Return of investment strategy for sheet metal parts

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Resumo

O ambiente atual e o nível de concorrência do mercado industrial exigem das empresas um alto grau de eficiência, a melhor execução com o menor desperdício de recursos possível. A partir de então, as empresas procuram não apenas funcionários mais eficientes, mas também ferramentas que possam reduzir o tempo gasto nas tarefas. Nesse sentido, estabelecer uma estratégia de retorno sobre o investimento é um facilitador, podendo ser vista como uma diretriz para a condução da estratégia de negócios das empresas. Neste projeto pretende-se estabelecer a estratégia de retorno de investimento em peças metálicas por meio da decisão prévia mais adequada para as quantidades anuais que o projeto estima.

Este projeto insere-se nesta linha de raciocínio, centrando-se nas peças em chapa metálica sob o ponto de vista do Departamento de Compras. Após o enquadramento teórico dos processos produtivos, foi utilizado o método de estudo de investigação-ação. Esse processo de investigação é composto por uma abordagem participativa e colaborativa desenvolvido para procurar soluções para problemas organizacionais reais. Essa investigação almejou o estudo das quantidades anuais de produção que limitam o retorno do investimento entre os diferentes métodos de produção nas cotações que diferentes fornecedores oferecem em peças de chapa metálica.

Este projeto teve como objetivo desenvolver uma tabela de Breakpoint e apresentar o retorno financeiro que esta ferramenta pode significar para a empresa. Para este projeto foi escolhida uma tabela e não um único Breakpoint, pelo que se recomenda alterar o método de produção uma vez que as peças em chapa podem ter diferentes aspetos em termos de tamanho, dificuldade e detalhes. Para abranger a grande diversidade de peças que um mesmo aparelho pode ter e considerando que podem ser bem diferentes entre si, desde grandes painéis aos pequenos e complexos suporte de outras peças, é que se optou pela separação em cluster, assim obtento uma tabela com as quantidades críticas.

Return of investment strategy for sheet metal parts

Abstract

The current environment and the level of competitiveness of the industrial market demand a high degree of efficiency from companies, the best possible execution with the least waste of resources possible. From then on, companies seek not only more efficient employees but also tools that can reduce the time spent on tasks. In this sense, establishing a return-on-investment strategy is a facilitator, and can be seen as a guideline for conducting companies' business strategies. In this project, it is intended to establish the return on investment strategy in sheet metal parts through the most appropriate prior decision for the annual quantities that the project estimates.

This project is part of this line of reasoning, focusing on sheet metal parts from the point of view of the Purchasing Department. After the theoretical framing of the productive processes, the research-action study method was used. This investigation process comprises a participatory and collaborative approach designed to look for solutions to real organizational problems. This investigation aimed to study the annual production quantities that limit the return on investment between the different production methods in the quotations that different suppliers offer in sheet metal parts.

This project aimed to develop a Breakpoint table and present the financial return that this tool can mean for the company. For this project, a table was chosen and not a single Breakpoint, at which point it is recommended to change the production method since the sheet metal parts can have different aspects in terms of size, difficulty, and details. In order to cover the great diversity of parts that an appliance can have and considering that they can be very different from each other, from large panels to small and complex brackets, we opted for the separation in clusters and thus resulted in a table with the critical production quantities.

Acknowledgments

Along my path, I met several people who taught me and provided wonderful opportunities. For this reason, I would like to place on record my thanks.

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Acronyms

AGV Autonomous Guided Vehicles
CAD Computer-Aided Design
CAM Computer Aided Manufacturing
CAPP Computer Aided Process Planning
CMM Coordinate Measurements Machines
CNC Computer Numerical Control
EDM Electrical Discharge Machining
FA Flexible Automation
FMS Flexible Manufacturing Systems
ISF Incremental Sheet Forming
ISMF Incremental Sheet Metal Forming
MMI Man-Machine Interface
NC Numerical Control
NCK Numerical Control Kernel
PLC Programmable Logic Control
SPIF Single-Point Incremental Forming
TPIF Two-Point Incremental Forming

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1 Introduction

The present dissertation was developed at Bosch Thermotechnology Aveiro, a German company in the Thermotechnology sector, more specifically in the Heat Pump Development sector. The development of this project takes within the scope of the Technical Buyer role, a position not only for purchasing parts but also related to cost evaluation and technical discussions regarding the parts.

A Technical Buyer is one of the several job positions that integrates the Purchasing Department and Cost Tracking is one of the responsibilities of the position. In addition to part price, Tooling Cost is also part of Cost Tracking and the company identified that this Tooling Cost is strongly influenced by the parts production process.

The world industrial sector produces sheet metal components using the forming process. The most used processes are stamping and deep drawing, which are based on large molds and presses that require a large initial investment, each part requiring dedicated tooling, making them inflexible and profitable only in large production volumes. Another process also used by the industrial sector and which is indicated for low-volume production is based on incremental sheet forming (ISF), which involves the gradual plastic deformation of flat metal sheets by the action of CNC-controlled tools (Maidagan, Zettler et al. 2007).

The ISF process involves the gradual forming of flat metal sheets using general purpose Computer Numerical Control (CNC) controlled forming tools. Usable parts can be formed directly from CAD data with a minimum of specialized tools. ISF is widely regarded as a more promising forming process than traditional processes such as deep drawing and stamping (Maidagan, Zettler et al. 2007).

This project aimed to evaluate the production decisions of sheet metal parts between the CNC manufacturing and stamping processes. The purpose was to establish a Breakpoint table by cluster of parts for each production process, allowing the Technical Buyer to have more precise information to proceed with the negotiation aiming at the lowest possible cost. Also, quantify the benefit that this table represents for the function.

1.1 Project Framework and Motivation

The Bosch Group is a technology and service provider of solutions for smart homes and cities, mobility, and industry (Bosch 2023). As several companies in this sector, efforts are made to keep up with market trends, continue the company's competitiveness, and become increasingly more sustainable.

Aiming to remain competitive, tool costs were identified as one of the sources of the greatest expense. Since the manufacturing method is a determining factor for the type of tool and the respective cost associated with it, its analysis has become relevant to support the achievement of goals.

As this is a point negotiated at the time of purchasing the parts, the responsibility for reducing this cost is under the Purchasing Department’s scope, specifically in the Technical Buyer role.

To allow the Buyer to have more reliable information for negotiating parts, it is relevant to define the Breakpoint for sheet metal parts, that is, from which annual quantity it is relevant to continue with CNC production or opt for stamping production.

1.2 Company Overview

1.2.1 Bosch Group

Bosch Group was founded in 1886 under the name of "Workshop for Precision Mechanics and Electrical Engineering" in Stuttgart, Germany. The company began as an installer of telephone systems and electric bells. Only after the request to build a magneto ignition device that was improved by Bosch, the company started to focus on installing better-designed magneto ignition into the automotive industry becoming the only supplier reliable in that business (Bosch 2023).

Expansion outside Germany began in 1898 with the first overseas factory in London. The outcome was that sales offices began to emerge throughout Europe. France was the first country with a subsidiary in 1899, and from 1905 onwards the French factory was able to respond by itself to the country's demand for magneto systems ignition by itself, without needing to resort to the production of Bosch factories in Germany (Bosch 2023).

At present Bosch Group is a global supplier of technology and services been CO_2 neutral since 2020 (Bosch 2022). The company employs more than 420,000 associates (December 2022) abroad with 88.4 billion euros of sales in 2022.

The Group is divided between Business Units (Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology) in 60 countries (Figure 1) with 440 subsidiaries (Bosch 2023).



Figure 1 - Presence of Bosch in the World

1.2.2 Bosch Thermotechnik GmbH

Bosch Thermotechnology offers solutions for room climate, domestic hot water, and decentralized energy management requirements through the company's previous know-how

of condensing technology, solar thermal systems, and heat pumps. Its production units are spread across the world (Austria, China, Germany, Great Britain, France, Netherlands, Portugal, Russia, Sweden, the Czech Republic, Turkey, and the USA) (Bosch 2023). This project was developed on the Plant in Cacia, Aveiro.

Bosch Thermotechnology is the only business unit managed by the Bosch Group to offer a solution for residential hot water. The presence of the Bosch Group in Aveiro started with the acquisition of Vulcano Termodomésticos in 1988. At present, the company provides solutions for water heaters (electric and gas), boilers, and heat pumps (Bosch 2023).

1.2.3 Purchasing

With the definition of the Breakpoint of the quantities between the production processes, it is intended to obtain a reduction in costs by choosing the most appropriate production process. This is one of the responsibilities of a role in the Purchasing Department, so an overview of the department is recommended. The Purchasing department is subdivided into Commercial Buyer, Technical Buyer, Purchasing Quality engineer, and Direct Material Purchasing.

This project was approached from a Technical Buyer perspective of the Engineering Design team. The Engineering Design is a team inside the Heat Pump division responsible for the appliance structure, insulations, and packaging. Technical Buyers are the connection between the Engineering Design Department and external suppliers, being responsible for: (i) technical discussions with suppliers; (ii) quality planning support for purchased parts; (iii) cost evaluation; (iv) samples planning, ordering, and follow-up; (v) support the introduction of new parts and ordering for projects in South, Middle, and Nordic Europe markets; (vi) make research, request, and analysis of quotations.

Project costing and cost tracking are within the scope of a Technical Buyer. When evaluating the request for quotation, Technical Buyers are, within the commercial buyer, responsible for deciding which supplier to choose. This decision involves not only evaluating the supplier's capacity and price per part, but also the price and production time of the tools, when necessary.

Technical Buyer must ensure that the project cost target is not exceeded. In past projects carried out by the company, it was identified that one of the factors pointed out in the main influence on the increase in project costs are tooling costs. This cost then became a critical point to be evaluated and questioned the production process criteria associated with each part that takes the need (or not) of a tool.

The assessment of the decision point between the methods of manufacturing metal parts, CNC, and stamping, allows the Technical Buyer to have more precise information to proceed with the negotiation aiming at the lowest cost and avoiding excessive costs with tools. Evaluating only metallic parts and excluding insulation from this analysis is a consequence of which type of part contributes most to the company's costs.

1.3 Scope of the Project

This project aims to define the decision point for the annual quantity of parts, here called Breakpoint, for changing the production of sheet metal parts in the Flexible Process for Stamping, which allows Technical Buyers to request a more specific quotation, aiming at a better tooling cost for achieve the project cost target. Given that the tooling cost is the main factor in increasing the project cost and is one of the Purchasing functions to remain within the target cost of the project, the definition of the Breakpoint contributes to a more adequate production and a higher return efficient investment.

The project begins with the analysis of some pieces whose award was initially made to a supplier that works with the Flexible production process. The objective is to analyze from what annual quantity it is economically feasible to switch to the Stamping Process. Considering that an Appliance has different types of parts, the need to have a table and not a single Breakpoint appears. Therefore, the analyzed parts are clustered according to their characteristics and the result is a Breakpoint table.

For this, a critical analysis of the production methods in two appliances developed by the Aveiro Plant team, as well as the evaluation of the costs for the alternative method for which it was chosen, is fundamental for this evaluation. This project required re-quoting and re-evaluating the sheet metal parts with suppliers and re-analyzing and comparing costs. Additionally, this project could be an initiative for defining the Breakpoint table in different material groups, allowing a better price assessment and, consequently, facilitating the achievement of the cost target of future projects.

In order to have an analysis of the time savings this table means for the Technical Buyer, an analysis of the purchase process itself was necessary. The tasks that are part of the process of purchasing a part were then reviewed, documented and the time for each step of the process was quantified. At this stage of the process, in addition to field observation, interviews with the team's Technical Buyers were also necessary. To also evaluate the financial savings that this time saving represents for the company, the cost data that a Technical Buyer represents was collected together with the Accounting Department.

1.4 Method followed in the project

The elaboration of the present project used techniques for the collection of information such as the list of parts of Appliances C and D, the segregation of the sheet metal parts, and the collection of the price information of the piece through the SAP software. In addition to data collection and to obtain a better overview of the purchase process carried out and the decisions taken; internal documents, scientific articles, and meetings with Technical Buyers who worked on the project and Commercial Buyer of the material group under analysis (sheet metal parts) were also analyzed, as dialogues with other collaborators involved in the Appliance development.

The analysis of internal documents focuses on the analyzed parts in relation to the details of the parts, the price of the piece, and mainly the previous costs with the tools and the manufacturing method used.

This project was carried out according to the following phases for the realization of the Breakpoint table for the production of sheet metal parts:

1. Identification and segregation of parts.
2. Collection of prior information on parts.
3. Request new quotations for the alternative method to the one used.
4. Cost Comparison.
5. Analyze the relevant variables.
6. CNC Breakpoint detection for Stamping for each part.
7. Cluster the parts.
8. Definition of Breakpoint table.
9. Investigation and documentation of the purchasing process and its timeline.
10. Purchasing Process Gantt Chart definition.

11. Identification of Purchasing Process steps affected by the Breakpoint table and quantify hours of active work.
12. Quantification of the economic benefit that the table represents.

It is considered that this set of steps gives the project a high probability of being carried out successfully and defines a Breakpoint table that will allow the company a more critical analysis that will lead to a decrease in tooling costs.

1.5 Dissertation Structure

This document is structured into five chapters starting with an introduction about Bosch Thermotechnology, Aveiro Plant, and the scope of the project. The department in which this project was developed, and its objectives were also presented. The second chapter will address the theoretical aspects of CNC production methods and sheet metal stamping. In the third chapter, the focus will be on the detailing of the methodology used in the development of the project. The fourth chapter will be a deepening of the scope of the project and its analysis. The fifth chapter will describe the further steps for this project, continuous improvement in cost reduction and cost tracking to improve the profit and decision on production.

2 Problem Statement

In this chapter we intend to identify and characterize the initial scenario of the problem situation. Starting with the contextualization of the problem, the project inside the Heat Pumps sector of Bosch Thermotechnology Aveiro focuses on the Purchasing Department in the role of Technical Buyer.

The company currently does not have a decision table for sheet metal parts that indicates from what annual quantity one should choose to remain in the Flexible Process or change to Stamping. This initial decision is made based on the theory learned by the engineers that make up the team, that the Stamping Process (as the Deep Drawing process is commonly called) is only indicated for large volumes and/or high complexity.

However, there is no numerical indication of what an annual 'large volume' of parts would be, so Technical Buyers are guided by theoretical concepts, work experience and know-how that they have from each supplier. With the aim of analyzing whether this internal common sense is verified in reality and documenting this decision point, this project begins.

This decision point, in the current project is called Breakpoint, will be the annual quantity for which it is preferable to use the Stamping (Figure 2) instead of the Flexible production process (Figure 3). Considering that a project has several types of parts that differ both in size and complexity, it is necessary to have a table and not a single Breakpoint for all parts. Given that the purchasing stage is relatively time-consuming, there is a need not only for analysis and documentation of how much time is being spent on these tasks, but also the financial benefit this project may have for the company by simplifying these tasks.



Figure 2 - Transfer machine

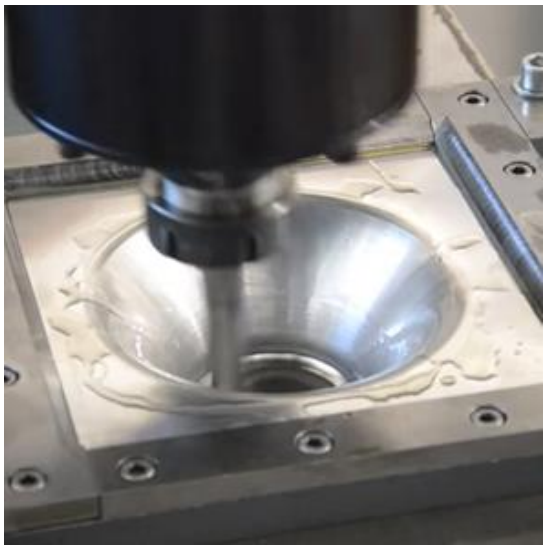


Figure 3 - Flexible Process machine

These parts are still in the Development Department, that is, they are parts that will integrate an appliance that will still be launched on the market. Therefore, the quantities are frequently revised, and it is forecasts that are sent by the Market Team. Due to the quantities being estimates of future forecasts, quantities are constantly reviewed and updated. Through these frequent revisions, the need arises, through a significant change, to review the awards and reassess them so that the productive capacity and the choice of supplier allow efficient production.

Due to these needs, this project arises to evaluate above which annual quantity the Stamping production process is recommended to the detriment of the Flexible process. This evaluation considers the difference between parts across clusters.

3 Literature Review

3.1 Numerical Control

According to the definition given by Suk-Hwan Suh (2008) Numerical Control (NC) machines refer to machine tool “that have a mechanical component and a numerical control system That is an electrical component”. These machines can be divided into 2 groups: "cutting machines" and "non-cutting machines". The first group refers to machines related to removal process: milling process, turning and EDM machines. The second group is related to the shape of the parts: press machine. In a more broad concept, robot systems for welding, cutting, and painting can also be considered NC machines (Suk-Hwan Suh 2008).

This automated control machining tool can precisely machine complex shaped parts. In the beginning, NC machines were mainly used in milling machines, however, as the industry evolved, NC machines started being used in new varieties of machines to increase productivity, such as turning machines, machining centers and drilling machines. In addition, the NC began to be used with wire electrode discharge machines and laser cutting machines called "non-conventional machines" (Suk-Hwan Suh 2008).

However NC meaning a “control device that machines a target part by activating the servo motor according to commands” (Suk-Hwan Suh 2008), the combination with Computer Numerical Control (CNC) allowed a development. The first NCs were based on a pulse division circuit composed of vacuum tubes, activated by an oil-pressure motor and controlled through a relay according to the logical process. Combined with industrial development, NC took advantage of the emergence of semiconductors, electrical motors, microprocessors, and software technology. Although currently the reference to NC and CNC has the meaning, NC refers to the machine and CNC refers to the system (Suk-Hwan Suh 2008).

With the technological evolution, the NC system began to integrate not only machine tools but all kinds of machines that could take advantage of this system such as Flexible Automation (FA) or Flexible Manufacturing Systems (FMS), robots, Autonomous Guided Vehicles (AGV), Coordinate Measurement Machines, drawing instruments, etc. Even with all the automation and technological evolution, this system still needs some offline inputs to be able to execute properly, the task flow can be organized as Offline tasks, Online tasks and Post-line tasks (Suk-Hwan Suh 2008).

Offline tasks are those necessary in an early stage of the NC, that is, before the machine instructions and/or programming. These tasks include Computer Aided Design (CAD), Computer Aided Process Planning (CAPP) and Computer Aided Manufacturing (CAM) (Suk-Hwan Suh 2008).

The first of the Offline tasks, CAD, refers to the modeling stage where design and analysis are developed. After finishing that task of geometric modeling, the CAPP is carried out generating the information related to the machine tool selection, tools, jig, fixture, conditions, and sequences for the machine. Compared to other Offline tasks, CAPP regarding technology

and process planning did not have the same development through time. Therefore, CAPP is the task most dependent on the planner's know-how. The third and last task, CAM, is the generation of the program for the machine compiling the output from CAD and CAPP. Due to that CAM is essential to generate 2.5D or 3D toolpaths for machines with more than three axes (Suk-Hwan Suh 2008).

The Online tasks are essentially related to the programming of the machine. This task is responsible for giving the input regarding memory and controls the movement of axes to enable the NC system to read and interpret the instructions, such as the rotation of a servo motor that is transformed into linear movement. The rigidity of the machine construction, e.g., insensitive design to vibration and temperature, the performance of the encoder and sensors, impact the machine's accuracy (Suk-Hwan Suh 2008).

In these tasks it is possible to monitor the process during the machining of the part. This monitoring can be performed through tool-breakage detection, compensation of thermal deformation, cutting force, heat, etc. (Suk-Hwan Suh 2008) Two techniques can be used to identify error through inspection on the final part, In-Process and On-Machine Measurement. Both process are "simple techniques for measuring on a machine tool to compensate for machining error" (Takaya 2014).

Technology and market development demands stricter quality criteria and therefore more variables need to be measured in the parts making the process more time consuming. The number of variables to be measured, the procedures and the work setting are crucial for machine tools, especially for those such as ultra-precision machining, micro and nanomachining, and simultaneous multiple-axis control machining. Therefore, In-Process and On-Machine Measurement are the simplest process to achieve a high accuracy and small uncertainty values (Takaya 2014).

Post-line tasks are closely related to the step previously mentioned (Machine Measurement), in which the inspection of final part can provide results through the Coordinate Measurement Machine (CMM) to compare geometry model and performance. These measurement results support the compensation such as re-machining and grinding taking advantage of the reverse engineering to achieve a more precise machining of the part (Suk-Hwan Suh 2008). All these task flow can be seen in Figure 2.

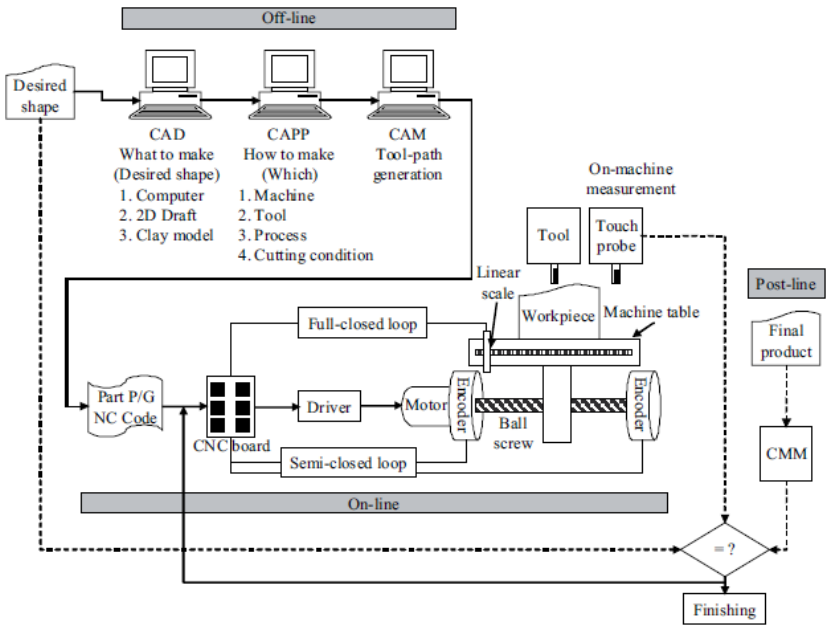


Figure 4 - The architecture of NC machine tools and machining operation flow

Source: Suk-Hwan Suh (2008)

Due to the versatility that NC can provide, these machines can be used for simple as well as complex parts. The variety of parts that can be machined, the high accuracy and productivity that enable the machining of complex shapes by changing and storing the program, allows NC machines can be used for general purposes (Suk-Hwan Suh 2008).

3.1.1 CNC System Components

CNC is a machine tool controlled by a device and its components can be divided into three units: NC unit, motor unit and driver unit. In this section, the focus will be the NC unit which includes the user interface and position control.

The NC unit system is composed by a Man-Machine Interface (MMI), a Numerical Control Kernel (NCK) and a Programmable Logic Control (PLC) as shown in Figure 3. The NCK is a fundamental part of this system, it is in this unit that the program is interpreted, executed, interpolated position controlled, and error compensated. The NCK controls the servo and is responsible for the machining.

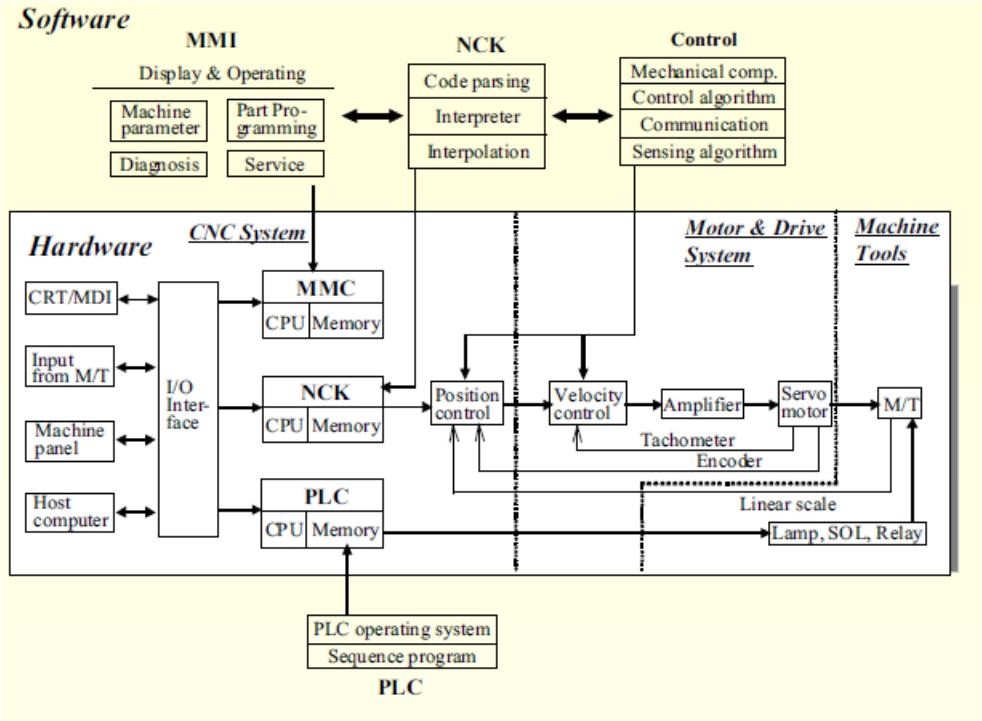


Figure 5 - The components of a CNC system

Source: Suk-Hwan Suh (2008)

The MMI unit is responsible for connecting the user and the machine through an interface. Also is where the operator can insert the commands and where the machine shows the status and functions. On the other side there is the PLC, responsible for controlling the tool's functions, tool changes, speed, change of the part worked, in/out signal, summarizing it controls the actions of the machine while working.

3.1.2 Incremental Sheet Metal Forming

Incremental Forming is a process that involves a tool path generated by a CAD geometry and performed through a CNC machine, the final component (Ajay, Boopathi et al. 2019). Although the ISF being patented in 1967 by Leszak (Edward 1967), the method was proven by Kitazawa (1996) forming rotational symmetric parts using aluminum.

Due to the advantages of "short lead time, high flexibility, high formability and lower cost in small batches, ISF (Incremental Sheet Forming) has received increasing attention from the academia and the industry" (Li, Chen et al. 2017). Advantages such as lower forming forces, improved formability, lower die tooling cost and flexible forming facilities were the main responsible to generate this attention for this process.

The lower forming forces are due to deformation occurring in a small area while allowing for a large reduction in forming forces. Also due to that factor, it is possible to use plastic or wood material to support the array. Additionally, the lower forming forces increase the formability in terms of sheet thickness (e.g. 0.1 to 4.0 mm) and material type (mild steels, aluminum, titanium and perforated steel mesh) (Li, Chen et al. 2017).

Regarding formability in incremental sheet metal forming, the literature indicate that metal forming has higher formability than deep drawing (Jeswiet and Szekeres 2005). Studies related to formability in ISMF are experimental in nature and the capability to form components with the proper accuracy and finishes becomes a relevant requirement for the market. It has been well accepted that conventional forming limits are not suitable for incremental forming(Li, Chen et al. 2017). The formability of sheet metal in conventional forming is currently characterized by the Forming Limit Diagram (FLD) introduced in the 1960s by Keeler (1961). The experimental measurements comparing forming limit curves of conventional forming (stamping) with the Single Point Incremental Forming shows that the limit curve for ISF is a straight line with a negative slope in the region of minor strain compared to the stamping that is present in both regions of minor strain as it is shown in the Figure 4 in the Schematic representation. (Reddy, Lingam et al. 2015).

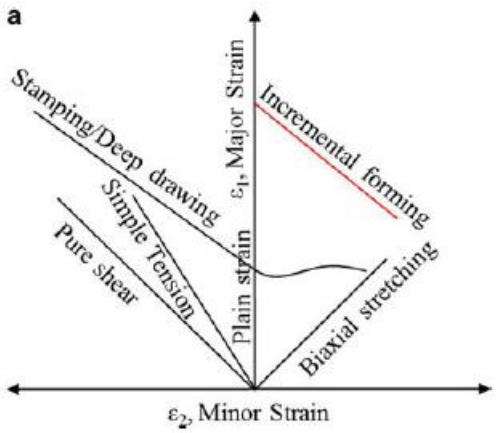


Figure 6 - Schematic representation of forming limit curve in SPIF against conventional forming

Source: Reddy, Lingam et al. (2015)

Regarding lower die tooling costs, depending on the shape of the part it may be possible to use partial dying or even eliminating dying in ISF. The forming die used for shapes such as cone, square, pentagonal, hexagonal, octagonal, dodecagonal is very simple and consists only of a base plate and six cylindrical posts and can be made inexpensively from wood or plastic. In ISF, a generic forming tool can manufacture an infinite variety of 3D shapes by adopting careful toolpath design (Li, Chen et al. 2017).

The fact that the tools are simple and versatile mean that, compared to the conventional stamping process, the ISF has energy inputs (maximum work potential of a substance) that can be saved by more than 64% to produce, for example, 50 pieces of box with AA6022 according to (Dittrich, Gutowski et al. 2012). Therefore, the cost of tooling is greatly reduced.

The ISF process, as a rule, can be carried out by any CNC-controlled three-axis machine. Initially, conventional milling machines were updated with the addition of a material clamping table. Around 2002, companies such as AMINO Corporation began supplying specialized equipment dedicated to ISF to the industry globally. An industrial robot can also be used for the ISF process today. Technological developments driven by market needs have made forming facilities more flexible (Li, Chen et al. 2017).

In the ISMF the tool and raw material parameters such as tool size dimension, incremental depth, tool rotational speed, feed rate, forming angle, sheet thickness and lubricant have different impacts on the result of the part forming. These impacts might be on the accuracy, maximum forming angle, formability, and thickness distribution. Therefore, optimization must be performed to find which parameter has more influence on the final part in order to get the better result (Ajay, Boopathi et al. 2019).

Given the different impacts that these parameters can have the ISF can be classified into different categories. The typical classification is made taking into account the forming method as in the schematic of Figure 5 below where it is possible to visualize how this division occur. (Ajay, Boopathi et al. 2019).

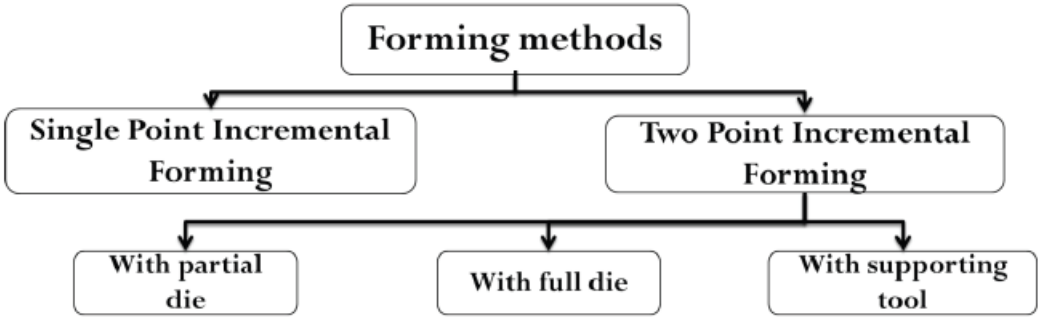


Figure 7 - Types of Incremental Forming

Source: Ajay, Boopathi et al. (2019)

The Single Point Incremental Forming (SPIF) is a process where no particular die is involved and the sheet metal is deformed by the moving tool (Li, Chen et al. 2017). The SPIF, also called as negative incremental forming, is a simple process best suited for prototyping purposes where there is no need for the part to have complex tolerances (Ajay, Boopathi et al. 2019).

The main advantages of SPIF are diverse, such as flexibility in terms of design. The necessary force is also one of the advantages, the force in this process is minimal due to the localized deformation. In addition, another advantage of the process is that it is highly economical for small batches of parts. Regarding the disadvantages, SPIF has the limitation that vertical walls cannot be formed, “due to spring back, the profile accuracy can be reduced and the wall thickness cannot be controlled and the thinning of the walls will not be uniform” (Ajay, Boopathi et al. 2019).

Two Point Incremental Forming (TPIF) is a forming process commonly used for complex parts. This process improves geometric tolerances without substantial extra costs due to the fact that the dies can be manufactured with woods or plastics given the low amplitude of forces contributes to the without extra costs (Li, Chen et al. 2017). In the TPIF, or positive incremental forming, there are two contacts, one contact between the forming tool and the sheet metal and another contact between the sheet metal and the support element such as die or support tool (Ajay, Boopathi et al. 2019).

The difference between SPIF and TPIF is related to the use of support elements that improve the forming characteristics of the part. Also, TPIF has better profile accuracy than SPIF, higher angles can be formed, and controlling of the wall thickness is improved (Ajay, Boopathi et al. 2019).

3.2 Deep Drawing

Deep drawing is one of the two categories within the press working process. Press working is a mechanical process of metals "in which the latter are subjected to plastic deformation in a cold state" (Hiremath and Ramesha 2015). In addition to deep drawing, or stamping, there is the cold die category. This division depends on the raw material used in the part.

Stamping is used for sheet metal parts, most of which are non-flat blanks, so it is not possible to produce them on a single die cutting machine. Parts made using this process aim to be light-weight, high strength, low density, and resistant to corrosion.

Deep stamping process is widely used for mass production. This sheet metal forming is simple and offers high productivity. The production cost can be considered low when the cost of the tool can be dissipated in large-scale production, because the tools are expensive and the cycle time is long. Common tools for this process are blank, punch, die and blank holder (Singh and Agnihotri 2015).

3.2.1 Failures that affect the Deep Drawing Process

The sheet metal region in the die shoulder area is subject to radial drawing stress and tangential compressive stress due to the material's holding property. These tensions impact on the final result and the quality of the part in different ways. The deep drawing process can be affected by factors such as material, properties, tool geometry, lubrification etc. These factors can generate some failures, the most common being tearing, necking, wrinkling, earing, and poor surface appearance.

Tearing and necking are consequences of tensile stresses resulting from the instabilities of this stress. By another stress analysis, and contrary to tearing and necking, wrinkling can be generated by compressive stresses, and it is specific to the process of deep drawing. When the radial design stress exceeds a certain value, the compressive stress in the circumferential direction becomes too high, then plastic buckling occurs. Therefore, the four major failures that can occur in the deep drawing are fracture, wrinkling, earing and spring back. Given these factors, a study of sheet stress-strain behavior and anisotropy is necessary to achieve an acceptable deep drawing process (Singh and Agnihotri 2015).

Other factors that also influence the process are radius on punch, draw radius on the die, draw speed, cracking load, die clearance, friction, and lubricants. A shaper radius requires greater force than sheet metal and this can result in excessive thinning or tearing. "A general rule of thumb to avoid excessive thinning is to design a punch with a nose radius of 4 to 10 times the sheet thickness" (Hiremath and Ramesha 2015).

Regarding the radius on the die, it should be as large as possible to allow complete freedom of sheet metal flow. For some metals such as heavy metal, this draw radius can be increased to 6 to 8 times the metal thickness. Regarding drawing speed, the draw operation is slow and gradual, and the material must enter the die at a uniform speed. The draw speed for low carbon steel CRCA-Draw quality ranges between 30 to 50 fpm and for non-ferrous material like brass, copper, aluminum it ranges between 150 to 200 fpm (Hiremath and Ramesha 2015).

The largest possible load is limited by the load that can be transmitted by the sheet which is called the cracking load. This load must be greater than the maximum drawing load. In

relation to the die clearance, if the gap is too large, the component may not form a true form and the top edge will remain expanded. If the die gap is too small, ironing can occur, which increases the drawing load and increases the risk of cracking. In addition, cold welding between the die and the workpiece is possible.

The static frictional force between blank workpieces and extraction die surfaces must be overcome in one extraction operation. Since static friction is overcome at the beginning of the blank movement, the continuous movement of the punch is very important because the force required to overcome dynamic friction is less than that required for static friction. Lubricants are generally used to reduce friction. For shallow drawing on light metals, lubricants are not always necessary. In these cases, the part can be removed with little or even no lubricants. In order to avoid wrinkling and tearing in case the forces are higher, a thin lubricating film between the punch and the materials must be used.

These factors that affect the deep drawing process can be categorized into three categories: (i) Process parameters, (ii) Geometric parameters and (iii) Machine parameters. The first category includes blank holder force, coefficient of friction, drawing ratio, material properties. The second one includes blank diameter, cup diameter, blank thickness, and corner radii of cup. The third category includes die radius and punch radius.

The main objective in the deep drawing process is to obtain fewer or minimal defects in the product. Instability in the workpiece (wrinkling of the walls) is the main factor that can affect this objective as it is something specific to this forming process. Therefore, predicting wrinkling is a very important process for a deep drawing operation, affecting the final quality of the part.

4 Research Methodology

In the context of carrying out a research project, for the objectives of a research project to be achieved, it is necessary to find and define a research methodology. In order to define the methodology, it is necessary to clarify the definition of research. According to Adams, Khan et al. (2007), a simplified definition of what research is would be that a "simple research is merely aimed at acquiring the most basic type of information - but it is still research in a very real sense because it requires an individual to first identify and then understand the problem, then find out where to go for information and whom to ask, and also know what questions to ask".

4.1 Research Approach

Research approach may have some different categorizations, in this work the definition of subdivisions analyzed were those implied by Saunders, Lewis et al. (2009) and Adams, Khan et al. (2007). The approach by Saunders, Lewis et al. (2009) implies three sub-divisions related to the reasoning adopted, which can be deductive, inductive and abductive. In contrast, the approach by Adams, Khan et al. (2007) implies sub-divisions by the type of research carried out: Descriptive Research, Explanatory Research and Predictive Research.

Deductive reasoning refers to when the conclusion is logically derived from a set of premises, the conclusion being true when all the premises are true. Inductive reasoning implies that the conclusion is analyzed to be supported by the observations made. Abductive reasoning begins with the observation of a "surprising fact", this being the conclusion and not a premise. For this conclusion, a set of possible premises considered sufficient or almost sufficient is determined, if this set of premises is true, then the conclusion would be true (Ketokivi and Mantere 2010).

Descriptive research aims to describe phenomena and is not concerned with understanding the motivation of behavior. This type of research is the starting point for projects known as exploratory studies. Explanatory research goes deeper into analyzing phenomena and understanding behavior. Research of this type aims to explain the phenomenon, advance knowledge, link factors, test and revise. Predictive research not only analyses, understands, explains and tests the phenomenon, but also predicts future behavior in the face of changes in any of the explanatory variables relevant to the phenomenon (Adams, Khan et al. 2007).

This research uses a deductive approach, because it starts from the company's internal assumption that for small batches the flexible method has a better return on investment than the stamped method, while the stamped method would be indicated for large batches. This internal assumption is based on the fact that the stamping process requires a significant initial investment due to the need to have a mold. In addition to the approach based on this assumption, there is also the objective of establishing a Breakpoint in relation to the number of parts per batch indicated for choosing the production method.

This deductive approach is implemented in five phases: deducing the hypothesis from the theory; expression of the hypothesis in operational terms; operational hypothesis testing; evaluation of the specific results of the experimentation; critical analysis of the obtained results (Saunders, Lewis et al. 2009).

This research for the concept of Adams, Khan et al. (2007) can be considered Explanatory research. This research intends, from the theoretical concepts of the productive processes and the assumption admitted by the company, to test, analyze and revise if the assumption is valid.

4.2 Research Strategy

When starting a research project, it is essential to define a strategy, in order to lead to the desired results. A research strategy can be defined as a plan for how a researcher will answer his main question. The choice of research strategy is guided by the main question and objectives. However, there needs to be consistency between the questions and objectives with the research approach and purpose, in addition to pre-existing knowledge, the amount of time, access to participants (if needed) and other data sources. Saunders, Lewis et al. (2009) presents the following research strategies:

- Experiment;
- Survey;
- Archival Research;
- Case Study;
- Ethnography;
- Action Research;
- Grounded Theory;
- Narrative Inquiry.

It is important to emphasize that these strategies should not necessarily be considered as mutually exclusive. The first two research strategies are mainly or exclusively linked to a quantitative research project. However, Archival Research and Case Study are more flexible strategies and may involve quantitative or qualitative research. The last four strategies are mainly or exclusively linked to a qualitative research project. In the context of this project, it was decided to use Action Research.

Action Research is an emergent and iterative process of inquiry that follows purpose, process, participation, knowledge and implications. This process can be described as designed to develop solutions to real organizational problems (Coghlan 2019) through a participatory and collaborative approach. Greenwood and Levin (2006) point out that Action Research is a social process in which members of an organization have active participation for a common goal. This intra-organizational collaboration suggests a democratic approach to decision-making and the research cycle (Reason 2006).

Action research also has implications beyond the research design, both for the participants and the organization. Academically the results of action research can develop into a new theory, while in an organizational context the results can be used to transfer the acquired knowledge to the work context (Saunders, Lewis et al. 2009).

4.3 Project Steps

The research project described in this document started with a general analysis of the Bosch group. This first understanding is fundamental to creating a perception of the global markets as well as the sub-divisions and deepen the knowledge of Bosch Thermotechnology.

The next step was a detailed understanding of the business of the company where this project was carried out, the Plant in Cacia, Aveiro. In this sense, an analysis was carried out of internal documents related to the project which this project used as a study population, analysis, and segregation of parts according to the material category, selection of a sample of parts for in-depth analysis.

From this stage, it was important to understand how the parts are awarded to the supplier. It was also important to understand the criteria used to choose the pool of suppliers. Currently, the selection criteria for the production process of sheet metal parts is based on common sense and on the theoretical foundation that the Stamping process is financially more efficient for large batches given the high initial investment. However, this assumption does not have a value and/or definition range to be followed, being, therefore, based on the professional experience and common sense of the responsible buyer.

During the preparation of the project, conversations were maintained with the buyers responsible for the analyzed parts, as well as the suppliers and the employee responsible for the internal consultancy on sheet metal parts. Also, during this phase, meetings were held for technical discussions with suppliers and internal collaborators, requests for quotations, analysis, and comparison. Finally, the Breakpoint was elaborated to define the limiting factor in relation to the batch size indicated for each production process.

After defining the Breakpoint, a quantitative analysis was then carried out in relation to the time spent on all tasks involving the standard process of awarding a piece. After defining the process and how much time is used in each phase of the process, a financial analysis was developed. This financial analysis is based on 2022 cost data for the Technical Buyer role. The objective of the financial analysis is to demonstrate, in euros, the time savings that having the Breakpoint table adds to the role of Technical Buyer.

This research was carried out at Bosch Thermotechnology facilities, starting in February and ending in June 2023. During this period, data collection was achieved through procedures such as documentation analysis, direct observation, negotiation and technical meetings with suppliers and employees. of the company and analysis of similar cases.

5 Project Development

5.1 Decision-making

In this section we intend to explore the decision process of this project and its steps for this a cost estimation process was carried out. As defined in Horngren, Datar et al. (2009) "A cost function is a mathematical description of how a cost changes with changes in the level of an activity relating to that cost.". However, in order to establish a cost function, it is necessary to define the cost drivers. “The relevant costs required for decision-making are only those that will be affected by the decision. (…) The relevant financial inputs for decision-making purposes are therefore future cash flows, which will differ between the various alternatives being considered. In other words, only differential (or incremental) cash flows should be taken into account, and cash flows that will be the same for all alternatives are irrelevant.” (Drury 2013). It was considered the cost of parts price, tool price and annual quantity as relevant costs.

The cost estimation method used was the qualitative analysis method, which is “an analysis that uses a formal mathematical method to fit cost functions to past data observations” (Horngren, Datar et al. 2009). In this case, through the past data referring to the quotations that were collected, an estimate is intended for decision-making in future parts. In order for the estimate to be used, the assumptions of Horngren, Datar et al. (2009) were also accepted that:

1. Changes at the level of a single activity (the cost driver) explain changes in related total costs (part price).
2. Cost behavior is approximated by a linear cost function within the relevant range.

The qualitative analysis method consists of 6 steps:

1. Choose the dependent variable (Price part);
2. Identify the independent variable, or cost driver. The independent variable is the factor used to predict the dependent variable (Annual quantity);
3. Collect data on the dependent variable and the cost driver;
4. Plot the data;
5. Estimate the cost function;
6. Evaluate the cost driver of the estimated cost function.

The cost function is given in this project by an equation where the price of the tool is added to the parts price, disseminated through the annual quantities of each scenario. This is because the stamping tool is made for a specific part, and it is not possible to use it for another part. Furthermore, when an appliance is no longer sold and this part is not used in other appliances, this part is also no longer purchased, and its production is no longer necessary. Even though this tool is owned by the company, it is allocated to the supplier, and its use for any purpose

other than the production of the Bosch part is prohibited. Therefore, when a part is no longer purchased, the stamping tool also loses its usefulness, so its real lifetime is the number of parts intended to be produced in the project and not that indicated by the supplier. This is valid whenever the project quantity is less than the supplier's lifetime.

The successful implementation of the strategy depends, in addition to an analysis of the value chain, on the decisions that those responsible for them make for the implementation of these strategies. For the decisions that were taken in this project, the Five-Step Decision-Making Process enunciated in Horngren, Datar et al. (2009) was applied:

1. Identify the problem and uncertainties;

   The company has two production process options for metal parts:

   a) Flexible Process

   b) Stamping

2. Obtain information.

   Information was gathered with suppliers and in the company's history before the decision was taken.

3. Make predictions about the future.

   On the basis of the information, it is possible to make predictions about potential quantities for the future and conclude which is the most suitable process.

4. Make decisions by choosing among alternatives;

5. Implement the decision, evaluate performance, and learn.

In the next sections, the steps described here will be highlighted, as well as the cost function used in this project. The next section focuses on cost estimation and the subsequent one focuses on future forecasts and data that can motivate the company's decision making and tool implementation, points 4 and 5 of the five-step Decision Making Process.

5.2 Breakpoint Table

The Breakpoint table represents the tool where the Technical Buyer can find per cluster, annual quantity above which it is indicated to opt for the Stamping production process instead of the Flexible process. As already mentioned in previous chapters, the choice of having a table and not a single value is because there is some diversity in the characteristics of the sheet metal parts and to cover these characteristics in the analysis and avoid large deviations, we opted for grouping of pieces in clusters according to their characteristics.

For this analysis, pieces that were already in the company's intention to be reviewed were chosen. These parts were initially awarded to a supplier that works with the Flexible production process. For reasons of confidentiality both for the company regarding this project and between the company and the supplier, some information will be kept confidential and other data will be anonymized.

Information such as the name of the suppliers, country or any other characteristic that may indicate which supplier is referred to will not be disclosed. For this project, suppliers will be referred using letters of the alphabet, with supplier A being the current supplier of parts. The drawings of the parts, the name and the internal numbering cannot be disclosed either. The name of the parts used in this project is representative of the general characteristics of the part and the indicative number was randomly generated with the help of the Excel program.

To meet the required data confidentiality, the values used in this project were anonymized by multiplying them by an α value which, also due to confidentiality, cannot be disclosed. To

maintain the proportion between values, all monetary values were multiplied by the same α value.

For this analysis, which lasted from February 2022 to the beginning of May 2022, the quote initially awarded was used together with interviews with the Technical Buyer responsible for the parts and meetings with new potential suppliers for the Stamping production process. In addition, there were meetings with the internal consultant for sheet metal parts to discuss parts and input for this project as well. After the meeting with suppliers, new quotations were now necessary for the Stamping process. When quotations are received, analysis of these new quotations and new meetings for final alignments and negotiations must be carried out. This entire process was accompanied by the Technical Buyer responsible for the parts.

There is an assumption that was made in relation to this analysis, which is that the same part price is considered for all quantities. This consideration comes from input given by the internal sheet metal parts consultant. As a rule, there is no great disparity in terms of the production that is carried out internally by the company itself, nor in terms of the criteria that companies that are suppliers must meet to be able to supply. The exception to this situation is when the supplier has an OEE (Overall Equipment Effectiveness), which is an indicator of efficiency and productivity, which is too low. In fact, it is known that the process can be influenced by the number of parts through economy of scale, but in the execution time of this project it would not be possible to obtain the number of quotations necessary to explore all the scenarios that were explored. Therefore, this assumption was accepted.

The investigation started by reviewing the parts award that had been made to a flexible process supplier and gathering information that was summarized in Table 1. Following this documentation process and together with the responsible Technical Buyer, new suppliers were contacted for new quotations for the Stamping process. Due to confidentiality, the current supplier was called Supplier A and the other suppliers were called Supplier B, C, D and E. The choice of 4 suppliers for consultation is part of the company's internal commercial strategy and, as already mentioned, is not a decision that belongs to the Technical Buyer, but to another role.

Part Number	Description	Painted	Supplier	Flexible process Price
36020	Panel Top - Painted Silver	Y	A	23,72 €
43615	Bracket Corrugated Pipe (1)	N	A	6,62 €
34496	Bracket Corrugated Pipe (2)	N	A	1,39 €
20908	Base Plate	Y	A	43,68 €
22688	Panel Top - Painted White	Y	A	23,04 €
27122	Panel Top - Painted Silver	Y	A	23,76 €
98865	Support HMI	Y	A	4,57 €

Table 1 - Initial award data

To cover the details of the pieces and since it is not possible to show the drawings of the pieces, clusters were used. The factors of dimension, painting, and complexity were considered in the realization of the clusters of parts (Table 2), avoiding deviations in the result of the Breakpoint.

	Part Number	Comments/Assumptions
I	Panel Top - Painted Silver Base Plate Panel Top - Painted White Panel Top - Painted Silver	Similar size Painted Usually Flexible Process
II	Bracket Corrugated Pipe (1) Bracket Corrugated Pipe (2)	Some level of complexity Not painted Usually Stamped Process
III	Support HMI	Simpler than brackets Painted Usually Stamped Process

Table 2 - Clusters

The quotes that were received and discussed were also summarized in a table (Annexe A). Discussions on these parts lasted from February to May 2023 and were monitored by the responsible Buyer. For minor issues related to the discussion, such as the productive limitations of each supplier, they must be kept confidential. It should be noted that not all suppliers were able to offer quotations for all parts, this is due to internal supplier production limitations.

Based on the quotes received, 35 scenarios were then simulated for annual quantities from 1,000 to 18,000 parts in intervals of 500 parts. A sum for 5 years was used in each scenario to maintain the standard of quotations and planning that the company already had. The definition of the maximum value of 18,000 parts/year was based on trial-and-error extrapolation.

It is important to emphasize that the annual quantities that the Technical Buyer receives are forecasts of the sales that are estimated to have in the years after the launch of the appliance. These forecasts are carried out by the team responsible for market forecasting. Therefore, the Technical Buyer receives estimated annual quantities to award the parts. As mentioned, the Technical Buyer role is part of the Development Team, that is, it is not involved in the mass production process, only until the ramp up process. If these quantities suffer significant changes, the award process can be revised and the Breakpoint table may be useful, however this responsibility does not fall under the Technical Buyer scope, as this role is no longer involved in this phase of the projects.

Moving on to the analysis of the next relevant variable, in order to introduce the price of the tool into the price of parts, some calculations were necessary. As already mentioned, the stamping tool is made for a specific part and cannot be reused. That said, and as the tool is owned by the company, the tools are only used for the part in question, cannot be used by the supplier for other jobs and are not useful for other parts. Hence, the calculation to insert the cost of the tool in the part price considers the 5-year quantity of each scenario as lifetime for the tool. Even when the lifetime tool is greater than this quantity, the quantity of 5 years is considered because from that quantity onwards, the part is no longer produced, the tool is no longer used and therefore its real lifetime is the quantity of parts it produced, and its cost must be dissolved in that amount. The insertion of the tool price by the 5-year quantity for each scenario was called β. Defined as the tool price increase will be represented, the β is then added to the part price, this sum was called γ.

$$\beta = \frac{Tool\ Price}{Quantity_{5y}} \tag{5.1}$$

$$\gamma = Part\ Price + \beta \tag{5.2}$$

These two procedures were carried out for all suppliers, resulting in a table similar to table 3 below for the 35 scenarios for each supplier. In addition to these 2 calculations, a column to aid decision-making was also inserted in the table. This column has a formula to help indicate that while the γ is higher than the indicated price of the current flexible process, it is recommended to keep the production process as flexible process. When this γ becomes lower than the part price of the flexible process, the column starts to give the recommendation for the change to the Deep Drawing process, popularly called Stamping.

Annual Quantities						Supplier B		
2023	2024	2025	2026	2027	Σ	β=Tool Price/ Q	γ=Price + β	Recommendation
1 000	1 000	1 000	1 000	1 000	5 000	23,52 €	25,66 €	Flexible Process
1 500	1 500	1 500	1 500	1 500	7 500	15,68 €	17,82 €	Flexible Process
2 000	2 000	2 000	2 000	2 000	10 000	11,76 €	13,90 €	Flexible Process
2 500	2 500	2 500	2 500	2 500	12 500	9,41 €	11,54 €	Flexible Process
3 000	3 000	3 000	3 000	3 000	15 000	7,84 €	9,98 €	Flexible Process
3 500	3 500	3 500	3 500	3 500	17 500	6,72 €	8,86 €	Flexible Process
4 000	4 000	4 000	4 000	4 000	20 000	5,88 €	8,02 €	Flexible Process
4 500	4 500	4 500	4 500	4 500	22 500	5,23 €	7,36 €	Flexible Process
5 000	5 000	5 000	5 000	5 000	25 000	4,70 €	6,84 €	Flexible Process
5 500	5 500	5 500	5 500	5 500	27 500	4,28 €	6,41 €	Deep drawing Process

Table 3 - Recommendation scenarios for annual quantities

From this table a summary table is developed. This summary table (Table 4) aims to simplify the breakpoint scenarios for each part by supplier. The table summarizes from which scenario it is recommended that the production process be changed to Stamping process by supplier. In the last column, an average is then made to have the average breakpoint for each part.

Part Number	Description	Supplier B	Supplier C	Supplier D	Supplier E	Breakpoint
36020	Panel Top - Painted Silver	40 000	17 500	40 000	No offer made	**32 500**
43615	Bracket Corrugated Pipe (1)	27 500	22 500	25 000	22 500	**24 375**
34496	Bracket Corrugated Pipe (2)	50 000	35 000	52 500	52 500	**47 500**
20908	Base Plate	No offer made	7 500	7 500	No offer made	**7 500**
22688	Panel Top - Painted White	42 500	20 000	37 500	No offer made	**33 333**
27122	Panel Top - Painted Silver	40 000	17 500	40 000	No offer made	**32 500**
98865	Support HMI	No offer made	12 500	20 000	17 500	**16 667**

Table 4 - Breakpoint of each part

Based on Table 2 of the clusters and on Table 4 of the Breakpoints of each piece, the Breakpoint Table was created. The Table 5 is the grouping of the parts according to the predefined clusters and the average of the values obtained in Table 4.

Breakpoint Table	
Cluster I	26 458
Cluster II	35 938
Cluster III	16 667

Table 5 - Breakpoint Table

5.3 Purchasing Process Timeline

The investigation of the purchasing process takes place not only through pre-existing internal documentation but also through interviews with other Technical Buyers to document, through work experience, the estimated deadlines of each phase of the process. The documentation of this process takes place through the creation of a Gantt chat (Annexe B).

This documentation started by listing the process steps based on pre-existing internal documentation and observation. The listing was then reviewed with other Technical Buyers and lead times estimated based on team input and field observation. The deadlines represent average estimates for each step in the process. Finally, a Gantt Chart was developed with all inputs collected.

The fact that the Gantt Chart considers only 3 suppliers per piece comes from an internal rule to ensure compliance with the minimum number of suppliers that must be contacted to carry out the awarding of metallic parts, with the usual use of 3 suppliers per piece per production method. Therefore, and as observed in the study that generated the Breakpoint table, in case the Technical Buyer wishes to explore alternatives to the current production process, a greater number of suppliers can be contacted.

The Gantt Chart starts with the process from receiving the part from the Design team and ends at the beginning of the request for parts, having 14 steps. Some of these steps can be subdivided for each potential supplier and some of the sub-steps can be performed in parallel and some cannot.

The first stage of the process is part analysis. After the part is received, it must be analyzed by the Technical Buyer and all questions initiated clarified between Design and Technical Buyer. The next step is the alignment of the pool of suppliers to be consulted for the part in question, the Technical Buyer can offer inputs in relation to which suppliers he would judge to have the best potential for supply, even if he is not responsible for the decision internally.

Once the supplier pool has been chosen, the Technical Buyer is responsible for validating it before consulting suppliers. This validation is done with other members of other departments in order to verify that the pool's suppliers meet all the internal supply prerequisites. Upon approval from the supplier pool, contact with each supplier can be initiated.

The suppliers' approach can occur simultaneously and is composed of 2 phases: the presentation of the project and the technical discussion regarding the part. The project presentation consists of informing the supplier of project details such as the production location (to which Plant will be supplied), annual forecast of quantities and an initial timeline. The technical discussion of the part can also include the Design Team whenever necessary. In the case of technical discussions, it is common for inputs to be exchanged between Purchasing, Design, and the supplier. However, whenever these inputs lead to a design change, a new design revision is necessary. At each new design revision, it is necessary to

align the other suppliers and, if necessary, start a new technical discussion. The presented Gantt Chart estimates an average time considering that there are no major design revision changes that significantly impact the process timeline.

Once the technical discussions with suppliers have been completed, an internal alignment between Purchasing and Design is carried out. The Design team, even though it is not responsible for choosing the supplier, can offer relevant inputs for the choice and quality of the part, thus making the alignment after technical discussions relevant to the process.

With the alignment between all people finalized, the Technical Buyer is responsible for requesting quotations from each of the suppliers. These requests are given a response lead time of approximately 3 weeks. After receiving the quotes, a detailed analysis of each one is required, it is recommended that this process not be done simultaneously, but sequentially.

Starting from the individual analysis of quotations, the comparison between quotations follows. After this comparison, there is often a final negotiation with each supplier, both to negotiate values and conditions, but also to clarify points related to the quotation. The next step is then the preparation of the final documents with the analysis of quotations and the decision recommendation for internal approval. Only after this approval can the parts ordering process begin.

This process took an average of 3 months and 21 days, which accounts for 81 business days. However, the Breakpoint table only affects the steps: technical discussion with the supplier, internal alignment, analyze quotations, comparison of quotation, and final negotiation.

In addition to the Technical Buyer's active working hours, the Gantt Chart also includes passive working hours (lead time), for example, the step 'Internal alignment between Purchasing and Design' is represented as 1 week since both functions there are other tasks going on at the same time and therefore a lead time to respond to emails and even to align a time for a meeting requires the availability of both. That said, and to have a more accurate analysis of the impact of the table, the Gantt Chart has been revised to delimit how many hours of active work the Technical Buyer spends on each stage affected by the table.

The identification of active work hours was carried out in a similar way to the identification of stages, through observation and review of other Technical Buyer inputs. The quantification of active hours for each step affected by the Breakpoint table can be seen in table 6 and accounts for a total of 49.5 hours per piece.

Active working hours (process for 3 supplier)		
Technical discussion with the supplier	16,5	2 meetings, 5 email exchanges
Internal Alignment	4	E-mails, meetings and/or analyzes
Analyze quotations	9	3h per supplier
Request quotation	2	2h per 3 suppliers
Comparison of quotation	9	3h per supplier (standard process)
Final Negotiation	9	3h per supplier
Σ	**49,5**	
Note: Each meeting equals 1.5 hour Each email equals 0.5 hour		

Table 6 - Active working hours on processes affected by the Breakpoint table

The accounting for these hours refers to the stage of the technical discussions, which becomes more aligned and therefore the quotations are more direct and clearer, the internal alignment is more immediate because there are not so many disparities in production processes and adaptations so that the part can be considered for different productive processes. In addition,

in the quotation analysis stage, a significant reduction in time can be identified, in consultation with suppliers, focusing on the recommended process, without so many adaptations and reservations. These same benefits are reflected in a quote comparison that becomes less time-consuming. Which also leads to a less extensive final negotiation.

Therefore, there will be time savings since only relevant suppliers will be consulted for that part under those conditions. This leads us to avoid spending time on discussions and analyzes that are not relevant to the decision. This saved time can then be applied in other phases of the project, in other projects that occur simultaneously or even in better, more extensive negotiation discussions, since the focus will be on the most suitable process.

5.4 Comparison of current awarding with the Breakpoint table

In order to evaluate the results obtained in the Breakpoint table, a comparison with the initial decisions was performed. The first comparison is carried out based on the quantities in which the parts were awarded. It should be noted that the initial decisions were made based on the forecasts that the market team provided at the time of the awarding.

It is possible to notice in Table 7 that of all the analyzed parts, two of them (Panel Top – Painted Silver and Base Plate) would be recommended to award to a supplier that works with the stamping process. The quantities of the sales forecasts are updated periodically even after the awarding of the parts, having said that, the same comparison was also carried out for the updated quantities of the project.

Part Number	Description	Annual Quantity awarded	Cluster	Suggestion
36020	Panel Top - Painted Silver	52 461	I	Stamping
43615	Bracket Corrugated Pipe (1)	27 422	II	Flexible
34496	Bracket Corrugated Pipe (2)	27 422	II	Flexible
20908	Base Plate	28 746	I	Stamping
22688	Panel Top - Painted White	8 009	I	Flexible
27122	Panel Top - Painted Silver	6 324	I	Flexible
98865	Support HMI	6 324	III	Flexible

Table 7 - Analysis of the annual quantities awarded through the Breakpoint table

A comparison similar to Table 8 was made for each of the suppliers, except supplier E because it did not bid for these parts. The awarding price of supplier A was compared with the offer of alternative suppliers for the quantity closest to the quantity that was awarded. In case there is no scenario with the exact annual quantity, the prices for the annual quantity closest to the awarded quantity were used. In Table 9 it is possible to see, in percentage, the cost reduction that the use of the Breakpoint table implies for the project, with supplier C being the most economically beneficial.

Description	Quantity	Supplier A Price	Supplier A Total Cost	Supplier B Price	Supplier B Total Cost
Panel Top - Painted Silver	52 500	23,72 €	1 245 510,00 €	20,42 €	1 071 840,00 €
Base Plate	29 000	43,68 €	1 266 720,00 €	No offer made	-

Table 8 - Stamping cost per supplier for the awarded quantity

Description	Supplier B	Supplier C	Supplier D
Panel Top - Painted Silver	-14%	-37%	-11%
Base Plate	-	-48%	-42%

Table 9 - Percentage of cost reduction per supplier for the awarded quantity

In Table 10 it is possible to verify that with the variation of the annual quantities, the parts for which the change of supplier is indicated also change. With the use of this tool, the analysis of the part through the cluster and the quantities becomes immediate.

Part Number	Description	Annual Quantity Updated	Cluster	Suggestion
36020	Panel Top - Painted Silver	57 240	I	Stamping
43615	Bracket Corrugated Pipe (1)	56 700	II	Stamping
34496	Bracket Corrugated Pipe (2)	82 800	II	Stamping
20908	Base Plate	25 938	I	Flexible
22688	Panel Top - Painted White	5 811	I	Flexible
27122	Panel Top - Painted Silver	20 127	I	Flexible
98865	Support HMI	20 127	III	Stamping

Table 10 - Analysis of annual quantities updated through the Breakpoint table

In Table 11 it is possible to see the potential cost reductions that the use of the Breakpoint table implies in view of the new project quantities. In this case, a different supplier would be economically more beneficial depending on the part in question. For most of the impacted parts, the supplier with the best offer is supplier C, with the exception of part Bracket Corrugated Pipe (1) where supplier E made the best offer.

Description	Supplier B	Supplier C	Supplier D	Supplier E
Panel Top - Painted Silver	-17%	-38%	-13%	-
Bracket Corrugated Pipe (1)	-37%	-41%	-42%	-44%
Bracket Corrugated Pipe (2)	-32%	-49%	-32%	-31%
Support HMI	-	-39%	-5%	-27%

Table 11 - Percentage of potential cost reductions per supplier compared to new project quantities

5.5 Economic Benefit

The economic benefit brought by the Breakpoint table is defined based on the standard purchasing process and the costs related to the Technical Buyer role in the year 2022. These costs come from the Accounting Department records and for this project are subdivided into direct and indirect costs. As with the other data used in this project and to ensure data confidentiality, the data were anonymized by multiplying them by the same α value that was used in the Breakpoint table to maintain the scales between the analyzed values.

The calculation of direct costs is related to labor and comes from the payroll summary, a monthly average of employees directly linked to the process, hours worked per month, social charges levied on the payroll. Thus, the total cost of direct labor was defined. The direct cost of the process for the company is defined by multiplying the hourly cost of direct labor by the time spent in the determined process.

Subsequently, and for each factory, the company will be able to determine the indirect costs and add them to the cost of the process. Indirect costs are the company's variable expenses

with the employee, referring to travel, food subsidy, training, material, security, and legal social benefits. These expenses can be added to the calculation by apportionment: dividing the total expenses by the total hours available in the month and multiplying by the time spent on the service.

Thus, the economic benefit will be given by the sum of the hours of active work that are affected by the Breakpoint table (49.5 hours) multiplied by the average cost of hours worked. This cost being the total cost, that is, the average (€/h) per employee of the sum of the direct cost and the indirect cost of the Aveiro Plant. To also obtain an estimate of this economic benefit in projects in general, the number of metallic parts in the project involving Appliances C and D analyzed was counted. This number of sheet metal parts was used as a basis to estimate the economic benefit that this tool represents for the complete project. These detailed calculations and the economic benefit both by parts and by design are represented in Table 12.

Variable	Description	Value
A	Direct costs	510 000,00 €
B	Indirect costs	55 200,00 €
C	Number of employees	7,09
D	Nº business days in 2022	251
E	Nº of daily working hours	8
F=D*E	Nº of hours worked in 2022	2 008
G=(A+B)/F	Technical Buyers costs per hour	281.47 €
H	Number of hours impacted by Breakpoint table	49.5
I=G*H	Economic Benefit per part	**13 932.97 €**
J	Number of sheet metal parts in both Appliances	69
K=I*J	Economic Benefit per project	**961 374.80 €**

Table 12 - Analysis of the economic benefit per part and per project

An important indication to be made is that this cost analysis must be carried out locally, since the factories that make up the Thermotechnology business unit are located in different countries. In addition to the salary value being different in each country, taxes and costs are also not comparable, so each Plant has a different direct and indirect cost for the same function.

6 Conclusions and Prospects of future work

The current technological context and business competition influence companies to seek to be increasingly efficient in their products and services, for which technology has been a great ally. Digital analysis and communication tools allow for fast and effective interaction between customers and suppliers, allowing greater agility in extensive studies such as the one developed. The Breakpoint Table is an example of a tool that allows the company to evaluate the most appropriate production process for that type of sheet metal part effectively, that is, obtaining the result with the lowest possible resource expenditure.

This document begins with a theoretical framework on the production processes in question, where the major differences and limitations are addressed, also aiming to support why there was an initial common sense in the company in relation to the quantities for each production process. Subsequently, action research was carried out, where parts were extensively negotiated and analyzed between potential suppliers and Bosch Thermotechnology of Aveiro, one of the residential hot water business units of the German Bosch group. This project arises from the company's need to gain greater efficiency and financial benefits in carrying out the most appropriate awarding for each part.

The information obtained through the series of meetings, conversations, emails, analyzes and documents allowed the understanding of the Purchasing process and which steps could benefit from these tools. It also allowed a better understanding of the analysis for each part. The Breakpoint table proves the great disparity in value between the clusters, confirming the need to have different Breakpoints for each type of part. In addition, the table allows that from the first awarding the Technical Buyer, guided by the characteristics of the part and the annual quantities, can already choose the most suitable process without having to carry out extensive field research for all parts to compare quotations and conclude which is the better process.

One of the project's objectives, in addition to the Breakpoint table, was to quantify the impact of this tool on the daily life of a Technical Buyer. To achieve this result, it was necessary to understand and document the process that this role plays in awarding parts and, after documentation, define the timeline and deadlines for each step. Subsequently, it was necessary to collect data together with the Accounting Department so that it was possible to calculate the average cost of a Technical Buyer in Aveiro, Portugal. Through these costs, the delimitation of the timeline and the hours of active work, it is possible to quantify how much a Technical Buyer spends on these tasks and, therefore, the economic benefit of 13,932.97 € per part that this tool represents for the company. In an extrapolation it was also identified, through the number of parts that are in the project, the economic benefit of 961 374.80 € per project.

Finally, it should be noted that the implementation of the Breakpoint table cannot be considered finished yet. In order for it to be implemented, to be successful and to be a tool that efficiently translates the company's strategy, it is necessary to carry out more quotes for more parts, in addition to checking all parts of a project to see if there is a need to create more clusters.

6.1 Suggestions for future research

During the elaboration of the project, an obstacle was identified, which is the fact that the project had a somewhat short duration - just over four months - to contact suppliers, have technical discussions, ask for quotations, analyze, compare and negotiate quotations, this is a deadline that does not allow a large number of parts to be analyzed. A longer duration of active investigation would be recommended to obtain a richer and more diverse table of parts.

This project also allows the company to develop the table from different points of view, either by type of material, which was the approach used in this project, or by supplier. Furthermore, given that the economic impact is significant, expansion beyond just sheet metal parts appears to be a viable opportunity for the company.

In the future, the company will be able to continue this process and carry out this Plant by Plant financial analysis. Since the economic factors vary in each country where the Plants are located, it is expected that the financial impact will also be impacted.

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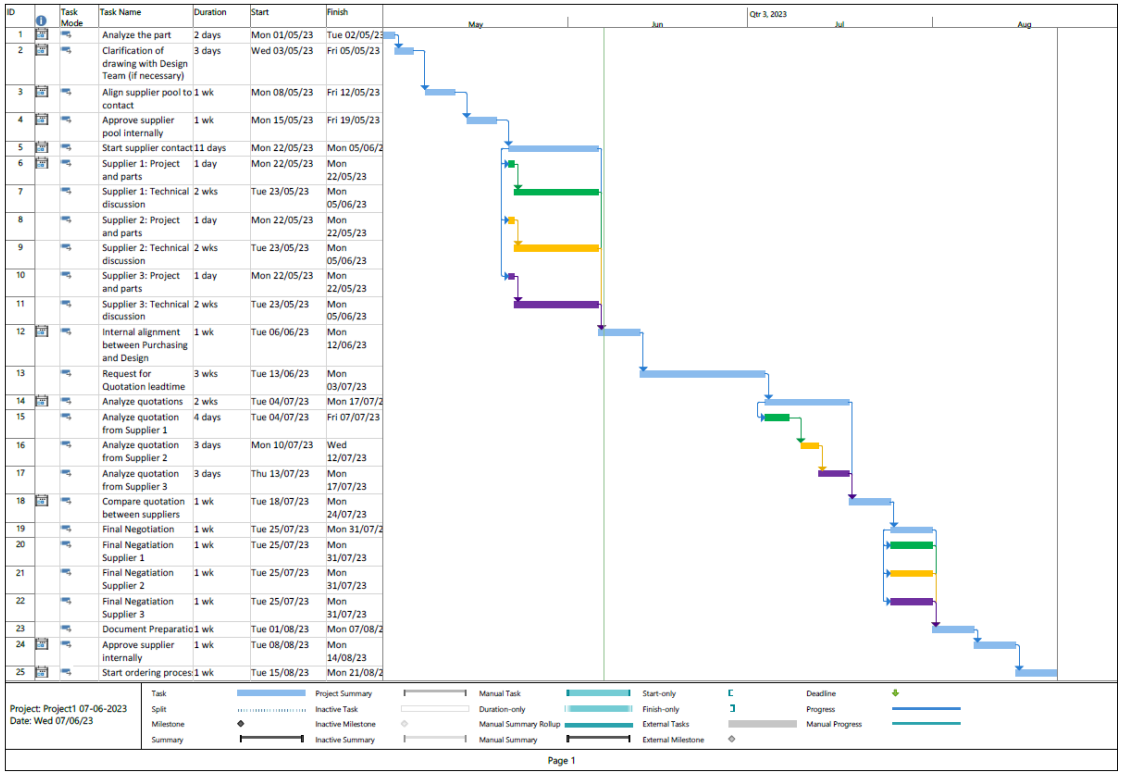
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ANNEXE A: Quotations for the Stamping process

		Supplier B			Supplier C			Supplier D			Supplier E		
Part Number	**Description**	**Price**	**Tool Price**	**Tool lifetime**	**Price**	**Tool Price**	**Tool lifetime**	**Price**	**Tool Price**	**Tool lifetime**	**Price**	**Tool Price**	**Tool lifetime**
36020	Panel Top - Painted Silver	11,62 €	462 000,00 €	1 000 000	11,04 €	210 000,00 €	500 000	14,50 €	346 797,60 €	2 000 000	-	-	-
43615	Bracket Corrugated Pipe (1)	2,14 €	117 600,00 €	1 000 000	2,34 €	89 040,00 €	500 000	1,69 €	122 170,80 €	2 000 000	2,06 €	93 312,00 €	2 000 000
34496	Bracket Corrugated Pipe (2)	0,32 €	52 800,00 €	1 000 000	0,25 €	38 640,00 €	500 000	0,25 €	58 977,60 €	2 000 000	0,29 €	57 024,00 €	2 000 000
20908	Base Plate	-	-	-	16,61 €	184 800,00 €	500 000	21,59 €	114 583,20 €	2 000 000	-	-	-
22688	Panel Top - Painted White	11,50 €	462 000,00 €	1 000 000	11,68 €	210 000,00 €	500 000	13,78 €	346 797,60 €	2 000 000	-	-	-
27122	Panel Top - Painted Silver	11,72 €	462 000,00 €	1 000 000	11,40 €	210 000,00 €	500 000	14,80 €	346 797,60 €	2 000 000	-	-	-
98865	Support HMI	-	-	-	1,14 €	36 960,00 €	500 000	2,69 €	37 213,20 €	2 000 000	0,54 €	63 408,00 €	2 000 000

Table M - Alternative quotations for the production process in Stamping

ANNEXE B: Gantt Chart



ID	Task Mode	Task Name	Duration	Start	Finish
1		Analyze the part	2 days	Mon 01/05/23	Tue 02/05/23
2		Clarification of drawing with Design Team (if necessary)	3 days	Wed 03/05/23	Fri 05/05/23
3		Align supplier pool to contact	1 wk	Mon 08/05/23	Fri 12/05/23
4		Approve supplier pool internally	1 wk	Mon 15/05/23	Fri 19/05/23
5		Start supplier contact	11 days	Mon 22/05/23	Mon 05/06/2
6		Supplier 1: Project and parts	1 day	Mon 22/05/23	Mon 22/05/23
7		Supplier 1: Technical discussion	2 wks	Tue 23/05/23	Mon 05/06/23
8		Supplier 2: Project and parts	1 day	Mon 22/05/23	Mon 22/05/23
9		Supplier 2: Technical discussion	2 wks	Tue 23/05/23	Mon 05/06/23
10		Supplier 3: Project and parts	1 day	Mon 22/05/23	Mon 22/05/23
11		Supplier 3: Technical discussion	2 wks	Tue 23/05/23	Mon 05/06/23
12		Internal alignment between Purchasing and Design	1 wk	Tue 06/06/23	Mon 12/06/23
13		Request for Quotation leadtime	3 wks	Tue 13/06/23	Mon 03/07/23
14		Analyze quotations	2 wks	Tue 04/07/23	Mon 17/07/2
15		Analyze quotation from Supplier 1	4 days	Tue 04/07/23	Fri 07/07/23
16		Analyze quotation from Supplier 2	3 days	Mon 10/07/23	Wed 12/07/23
17		Analyze quotation from Supplier 3	3 days	Thu 13/07/23	Mon 17/07/23
18		Compare quotation between suppliers	1 wk	Tue 18/07/23	Mon 24/07/23
19		Final Negotiation	1 wk	Tue 25/07/23	Mon 31/07/2
20		Final Negatiation Supplier 1	1 wk	Tue 25/07/23	Mon 31/07/23
21		Final Negatiation Supplier 2	1 wk	Tue 25/07/23	Mon 31/07/23
22		Final Negatiation Supplier 3	1 wk	Tue 25/07/23	Mon 31/07/23
23		Document Preparatio	1 wk	Tue 01/08/23	Mon 07/08/2
24		Approve supplier internally	1 wk	Tue 08/08/23	Mon 14/08/23
25		Start ordering proces	1 wk	Tue 15/08/23	Mon 21/08/2

Figure H - Gantt Chart of the Purchasing process from receipt of the part to the beginning of the ordering process