)$$

Eq. 7.2.2

Where

<table>
<thead>
<tr>
<th>Interest Rate ($i$)</th>
<th>4.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Profit Margin ($r$)</td>
<td>10.00%</td>
</tr>
<tr>
<td>Number of products assumed to be sold per year ($n_p$)</td>
<td>10907</td>
</tr>
</tbody>
</table>

Accordingly the selling price of the product is found to be

Selling price of a Gear Box $C_{sp} (€)$ 286.45

7.3. Verification of Profitability of the Investment

Whatever the design of a product and its manufacturing process, at the end investing on it needs a decision-making as to whether the project is worth undertaking. There are different tools that help us analyze those situations and among them are pay back period, Net Present Value (NPV) and Internal Rate of Return (IRR). They are applied to this specific project and will be discussed in detail here under.

7.3.1. 5 Year Forecast

Forecasting includes making estimates or predictions of conditions in the project’s future based on the information and knowledgeable available at the time of the forecast. As the project progresses, the forecasts can be adjusted in such a way that fits with the existing reality.

<table>
<thead>
<tr>
<th>Forecast for 5 years</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of Product per year</td>
<td>10907</td>
<td>11452</td>
<td>12025</td>
<td>13227</td>
<td>14550</td>
</tr>
<tr>
<td>Number of direct workers</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Lathe Machine</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Milling Machine</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Circular Saw</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gear Hobbing</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Broaching</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Grinding</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7.10 Forecast of 5 years
Owing to the big volume of products assumed to be sold on the first year of production, only a 5% product increase is assumed in the 2nd and 3rd year. Starting from the 4th year, the plant is thought to export its products to neighboring countries like France and North Africa and a product growth of 10% is anticipated. The plant is also assumed to operate for the first two years with the same number of machineries and direct workers as the calculated work load (%) is well below the critical limit to add additional manpower and machineries.

### 7.3.2. Cash Flow

Based on the above 5 year forecast the respective cash flow for each year is calculated in the table below. All the possible expenditures and incomes including a 35% tax are considered and they are subtracted and added from the respective annual sale volume.

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash Flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sale Volume</td>
<td>3124292.01</td>
<td>3280506.61</td>
<td>3608557.27</td>
<td>4330268.73</td>
<td>5196322.48</td>
</tr>
<tr>
<td>Cutting Tool and Material's Cost</td>
<td>-1475616.99</td>
<td>-1918302.08</td>
<td>-2493792.71</td>
<td>-3241930.52</td>
<td>-4214509.68</td>
</tr>
<tr>
<td>Salary</td>
<td>-220800.00</td>
<td>-242880.00</td>
<td>-291456.00</td>
<td>-349747.20</td>
<td>-349747.20</td>
</tr>
<tr>
<td>Electricity Cost</td>
<td>-9290.20</td>
<td>-9290.20</td>
<td>-10219.22</td>
<td>-11148.24</td>
<td>-11148.24</td>
</tr>
<tr>
<td>General Cost</td>
<td>-184800.00</td>
<td>-184800.00</td>
<td>-184800.00</td>
<td>-184800.00</td>
<td>-184800.00</td>
</tr>
<tr>
<td></td>
<td>1235792.82</td>
<td>927243.33</td>
<td>630299.34</td>
<td>544653.76</td>
<td>438129.35</td>
</tr>
<tr>
<td>Amortization of Machines</td>
<td>-137500.00</td>
<td>-137500.00</td>
<td>-137500.00</td>
<td>-137500.00</td>
<td>-137500.00</td>
</tr>
<tr>
<td>Amortization of Plant Construction</td>
<td>-70000.00</td>
<td>-70000.00</td>
<td>-70000.00</td>
<td>-70000.00</td>
<td>-70000.00</td>
</tr>
<tr>
<td>Profit before Tax subtracted</td>
<td>1028292.82</td>
<td>719743.33</td>
<td>422799.34</td>
<td>337153.76</td>
<td>230629.35</td>
</tr>
<tr>
<td>Tax subtracted (35%)</td>
<td>-359902.49</td>
<td>-251910.16</td>
<td>-147979.77</td>
<td>-118003.82</td>
<td>-80720.27</td>
</tr>
<tr>
<td>Profit after Tax subtracted</td>
<td>668390.33</td>
<td>467833.16</td>
<td>274819.57</td>
<td>219149.95</td>
<td>149909.08</td>
</tr>
<tr>
<td>Amortization of Machines</td>
<td>137500.00</td>
<td>137500.00</td>
<td>137500.00</td>
<td>137500.00</td>
<td>137500.00</td>
</tr>
<tr>
<td>Amortization of Plant Construction</td>
<td>70000.00</td>
<td>70000.00</td>
<td>70000.00</td>
<td>70000.00</td>
<td>70000.00</td>
</tr>
<tr>
<td><strong>Net Cash Flow</strong></td>
<td><strong>875890.33</strong></td>
<td><strong>675333.16</strong></td>
<td><strong>482319.57</strong></td>
<td><strong>426649.95</strong></td>
<td><strong>357409.08</strong></td>
</tr>
</tbody>
</table>

Table 7.11 Projected 5 year cash flow
7.3.3. Pay Back Period

The Payback Period is defined as the length of time required to recover an initial investment through cash flows generated by the investment. The Payback Period lets you see the level of profitability of an investment in relation to time.

<table>
<thead>
<tr>
<th>Interest rate (i(%)</th>
<th>0.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>0</td>
</tr>
<tr>
<td>Net Cash Flow</td>
<td>-1521222.55</td>
</tr>
<tr>
<td>Cumulative Cash Flow</td>
<td>-1521222.55</td>
</tr>
<tr>
<td>Pay Back Period</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Table 7.12 Pay Back Period

Investments with a shorter payback period are generally considered to be preferable than those with longer payback period. In other words the shorter the time period to recover the investment, the better the investment opportunity.

7.3.4. Net Present Value (NPV)

The Net Present Value (NPV) of a project or investment is defined as the sum of the present values of the annual cash flows minus the initial investment. It is given by the formula

\[ NPV = \sum_{t=0}^{\infty} \frac{\text{Cashflow}_{t=0}}{(1+i)^t} \]

Eq. 7.3.1

Where \( t \) is the time of cash flow and \( i \) is the interest rate (4%).

<table>
<thead>
<tr>
<th>Interest rate (%)</th>
<th>4.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>0</td>
</tr>
<tr>
<td>Net Cash Flow</td>
<td>-1521222.55</td>
</tr>
<tr>
<td><strong>Net present value NPV</strong></td>
<td>992,894.12</td>
</tr>
</tbody>
</table>

Table 7.13 Net Present Value (NPV)
7.3.5. **Internal Rate of Return (IRR)**

The Internal Rate of Return (IRR) is a capital budgeting method used by firms to decide whether a long-term investment should be made or not. The IRR is expressed in terms of percentage and is calculated by equating the NPV formula to 0. A project is a good investment proposition if its IRR is greater than the rate of interest rate considered.

<table>
<thead>
<tr>
<th>Interest rate (%)</th>
<th>4.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Net Cash Flow</strong></td>
<td>-1521222.55</td>
</tr>
<tr>
<td><strong>Internal Rate of Return IRR</strong></td>
<td>31%</td>
</tr>
</tbody>
</table>

As obtained above the IRR=31% > 4% and it is recommended to realize the investment. The invested capital will be recovered in 1 year and 355 days and at the end of the 5th year the value of the capital will be 992,894.12.
8. Plant Layout and Location

Plant layout is often a compromise between a number of factors such as:

- The need to keep distances for transfer of materials between plant/storage units to a minimum to reduce costs and risks;
- The geographical limitations of the site;
- Interaction with existing or planned facilities on site such as existing roadways, drainage and utilities routings;
- Interaction with other plants on site;
- The need for plant operability and maintainability;
- The need to provide access for emergency services;
- The need to provide emergency escape routes for on-site personnel;
- The need to provide acceptable working conditions for operators.

Taking those factors into consideration, a preliminary layout of the plant is proposed in Fig. 8.1. The main factor considered while making the layout in this specific project is the flow of materials. After passing the raw material quality control point, the material will be temporarily stored in the stock position. Basically there are two types of raw material, those which require a cutting operation and those which don’t. Therefore the milling and lathe machines are arranged parallel to the circular disc sawing machine so that they can get the material to be processed with the minimum possible material travel time. It is also proposed to have two temporary finished part stock points because there are also parts which require a machining operation only on a lathe or milling center. The broaching, gear hobbing and grinding machines are located in the center owing to the fact that the material to be processed there comes from the lathe and milling machines. Then the final part passes through a Quality control and assembly point and will go out of the plant via the packaging and Shipment point.

Due to lack of the exact dimension of the machineries, this layout was carried out with a random dimension and needs to be revised once those data are known.
As to the possible location of the plant, like all the big cities in the world, here in Barcelona too there are marked industrial zones in which investors are advised and obliged to locate their plants. This is mainly to minimize the negative effect that these manufacturing plants would have in the day to day life of the people living around the sites. In light of this idea, the Hospitalet de Lloberga district that is located on the south-west of Barcelona is chosen to be the location of the plant. This district is one of the localized industrial zones by the municipality of Barcelona and is a home for many industries.

The exact location of the plant is shown below in the map Fig 8.2. It is located in the industrial zone “Poligon Industrial Carretera del Mig” at the end of Carrer Arquimedes.

Fig. 8.1 Proposed layout of the plant
Fig. 8.2 Location of the plant
Conclusion

In line with the intended targets of the project, the manufacturing process of each part is defined in such a way that it will minimize the cost of production and the required time and with a relatively less effort than the other possibilities that can be used. Moreover, the obligatory guidelines and formats have been developed for each part, so that it can be used by the operator for getting all the necessary information on the type of tool, measuring equipment and type of fixtures need to be used.

The cutting parameters of each part and each operation is also calculated and the output is used while selecting the type and quantity of machineries, the number of direct workers and also in the determining the viability of the project.

As can be observed from the results obtained on the economical part of the study, investing on this project is recommendable. Apart from that its design considerations and the overall small dimensions of the product as compared to the ones that already exist in the market can make it a successful business. A detailed and complete manufacturing analysis of all its components along with precise information on the cost of material and machineries can also give a more clear vision on the outcomes of investing on the project.

The wastage treatment from the plant is also another factor which needs to be considered. Regenerating some percent of the material cost from the sell of chips and scrap parts and environmental conscious removal of plant wastes are some of the points that need to be explained before the plant set up.

Once the plant is on a healthy economical state and by further consideration of the market trends, the manual machines can also be changed to an automatic one. This will further introduce the idea of setting up a flexible manufacturing cell where all the process in the plant can get automatized which will greatly help the plant to stay competitive in the modern market. This idea should also be taken in to consideration while caring out the layout of the present manufacturing plant.

After the plant is in operation, a continuous market analysis and upgrading the knowledge level of operators could also be an important factor that contributes to the continuous success of the plant.
Annex

- Annex 1 - Detailed manufacturing process of the parts.
  - Annex 1.1 – DOP and LOP of Transmission Plate.
  - Annex 1.2 – DOP and LOP of Shaft 3.
  - Annex 1.4 – DOP and LOP of Clutch Sleeve.
  - Annex 1.5 – DOP and LOP of Washer.
  - Annex 1.6 – DOP and LOP of Seal Cover.
  - Annex 1.7 – DOP and LOP of Head.
  - Annex 1.8 – DOP and LOP of Arm Bracket.
  - Annex 1.9 – DOP and LOP of Gear 3.

- Annex 2 - Calculation of cutting parameters for all parts.
- Annex 3 - Calculation of production and cycle time for all parts.
- Annex 4 - Machinery Specification, Calculation of number of machines and direct workers.
- Annex 5 – Drawing of the parts at each stage of operation (Enclosed only in the CD).
Acknowledgment

First and foremost, my cordial thanks go to my advisor Prof. Irene Buj for her continuous support throughout the project. She has been patient and helpful with all my questions and gave me the necessary assistance. I would like also to pass my sincere thanks to the EMMME consortium for giving me the chance of participating in this adventurous masters program, in which I have come across through a great deal of experience and challenges.

My special thanks are extended to Prof. Ana Barjau, coordinator of EMMME in ETSEIB for her continuous and unlimited support throughout my stay in Barcelona. All the GMC staffs of INSA de Lyon also deserve my appreciation for their part in making this program a success. My family, friends, fellow students and my roomies all thank you for everything. In our two years of stay, we have almost bonded like a family and laid a strong relationship which I believe will last forever.

And last but not of course the least; I thank God for all his blessings.

Barcelona, June 2007.
Bibliography


