Costs Assessment for a Laser-Arc Hybrid Welding Process

Guillermo González Portas
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Mechanical Engineering

Luleå University of Technology
Department of Engineering Sciences and Mathematics
Abstract

LAHW (laser-arc hybrid welding) is a process that has been thoroughly studied and improved since its creation in the 1970s. Although today it has many industrial applications, but actually it might be said that those are rarely used and that companies have a lack of confident and knowledge of this welding process. For that reason it is justified to make new efforts on to give the LAHW a business point of view in order to help introduce the process to companies.

The aim of this project is to decrease the gap between theoretical investigation and practical applications of this process. It’s mainly target is to show up which economic and organizational matters are critical for a possible implantation of LAHW processes.

The basis of the study will be a front loaders manufacturing company in which the object of the exercise and analysis will be those processes and activities where welding intervenes. From this study, cost measures will be extracted and they will help in identifying those processes that are susceptible to be replaced by an economically feasible LAHW based process. From that, not only technical advantages of LAHW should be considered, plus taking advantage of organizational benefits in order to improve the efficiency.

The company is currently developing a new products range; this Master Thesis will help them in making a decision about choosing a feasible welding process. For this, the project will be focused on analyzing whether investing in a LAHW process is worthy or not.
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1. Background

1.1 Ålö Company

The work of this Master Thesis was performed in collaboration with Ålö, a manufacturing company placed in Umeå.

1.1.1 History

Since its foundation in 1949, Ålö has been continuously developing and improving solutions for tractor’s utilities. Nowadays, it has become the world leader in this market.

In 1947, Karl-Ragnar Åström designs the first Swedish front loader for his own use. This device was named Quicke, due to the easy assembly it had. This device helped improving the exploitation of the land by permitting an easiest maintenance of tractors. In 1949, a small scale, handmade production starts and a year later the company is registered under the name Ålö-Maskiner.

In the late 50’s, Quicke is introduced to the world as the first quick-coupling front loader. Just a decade later, Ålö gained a leading position in the European market; its exports exceeded its domestic sales by that time.

During the 90’s the production of loaders increased from 5.000 to 14.000 loaders per year. A more efficient use of the resources was achieved by that time.

In 1997 Ålö acquired its main competitor; Trima. This kind of front loaders is characterized by a more simple design.

In 2004 Ålö presents the new loader products; Quicke Dimension and Trima Plus. By that time, a new factory in Brännland, Umeå was founded. New markets were established in Poland, Hungary, Bulgaria and South Africa. In this year a significant change on the production organization took place, it changed from the old-fashioned workshop to a modern Lean Manufacturing process. Sales reached their highest level that year. By 2008, orders were approximately 37.000 loaders per year.

A new factory was opened in 2008, in Tennessee, USA. This factory covers the needs of North American’s market.
Nowadays, Ålö is represented in more than 40 countries and has a leading position in more than 15 of them, producing approximately 33,000 loaders and 47,000 implements per year. The company has more than 25 percent of the world market in the segment of agricultural tractors with engines stronger than 50 hp. About 90 percent of the total production is exported. It still maintains the position as the world leader in front loaders with associated implements. [1].

1.1.2 Location

Due to its expansion, Ålö has set new factories around the world in the last years. More than that, the company set sales offices in every country in which they have market, following a decentralized sales model. This model helps giving a rapid delivery and an effective answer to customers’ demands.

Ålö has factories at:
- Brännland and Umeå (Sweden)
- Tennessee (USA)
- Matha (France)
- Ningbo (China)

Figure 1: Ålö’s factories emplacement
Umeå (Sweden) and Matha (France) factories produce for the European country. Tennessee factory produces for North America. All of them produce both kinds of front-loaders; Trima and Quicke. 50% of this sales goes for the OEM customers.

Ningbo factory produces implements and utilities for tractors.

The company has nowadays 671 employees, the biggest factory is the Swedish one followed by the factory in France.

![Employees chart](Chart1.png)

**Figure 2: Number of employees chart**

In the last years, the number of employees has decreased, due to the economic crisis and to the modernization of the factories; Automation, new organizational models as JIT, etc.

![Sales per region chart](Chart2.png)

**Figure 3: Sales per region chart**
1.1.3 Manufacturing process

The factory in Umeå produces 30,000 front loaders per year, about 650 per week.

As an overview, the manufacturing process in Umeå consists of:

1. Reception of raw materials
2. Storage (1.5 days maximum of Stock)
3. Welding
4. Handling and welding devices are automated
5. Superficial Treatments (Automated)
6. Painting (Automated)
7. Details and implements assembly (AGV vehicles)
8. Delivery

Figure 4: Manufacturing process

Our case of study is focused on the welding process:

Figure 5: Welding process

Preparation

Components are carried to the entrance of the process. Then, a worker makes the pre-assembly work by locking the components into a fixture. After, a robot makes tack welds in the arms. At this part, the process is assisted by a handling robot, which is programmed to identify each component by reading its code, and after making the needed handling operations.
After that, the pre-assembled front loader is carried by the handling robot to the welding assembly station. This space is not accessible to workers due to security matters. The MAG welding process is fully automated, and it consists of two parallel welding stations. With three welding robots each one.
Figure 8: Welding robots

Post welding

After the main welding process, the front loader is carried to a zone where another worker makes the finishing touches to the front loader. This worker also does a quality inspection, in order to identify any welding defects (e.g. spatter).

Figure 9: Post welding, TIG welding & Quality inspection
1.1.4 Products

Ålö has a guide range of front loaders, covering every specification in customers’ needs. Their front loaders are classified in two kinds; Quicke and Trima.

**Quicke**

This range is divided in three series, each one covering a different range of utilities, from small tractors of 20hp to bigger ones of more than 200hp.

These series are: “Compact”, “200” and “Dimension”.

![Figure 10: Quicke Compact (180C)](image1)

![Figure 11: Quicke 200 Series (260N)](image2)
The operational range for the different Quicke series can be seen in the next table:

<table>
<thead>
<tr>
<th>Series</th>
<th>Compact</th>
<th>200</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor size (hp)</td>
<td>20-60</td>
<td>40-110</td>
<td>70-200</td>
</tr>
<tr>
<td>Loader weight (kg)</td>
<td>175-280</td>
<td>310-445</td>
<td>436-935</td>
</tr>
<tr>
<td>Lifting force (kgf)</td>
<td>930-2610</td>
<td>1870-2770</td>
<td>2350-4450</td>
</tr>
<tr>
<td>Lift height (m)</td>
<td>1,9-2,81</td>
<td>3-3.9</td>
<td>2,35-4,95</td>
</tr>
</tbody>
</table>

**Trima**

This range is characterized by a simpler design than the Quicke one. It is also divided in three series; “Compact”, “200” and “Plus”.

---

*Figure 12: Quicke Dimension Series (Q98)*

*Figure 13: Quicke series*

*Figure 14: Trima series; Compact, 200 and Plus*
### Series

<table>
<thead>
<tr>
<th></th>
<th>Compact</th>
<th>200</th>
<th>Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tractor size (hp)</strong></td>
<td>20-60</td>
<td>40-110</td>
<td>50-200</td>
</tr>
<tr>
<td><strong>Loader weight (kg)</strong></td>
<td>175-280</td>
<td>310-445</td>
<td>436-935</td>
</tr>
<tr>
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<td>930-2610</td>
<td>1870-2770</td>
<td>2350-4450</td>
</tr>
<tr>
<td><strong>Lift height (m)</strong></td>
<td>1,9-2,81</td>
<td>3-3,9</td>
<td>3,2-4,95</td>
</tr>
</tbody>
</table>

*Figure 14: Trima series*

The only difference between the two models linked to their implementation, is that Trima has a wider range of front loaders in the Plus series, in the range of low power of big tractors.

**Implements**

Apart from the main products (front loaders), Ålö also produces utilities for tractors. Implements consist of wide range of products, such as:

- Silage grips
- Buckets
- Forks
- Lifting implements

*Figure 15: Implements; Silage grip, bucket, lifting implement*
1.2 Welding

Welding is a fabrication process used to join similar or different metal types, to achieve a continuous piece.

Most methods and welding processes are currently associated with local heating and cooling of the material to be welded. These methods require an energy input, in the form of heat input, to elevate the temperature in the weld joint and to melt the filler material.

The heat input produced by the source causes some changes in the microstructure of the metal. For that reason, there is a region which is close to the weld joint that is affected by the heat input; it is called HAZ, Heat Affected Zone. There are some problems that appear due to these thermal processes, which are very significant in the frame of modern welding manufacturing. Some of them are: cracks, distortion, gas inclusions (porosity), no-metallic inclusions, lack of fusion, incomplete penetration, lamellar tearing and undercutting.

There are many different types of welding processes and it is very complicated to make a systematic classification of them. Some classifications attend to:

- Energy input: Arc welding, joule effect, mechanical energy, chemical energy, radiate energy...
- Physical processes in the joint: Fusion, solid state, solid-liquid interaction.
- Shielding types: Inert gases, active gases...

![Figure 16: Welding classification [2]](image-url)
There are two important standardized classifications, one in the ISO 4063 and the other done by the AWS. The first one identifies each method with 1, 2 or 3 digits. The second one is regulated by the American Welding Society and is commonly used in North America.

<table>
<thead>
<tr>
<th>Name</th>
<th>ISO 4063</th>
<th>AWS</th>
<th>Description</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas metal arc welding</td>
<td>131,135</td>
<td>GMAW</td>
<td>Continuous consumable electrode and shielding gas</td>
<td>Industry</td>
</tr>
<tr>
<td>Gas tungsten arc welding</td>
<td>141</td>
<td>GTAW</td>
<td>No consumable electrode, slow, high quality welds</td>
<td>Aerospace, construction</td>
</tr>
<tr>
<td>Plasma arc welding</td>
<td>15</td>
<td>PAW</td>
<td>No consumable electrode, constricted arc</td>
<td>Tubing, Instrumentation</td>
</tr>
<tr>
<td>Laser beam welding</td>
<td>521,522</td>
<td>LBW</td>
<td>Deep penetration, fast, high equipment cost</td>
<td>Automotive industry</td>
</tr>
<tr>
<td>Laser arc hybrid welding</td>
<td></td>
<td>LAHW</td>
<td>Combines laser beam welding with arc welding</td>
<td>Automotive, shipbuilding, steelwork industries</td>
</tr>
</tbody>
</table>

**Figure 17: ISO/AWS welding classification**
1.2.1 Laser-Arc Hybrid Welding

Hybrid laser-arc welding is noted as a promising joining process since it can compensate for the drawbacks or weaknesses in laser welding and arc welding by utilizing both features.

Laser welding has gained great popularity as a promising joining technology with high quality, high precision, high performance, high speed, good flexibility and low distortion.

Furthermore than these technical aspects, this welding process also offers some great benefits by permitting a full automation, reduced man-power and systematization of manufacturing lines.

Hybrid welding with CO2, YAG, diode, disk, or fibber laser and TIG, MIG, MAG, plasma or another arc heat source can achieve many advantages such as deeper penetration, higher welding speeds, wider gap tolerance, better weld bead surface appearance and reduced welding defects leading to a smaller amount of porosity.

1.2.1.1 Heat sources of LAHW processes

Heat source refers to the thermal tool that is used in the fusion welding process. Its energy is transformed, with a determinate performance ratio, into internal energy at the weld zone between the parts to be joined. The amount of energy must be sufficient to melt locally the material and sometimes some additional material (filler).

There are many different types of welding heat sources. The election of the heat source for any particular welding assignment depends on a multitude of factors.

An important characteristic of the heat sources is the energy density; Laser and electrode are high energy density sources since its intensity is much higher than the electrics arcs one.

LAHW uses a combination of high and low energy density by combining the electric gas-shielded arc and a laser beam.

1. Laser sources

Only some types of lasers can be used for welding processes. A high output power is required for that kind of application.

The most important features that a laser source must reach are the emitted wavelength of the used lasing medium, the power conversion
efficiency, the maximum output power available and the mobility of the laser system.

Some laser sources are detailed below, being the most popular the CO2 and the Nd:YAG.

**CO2**

Is the most popular gas laser for material processing nowadays.

One of the most important disadvantages of this laser is the long wavelength of the emitted radiation. One consequence is the high reflectivity of metals commonly used in materials processing and the increased interaction of the radiation with laser-induced plasmas. Due to this, Helium is needed as a shielding gas.

**Nd:YAG**

It has a shorter wavelength than the CO2. However, it has an important disadvantage, which is that the beam quality decreases with increased output power. For that reason the beam quality is considerably lower than the beam quality of the CO2.

In contrast with this disadvantage, the Nd:YAG laser present some interesting advantages. First, the possibility of leading the laser beam through optical fibres, what can permit the use of a robot or make easier the welding processes in complex three-dimensional structures.

Another important advantage is that there is no significant interaction between the incident laser radiation and the generated metal vapour, and, therefore, the problem of perturbing plasma as present in deep penetration laser welding with CO2 lasers does not occur. Argon gas can be used as a shielding gas instead of the more expensive Helium.

**Disc and fiber laser**

The main advantage of these lasers is the possibility of delivering the beam through optical fibres. They also offer high optical output powers, high conversion efficiencies, high beam qualities and a short emission wavelength.
**Diode laser**

For a long time, high-power diode laser systems were limited to low output powers and low beam qualities. The focal intensities only permitted welding applications in the heat conduction mode. However, recently the laser beam power and beam quality have been improved, allowing a deeper penetration in welding processes.

One important advantage of diode laser systems is their compact size and low weight, which is very useful for its use in robotically welding processes.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitted wavelength (µm)</td>
<td>10.6</td>
<td>1.06</td>
<td>1.06</td>
<td>1.03</td>
<td>1.07</td>
</tr>
<tr>
<td>Power efficiency (%)</td>
<td>10-15</td>
<td>1-3</td>
<td>10-30</td>
<td>10-20</td>
<td>20-30</td>
</tr>
<tr>
<td>Maximum output power (kW)</td>
<td>20</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>BPP at 4 kW (mm mrad)</td>
<td>4</td>
<td>25</td>
<td>12</td>
<td>2</td>
<td>0.35</td>
</tr>
<tr>
<td>Fibre beam delivery</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Maintenance interval (h)</td>
<td>1000</td>
<td>500</td>
<td>10000</td>
<td>&gt;25000</td>
<td>&gt;30000</td>
</tr>
</tbody>
</table>

*Figure 18: Feature comparison for typical materials processing laser sources [2]*

2. **Arc heat sources**

The welding arc is based on an electrical gas discharge between two open terminals; the welding electrode and the work piece. There is a gaseous zone between these terminals, which is partially ionised. The circuit closes through the visible plasma arc and permits the transfer of energy between the electrode and the work piece.

Arc welding processes require a continuous supply of electric current of sufficient amperage and voltage to maintain a stable arc. This current may be either alternating (AC) or direct (DC). The device that supplies this current is called the power source.

The election of determined type of power source is essential for controlling the arc characteristics needed for a specific job.

The welding process requires a determined type of power source:

<table>
<thead>
<tr>
<th>Welding process</th>
<th>Output characteristics</th>
<th>Type of current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shielded metal arc</td>
<td>Variable voltage</td>
<td>AC or DC</td>
</tr>
<tr>
<td>Gas tungsten arc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submerged arc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas metal arc</td>
<td>Constant voltage</td>
<td>DC</td>
</tr>
</tbody>
</table>

*Figure 19: Current and voltage for power sources*
The election of the polarity of the electrodes is very significant, it has a strong influence in the welding result because of the different amounts of energy that are dissipated within the cathodic and anodic spot. Approximately 70% of the total amount of heat is generated at the anode and 30% at the cathode.

**Non consumable electrodes**

This process utilizes an electrode which does not melt. It generates an arc to melt both the base metal and the welding consumable.

Gas tungsten arc welding and plasma arc welding are typical processes of this type.

**GTAW**

An advantage of the GTAW process is that the addition of filler material is separated from the electric circuit. This separation enables an independent determination of amperage and filler metal deposition rate, what is very helpful when trying to establish optimal parameters for a certain welding.

However, in some situations there is no need of filler material. In these cases, there are no molten droplets of spatter. Consequently, high-quality welds are achieved with this process.

Tungsten inert gas (TIG) and plasma arc welding (PAW) are two important variants of GTAW.

![Schematic of a GTAW set up.](image)

**Figure 20: Schematic of a GTAW set up. [2]**
Consumable electrodes

The welding consumable serves as the electrode to generate an arc and simultaneously as the filler metal to supply the deposited metal for the weld.

There are many types of arc welding sources with consumable electrodes, such as shielded metal arc welding (SMAW) process using electrodes with an external flux coating, the submerged arc welding (SAW) process using a layer of flux that covers the weld zone and protects the molten material from reaction with oxygen and nitrogen in the air, and the gas metal arc welding (GMAW) in which the weld zones is protected by a shielding gas.

With respect to LAHW, the GMAW process is of primary interest.

The GMAW uses a continuously fed electrode wire with the composition that is similar to the base metal composition. The electrode and base material are shielded from the atmosphere by use of a shielding gas.

Figure 21: Schematic of a GMAW set up. [2]

There are two types of GMAW processes, depending the shielding gas; Metal inert gas (MIG) usually applied for joining of aluminium and stainless steel and Metal active gas (MAG) welding for joining of mild steels, low-alloyed steels and nickel alloys. MAG uses CO₂ and several gas mixtures, which are based on Ar and contain additions of O₂, CO₂ and He.
1.2.2 Election of the welding technology

Before making a definitive election of the welding technique for this case, some factors shall be considered.

- The welded workpiece must have at least the same Yield Strength and Tensile Strength of the material.
- The whole process time and costs shall be considered; pre and post treatment of the workpiece shall be taken into account.
- A high welding speed is wanted. However this factor usually means a higher power output, thus, the solutions should have a balance between these aspects.
- Modern industries require a high level of flexibility, according to Lean Manufacturing principles. For that reason, some characteristics are recommendable:
  - Movable
  - Low set-up time
  - Low maintenance
  - Flexible; adaptable to new processes
  - Hours of use. Devices should not be stopped

Despite the case shows a welding problem of a single component, the election should be made in order to be applicable to other components.

1.2.2.1 Comparison between laser welding against other welding technologies

Laser welding is becoming a technology commonly used in different industries. In this section, the main advantages and disadvantages of laser welding against conventional technologies shall be presented.

One of its advantages is the ability to focus the laser beam in a small area and move the beam with a relatively high velocity through the joint to be welded. In this aspect laser beam welding is comparable to electron beam welding, but has the added advantage that it can be carried out at atmospheric pressure. [3] Nevertheless, with E-beam there is no need of using shielding gas.

Electron beams can produce a smaller spot than laser, thus, high intensities act on the workpiece. Very high welding speeds can be reached with this technology.
Due to the extremely low divergence of E-beams compared to laser beams, very large penetration depths up to 1m are feasible.

E-beams present some important disadvantages against lasers:

- E-beam systems are even more expensive than laser systems
- The process must be carried into a vacuum chamber; Thus, the size of the workpiece is limited and, an interruption of the production flow is necessary for evacuating the chamber. Therefore production time and cost are strongly increased.
- Safety requirements are higher. The latter radiation is very dangerous and therefore the vacuum chamber must be strictly shielded to avoid any exposure of operating staff. [4]

Laser welding can be used in more different situations than E-beams. For example in 3D components where the introduction of electron beams is impossible.

An important advantage that laser welding shows in this particular case is that there are some kind of joints that with conventional systems such as MAG or TIG should be welded from different sides and positions. The lap joint of our components can be welded by one side when using laser welding, as it has been determined in the Ålö – IndLas demonstration. This is a possibility that opens many doors in joint designing. For example, welds could be done near the neutral line of the workpieces.

Another welding technique that should be considered is TIG (tungsten inert gas) welding. In this process usually a filler wire is supplied to the melt pool. Since the cross section of the arc at the workpiece is much larger than the focus of a laser beam, the width of the weld seam must also be considerably larger, what means that a higher volume of the workpiece must be molten and thus stronger heat supply is necessary.

Since then, also more heat is lost into the workpiece by heat conduction and thermal stresses and deformations are more significant. Due to the larger volume to be molten, usually the welding speed is smaller. [4]

The cost of the TIG equipment is much lower than the laser one, although the production cost per unit is much higher because of the lower welding speed and the need of adding filler wire and shielding gas.

Another welding technology to be considered is MAG (metal active gas welding). It is a very common technology used in welding processes. It has some significant advantages, such as flexibility and
low cost of implantation. Other important characteristic of MAG welding is the possibility of automation and robotization. The disadvantages of this welding technique are:

- As in TIG welding, the cost per unit is higher than in laser welding, because of the lower welding speed and the need of adding filler wire and shielding gas.
- Worse weld appearance
- Emissions of the combustion process
- Higher input energy

Some disadvantages of laser welding and MIG/MAG welding are avoided when using an hybrid process; LAHW. It has gained great popularity as a promising joining technology with high quality, high precision, high performance, high speed, good flexibility and low distortion. Otherwise, this technology requires a high investment, due to this, LAHW devices must have a great degree of utilization in a company, in order to reach accurate paybacks. Another important disadvantage is the lack of “know how” that companies have about this technology.

After this comparison between laser welding and other technologies, some general advantages of laser utilization on welding processes shall be presented:

- Small heat-affected zone
- Deep penetration
- High processing speed
- Allows using the same device for welding/cutting
- Cost reductions
- Enhance productivity
- Flexibility, fast setups achieved with computer control
- Full automation
- Non-contact processing avoids unwanted stress on materials
- Can make some 3D welds with 2D systems (as in lap joints)
- Reduces man-power

1.2.2.2 Advantages of LAHW

This process combines the main advantages of both processes; laser welding and GMAW. It can reach a deep penetration and high speed (associated with laser welding) and higher gap tolerance (associated with GMAW). The amount of filler wire that is needed is also reduced. LAHW also inherits a slower cooling rate from GMAW, which gives more stability and strength to the workpiece.
Figure 22: Graphic illustrating differences between GMAW, Laser and LAHW weld profiles [5]

The main advantages of LAHW are:

- Deeper welding penetrations and higher welding speeds
- Can be performed in all welding positions
- Lower heat input and less distortion than GMAW
- Can produce narrow welds with small HAZ
- Higher gap tolerance than conventional laser welding
- Can be used with a wide range of metal alloys
- Automated process
- Reduces man power
- Flexibility

Its limitations are:

- Limited implementation in production manufacturing
- Higher investment cost
- Additional safety requirements, compared to GMAW [6]

1.2.2.3 Election

After comparing the different welding technologies, the conclusion is that laser arc hybrid welding is a feasible solution for the case of study.

LAHW is meant to be an advantageous technology, not only because of its technological aspects (smaller HAZ, deep penetration, etc) if not that it can also improve productivity as it permits higher welding speeds and full automation.
Another significant benefit is that a specific welding device can provide a good degree of flexibility into a company. This technology supports different welding geometries, so it might be adaptable to future changes. Nowadays, considering the uncertainty of the demand and the changes in the habits of the customers, new equipments should be easily adaptable to changes.
2. Calculation model background

Ålö is currently developing a new range of products. At this point they are starting to design a new welding process that results efficient and economically feasible. For that reason, the work of this Master Thesis will be to analyze how the implantation of a LAHW process would influence the costs.

The methodology for this will be:

1\textsuperscript{st}: Analyze the costs of the current welding process

2\textsuperscript{nd}: Analyze the costs of the current welding process as if it was working with LAHW devices

3\textsuperscript{rd}: Comparing the two costs will lead to an operational savings result

4\textsuperscript{rd}: For the new range of products, the expected cost and investment will be calculated, assuming that the savings will be the ones before calculated

For developing these steps, a LCC cost model will be used, which is described in the section 2.3.

2.1 Costs analysis

This section will try to show the needed theoretical information for reaching a sound knowledge about accounting and costs analysis.

2.1.1 Goals

Cost accounting analyzes how the expenses and revenues that a company generates are distributed between:

- The different products and/or services that a company manufactures or commercializes
- The different departments-sections of the company
- Its customers

It allows knowing the costs of each part of the manufacturing process. In our case of study, a cost of the welding process will be predicted.
Cost accounting also permits valuating inventories, in relation to the expenses they have generated in a certain part of the manufacturing process.

Once a suitable model of costs is implemented, it is possible to detect if there are activities, products or customers where the company loses money.

Finally, it permits fixing the price of each product with a determined margin.

2.1.2 Classification

There are several ways of classifying costs, depending on:

*Assignment:*

a. Direct Costs

They can be easily charged to the product.

Direct costs are further classified into:

i. Direct materials: Cost of the materials that can be assigned directly to the product in a certain part of the process. For example: raw materials (steel), components.

ii. Direct labour: Represents the cost of the man power spent in a certain part of the process, when it can be assigned directly.

The sum of the cost of direct materials and direct labour is called “Prime Cost”.

Manufacturing overhead: Represents the rest of the direct costs; electricity, depreciation, etc. [7]

b. Indirect costs

It includes the rest of the costs, for example: marketing costs, administrative costs, rents, consumables (filler wire in a welding process), etc.

*Variability:*

Attending to their variability, costs can be Fixed or Variable. When a company changes the level of its activity, some costs stay stable
(rent, investments, etc.) and some change (raw materials, labour cost, etc.)

In some cases it is doubtful to make a distinction between them, sometimes a cost can change under a determinate circumstance, for example the cost of the energy.

2.1.3 **Breakeven Point**

The breakeven Point represent the level of sales that covers the expenses (fixed and variables). From this point, the company starts to have profits, that is; expenses are equal to revenues.

![Breakeven Point Diagram](image)

**Figure 23: Breakeven point**

The goal of the company should be to reduce the Breakeven Point. There are three ways to reach this goal:
• Reducing fixed costs

Figure 24: Influence of fixed costs on B.P.

• Reducing variable costs

Figure 25: Influence of variable costs on B.P.
• Increasing the price of sales

**Figure 26**: Influence of the sales’ price on B.P.

### 2.1.4 Methods for calculating costs

There are two sources for the input information:

- General accounting
- Information about production times, performance, remains, devices, etc.

It is also necessary to define a period for calculating costs, which should be short enough to avoid any change in the value of the costs.

All the different methods for calculating costs charge in the same way the direct costs to the final product. They differ on how they distribute the indirect costs. [8]

#### 2.1.4.1 Empirical method

This method is considered old-fashioned since it leans on the concept of general costs, nowadays in disuse. It considers the general costs
(all the costs except labour and raw material) without analyzing its components, and then charges its value to the final product with a single coefficient.

2.1.4.2 Homogeneous sections

This model introduces a more flexible and “just” concept for distributing costs between the different products.

Products do not go through every section in a manufacturing process; therefore, it is not accurate to gather all the indirect costs without distributing them between the different sections.

For distributing indirect costs between the different sections, we use the term “Work Unit”. The Work Unit can be a complex or simplex unit and it is different for each section.

For example: a section could be “Painting”, and an indirect cost could be “Rent”. In that case, we would use as a work unit “square meters”.

The methodology of this model is the next:

1. Classify cost between direct and indirect
2. Define work units for each section and distribute indirect costs in these sections
3. Divide sections in main sections and auxiliary sections
4. Charge the auxiliary sections to the main sections
5. Total number of work units and its costs
6. Calculate the unitary cost

2.1.4.3 Standard costs

This method is a continuation of the previous models. It is based on calculating and controlling variances of a determined model. A periodic analysis allows finding variances caused by changes in prices and in quantities of raw materials.

This method is found to be a very strong tool and it cannot be implanted without setting a previous model. When the deviations between predictions and reality are significant, it is necessary to define a new costs model.
The main advantages of this method are:

- It provides an essential help for price formulation
- Helps valuating stocks
- Variances that appear when comparing standard cost with the real cost, allow making decisions for management control

**Calculation of deviations:**

**a. Raw materials**

Is a direct cost which originates two kind of variances; technical and economic.
<table>
<thead>
<tr>
<th>Term</th>
<th>Prevision</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_s$</td>
<td>Unitary quantity of raw material per product</td>
<td>Standard</td>
</tr>
<tr>
<td>$a_r$</td>
<td>Unitary quantity of raw material per product</td>
<td>Real</td>
</tr>
<tr>
<td>$p_s$</td>
<td>Production</td>
<td>Standard</td>
</tr>
<tr>
<td>$p_r$</td>
<td>Production</td>
<td>Real</td>
</tr>
<tr>
<td>$i_s$</td>
<td>Price</td>
<td>Standard</td>
</tr>
<tr>
<td>$i_r$</td>
<td>Price</td>
<td>Real</td>
</tr>
</tbody>
</table>

**Figure 28: Deviations**

- **Technical variance ($D_t$)**

 Represents the difference between standard consumption of raw materials and the real consumption, for a certain production evaluated at standard price. [8]

$$D_t = [(p_r \times a_s) - (p_r \times a_r)] \times i_s = p_r \times i_s \times (a_s - a_r)$$

- **Economic variance ($D_e$)**

 Represents the difference between standard price and effective price, for a certain quantity of raw materials.

Raw materials are storable; therefore, there is a time gap between the moment of its acquisition and the moment when it is introduced in the productive process. Due to this, it is necessary to consider two different components for the economic variance; The first one is calculated in the moment of the acquisition and the second one in is calculated when raw materials are introduced in the productive process. For the second economic deviation, indirect costs should be considered. Variances caused by indirect costs have a different treatment than the direct costs ones.[8]

$$D_{e1} : \text{Economic variance (in the acquisition moment)}$$

$$D_{e1} = [(a_r \times i_s) - (a_r \times i_r)]$$

Global deviation in raw materials: $D_T$

$$D_T = D_t + D_e$$

31
b. Direct labour

It is also a direct cost, therefore, it will be calculated in a similar way as in the raw materials case.

- Technical variance ($D_t$)

Represents the difference between the standard time for a certain production, and the real time spent in this production. It measures the productivity of the human factor. [8]

$$D_t = [(p_r \times b_s) - (p_r \times b_r)] \times i_s$$

$b_s$: needed time per product

$i_s$: price per hour

- Economic variance ($D_e$)

It involves the actual cost of direct labour in comparison to the standard cost of direct labour. It is caused by the difference between the real and the standard price of labour in a certain production. [8]

$$D_e = [(b_r \times i_s) - (b_r \times i_r)] \times p_r$$

Global variance in labour: $D_T$

$$D_T = D_t + D_e$$
2.2 Capital budgeting analysis

2.2.1 Investments

Investments are understood as fixing funds with the aim of generating benefits in the future. Investments should be analyzed along a determined time horizon.

Therefore, it is necessary to compare capital amounts in different moments of time (current investments against future refunds), and hence, it is also necessary to make the appropriate adjustments to the value of money.

2.2.2 Time value of money

A certain amount of money today has different value than the same amount of money in the future. This is caused because there is an opportunity to earn interest on the money and because inflation makes prices go up. An Euro received today is more valuable than an Euro to be received in the future.

The variable that links the present and future values is called Interest Rate (IR).

2.2.2.1 Future value

The capitalization is the process through which the future value of money of a present amount is calculated, considering a given Interest Rate.

a) Simple capitalization method

This method only considers the accumulation of the amounts, regardless of compounding (earning interest on interest).
Figure 29: Simple capitalization method

\[ FV = PV \times (1 + n \times r) \]

The unit of time can be different from a year, but it must be the same unit for which the interest rate is measured. [9]

a) Compound capitalization method

This method considers the compounding on interests that are generated in every period of time.

Figure 30: Compound capitalization method
Notice that the power of compounding is very significant. It can be illustrated by computing how long it takes to double the value of an investment:

<table>
<thead>
<tr>
<th>Interest Rate (r)</th>
<th>Time Until Initial Value is Doubled</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>35 years</td>
</tr>
<tr>
<td>0.05</td>
<td>14.2</td>
</tr>
<tr>
<td>0.10</td>
<td>7.3</td>
</tr>
<tr>
<td>0.15</td>
<td>5.0</td>
</tr>
<tr>
<td>0.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

*Figure 31: Double to 72 rule. [9]*

A useful rule in finance is the “double-to-72” rule, where for wide ranges of interest rates, \( r \), the approximate doubling time is \( 0.72/r \).

Concluding with the future value of money, the equation for this method is:

\[
FV = PV \times (1 + r)^n
\]

- \( c_n \) = Future value
- \( c_0 \) = Present value
- \( n \) = Number of periods in the time horizon
- \( r \) = Interest Rate

### 2.2.2.2 Present value

Today, most part of the companies use different variations of discounted cash flow techniques (DCF) in their capital budgeting. To realize a DCF analysis, it is necessary to find the present value of future sums of money. Due to this, the needed mathematic operations will be shown:

\[ a) \text{ Simple discount method} \]

It is the reverse process to the simple capitalization. It determines the present value of a future amount of money, without compounding.
Figure 31: Simple discount method

\[ PV = \frac{FV}{(1 + r \times n)} \]

\[ [9] \]

\[ b) \text{ Compound discount method} \]

It is the reverse of the compound capitalization method, thus, it considers compounding (earning interest to interest).

Figure 32: Compound discount method

\[ PV = \frac{FV}{(1 + r)^n} \]
2.2.3 Parameters to assess

When making an investment, some concepts should be taken into account.

a) Initial outlay

It includes:

- Purchase price of acquisition
- Set-up expenses; Transport, assembly, training actions, etc.
- Investment in current assets
- Fiscal adjustments

b) Time horizon

It is defined as the period in which the investment generates cash flows. If the investment is in fixed assets, it is recommended to approximate the time horizon to the service life of the device, without going over 10 years.

c) Cash-Flow

The cash-flow of an investment is defined as the difference between the inflow and the outflow cash which the investment generates in each period of time along the time horizon. They are the amounts of money that are available at the end of each period of time.

Usually, these periods coincide with the financial year.

Inflows to be considered:

- Earning increments
- Fixed and variable cost reduction
- Tax savings caused by the increase of depreciations.

Outflows to be considered:

- Earning reductions
- Fixed and variable cost increments
Fixed or current assets investments linked to the main investment

d) Investment risk

It is the probability that the project do not generate the previewed profits or even generates losses.

The profitability of a project is the interest rate that links the initial expense with the future cash flows. From that standpoint, the profitability is called Discount Tax; the higher the risk is, the higher the Discount Tax should be.

Therefore, the discount tax includes: The interest rate and the risk premium. The risk premium is included in order to consider the risk of the investment.

2.2.4 Methods of investment analysis

Each method of investment analysis has limitations and advantages, and frequently they are used in combinations with each other. If we take a group of investment proposal and rank them by each of these methods, we shall find that each method will frequently give a different ranking to the same set of investment proposals.

There are some aspects that any method must fulfill:

- Every cash-flow must be taken into account
- It must include opportunity costs

For example; if a warehouse is used for a new product and the alternative is to rent the space, the lost rentals are the opportunity cost, and they should be taken into account.

- With mutually exclusive investments, the one that maximizes the wealth of the stockholders must be chosen

The next table of contents shows the frequency of use for different methods:
<table>
<thead>
<tr>
<th>Method</th>
<th>Use (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Rate of Return (IRR)</td>
<td>75,61</td>
</tr>
<tr>
<td>Net Present Value (NPV)</td>
<td>74,93</td>
</tr>
<tr>
<td>Payback Period</td>
<td>56,74</td>
</tr>
<tr>
<td>Hurdle Rate</td>
<td>56,94</td>
</tr>
<tr>
<td>Sensitivity Analysis</td>
<td>51,54</td>
</tr>
<tr>
<td>Earnings Multiple Approach</td>
<td>38,92</td>
</tr>
<tr>
<td>Discounted Payback Period</td>
<td>29,45</td>
</tr>
<tr>
<td>Accounting Rate of Return</td>
<td>20,29</td>
</tr>
<tr>
<td>Simulation Analysis</td>
<td>13,66</td>
</tr>
<tr>
<td>Adjusted Present Value</td>
<td>10,78</td>
</tr>
<tr>
<td>Profitability Index</td>
<td>11,87</td>
</tr>
</tbody>
</table>

Figure 33: Frequency of use on investment analysis methods [10]

2.2.4.1 Payback

It is the length of time required to recover the cost of an investment. It is one of the simplest and most commonly used methods in investment analysis.

There are two variations of this method:

   a) Simple Payback

It is a static method since it does not consider the moment in time when the cash-flows occur.

In accordance with this method, any investment is feasible if its Payback is below a certain term, defined by managers. Between several projects, the best choice is the one which has less Payback.

This method presents some significant limitations. The next example shows one of these limitations.

Consider two different investments, A and B, with the next cash-flows:

<table>
<thead>
<tr>
<th>Inv. A</th>
<th>-1000</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inv. B</td>
<td>-1000</td>
<td>1000</td>
<td>100</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 34: Alternatives, example

The accumulated cash flow is shown in the next chart:
Investment B has a Payback of 1 year, while investment A has 1.5 years. According to this; PB(B) < PB(A), therefore, investment B is more feasible than A. However, just taking a look at the chart, we can realize that investment A generates much higher profits than B.

In conclusion, the Payback period does not consider what happens after recovering the initial investment. Another limitation of this method is that it does not consider the moment in time of the cash-flows; value of money is not actualized.

b) Discounted Payback

This method is similar to the one above, however, it actualizes the cash-flows, in order to avoid one of the limitations.

Considering the same example with an interest rate of 10%:

\[
*PV = \frac{FV}{(1+r)^n}
\]

Figure 35: Simple Payback example chart

Figure 36: Discounted payback. Example with IR=10%
Considering actualization, B does not make any profit and A has a Payback of 1.66 years. Therefore A results more feasible than B.

However, this method also presents some limitations:

It does not consider what happens after recovering the initial investment. This, despite being a limitation, in some cases is considered an advantage; It gives more relevancy to the first cash-flows, which are the most likely to happen.

Another limitation is that the maximum period that makes an investment feasible, is found an arbitrary decision.

2.2.4.2 Net Present Value (NPV)

NPV is a widely used investment analysis method.

The net present value method is a direct application of the present value concept. Its computation requires the following steps:

a. Choose an appropriate rate of discount

NPV decreases when rate of discount (Discount tax) increases, as shown in the next chart [6]
b. Compute the present value of cash inflows expected from investment

c. Compute the present value of cash outflows required by the investment

d. Add the present value equivalents to obtain the investment’s NPV

The NPV method studies whether a company is generating or destroying value with an investment.

Following the NPV criteria, decision making must consider:

If NPV>0: The investment is acceptable

If NPV<0: The investment is regrettable

If NPV=0: The investment does not generate value, thus it is regrettable.

If there are different alternatives, following the NPV criteria, the most suitable is the one that has a higher NPV.

The formula for NPV is:
A significant matter when calculating the NPV is to choose an appropriate tax of discount; it is one of the most subjectively concepts in economic assessment.

As it was explained in the section 2.2.3.d (Investment risk), the tax of discount includes the interest rate and the risk prime:

\[ r = k_0 + rp \]

The minimum profitability an investment must keep is the cost of equity \((k_0)\). The cost of equity is the cost in which the company obtains its financing. Companies have two financing sources:

- Self-financing
- External financing

Each kind of financing has an associated cost; \(k_e\) (self-financing) and \(k_i\) (external financing). Then, the way of calculating the cost of equity is by weighing factor:

\[
k_0 = k_e \frac{E}{L+E} + k_i \frac{L}{L+E}
\]

\(E=\) Equity
\(L=\) Liabilities

In spite of being a relatively suitable tool for investment analysis, NPV also presents some limitations:

- It assumes that each cash-flow is compounded with the same tax of discount, what, in many cases is not very probable
- For large time horizons, it is not easy to make forecasts about the future cash-flows
In some cases, the election between different alternatives depends on the tax of discount used.

### 2.2.4.3 Internal rate of return (IRR)

IRR is defined as the discount tax that makes $NPV=0$, this is:

$$NPV = -A_0 + \sum_{t=1}^{n} \frac{CF_t}{(1 + r^*)^t} = 0; \quad IRR = r^*$$

It can be also defined as the minimum profitability that an investment requires. The profitability of a project must be at least the same as the cost that the company has to assume to finance the project.

If $IRR > k_0$: The investment generates value, thus is acceptable

If $IRR < k_0$: The investment destroys value, thus is regrettable

Usually, investments consist in a first outlay followed by revenues, in these cases, we will have only a single value for IRR. Although, when an investment requires several outlays in time, the cash flows can change from positive to negative many times, in these cases there might be several IRR values.

Therefore, the condition that guarantees the existence of a single IRR value is:

- FC must change from + to − just once
- The sum of FC < 0 must be inferior to the sum of FC > 0

In other cases, it is recommended to use the James C. T. Mao algorithm. [9]

### 2.2.4.4 Sensibility analysis

This method studies how $NPV$, $IRR$, etc. values change when modifying each one of the variable of the project. This allows knowing which variables are more important towards the expected value of the project. A precise effort on predictions should be focused on these variables.

For this, any cost category can be modified in order to show how results vary. It is common to focus the analysis in those variables which have more level of uncertainty. Variables that are often studied are:
- Acquisition cost
- Project life
- Discount tax
- Man hour rate
- Residual value
2.3 Life Cycle Cost

2.3.1 Introduction

Life cycle cost (LCC) is an analytic method for estimating the whole amount of costs that an asset will incur during its lifetime. The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives so the least long term cost of ownership is achieved while considering cost elements which include design, development, production, operation, maintenance, support, and final disposition. LCC is the sum of acquisition, logistic support and operating expenses. [11]

It is a fact that many times, expenses generated by the use of equipment during its lifetime exceed the initial purchase investment. Therefore, LCC is meant to be a strong tool for decision making, under an engineering point of view.

Any cost that appears in a certain project must be taken into account, therefore, each project has different expenses and due to this there each project will have a modified LCC model. For this Master Thesis, a LCC based-model will be presented.

2.3.2 LCC models

LCC based-models have many variations. A commonly used model was developed by Barringer & Weber, the “Life Cycle Cost Tree”. (Figure 39)

Acquisition and sustaining costs are not mutually exclusive. If you acquire equipment or processes, they always require extra costs to sustain the acquisition, and you cannot sustain without someone having acquired the item. Acquisition and sustaining costs are found by gathering the correct inputs, building the input database, evaluating the LCC and conducting sensitivity analysis to identify cost drivers.

Frequently the cost of sustaining equipment is 2 to 20 times the acquisition cost. Every example has its own unique set of costs and problems to solve for minimizing LCC. [12]
SAE (SAE 1993) also has a LCC model directed toward a manufacturing environment:

**Figure 39: LCC Barringer Model [12]**

**Figure 40: LCC SAE model [12]**
LCC = Acquisition Costs + Operating Costs + Scheduled Maintenance + Unscheduled Maintenance + Conv/Decom Costs

2.3.3 Proposed model

The basis of LCC model is to gather all the costs that a certain equipment will incur during its lifetime and evaluate them at their present value.

LCC needs to address costs that are pertinent to the scope of the project. However, when comparing different alternatives, these must incorporate the same cost categories.

The proposed LCC model is shown next:

Figure 41: LCC Proposed model

2.3.3.1 Investment Costs

This category includes those expenses that must be made before the implementation of the equipment. Usually, these costs are incurred on the Base year (Year 0). If the project requires a complementary investment in a future point, expenses must be discounted to the present value.

Investment Costs will include:

- Equipment Purchase Cost
- Installation Cost
- Engineering Cost
2.3.3.2 Operating Costs

Operating costs are expenses which are incurred during a certain process. In this particular case, our project is focused in calculating the cost of a welding process, therefore, only direct costs of this welding process shall be considered as operational costs; we assume that overhead costs shall stay stable when comparing different alternatives. However, further studies should include those other processes that the implantation of this project might affect.

Operational costs depend straightly on the amount of production. Therefore, this model shall calculate them as SEK/piece. After that, with the total expected production for a certain year, the total operating cost for that year can be easily calculated.

Operating costs will include:

- **Labour costs**
- **Consumables costs**
- **Cost of deferred production**

In this case, workers that take part into the welding process have the same work qualification, thus, the Man-hour rate shall be constant. Then, labour costs depend on the number of workers that are needed for a certain operation, and the needed time for that operation.

The second category of operating costs, consumables costs, include those items that are needed to realize the process, excluding raw materials and components, which will be included as overhead costs and shall only affect to the investment analysis, not to the LCC model. In this particular case, consumables costs shall include: Filler wire, shielding gas and electric power (for welding devices). Spare parts will be included as maintenance costs, which are explained in the next costs’ category.

Operating costs have a great influence in the LCC. Most part of the earnings that the new process might generate are earned in this section. Another important factor for making this project feasible is to have a high grade of
operational time for the new process. It would decrease depreciations and the final LCC cost per hour.

2.3.3.3 Maintenance Costs

Maintenance includes every operation that is required for an asset to keep it working on good conditions. There are two main different kinds of maintenance activities:

i. Corrective Maintenance (CM)

In this kind of maintenance, the equipment is fixed after a failure. It is recommended for those cases in which the repair of the equipment does not affect the rhythm of production.

The formula for annual cost of corrective man hour maintenance is as follows:

\[ CMM = \lambda_T \times H \times MTTR \times A_c \times M_c \]

Where:
- \( CMM \): Average man hour annual cost for corrective maintenance
- \( \lambda_T \): Total failure rate (fails/hour)
- \( H \): Working hours a year (hours)
- \( MTTR \): Mean time to repair (hours/fail)
- \( A_c \): Number of workers required to do the work
- \( M_c \): Man hour rate (SEK/hour-men)

And

\[ CMSP = \lambda_T \times H \times ccsp \times SP_c \]

Where:
- \( CMSP \): Average spare parts cost for corrective maintenance
- \( ccsp \): Average cost for spare parts (SEK/spare part)
- \( SP_c \): Average number of spare parts for repair (spare parts/fail)

\[ CM = CMM + CMSP \]
ii. Preventive Maintenance (PM)

Preventive maintenance activities are aimed to decrease or avoid repairs in machinery, in order to ensure availability at the lowest cost.

The formula for annual preventive maintenance man hours (PMM) is as follows:

\[
PMM = I \times MTTI \times A_p \times M_p
\]

Where:

- PMM= Average preventive maintenance man hour cost
- I= Average inspections per year
- MTTI= Mean time to inspect (hours/inspection)
- \(A_p\)= Number of workers required to do the inspection
- \(M_p\)= Man hour rate (SEK/hour)

And:

\[
PMSP = I \times pcsp \times SP_p
\]

Where:

- PMSP= Average spare parts cost for preventive maintenance
- pcsp= Average cost for spare parts (SEK/spare part)
- \(SP_p\)= Spare parts per inspection

\[
PM = PMM + PMSP
\]

[13]

2.3.3.4 End of Life Costs

This category refers to the costs (and revenues) that the equipment will incur at the end of its productive lifetime. Estimating costs for the end of the period implies a higher level of uncertainty than other estimations.

This category includes:

- Residual value
- Decommission costs
The residual value is understood as the price at which the equipment will be sold after its lifetime. It decreases year by year and in the most unfavorable case, its value will be 0 SEK. It is very common to define the residual value as a % of the purchase cost. In this case this percent will be between 4% and 60%.

2.3.3.5 Depreciation costs

Assets as machinery, devices, etc. lose their value over time, due to its utilization, obsolescence and age, in other words, its value becomes depreciated. Depreciation is found to be a non-cash expense, this is, a “virtual” expense. However, it must be considered in the accounting balance. An example of how it influences the profit is shown next:

<table>
<thead>
<tr>
<th>Accounting Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
</tr>
<tr>
<td>Sales</td>
</tr>
<tr>
<td>Depreciation</td>
</tr>
<tr>
<td>EBITDA</td>
</tr>
<tr>
<td>EBIT</td>
</tr>
<tr>
<td>Tax Provision (30%)</td>
</tr>
<tr>
<td>Net Income</td>
</tr>
<tr>
<td><strong>Profit</strong></td>
</tr>
</tbody>
</table>

**Figure 42: Depreciation influence on profit. Example 1**

Since the depreciation is a cost, it decreases the EBIT (Earnings Before Interests and Taxes). The EBIT is the basis in which Taxes are calculated, thus, the higher is the depreciation, the lower will be the basis. For example if depreciation is not considered, the balance would be:

<table>
<thead>
<tr>
<th>Accounting Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
</tr>
<tr>
<td>Sales</td>
</tr>
<tr>
<td>Depreciation</td>
</tr>
<tr>
<td>EBITDA</td>
</tr>
<tr>
<td>EBIT</td>
</tr>
<tr>
<td>Tax Provision (30%)</td>
</tr>
<tr>
<td>Net Income</td>
</tr>
<tr>
<td><strong>Profit</strong></td>
</tr>
</tbody>
</table>

**Figure 43: Depreciation influence on profit. Example 2**
Tax provision increases from 45.0000 to 90.0000 SEK, and the profit would decrease from 195.000 to 90.000 SEK.

There are four main methods for calculating the depreciation. They will be shown using the next example:

*Acquisition cost (A): 200.000SEK*

*Residual value (R_v): 10% (20.000 SEK)*

*Life time (n): 20 years*

i. Straight Line Depreciation

It is the simplest and the most frequently used method for calculating the depreciation. Depreciation quotes are constant during the equipment’s lifetime and the value of the machinery decreases constantly from its acquisition price until the residual value.

The quote for each year ($Q_i$) will be calculated as:

$$Q_i = Q = \frac{A - R_v}{n}$$

In this case

$$Q_i = Q = \frac{200.000 - 20.000}{20} = 9.000 \text{ SEK}$$

![Figure 44: Straight Line Depreciation](image)
ii. Diminishing Balance

This method calculates a fixed value \((t)\) that will be applied to the remaining depreciation.

The first step is to calculate the fixed value:

\[
R_v = A \times (1 - t)^n, \text{ then}: \\
t = 1 - \frac{n}{\sqrt[200000]} 
\]

And the quotes are:

\[
Q_i = A \times t \times (1 - t)^{i-1} \\
i = 1, 2, ..., n
\]

For example, if we want to calculate the quote for the 6th year:

\[
t = 1 - \frac{20\sqrt{20.000}}{200.000} = 0.10874
\]

\[
Q_i = 200.000 \times 0.10874 \times (1 - 0.10874)^{6-1} = 13.723,2039
\]

Then, the chart will be:

![Figure 45: Diminishing Balance Depreciation](image-url)
*Note that if we take the residual value as a percent of the acquisition cost (A%), the equation becomes:

\[ t = 1 - \frac{n}{\sqrt{n}A} \]

iii. Years digits

This method, as the diminishing balance, multiplies the amount to depreciate by fixed value. The difference is that in this method we can chose between increasing or decreasing quotes.

For increasing quotes:

\[ Q_i = (A - R_y) \times \frac{i}{\sum_{1}^{n} i} \]

For decreasing quotes:

\[ Q_i = (A - R_y) \times \frac{n - (i - 1)}{\sum_{1}^{n} i} \]

\[ \sum_{1}^{n} i = \frac{1 + n}{2} \]

Figure 46: Years Digits Depreciation
iv. Units of Production

This method considers that depreciation is only influenced by the production, and not by its age. Therefore, the quotes are weighted up in relation with the production of a certain year.

\[ Q_i = (A - R_v) \times \frac{P_i}{P_t} \]

Where:
- \( P_i \) = Production of the year \( i \)
- \( P_t \) = Total production during the lifetime

Production estimations for future years are commonly estimated as increases of the production, thus, quotes will increase year by year. For example, if we assume an annual increase of 10% of production:

![Figure 47: Units of Production Depreciation](image)

As a conclusion, it can be said that depreciation methods can lead to increasing or decreasing quotes. This point has a significant relevance because the election of the depreciation cost will influence the profit.

If an increasing-quotes method is chosen:

- ✓ More cash-flow will be available at the beginning of the project, which is an advantage since this period is the most risky
- ✓ Liquidity will increase at the beginning of the project
- ✗ Costs will increase during the last years of the project, in this period, uncertainty is also higher
3. Method

3.1 Scopus

This Project is developed from an Organization and Industrial Management point of view. For that reason, technical parameters that take part in the LAHW processes will not be studied. It is not the aim of this Project to find the best combination of parameters (welding speed, heat input, etc.) in a particular case of welding, but it will try to evaluate in what way a welding process is susceptible to be changed by a LAHW process as long as if it is economically and productively viable.

Two models were defined and combined for this project; The LCC model and the Investment Analysis.

Both models were designed in a Microsoft Excel spreadsheet. This spreadsheet was prepared in order to be used by any user; it has a friendly and easily understandable interface and all the results are calculated and shown automatically. Furthermore, an analysis “What if?” is already prepared and be executed in order to make different sensibility analysis.

This model is oriented to make the costs assessment for this particular case. However, it was thought that it would be a good and helpful tool for future costs assessment’s studies. Thus it was designed in order to support the study of different welding processes by external users.

3.2 Literature Search

The first step of this project has been to collect and gather information about modern welding technologies, this research has been focused on the LAHW technology. Not only books have been consulted, also publications made in the LTU have been checked. For example, the paper: “Laser-arc hybrid welding – a case based study for further understanding of its industrial feasibility”, published by the LTU’s Department of Engineering Sciences and Mathematics. This paper gave a starting point for the understanding of the capabilities of the LAHW technology in our case.

The second part of the research has been focused on the economic aspects. It might be said that the investment analysis literature has many material that gives the same information, therefore, only two books were consulted.

The literature about the LCC model has many publications, papers can be focused on a process LCC model, equipment LCC model, buildings, etc. Our model has been based on a process model, which has been described by

### 3.3 Case Development

At first, a Gantt chart has been designed in order to plan the steps of the Master Thesis.

The next step has been the literature research, explained in the section 3.2.

After this, an evaluation of the current situation at the company has been made. This evaluation has been made by visiting the company and with several contacts with them. The scopus of the project has been determined at this step.

Then, the election of the tools has been made. A LCC supported with an investment analysis model has been chosen to be developed.

Finally, the model has been designed using Microsoft Excel. After making the appropriate corrections, data have been introduced, and the first calculations were made.

At this point it was found that a sensibility analysis could be helpful. The uncertainty in the value of several variables has been the cause of this decision. Therefore, different scenarios with probable values have been defined, and, with the support of the Excel's tool 'What if? Analysis', several ranges of results have been determined.
4. Calculation Model

4.1 LCC and Investment Analysis Calculation Model

The model was designed in three Excel sheets; “Data Input”, “LCC Worksheet” and “Calculations”. The categorizes used is according to what was described in section 3, Calculation Model Background.

Data Input

The first sheet, “Data Input”, has several tables for introducing data:

✓ Project

This table collects required data for the investment analysis and LCC.

The rate of discount and the project life will be used for calculating the present value of future amounts of money, whether they are expenses or revenues.

Project life, residual value (% of acquisition price) and decommission cost will lead to depreciation’s quotes. In the cell “Depreciation” there is a list in which the user can select from one of the methods that have been explained before.

The middle column is yellow coloured, all cells that are in yellow are for data input.

<table>
<thead>
<tr>
<th>PROJECT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Life</td>
<td>years</td>
</tr>
<tr>
<td>Rate of discount (%)</td>
<td></td>
</tr>
<tr>
<td>Tax Provision (%)</td>
<td></td>
</tr>
<tr>
<td>Residual Value (%)</td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>pieces/year</td>
</tr>
<tr>
<td>Production Increase (%)</td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td></td>
</tr>
<tr>
<td>Decommission Cost</td>
<td>at year 15</td>
</tr>
<tr>
<td>Hours per Day</td>
<td>hours/day</td>
</tr>
<tr>
<td>Working Days per Year</td>
<td>days/year</td>
</tr>
<tr>
<td>Sales</td>
<td>SEK/year</td>
</tr>
<tr>
<td>Overhead Cost</td>
<td>SEK/year</td>
</tr>
<tr>
<td>Savings Increase/Decrease</td>
<td></td>
</tr>
</tbody>
</table>

Figure 48: Data Input table
For this case, it was assumed that sales amount and overhead cost do not vary from different alternatives. A deeper study of the implications that this assumptions might cause is required for a better approximation.

- **Acquisition Costs**

This table collects the data for this part of the LCC model. In certain projects, reinvestment costs should be done in a different year than the base one (year 0). Those reinvestment costs must be introduced directly in the “LCC Worksheet”.

<table>
<thead>
<tr>
<th>AQCUISITION COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Purchase Cost</td>
</tr>
<tr>
<td>Installation Cost</td>
</tr>
<tr>
<td>Engineering Cost</td>
</tr>
<tr>
<td>Insurances</td>
</tr>
</tbody>
</table>

**Figure 49: Acquisition costs input table**

- **Maintenance Costs**

Maintenance costs’ data are collected from the next table:

<table>
<thead>
<tr>
<th>MAINTENANCE LAHW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CORRECTIVE</strong></td>
</tr>
<tr>
<td>Corrective Man Hour Maintenance (CMM)</td>
</tr>
<tr>
<td>( \lambda ) = (fails/hour)</td>
</tr>
<tr>
<td>( H ) = (hours/year)</td>
</tr>
<tr>
<td>( MTTR ) = (hours/fail)</td>
</tr>
<tr>
<td>( A_e ) = (men)</td>
</tr>
<tr>
<td>( M_c ) = (SEK/hour-men)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Corrective Spare Parts Maintenance (CMSP)</td>
</tr>
<tr>
<td>( \lambda ) = (fails/hour)</td>
</tr>
<tr>
<td>( H ) = (hours/year)</td>
</tr>
<tr>
<td>( ccsp ) = (SEK/spare part)</td>
</tr>
<tr>
<td>( SP_c ) = (spare parts/fail)</td>
</tr>
<tr>
<td>CM = CMM + CMSP =</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Figure 50: Maintenance costs input table**
Maintenance cost is calculated following the method described in section 2.3.3.3. It varies in time with an expected increase/decrease tax.

There are two tables for maintenance, the second one refers to the current process so an expected saving/expense can be calculated.

✓ Operating Costs

This category of costs is very significant and requires special attention. The benefits from the new process depend strongly from the operating costs and every parameter in the new process might have great influence in the results.

Again, two tables are presented for collecting data, one for the LAHW process and another for the current process.

Those tables are at the same time divided in several sections:

<table>
<thead>
<tr>
<th>Labour Activity</th>
<th>(min/piece)</th>
<th>Manual or Automated</th>
<th>(workers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for joint preparation</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>Time to prepare material for welding</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>Time to preheat the joint</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>Time for tack-up</td>
<td></td>
<td>Automated Welding</td>
<td></td>
</tr>
<tr>
<td>Time for positioning</td>
<td></td>
<td>Automated Handling</td>
<td></td>
</tr>
<tr>
<td>Time for welding</td>
<td></td>
<td>Automated Welding</td>
<td></td>
</tr>
<tr>
<td>Time to remove slag &amp; spatter</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>Time for inspection</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>Time to change welding machine settings</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>Time to repair or re-work defective welds</td>
<td></td>
<td>Manual</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 51: Labour input table**

The first one refers to the times of the activities which take part directly in the process. The type of activity (manual, automated welding or automated handling) can be chosen from a list. Specifying the number of workers is required for manual activities.

After that, manual activities will be charged with the man hour rate, and automated activities will be charged with the electric power costs. Notice that for the welding device, the input parameter is the output power. Output power is a significant parameter when optimizing welding processes, therefore, calculations should be made in relation with it. Thus for the welding device the electrical consume is calculated dividing the output power by the efficiency.

\[
\text{Time for Welding} = \frac{\text{Welding length}}{\text{Welding speed}}
\]
Data Input

<table>
<thead>
<tr>
<th>Data Input</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Man hour rate</td>
<td>SEK/hour-men</td>
</tr>
<tr>
<td>Power efficiency (%)</td>
<td>kW</td>
</tr>
<tr>
<td>Power output</td>
<td>kW</td>
</tr>
<tr>
<td>Wire feed speed (m/min)</td>
<td></td>
</tr>
<tr>
<td>Flow Rate (m³/min)</td>
<td></td>
</tr>
<tr>
<td>Welding speed (m/min)</td>
<td></td>
</tr>
<tr>
<td>Welding length (m/piece)</td>
<td></td>
</tr>
<tr>
<td>Deferred production (%)</td>
<td>%</td>
</tr>
<tr>
<td>Power (handling devices)</td>
<td>kW</td>
</tr>
</tbody>
</table>

**Figure 52: Consumables and labour input table**

Wire feed speed, welding speed, flow rate and welding length are also significant parameters in welding processes. The main earnings in this project shall be produced by improvements in these parameters.

The last data inputs are related with consumable’s prices. There are different units for these consumables. For this case, International System of Units was used.

Consumables Costs

<table>
<thead>
<tr>
<th>Consumables Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of filler wire</td>
<td>(SEK/m)</td>
</tr>
<tr>
<td>Cost of shielding gas</td>
<td>(SEK/m³)</td>
</tr>
<tr>
<td>Cost of electric power</td>
<td>(SEK/kWh)</td>
</tr>
</tbody>
</table>

**Figure 53: Consumables costs input table**

After collecting all this data, a calculation table for operating costs was designed:

**OPERATING COSTS CALCULATIONS**

<table>
<thead>
<tr>
<th>OPERATING COSTS CALCULATIONS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour Time per piece (min/piece)</td>
<td>Labour cost (SEK/piece)</td>
</tr>
<tr>
<td>Filler wire per piece (m/piece)</td>
<td>Filler wire cost (SEK/piece)</td>
</tr>
<tr>
<td>Shielding gas per piece (m³/piece)</td>
<td>Shielding gas cost (SEK/piece)</td>
</tr>
<tr>
<td>Power Input Welding kW</td>
<td>Power supply cost (SEK/piece)</td>
</tr>
<tr>
<td>Power Input Handling kW</td>
<td>TOTAL COST (SEK/piece)</td>
</tr>
</tbody>
</table>

**Figure 54: Operating costs table**

\[
\text{Labour Cost} = [(\text{manual time})_i \times (\text{number of workers})_i] \times \text{man hour rate}
\]

\[
\text{Filler Wire Cost} = \text{Time for welding} \times \text{Wire feed speed} \times \text{Cost of filler wire}
\]
It gives a cost expressed in SEK/piece, therefore, it shall vary through the project lifetime in relation with the year’s production.

End of life Costs

As it was explained in section 2.3.3.4, it includes decommission costs and residual value. Both data are collected from the table “Project”.

Residual value is expressed as percent of the acquisition cost. Its value is a forecast, thus, it shall be studied in the sensibility analysis.

LCC Worksheet

The first part of this sheet is focused on calculating the LCC. For that, a table is used, in which costs of each category (operating, maintenance, etc) are shown for every year of the project life.

\[
\text{Shielding gas cost} = \text{Time for welding} \times \text{Flow rate} \times \text{Cost of shielding gas}
\]

\[
\text{Power supply cost} = (\text{EC welding} \times \text{EC handling}) \times \text{Cost of electric power}
\]
Each cost is discounted to the present value, according with the discount factor.

After discounting every cost and revenue, the LCC can be easily calculated by summing all categories.

\[
\text{LCC} = \text{X SEK} \\
\text{X SEK/hour}
\]

**Figure 56: LCC cost. LCC spare costs**

After calculating the LCC, the next step is to make the investment analysis. The next table shall show how the investment analysis model works, in order to make simpler the understanding of the model.

<table>
<thead>
<tr>
<th>CASH FLOW</th>
<th>Sum of every costs for each year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>Savings of operating and maintenance + Sales – Cost of non-welding activities (overhead)</td>
</tr>
<tr>
<td>Earnings</td>
<td>Depreciation quotes for each year. Just choosing a depreciation method at ‘Data Input’ sheet, and the quotes will be automatically calculated</td>
</tr>
<tr>
<td>Depreciation   Straight Line Depreciation</td>
<td>EBITDA - Costs</td>
</tr>
<tr>
<td>EBITDA</td>
<td>EBITDA - Depreciation</td>
</tr>
<tr>
<td>EBIT</td>
<td>It is assumed that taxes will only be applied when the EBIT is positive.</td>
</tr>
<tr>
<td>Tax Provision 35% of Profit Before Taxes</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 55: LCC worksheet summary**
<table>
<thead>
<tr>
<th>Net Income</th>
<th>EBITDA- Tax Provision</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CASH FLOW</strong></td>
<td>Net income + Depreciation</td>
</tr>
<tr>
<td><strong>DISCOUNTED CASH FLOW</strong></td>
<td>Discount factors are applied to the cash flow</td>
</tr>
<tr>
<td><strong>ACUMULATED</strong></td>
<td>Sum of discounted cash flows. When this value turns positive, it means that the project is generating profits.</td>
</tr>
</tbody>
</table>

**Figure 57: Cash flow calculation method**

Notice that depreciation reduces the base where tax provision is applied, therefore high quotes can increase the cash flow.

Finally the NPV, IRR and payback are calculated

<table>
<thead>
<tr>
<th>Net Present Value =</th>
<th>X SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRR =</td>
<td>X%</td>
</tr>
<tr>
<td>PAYBACK =</td>
<td>X years</td>
</tr>
</tbody>
</table>
*Those data are not the real ones used in the project.*

Figure 58: LCC worksheet example
4.2 Sensibility Analysis Model

A sensitivity analysis can be performed with some Excel tools. These tools can allow a user to see how a desired result of the model would change under different circumstances.

The first tool is the algorithm solver. This algorithm finds the value of a certain combination of cells (changing cells) in order to get to desirable value in the target cell (0, maximum or minimum value can be searched).

This algorithm is useful for lineal problems and restrictions.

By the way, the strongest and most useful tool for sensibility analysis is the “Analysis What if?”. This tool allows the user to create different scenarios and to analyze how certain results might change. Each scenario can manage 32 changing cells at the same time. In this case the scenarios were designed as follows:

<table>
<thead>
<tr>
<th>Studied Results</th>
<th>Changing variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV LCC</td>
<td>Discount Tax Welding Speed Residual Value</td>
</tr>
</tbody>
</table>

**Figure 59: Sensibility analysis model**

The goals of this analysis shall be:

- Which are the range of combinations that make NPV>0 ?
- Which combinations help making LCC minimum?
For this sensibility analysis, a first kind of scenario has been designed. In this scenario, different combinations between acquisition costs and rate of discount were programmed.

**Figure 60: NPV chart. Discount tax and purchase cost as variables**

Values from 1% to 30% were considered for the Discount Tax, and from 18.000.000 SEK to 27.000.000 SEK for the Acquisition Cost (Equipment Purchase Cost)

The same methodology has been used for the LCC analysis.
At the third part of the sensibility analysis, the combinations between three variables were calculated; Welding speed, Discount tax and Acquisition cost. For this reason, 3,300 values for the NPV have been obtained. Each value of the discount tax (from 1% to 30%) produces 110 values. In order to avoid non-representative data, only some combinations shall be presented.

Figure 61: LCC chart. Discount tax and purchase cost as variables

Figure 62: NPV – Purchase costs chart. Discount tax=10%
Every investment project has a certain level of uncertainty. This analysis may help making an accurate decision for this investment. The most probable scenarios have been considered, however the final decision relies in the company, because their knowledge about the current situation shall lead to indentify which scenarios are really the most probable ones.
5. Results and Conclusions

As it was explained before, due to confidentiality matters, real data are not able to be shown in this report. Therefore, results shall be shown as a combination of values and different levels of expected values.

<table>
<thead>
<tr>
<th>RATE OF DISCOUNT</th>
<th>EQUIPMENT PURCHASE COST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18.000.000</td>
</tr>
<tr>
<td>0,02</td>
<td>19.357.090</td>
</tr>
<tr>
<td>0,08</td>
<td>9.563.413</td>
</tr>
<tr>
<td>0,09</td>
<td>8.310.805</td>
</tr>
<tr>
<td>0,1</td>
<td>7.142.881</td>
</tr>
<tr>
<td>0,11</td>
<td>6.052.621</td>
</tr>
<tr>
<td>0,12</td>
<td>5.033.674</td>
</tr>
<tr>
<td>0,13</td>
<td>4.080.284</td>
</tr>
<tr>
<td>0,14</td>
<td>3.187.230</td>
</tr>
<tr>
<td>0,15</td>
<td>2.349.772</td>
</tr>
<tr>
<td>0,16</td>
<td>1.563.598</td>
</tr>
<tr>
<td>0,17</td>
<td>824.783</td>
</tr>
<tr>
<td>0,18</td>
<td>129.751</td>
</tr>
<tr>
<td>0,2</td>
<td>-1.141.733</td>
</tr>
<tr>
<td>0,21</td>
<td>-1.723.891</td>
</tr>
<tr>
<td>0,24</td>
<td>-3.285.396</td>
</tr>
</tbody>
</table>

Figure 64: NPV, discount tax and purchase cost table
The most probable values for the NPV are shown in green cells. As it is shown in the chart, there is a small area of probable values were the investment is not feasible.

Payback period can also be applied to evaluate the investment’s feasibility, as it was mentioned before. When considering the probable range of values, the payback period varies between 7 and 10 years (if the NPV is less than 0, the payback is more than 10 years, thus it is not feasible).

Other variable that shall be considered is the Residual Value;

An increase of 0,5% in the residual value makes a decrease of a 1,5% in the LCC and an increase of 3% (approximately) in the NPV. However, it is recommended to have a conservative forecast in this variable, due to its uncertainty.

The depreciation model influences the cash flow. Some models imply a higher need of capital at the beginning of the project.

Finally, as the conclusions it might be said that:

- The investment might be feasible if the acquisition cost does not exceed 21.000.000 SEK
- Life cycle costs will increase the total investment in 25%, approximately
- At the first years of the project, a higher available capital is needed
- It is essential to choose an accurate balance between the depreciation model and the level of uncertainty in some variables such as the residual value
- 10 years is a reasonable figure for the project life. For higher values, the uncertainty is too high to make forecasts
6. Future Work

For the next steps of this project it is recommended to:

- Define and implement a cost model, as it was explained in 2.1.4
- Calculate and control the deviations of the model
- Control de variations between the forecasts and the real values obtained when implementing the project

This project might also support the introduction of the LAHW in new companies. The spreadsheet can be used with some modifications to analyze weather an investment on LAHW is feasible or not.

In the future this model could be used by an external user to make costs assessments when searching for a new laser welding solution.
7. References

[1] www.alo.se


[8] Business Creations and Projects Economic Assessment- ETSEI. UVIGO.


## 8. Appendix

<table>
<thead>
<tr>
<th>Year</th>
<th>Discount Tax 11%</th>
<th>Year</th>
<th>Discount Tax 12%</th>
<th>Year</th>
<th>Discount Tax 13%</th>
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Figure 65: NPV, discount tax and purchase cost table