TECHNOPROBE
Wafer Probing Technologies

LASER DRILLING PROCESS OPTIMIZATION

Application of Lean Management to Improve a Production Process

Benaglia Matteo – Bonetto Alessandro | October 2020

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LASER DRILLING PROCESS OPTIMIZATION

Application of Lean Management to Improve a Production Process

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Industrial Management

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ABSTRACT

For a 21st century company, success is represented by the ability to keep up with a constantly growing demand, respecting increasingly customized requests and an ever-increasing level of product quality.

To do this it is necessary not only to increase the production capacity of the company but also to optimize the production processes by limiting waste. Optimization can be achieved thanks to the principles of modern management theories such as Lean Manufacturing and Industry 4.0.

The goal of this thesis path is to analyze a production process in a highly competitive and constantly developing work context in order to increase company performance through the application of the aforementioned principles.

The first part of this work illustrates the company and the market in which it operates, in particular, the attention will be placed on a specific department.

The second part identifies the main problems of the production process under consideration, through the direct observations of performance in the company.

In the third part, the objectives of this project are defined, countermeasures are developed and possible impacts are assessed.

Finally, in the last part of the work are described the scheduling and methodology of countermeasures' implementation. The last chapter is dedicated to the description of possible follow up actions and to the thanks of all those who made possible the realization of this project.

INTRODUCTION

PROJECT OVERVIEW

This thesis aims to describe the path that our team has taken over in the last few months. This project involves a team composed of two students, Benaglia Matteo and Bonetto Alessandro, one methodological tutor, Costa Federica, and one company tutor, Schiariti Valentino. It is classified as “Full Project” with a duration of 4 months, for a total of about 550 hours each, distributed over 4 days a week. The initial schedule envisaged the start of the internship in the first days of March, thus concluding in July; unfortunately, the well-known global pandemic of COVID-19 broke out shortly before starting, postponing the entire internship for a few months and initially obliging the team to work from home in smart working.

COMPANY OVERVIEW

The project takes place in the headquarters of Technoprobe S.p.a in Cernusco Lombardone in the province of Lecco, a very modern and constantly expanding structure that houses about 700 employees divided into the various production areas of the company. Technoprobe is also present in various countries spread all over the world, particularly in areas where the microtechnology sector in which it operates is very relevant, for example Japan, China, Korea and the United States (California).

Technoprobe despite being a relatively young company, founded by Giuseppe Crippa in 1995, has established itself on world markets in a short time, becoming one of the first companies in the world and the first Italian company in the semiconductor field; in particular, in the last 3 years company's growth has been exponential and since 2018 it has been the second-largest company in the world for the production of Probe Cards.

The Probe Card is a highly technological product that Technoprobe manufactures to order for the largest technology companies; the final product consists of an interface that allows chips to be tested while they are still at wafer level (figure 1).

Considering that each chip produced must be tested before being sold on the market, it is easy to understand why the company has such an important growth and development. The production of chips worldwide is constantly growing, just considering the production of PCs, mobile phones, tablets, TVs, credit cards and more recently also the automotive field which is becoming a driving sector for manufacturers of chips.

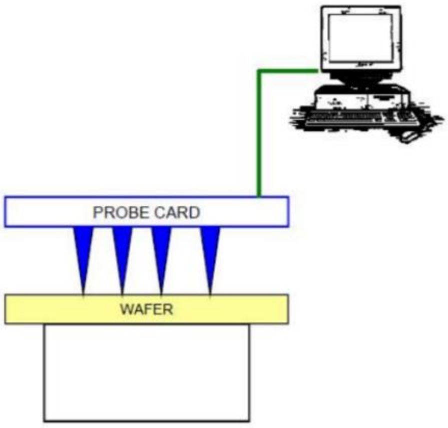


Figure 1: Task of Probe Card

The Probe Card is an electromagnetic interface between the machine that moves the wafer on which there are numerous chips and the computer that sends the signals to simulate the operation of the chips. The finished product is a complex set of components (figure 2) such as the PCB board, the Probe Head, the probes, and different connection mechanisms. All these components are made with margins of errors in the micron range and , therefore, require sophisticated machinery and highly specialized workforce to achieve the quality objectives required by the customer.

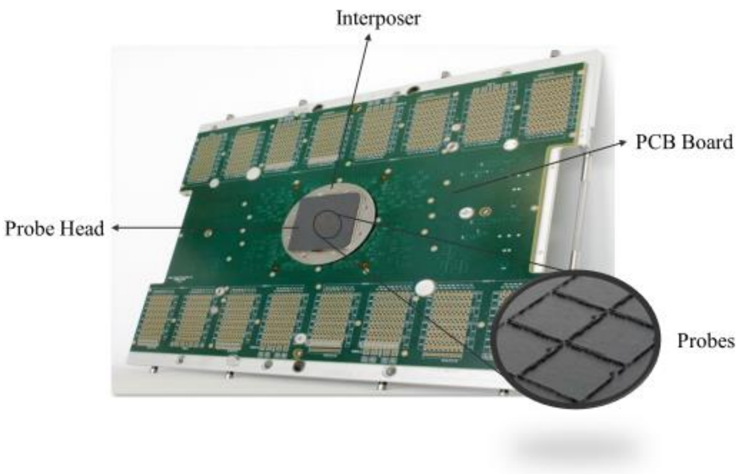


Figure 2: Probe Card's components

In addition to this complex production, Technoprobe has to deal with both fierce competititors which, having numerous funds, may be intent on copying the new patents issued by Technoprobe every year, and with the strong pressure from customers to reduce of prices and timing. In the complex and difficult market just described, reactivity and speed in solving qualitative and technical problems become of fundamental importance, as well as on-site after-sales support in order to maximize customer satisfaction. Technoprobe, therefore, represents an Italian excellence in the world, and it is also important to underline its commitment to social and eco-sustainability by supporting numerous cultural, sports and hospital associations, engaging in campaigns to reduce the use of plastic and promoting the use of clean energy by encouraging the use of public transport and investing in photovoltaic panels.

COMPANY HISTORY

Technoprobe was born in 1993 in a garage of a small house nearby Milan. Initially, no one would ever have thought of such a prosperous future, in fact, the Probe Card market was not yet well defined and was taking its very first steps, but the ideas of the founder Giuseppe Crippa were many and the desire to invent and create new products was great. The real date of foundation, however, is 1995, when the small garage began to evolve into a small company that designed and produced highly complex Probe Cards for the increasingly emerging microelectronics market.

Figure 3: Cobra technology

Over the years Technoprobe began to create more and more different products and to develop new technologies, to remember the first vertical technology of Probe Head realized in 2000 composed by 920 probes with Cobra technology (figure 3), a number that was already very high at the time. This technology turned out to be Technoprobe's first successful product. In a short time, the company starts an incredible expansion, starting in 2001 with France, building in Rousset, Provence. Subsequently, the impressive development of the Asian markets led Technoprobe to become increasingly interested in those regions which are so important from a strategic point of view for the semiconductor market. Technoprobe wasted no time already in 2002 building a service center in Singapore, which remains the second largest office with around 120 employees.

Technoprobe's technological development has never stopped, in fact, in 2007 it was awarded by the Semiconductor Wafer Test Conference (SWTest) in San Diego, for the development of the most innovative technology: a revolutionary production system, based on MEMS needles, assembled in a vertical configuration. Another significant step forward was made in 2008, with the expansion also in the United States, the first world market in technological research. The choice was strategic, in fact, they settled in San Jose in California, in order to serve the largest semiconductor sector in the world based in Silicon Valley. In 2009 a partnership with MS Sun helped Technoprobe to promote and distribute its products in the rapidly expanding market and to provide local support services in Taiwan. The same development was made in the Philippines, where a service center was created that reached 90 employees in 2015. Driven by the ever-increasing demand, in 2011 Technoprobe began an enlargement of the Italian plant by adding 4000 sqm to the production plant and the offices.

The same year a new probes technology called TPEG MEMS was invented which became the standard used by the entire semiconductor industry. Another technological milestone was reached in 2014, when Technoprobe became the first world producer of Probe Cards of the so-called On-Chip system, and third overall in the production of Probe Cards, reaching the coveted milestone of 100 M$ revenues. Another service center to provide local customer service and support was built in South Korea, a very important and strategic location for the microtechnology market. In 2017 Technoprobe invested more than 30 M$ to further increase the production capacity of the Italian site, increasing the production area and offices by 7000 sqm, with a highly technological building created on the American footprint (figure 4).

Figure 4: Technoprobe HQ

The inauguration of the headquarters was enormously successful, many customers attended and Technoprobe's image in the world increased, showing the new technological center. An important milestone was also reached in 2017 in terms of sales and earnings, becoming the third-largest producer in the world and reaching 180 M$ annual revenues. This number was soon overcome thanks to the expansion of the TPEG MEMS portfolio, reaching 230 M$ annual revenues. In 2019 Technoprobe acquires Microfabrica, a leading company in the high-volume production of micro-scale and high-precision products. In this way, the company was able to express its potential and keep up with the continuous expansion of the world market. To strengthen the presence in the Asian regions, three other technical assistance bases were implemented in 3 countries of fundamental importance: Taiwan, Japan and China. Following this expansion Technoprobe earned the second position in the world production of Probe Cards with annual revenue of 264 M$ and counting more than 1000 total employees worldwide.

SEMICONDUCTOR MARKET

The market in which Technoprobe moves is undoubtedly a wide field that is always ready for changes and sudden fluctuations due to the technological innovations that follow one another quickly over the years and that strongly impacts a market strictly linked to the technology for products.

The strongly expanded semiconductor market from 2017 recorded an increase of 13.7% in 2018, reaching an all-time high of 468.8 B$. In 2019, a slight decline occurred, falling to a total value of 454.4 B$ while for 2020 a modest growth was expected before the breakout of the Covid-19 pandemic at the end of February whose impacts are yet to be verified. Figure 5 shows the continuous improvement and expansion of the semiconductor market starting from 1978 until 2019, demonstrating the incredible importance it has assumed over the years with the advancement of technology. As anticipated, it’s possible to see how it has increased considerably from 2017 onwards, reaching the peak of units sold in the world in 2019.

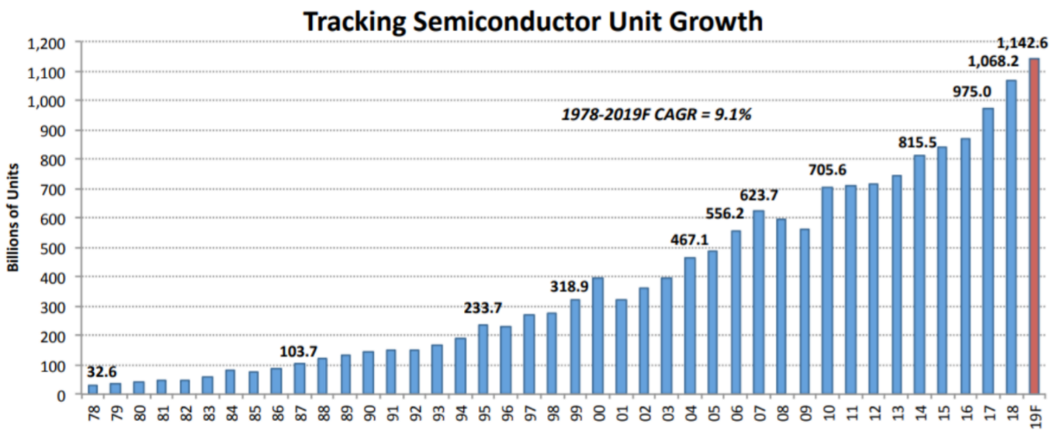


Figure 5: Semiconductor market growth

The main players in this market are those shown in figure 6.

1Q19 Top 25 Semiconductor Sales Leaders ($M, Including Foundries)

1Q19 Rank	1Q18 Rank	Company	Headquarters	1Q18 Total IC	1Q18 Total O-S-D	1Q18 Tot Semi	1Q19 Total IC	1Q19 Total O-S-D	1Q19 Total Semi	1Q19/1Q18 % Change
1	2	Intel	U.S.	15,832	0	15,832	15,799	0	15,799	0%
2	1	Samsung	South Korea	18,491	910	19,401	11,992	875	12,867	-34%
3	3	TSMC (1)	Taiwan	8,473	0	8,473	7,096	0	7,096	-16%
4	4	SK Hynix	South Korea	7,996	145	8,141	5,903	120	6,023	-26%
5	5	Micron	U.S.	7,486	0	7,486	5,475	0	5,475	-27%
6	6	Broadcom Inc. (2)	U.S.	4,125	434	4,559	3,940	435	4,375	-4%
7	7	Qualcomm (2)	U.S.	3,897	0	3,897	3,722	0	3,722	-4%
8	9	TI	U.S.	3,339	227	3,566	3,199	208	3,407	-4%
9	8	Toshiba/Toshiba Memory	Japan	3,517	310	3,827	2,355	295	2,650	-31%
10	12	Infineon	Europe	1,360	907	2,267	1,352	901	2,253	-1%
11	10	Nvidia (2)	U.S.	3,108	0	3,108	2,220	0	2,220	-29%
12	11	NXP	Europe	2,033	236	2,269	1,885	209	2,094	-8%
13	13	ST	Europe	1,696	518	2,214	1,581	485	2,066	-7%
14	25	HiSilicon (2)	China	1,245	0	1,245	1,755	0	1,755	41%
15	19	Sony	Japan	200	1,335	1,535	192	1,554	1,746	14%
—	—	Top-15 Total		82,798	5,022	87,820	68,466	5,082	73,548	-16%

Figure 6: Top 25 semiconductor sales leaders

The unpredictability and instability of the market are perfectly identifiable in the percentage variations in the sales of the main semiconductor manufacturers. On one hand, companies such as Samsung Sk Hynix, Micron and Toshiba reported a decrease in their sales of about 30% in the first half of 2019 compared to the same period of 2018, on the other companies such as Intel, Sony and HiSilicon have kept unchanged or even increased their sales volume, climbing positions in the ranking of the top 25 semiconductor sales leaders.

These companies deal with sectors and fields that are more or less growing, such as fixed and portable computers that are having a decline in recent years in the face of the great development of smartphones, smart TVs, automotive, servers, smart speakers and also of artificial intelligence (figure 7).

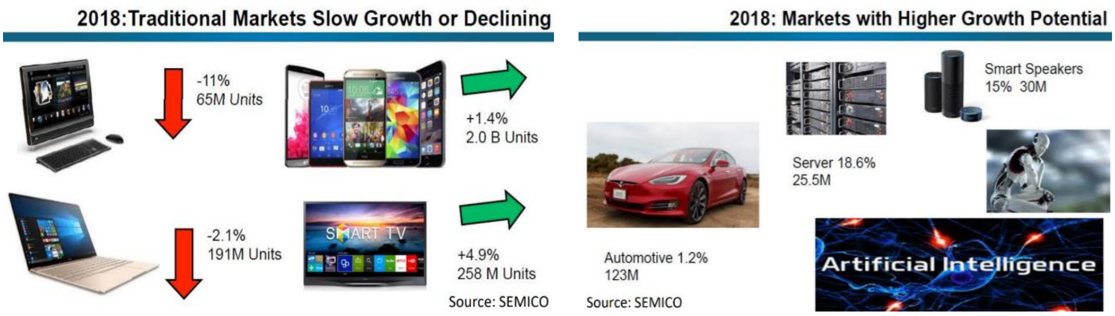


Figure 7: Market's trends

In particular, the automotive field is experiencing the greatest development approaching an annual increase of 15% and dividing itself into applications that are all considered major drivers for the development of the semiconductor market. The sales of the various sectors are illustrated below with the relative development index (figure 8).

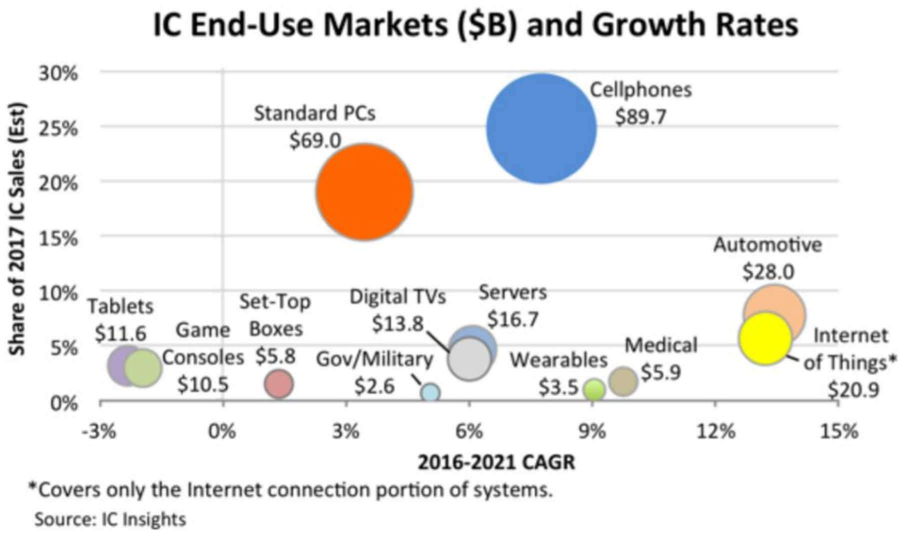


Figure 8: Growth rates of principal end-use markets

As shown, the two main end-use markets are cellphones and PCs; while the first is still growing strongly with about 8% annual increase in sales, the second shows a slight slowdown, reaching + 3% annually. Currently, there are other sectors, automotive and internet of things, which have a very high growth rate, + 13%, while covering a smaller slice of the market, looking forward to being future drivers of the semiconductor market (figure 9).

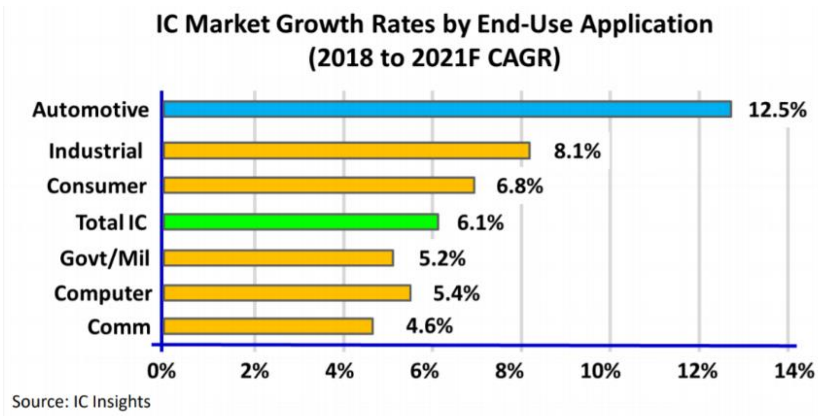


Figure 9: Automotive relevance's growth

Looking more closely at the Probe Card market, the most requested and most widespread technologies on a global scale are depicted in figure 10. It shows that since 2016 more than half of the requests are represented by the MEMS type, and the rest is divided between Vertical and Cantilever.

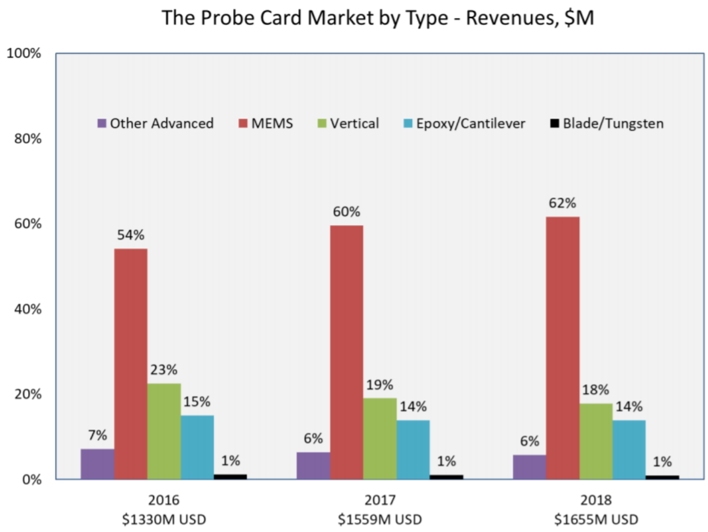


Figure 10: Different types of Probe Card required

A ranking drawn up in 2019 by SWTest identified the top 10 Probe Card sellers in the world (figure 11). The main producer of Probe Card is FormFactor which covers almost a third of the total world production; however, it recorded a 5% reduction in sales due to an increase in market competitiveness. Many companies have registered an increase in units sold, but none like Technoprobe which, with + 26%, recorded the most important growth of the entire market and it has established itself as the second producer in the world.

Rank	Company	2017	2018	Change (%)
1	FormFactor	454.79	434.27	-5%
2	Technoprobe	179.88	227.10	26%
3	Micronics Japan	201.80	216.51	7%
4	JEM	120.13	123.99	3%
5	MPI Corporation	78.60	90.69	15%
6	Nidec SV TCL	49.10	48.80	-1%
7	Korea Instrument	42.41	47.39	12%
8	TSE	37.01	45.82	24%
9	Will Technology	39.80	37.64	-5%
10	Microfriend	45.42	36.77	-19%
	Other	308.07	346.27	12%
	Semiconductor Probe Cards	1557.01	1655.25	6.3%
	Annual Growth		6.3%	

Figure 11: Top 10 Probe Card vendors of 2018

PROJECT’S TARGET

The Laser Drilling Project aims to optimize the production process in the PH Front End department, in particular the cutting process of the ceramic necessary for the realization of the Probe Head. The area manager is Valentino Schiariti that also covers the role of company tutor for our internship. In this department, starting from raw materials, ceramic plates of different sizes, various shapes and sizes of Probe Head are made which represent one of the most important components of the final product, in fact the needles will pass through the Probe Head and guarantee the performance and product quality. The raw material purchased has a very high cost and the remaning ceramic parts after the first cut are hardly re-usable being often considered as scraps.

The project's requests are, therefore:

- To minimize the cost of the ceramic supply
- To analyze the present usage of the row ceramic and the related costs
- To identify the best supply strategy that maximizes material usage not affecting the final quality
- To evaluate the required driller machines changes to accommodate the new sized row materials
- To define an implementation plan with the technical Teams.

METHODOLOGICAL APPROACH

As emerged from the history of Technoprobe, development and innovation have always been the foundations on which the success of this company has been built. To confirm itself, year after year, as one of the main leading companies in such a highly competitive market, it is necessary to constantly improve both the product and the production processes. To pursue these objectives, especially in recent years, the desire to apply modern business management concepts such as Lean Manufacturing and Industry 4.0 was born within the company management. The following chapters present an in-depth analysis of the aforementioned theories, underlining the advantages that these methodologies bring to industrial production processes.

At the end of these in-depth analyzes, the focus was on the A3 Thinking methodology, widely used for problem setting and solving. This technique represents the basis on which the entire project carried out by the team during this internship was built.

LEAN MANUFACTURING

Technoprobe is one of the most advanced companies in the whole national territory, not only from the technological point of view but also from the management point of view.

Since its foundation in 1995, the company has always focused on development and improvement, fundamental characteristics in the modern economy, especially in the sector where it operates where speed and innovation are the ingredients for the recipe of success.

The numbers, especially in recent years, have proved Technoprobe's right, thanks to figures such as COO Alessio Guerci, modern business management philosophies such as Lean Manufacturing and techniques related to Industry 4.0 have become the order of the day.

Lean Manufacturing is the set of concepts that well represents process management from the TPS, Toyota Production System. This methodology has become very popular in recent years and can be applied to any process to improve its performance. To pursue perfection the company must identify customers' value, map the stream, eliminate wastes and satisfy customer's requests (figure 12).

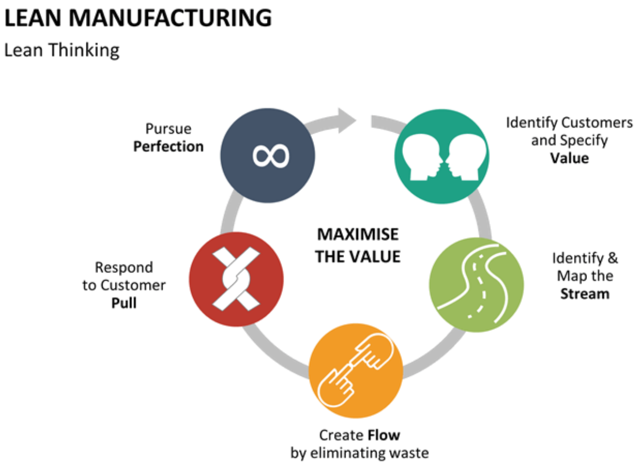


Figure 12: Lean Manufacturing philosophy

This principle is based on the main objective of any manufacturing company, that is to increase profits, in this regard it is possible to act on two different levers, the increase in sales or the reduction of costs. While on one hand the increase in sales is not always a feasible solution, as in the case of a declining market or an already mature market, on the other hand the cost reduction is always actionable as it does not depend on other players but is entirely an internal issue; it is, therefore, the task of the company itself to resort to skills, knowledge and resources to reduce costs.

The cost reduction can be summarized in three main categories:

- Reduction of product's features: no customer is willing to spend money on unsolicited features. In the case of Technoprobe, however, this path is not viable as all products are developed in co-design with the customer. All the characteristics of the product are therefore agreed together and are essential.
- Reduction of the material used: based on concepts such as sustainability, or lighter and smarter products, with the fundamental idea that less material is needed, fewer costs and machining time to produce the product. The project,

carried out by our team, will focus on this goal trying to optimize the production process of the Probe Card.
- Reduction of processing time: feasible through two levers either the reduction of raw materials needed or the development of new production techniques and/or logics to produce more efficiently.

In the philosophy of Lean Manufacturing the activities are classified as follows:

- Value-adding activities, those activities requested by the customer, so valuable according to the customer's point of view.
- Not value-adding activities, those activities that the customer does not require and are unavoidable in the short term.
- Not value-adding activities, those activities that are avoidable in the short term.

At the same time, it is possible to classify the waste in 7 different ways (called Muda):

- Overproduction, which is a higher output of the process than the required quantity by customers.
- Over-processing, which means the processing or re-processing of a product more than once.
- Defects, or quantity problems that do not allow the correct processing of products causing the waste of material, energy and time-related.
- Transportation, which is the movement of products internally or externally not necessary.
- Inventory, which is the accumulation of products that represents a capital cost, how much is necessary a warehouse where to store the inventories with the relative waste of space and people to manage it.
- Movement, or some unnecessary movements around the machine during the process.
- Waiting, or waiting times due to queues that the customer is not willing to pay.

At the base of this philosophy there is the standardized work, which is the attempt to design processes and activities and trying to make them standard. Everything is already decided previously, it is only necessary to solve the problem and provide a solution to the whole company. In addition to this, there is the Kaizen methodology, or continuous improvement, which means never stopping to look for new solutions and ideas, any process can be improved.

The objective of Lean Manufacturing is therefore the reduction of the number of activities that do not add value and the elimination of the wastes, the "Muda". In this regard, it is necessary to identify the problems, weaknesses, defects and inefficiencies of the production process to resolve them.

For this purpose, our team will use a technique called A3 Thinking, which will be analyzed in the next chapter.

INDUSTRY 4.0

The term Industry 4.0 refers to an industrial revolution aimed at automated and interconnected production. The introduction of new digital technologies impacts on 4 fundamental themes for development. The first of these is the use of data which is represented by concepts like the Internet of Things, open data, big data and cloud computing for the centralization and storage of information. The second is called analytics, the ability to derive value from the large amount of data collected. The third is human-machine interaction, supported by touch interfaces and augmented reality. Finally, the fourth is the translation from digital to real through technologies such as 3D printing, additive manufacturing, and robotics.

These concepts have also led to the modification of the canons of skills and abilities sought such as soft skills like problem-solving, critical thinking and creativity. The concrete realization of these principles is concretized by the Smart Factory, which is the process of optimizing the production layout and the connectivity between machines, operators and available information to make the processes more flexible and efficient. The flexibility of a company is a fundamental feature to increase productivity in the face of a demand for highly customized products. The ability to easily adjust production to the changing needs of the reference context is also fundamental to optimize the management of energy resources and to reduce time to market.

A3 THINKING

A3 thinking is a methodology used to support problem-setting and problem-solving, in addition to this, it is a managerial approach useful for developing a culture of continuous improvement.

The main elements on which this technique is based are logical thinking process, objectivity, results and process, synthesis, alignment, coherence within and consistency across and systems viewpoint. Through this methodology, the team has developed the work according to a coded path. This sequence of phases to be developed to complete the project is known as the Deming wheel or PDCA method (figure 13).

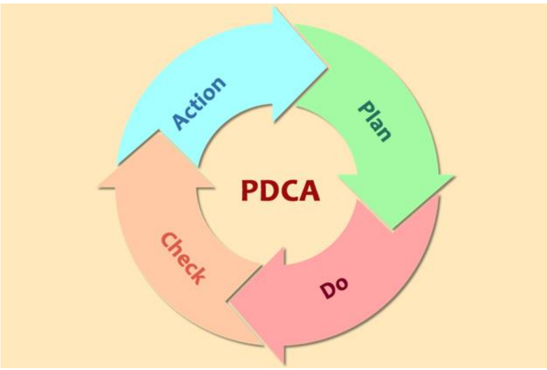


Figure 13: PDCA methodology

Plan: analysis of the issue, identification of the problem, collection of the necessary elements, analysis of the actions to be tested.

Do: implementation and testing of actions.

Check: evaluation of the results achieved.

Act: consolidation and standardization of validated change.

In particular, the team will follow the steps below; the first 5 steps belong to the planning phase, then the following represent the do, check and act phases (figure 14).

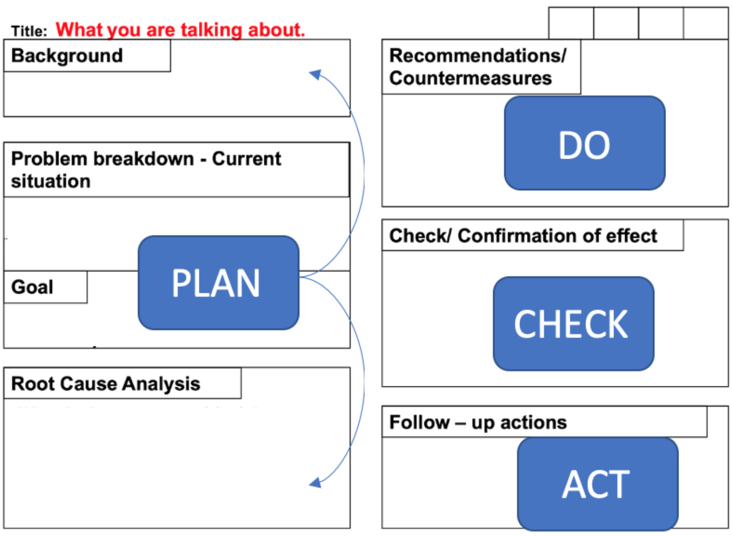


Figure 14: A3 thinking

- Problem background: the first step in which to define the boundaries of the analysis. In this part the is/is not is defined, i.e. the distinction between what is inherent to the problem under analysis, such as the departments involved, the company figures involved, the fundamental KPI, and all the rest of which it is not important to consider in the problem-setting.

- Problem Breakdown: the second step in which the team analyzes the whole context in which the problem is inserted. This section collects and analyzes current performance data, in terms of efficiency, effectiveness, process quality, costs, time and logistics.

- Target: the third step in which two targets are defined, a Must to Have and a Nice to Have, with the involvement of the company management. Defining a goal is essential to be able to assess the impact of a project, it is indeed essential to define a goal that is significant for the company and at the same time achievable in the short term.

- Analyze the root causes: the fourth step in which the team will investigate the origins of the problem through various techniques, such as 5Whys analysis. This step is fundamental as the goal is not so much to define responsibilities as to identify improvement interventions. These techniques present an accident as an unwanted final event of a path that starts from organizational conditions with gaps, inefficiencies and design errors, to then analyze human actions and errors.

- Develop countermeasures: the fifth step in which the team will develop countermeasures to solve the problems that emerged in the analysis of the root causes. In this part, it is important to define the total impact of these improvements by trying to identify not only the direct but also the indirect consequences of these changes in the process.

- Implement countermeasures: the sixth step in which the team intervenes by modifying the current process through the implementation of countermeasures. At this stage, it is essential to spread awareness of these changes and to involve all the staff. It is of fundamental importance to convince the operators of the effectiveness of these improvements and to be sure of the lack of doubts or perplexities in the operators.

- Monitor results & process: the seventh step in which the team checks the impact of countermeasures. In this phase of data collection and analysis, it is important to check for any deviations between what has been planned and what actually occurs.

- Standardize & share success: the eighth and last step in which all the procedures introduced are standardized and the results of the countermeasures are shared. In this last phase, it is also important to define possible future steps so as not to interrupt the continuous improvement process.

PROBLEM BACKGROUND

THE PROBE HEAD

The "Laser Drilling" project is located in the PH FE department in which the PHs are made. The Probe Heads are a fundamental component of the final product and they are particularly delicate as they are made with a ceramic material that can be easily damaged. Like all components of the Probe Card, the PH also requires very high precision machining (in the order of micrometers) and these operations are carried out, based on the phase in progress, either on sophisticated laser machines or manually by expert operators. The PH, as shown in figure 15, is made up of 3 main parts, an upper pack, a lower pack and a housing on which they are fixed and which gives them the necessary alignment.

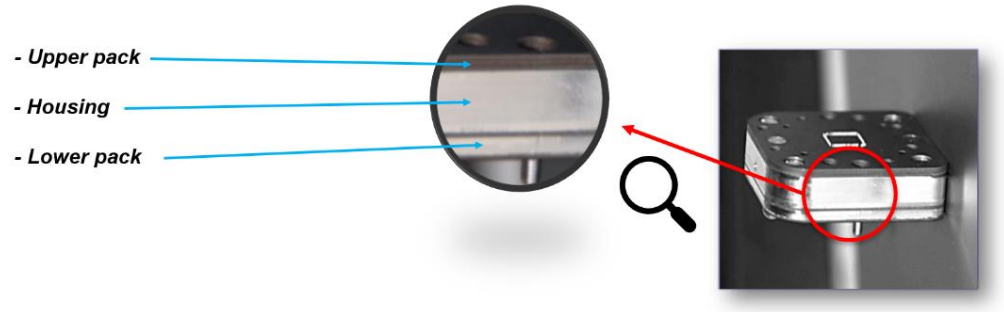


Figure 15: PH's main components

The housing is made in another department, called Mechanical Workshop, while the two upper and lower packages are made in the PH FE department and they are composed of 2 or more layers glued together. These layers can be either simple frames or drilled layers, which are essential to contain the probes that will be inserted into the finished PH (this operation is done in the PH Back End department). In figure 16 is shown an example of a final product's composition with

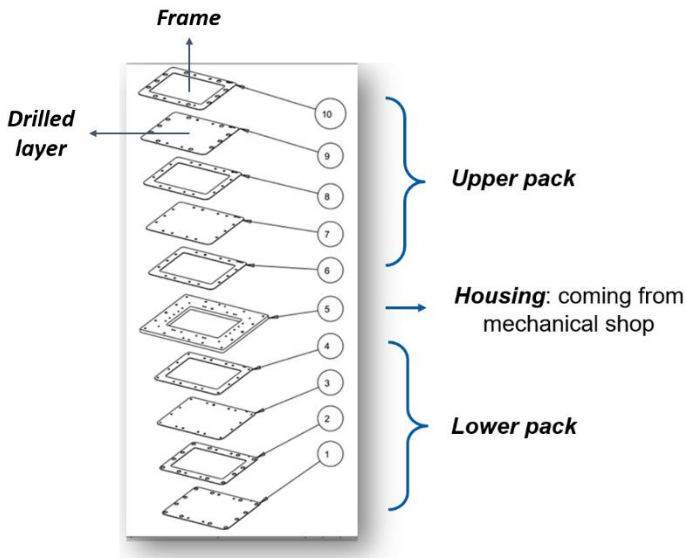


Figure 16: Exploded view of a PH

the layers that compose the upper and lower packs. The size of each layer of the Probe Head is the same while their thickness level can vary even within the same pack and depending on the projects it usually varies from A to C micrometers. Once the upper and lower packages are assembled on the housing, the completed PH is sent to the PH Back End department.

PH FE DEPARTMENT

Overall Information

Technoprobe manufactures highly customized products designed specifically for the customer. With the arrival of customer's requests, the company activates the Design department, which creates a draft of the project. Then, the project is sent to the Sales department which prepares a proposal in technical and economic terms for the customer. The customer can accept this proposal or not, in case of negative answer it is necessary to re-design a completely new draft, otherwise it is possible to proceed with the production. In this case, the Design department sends a production runsheet to the various departments including the PH FE. This quick overview is schematized in figure 17 and it's very useful for understanding where the department under consideration is located in the complete process from a temporal point of view.

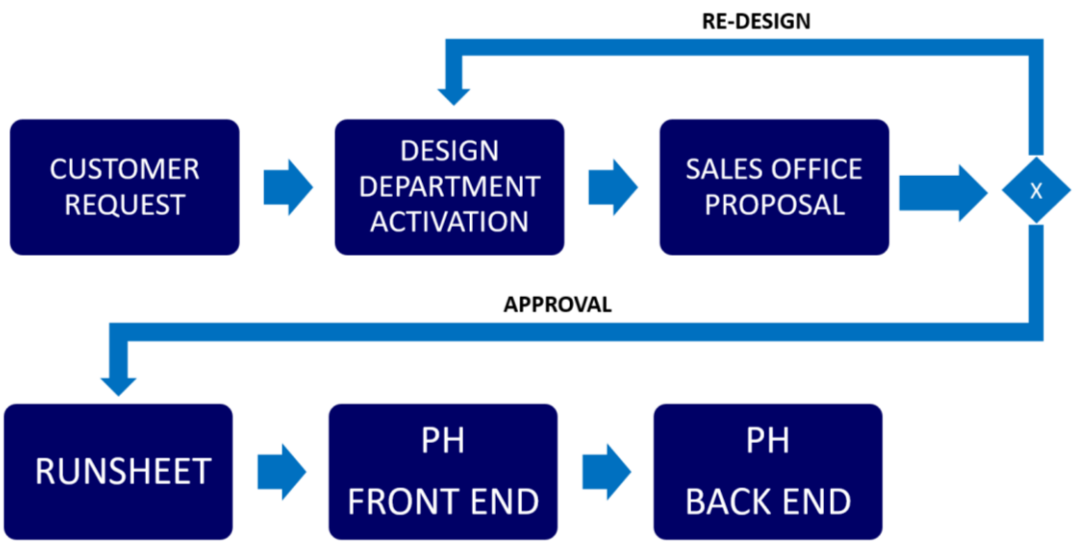


Figure 17: PH FE overview

The Probe Head Front End department is located in the TPI2 building and it takes care of the first part of the work necessary for the realization of the PH. As anticipated, the production starts with the reading of the runsheet that contains numerous information essential for the operator.

The basic information is:

- the size of the PH
- the type of material to be used (two different ceramic finitures are available)
- the composition of the PH and the number of frames and drilled layers to be created (figure 18)
- the thickness required for each layer (figure 18).

10	Frame Upper 2 Superiore	A
9	Upper 2	B
8	Frame Upper 2 Inferiore	B
7	Upper 1	B
6	Frame Upper 1 Inferiore	B
5	Housing (Spacer)	H
4	Frame Medio Superiore	B
3	Medio	B
2	Frame Lower	A
1	Lower	B
POS.	DESCRIPTION	SPESSORE

Figure 18: Runsheet's information (composition and thicknesses)

In addition to the data relating to the physical characteristics that allow the operator to select and prepare the correct materials to be processed, there is also a drilling file for the drilled layers that will allow the operator to set the laser machine in order to drill in the correct points the layers of the project.

PH FE Production Steps

Once the runsheet has been read, the production process begins and the steps followed for the realization of the PH are illustrated in figure 19.

Figure 19: PH FE's steps

The first step is the selection of the raw material, the operator goes to the warehouse, he selects a new or partially used plate and he measures its thickness manually with a micrometer to be sure not to have problems in subsequent processing; then he updates the warehouse database by removing the plate taken.

The second step involves the positioning of the plate on a special template, called jig, which will be inserted into the laser machine that is set following the directives of the runsheet and the drilling file. The realization of the drilled layers requires several hours (the machine makes 2,000 holes/hour and the number of holes per layer can reach up to 50,000), while the frames are much simpler and faster to be realized, that is the reason why they are made on a dedicated laser machine. Currently there are around 40 laser machines in the department. At the end of the laser task, the machine is placed in the safety position and the machined pieces are unloaded.

The third step performed is the washing of the pieces with water and ultrasounds to remove the ceramic particulate, then the pieces are dried with compressed air. Even if these operations may seem trivial, they are essential for the package to be properly pasted, any minimal ceramic particles not removed could affect the entire project. These operations are done manually by the operators. Currently, for each shift there are 3 operators involved in these operations.

The fourth step involves a 100% check of the pieces in terms of presence and size of the holes with a dedicated machine, where a specialized operator is in charge of the control and maintenance of the machine, while a sample check is carried out on the positioning of the holes through of a cartesian coordinate system with a specific tolerance. If all parts of the PH comply with the required specifications they move on to the next step. These control operations have fundamental importance, since once the various layers are overlapped the probe has to be able to flow but at the same time it has to find a resistance so that it does not fall.

In the fifth step, the upper and lower packages are composed gluing manually the layers, aligning them with special positioning pins. An operator is responsible for the application of a special glue resistant to high temperatures, it is necessary to be careful during this operation so that the glue is not placed too close to the edge and corners. The pressure one layer on the other could push the glue beyond the edges or cover the holes made. Once glued, the packages are inserted between two metal supports and pressed mechanically. The packages then undergo a thermal cycle of about 2 hours at a fixed temperature of 190°, during this period the pressure to which the layers are subjected remains constant.

The sixth step is a cleaning phase carried out using sand and microspheres to eliminate any excess glue residue and it is followed by a final microscope check to evaluate the correct alignment of the layers. This operation, called "sabbiatura", is carried out outside the PH FE department, on the floor below.

The last step is the assembly of the packages with the housing coming from the Mechanical Workshop; the assembly is carried out with cap screws and special pins for aligning the upper and lower packages. Once these operations are completed the PHs are placed inside plastic boxes, than they are transported to the next department, PH BE, where probes will be inserted.

Department key points

In the process described there are currently no fixed bottlenecks; in this production process there are both automatic activities, such as machining on laser machines, and manual activities, such as control, washing and gluing operations. The duration of such operations is, therefore, very variable and many uncertainties may arise.

Laser machines consist of a moving head that acts along the x, y and z axes. Jigs of different sizes can be inserted inside these machines. Currently, in the department, jig with single positioning are used for all types of raw material available, while for smaller formats are jigs with double positioning and jigs with quadruple positioning are used too (figure 20).

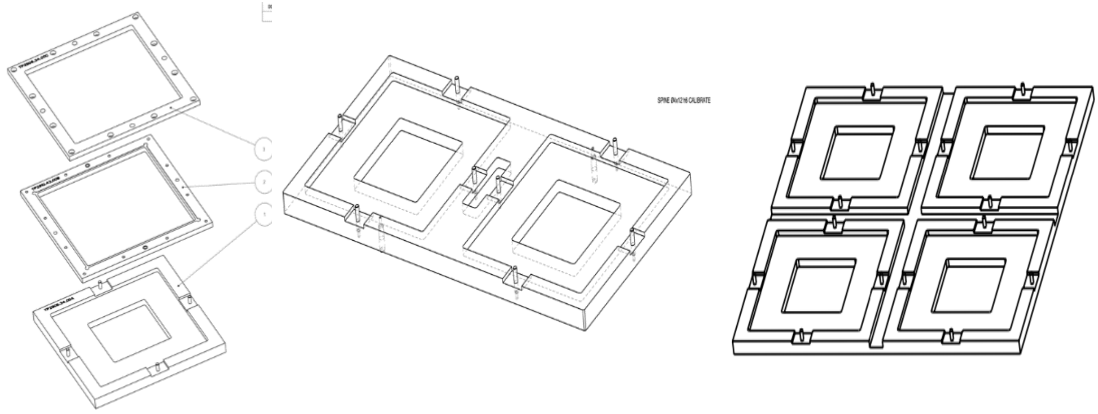


Figure 20: jig with single, double and quadruple positionings

Such jigs allow greater machine autonomy being able to work in sequence more than one plate without the intervention of an operator.

The suppliers involved in the realization of the Probe Head are only two, this is due to the particularity of the raw material demanded that are used only in this very specific field. Besides, the production of this particular ceramic is not the core business for these suppliers, it is, therefore, clear how high is the bargaining power of the supplier, which is not willing to cooperate for the production of sizes congenial to Technoprobe.

Actually, a high percentage of plate are hardly re-usable after the first cut and they remain stored in the warehouses for years. This is due to the fact that many processes have to be carried out on new plates, thus creating ceramic leftovers, which are used to carry out the smaller processes but only a small part of the ceramic residuals are needed to satisfy the latter's demands, the rest is continuously put in stock.

PROBLEM STATEMENT

From the first observations, the team was able to ascertain that the problem is related to the optimization of the material used. In particular, it refers to the process of selecting raw materials and positioning of the machining operations in the laser. However, there were no problems in the control, gluing and washing processes. The team consequently set the following problem statement:

"*Due to the high demand variability in terms of layers' dimensions and the high standardization of supplier's raw materials, in the current situation, there is a high percentage of ceramic hardly re-usable after the first cut*."

PROBLEM BREAKDOWN

SMART WORKING

As anticipated in the introduction, the schedule of the internship has been heavily modified following the explosion of the Coronavirus pandemic at the end of February. Therefore, the first steps and the first meetings (obviously remotely) began around mid-April, allowing the team to receive the first data about the company and the project. Thanks to all the information received, to the support and the advice of both Valentino and Federica Costa, the team identified in a short time the problem statement of the project (highlighted in the previous chapters), allowing them to focus only on the steps that impacted the problem, so the material selection and processing on the laser machines.

Warehouse Analysis

The first analysis done by the team is based on the inventory of the warehouse dated December 2019. In this Excel file, there were listed all the raw materials in the department warehouse, both virgin and partially processed. Both types of raw materials (virgin or not) are actually stored in boxes and divided by the finiture, each one is linked to the specific supplier (in figure 21 the three finiture levels are indicated with 1,2,3), by the thickness level, by size and/or by shape.

	PLATE MP	PESO (gr)	€/Plate	Prezzo/g
1	127 x 127 A lucido	9	254,00 €	28,22 €
	127 x 127 B lucido	13	227,00 €	17,46 €
	127 x 127 C lucido	17	226,00 €	13,29 €
	Ø A lucido	17	268,00 €	15,76 €
	Ø B lucido	23	248,00 €	10,78 €
	Ø C lucido	26,5	247,00 €	9,32 €
	Ø D lucido	41	244,00 €	5,95 €
	Ø E lucido	43	244,00 €	5,67 €
	186 x 186 B lucido	28,5	452,00 €	15,86 €
	186 x 186 C lucido	35	444,00 €	12,69 €
	186 x 186 E lucido	53,5	440,00 €	8,22 €
2	127 x127 F opaco	7	528,88 €	75,55 €
	127 x127 A opaco	9,5	279,00 €	29,37 €
	127 x127 B opaco	13,5	196,48 €	14,55 €
	127 x127 C opaco	17	227,13 €	13,36 €
	186 x186 A opaco	21	471,55 €	22,45 €
	186 x186 B opaco	33	457,40 €	13,86 €
3	127 x127 A	-	1.101,67 €	-
	127 x127 B	-	1.101,67 €	-
	186 x186 A	26,5	1.731,60 €	65,34 €
	186 x186 B	37	1.849,77 €	49,99 €

Figure 21: Price per gr for all the plate typologies

The fundamental difference in archiving between virgin and partially processed plates is the unit of measurement used; the former have been counted for pieces in stock as they are completely intact, the latter, being more or less processed parts, are stored based on weight (expressed in grams). For this reason, being the team's intention to calculate the stock value of both categories of raw materials, they calculated, starting from the price list provided, the price/gram of all the various typologies of the plates (the result of the calculation are shown in figure 21).

Based on the price list and the calculated price/gram, our team was able to calculate in economic terms the total amount in stock of the virgin and partially processed plates (figure 22).

Tipologia	Descrizione	gr	pz	prezzo/plate	prezzo/g	Valore a magazzino
Ceramiche - MP	127 x 127 A lucido		2374	254		602.996,00 €
	127 x 127 B lucido		3255	227		738.885,00 €
	127 x 127 C lucido		203	226		45.878,00 €
	127 x127 F opaco		210	528,88		111.064,80 €
	127 x127 A		30	1101,67		33.050,10 €
	127 x127 A opaco		500	279		139.500,00 €
	127 x127 B		50	1101,67		55.083,50 €
	127 x127 B opaco		226	196,48		44.404,48 €
	127 x127 C opaco		650	227,13		147.634,50 €
	186 x 186 B lucido		299	452		135.148,00 €
	186 x 186 C lucido		190	444		84.360,00 €
	186 x 186 E lucido		14	440		6.160,00 €
	186 x186 A		57	1731,6		98.701,20 €
	186 x186 A opaco		0	471,55		- €
	186 x186 B		76	1849,77		140.582,52 €
	186 x186 B opaco		234	457,4		107.031,60 €
	Ø A lucido		1130	268		302.840,00 €
	Ø B lucido		548	248		135.904,00 €
	Ø C lucido		360	247		88.920,00 €
	Ø D lucido		62	244		15.128,00 €
	Ø E lucido		120	244		29.280,00 €
			10588			3.062.551,70 €
Ceramiche - Parzialmente lavorati	127 x 127 A lucido	7915			28,2	223.378,89 €
	127 x 127 B lucido	57688			17,5	1.007.321,23 €
	127 x 127 C lucido	1968			13,3	26.162,82 €
	127 x127 F opaco	29			75,6	2.191,07 €
	127 x127 A opaco	1460			29,4	42.877,89 €
	127 x127 B opaco	1360			14,6	19.793,54 €
	127 x127 C opaco	22			13,4	293,93 €
	186 x 186 B lucido	485			15,9	7.691,93 €
	186 x 186 C lucido	0			12,7	- €
	186 x 186 E lucido	0			8,2	- €
	186 x186 A	250			65,3	16.335,85 €
	186 x186 A opaco	3140			22,5	70.507,95 €
	186 x186 B	972			50,0	48.593,96 €
	186 x186 B opaco	460			13,9	6.375,88 €
	Ø A lucido	32619			15,8	514.228,94 €
	Ø C lucido	5762			9,3	53.706,19 €
	Ø D lucido	0			6,0	- €
	Ø E lucido	90			5,7	510,70 €
		114220				**2.039.970,78 €**
						5.102.522,48 €

Figure 22: Amount of stocks in economic terms

As can be seen from the pie chart (figure 23), the value of processing waste kept in stock for months or even years has accumulated, currently reaching 40% of the total stock's value. This percentage is very high considering that used-plate weighs about a third of a new plate, therefore 2.000.000 € indicates a huge number of partially processed plates that will be hardly re-usable.

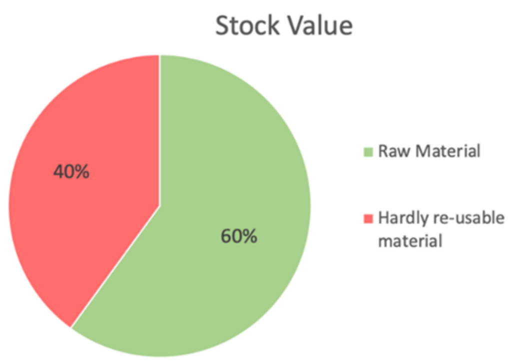


Figure 23: Pie chart of stock values

Data Selection

A particular turning point of the project was possible thanks to the authorization of Stefano Lazzari to meet the manager of the company database "Prometeo", Michele Moruzzi, who provided to the team a huge amount of data that allowed the beginning of the work despite the distance and without ever having physically seen neither the product nor the department. More specifically, the data provided was an Excel sheet with thousands of information relating to the years 2019 and 2020 (up to May).

Therefore, starting from this "raw" file, thanks also to the directives of Federica Costa, our team began to analyze them more and more specifically to extract the information useful for the project.

The first step was to match the client of each project with the relative required PH size through several "search.vert". During this first phase, the team realized that for some projects there was no correlation between the customer and the relative requested size and, therefore, there was an initial cleaning of the data, forcing to consider only the projects with the complete data available. In the new table, all the projects of 2019 and 2020 have been correlated to their specific customer and PH size. The team has also decided to filter the date of the projects focusing only on the last year, taking all the projects from May 2019 until in May 2020.

The last data-cleaning action done is related to the PH size; 3 kinds of dimensions appeared in the dimension list: dimensions in numerical terms, dimensions with particular names assigned by the company (for example "Grande" or "Grandissima Super Special") but attributable to a numerical dimension and dimensions classified as “Custom Size”.

The latter is very variable dimensions that are not identified in numerical terms and they are requested in large quantities by a particular customer who turns out to be one of Technoprobe's main customers. Unfortunately not having a physical dimension of these PHs, these projects were not useful for the analysis, so the team decided not to consider them. At the end of this cleaning phase, the Excel table available, appeared as in figure 24 (real customer name are hidden for obvious privacy reasons).

	A	B	C	D	E	F
1	VALUE	CUSTOMER	DATE			
2	36x34	Customer name	10/05/2019			
3	36x34	Customer name	10/05/2019			
4	36x34	Customer name	14/05/2019			
5	GRANDE	Customer name	13/05/2019			
6	GRANDE	Customer name	15/05/2019			
7	GRANDE	Customer name	15/05/2019			
8	INTERMEDIA	Customer name	13/05/2019			
9	36x34	Customer name	14/05/2019			
10	GRANDE	Customer name	16/05/2019			
11	D22	Customer name	16/05/2019			
12	36x34	Customer name	16/05/2019			
13	GRANDE	Customer name	16/05/2019			
14	INTERMEDIA	Customer name	16/05/2019			
15	GRANDE	Customer name	17/05/2019			
16	36x34	Customer name	21/05/2019			
17	D22	Customer name	22/05/2019			
18	INTERMEDIA	Customer name	16/05/2019			
19	36x34	Customer name	24/05/2019			
20	D22	Customer name	27/05/2019			
21	22x29	Customer name	29/05/2019			

Figure 24: Clean data from Prometeo

Starting from this Excel table, a series of analysis followed allowing the team to observe the performance of the PH FE department and Technoprobe in general from different points of view over the last year. This analysis of past data has allowed having a much broader vision not focused only on the months spent by the team in the company, allowing to compare today's trend with the past one.

Analysis of PH request

The first step of this analysis was a screening of all the PH dimensions present in the database (23 different PH sizes), extracting the respective requests for the last year thanks to a pivot table. On this selection of data, the team performed a Pareto analysis, to highlight the most requested PHs classifying the dimensions in three main classes as can be seen in figure 25.

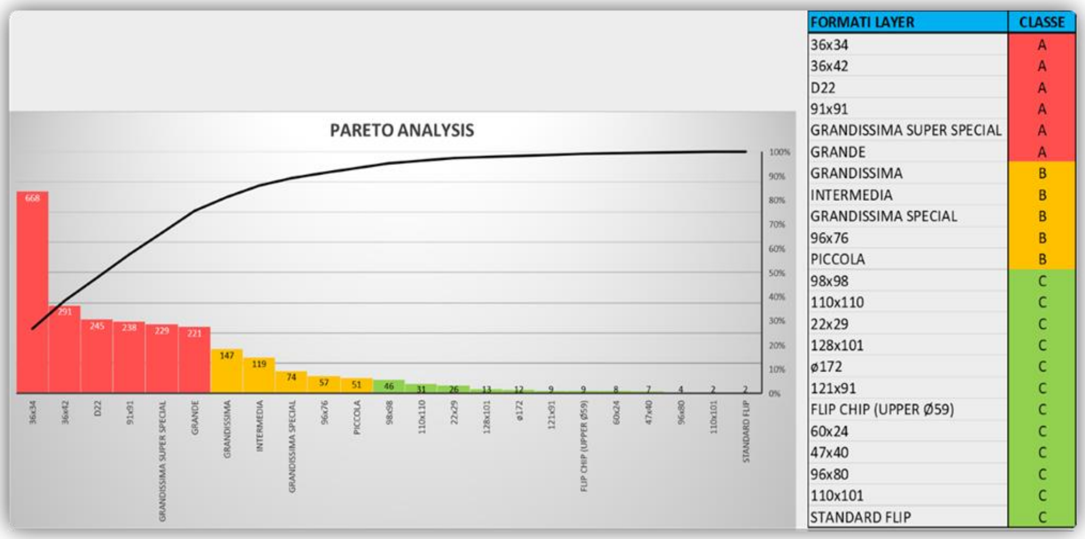


Figure 25: Pareto analysis of PH's dimensions

The Pareto analysis is based on the general 80/20 rule, according to which 20% of the causes (in this case PH) represent 80% of the effects (therefore of the requests); the PHs that represent up to 80% of the requests are placed in class A, from 80% to 95% are in class B and the remaining in class C. Apparently unlike what Valentino had already told in the first meetings, that the most requested PHs currently have large dimensions. From the Pareto analysis it emerged that the first three positions are occupied by small dimensions. This is because the analysis is carried out on last year's data and this fact is explanatory as it makes it easy to understand how rapid the change in the trend is within this company and in general in the microtechnology market. Currently, according to the indications given by Valentino, the most requested sizes are the "Grandissima super special", the "91x91" and "98x98", which cover positions of average requests as represented in the table (figure 25).

Criticality Analysis

Subsequently, our team was interested in understanding which PHs are more difficult to be realized based on their size or in other words which ones involve worse exploitation of the raw material. To calculate the level of difficulty, the team started from the main raw materials' dimensions and shapes currently available in the department (figure 26), focusing on how many PHs can be made on a virgin plate, for each dimension.

PLATE	Usable size
lucido 127x127	122x122
lucido D180	D180
lucido 186x186 ottagonale	180x180
opaco 127x127	122x122
opaco 186x186	180x180

Figure 26: Available virgin plates

Available virgin plate shapes and sizes (mm)		
127x127	186x186	D180

Figure 27: Available sizes and shapes

As shown in figure 27, the shapes and sizes of virgin plates available are three (considering all suppliers/finiture levels), and on these three initial plates the team has virtually placed all the 23 PH dimensions, in order to observe how many different dimensions can be realized at most.

The positioning was carried out taking into consideration the workable dimensions of each plate listed in figure 26 (eliminating the part that is blocked by the jig that is not workable), and also taking into account the machining specifications that plans to maintain 1 mm between cuts on the same plate. Figure 28 shows an example of the positioning of a 50x74 mm PH on a virgin 127x127 plate, reduced to 122x122 due to the specifications. Only two layers can be cut from this plate size.

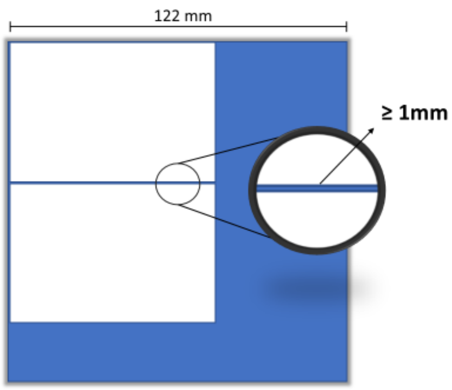


Figure 28: Example of positioning

Extending this analysis to all dimensions the team obtained the following tables(figure 29)in which three classes were created to identify the more or less difficult PHs.

127x127

127x127(opaco e lucido)[122x122]		n° layer	Class
PICCOLA	D36	9	C
GRANDE	30x60	6	B
INTERMEDIA	50x60	4	B
GRANDISSIMA	44x74	2	B
GRANDISSIMA SPECIAL	50x74	2	B
GRANDISSIMA SUPER SPECIAL	74x76	1	A
STANDARD FLIP	D76	1	A
FLIP CHIP (UPPER Ø59)	D59	2	B
CUSTOM SIZE	D22	25	C
	110x101	1	A
	110x110	1	A
	98x98	1	A
	22x29	20	C
	36x34	9	C
	36x42	6	B
	47x40	6	B
	60x24	8	C
	91x91	1	A
	96x76	1	A
	96x80	1	A

186x186

186x186(opaco e lucido)[180x180]		n° layer	Class
PICCOLA	D36	16	C
GRANDE	30x60	10	C
INTERMEDIA	50x60	6	B
GRANDISSIMA	44x74	8	B
GRANDISSIMA SPECIAL	50x74	6	B
GRANDISSIMA SUPER SPECIAL	74x76	4	B
STANDARD FLIP	D76	4	B
FLIP CHIP (UPPER Ø59)	D59	9	B
CUSTOM SIZE	D22	49	C
	Ø172	1	A
	110x101	1	A
	110x110	1	A
	121x91	1	A
	128x101	1	A
	98x98	1	A
	22x29	42	C
	36x34	20	C
	36x42	16	C
	47x40	12	C
	60x24	14	C
	91x91	1	A
	96x76	2	A
	96x80	2	A

D 180

D180 lucido		n° of layer	Class
PICCOLA	D36	19	C
GRANDE	30x60	9	B
INTERMEDIA	50x60	5	B
GRANDISSIMA	44x74	4	B
GRANDISSIMA SPECIAL	50x74	4	B
GRANDISSIMA SUPER SPECIAL	74x76	2	A
STANDARD FLIP	D76	3	B
FLIP CHIP (UPPER Ø59)	D59	7	B
CUSTOM SIZE	D22	44	C
	Ø172	1	A
	110x101	1	A
	110x110	1	A
	121x91	1	A
	128x101	1	A
	98x98	1	A
	22x29	24	C
	36x34	12	C
	36x42	10	C
	47x40	8	B
	60x24	12	C
	91x91	1	A
	96x76	1	A
	96x80	1	A

Figure 29: Level of difficulty based on three classes

The three classes allow to evaluate the difficulty of realization and the criterion followed for their creation is the following:

- Class A: layers obtainable once or twice maximum per plate.
- Class B: layers obtainable no more than 7 times per plate.
- Class C: layers obtainable 8 or more times per plate.

The dimensions "Ø172", "121x91" and "128x101" are missing in the analysis made on the 127x127 as they cannot be made even 1 time on it, becoming part of a special category of PH.

In the summary table below (figure 30), the overall results for each PH dimension are shown, unifying the 3 classes assigned to each in a single code and, based on of that code, 4 categories of overall criticality have been defined. The first criticality class called "Special" is dedicated to those particularly large products described above; the criticality class "1" represents those PHs that require an entire plate to be realized as they usually fit 1 or 2 times per plate. Class "2" identifies a moderate criticality, they are dimensions that do not necessarily require new plates to be made. Finally, the class "3" indicates the PH with small dimensions that can be realized on already processed plates.

Tipologia Layer	Dimensione	Tot Class	Criticità
CUSTOM SIZE	Ø172	-AA	S
CUSTOM SIZE	121x91	-AA	S
CUSTOM SIZE	128x101	-AA	S
CUSTOM SIZE	110x101	AAA	1
CUSTOM SIZE	110x110	AAA	1
CUSTOM SIZE	98x98	AAA	1
CUSTOM SIZE	91x91	AAA	1
CUSTOM SIZE	96x76	AAA	1
CUSTOM SIZE	96x80	AAA	1
GRANDISSIMA SUPER SPECIAL	74x76	ABA	1
STANDARD FLIP	D76	ABB	2
INTERMEDIA	50x60	BBB	2
GRANDISSIMA	44x74	BBB	2
GRANDISSIMA SPECIAL	50x74	BBB	2
FLIP CHIP (UPPER Ø59)	D59	BBB	2
GRANDE	30x60	BCB	2
CUSTOM SIZE	47x40	BCB	2
CUSTOM SIZE	36x42	BCC	3
PICCOLA	D36	CCC	3
CUSTOM SIZE	D22	CCC	3
CUSTOM SIZE	22x29	CCC	3
CUSTOM SIZE	36x34	CCC	3
CUSTOM SIZE	60x24	CCC	3

Figure 30: Criticality classes

Setting of Priority

At this point in the analysis, our team had available a classification of the PHs in terms of difficulty of realization and from the Pareto analysis a distinction of them based on the request. In order to have an overview and make a comprehensive evaluation of the PHs that could give a general indication of the priority that must be assigned to a project based on its size, the team decided to concatenate the two analyzes' output in a single alphanumeric code. Figure 31 highlights the dimensions (cited several times) most requested in the

Tipologia Layer	Dimensione	Priorità
CUSTOM SIZE	**91x91**	**A1**
GRANDISSIMA SUPER SPECIAL	**74x76**	**A1**
GRANDE	30x60	A2
CUSTOM SIZE	36x42	A3
CUSTOM SIZE	D22	A3
CUSTOM SIZE	36x34	A3
CUSTOM SIZE	96x76	B1
INTERMEDIA	50x60	B2
GRANDISSIMA	44x74	B2
GRANDISSIMA SPECIAL	50x74	B2
PICCOLA	D36	B3
CUSTOM SIZE	110x101	C1
CUSTOM SIZE	110x110	C1
CUSTOM SIZE	**98x98**	**C1**
CUSTOM SIZE	96x80	C1
STANDARD FLIP	D76	C2
FLIP CHIP (UPPER Ø59)	D59	C2
CUSTOM SIZE	47x40	C2
CUSTOM SIZE	22x29	C3
CUSTOM SIZE	60x24	C3
CUSTOM SIZE	Ø172	CS
CUSTOM SIZE	121x91	CS
CUSTOM SIZE	128x101	CS

Figure 31: Priority classes

last period, which have a high level of priority, or more particularly for “98x98” with a high level of criticality (level 1). Particular consideration is needed for the dimensions belonging to the "Special" category (S) which despite the high criticality have found a very low request, about 1 or 2 requests in total in the last year, thus becoming completely irrelevant for our analysis.

Creation of Grande, Medio And Piccolo Classes

Continuing with the analysis, the team realized how complicated it was to manage a large number of PH dimensions and noting that the division into priority and criticality classes was mainly based on size, they decided to create macro subdivisions in which to group the PHs . The division was based on the area occupied by each dimension, dividing them into three groups when there was a great difference in the area from one PH to the next one. The subdivision was set in "Grande", "Medio", "Piccolo" as shown in figure 32.

Tipologia layer	Dimensione	Area	Categoria
CUSTOM SIZE	Ø172	23.223,44	Grande
CUSTOM SIZE	128x101	12.928,00	Grande
CUSTOM SIZE	110x110	12.100,00	Grande
CUSTOM SIZE	110x101	11.110,00	Grande
CUSTOM SIZE	121x91	11.011,00	Grande
CUSTOM SIZE	98x98	9.604,00	Grande
CUSTOM SIZE	91x91	8.281,00	Grande
CUSTOM SIZE	96x80	7.680,00	Grande
CUSTOM SIZE	96x76	7.296,00	Grande
GRANDISSIMA SUPER SPECIAL	74x76	5.624,00	Medio
STANDARD FLIP	D76	4.534,16	Medio
GRANDISSIMA SPECIAL	50x74	3.700,00	Medio
GRANDISSIMA	44x74	3.256,00	Medio
INTERMEDIA	50x60	3.000,00	Medio
FLIP CHIP (UPPER Ø59)	D59	2.732,59	Medio
CUSTOM SIZE	47x40	1.880,00	Piccolo
GRANDE	30x60	1.800,00	Piccolo
CUSTOM SIZE	36x42	1.512,00	Piccolo
CUSTOM SIZE	60x24	1.440,00	Piccolo
CUSTOM SIZE	36x34	1.224,00	Piccolo
PICCOLA	D36	1.017,36	Piccolo
CUSTOM SIZE	22x29	638,00	Piccolo
CUSTOM SIZE	D22	379,94	Piccolo

Figure 32: Classification by the area

Category	Size	
Grande	Ø172 128x101 110x110 110x101 121x91 98x98 91x91 96x80 96x76	**1 or 2 layer per plate**
Medio	74x76 D76 50x74 44x74 50x60 D59	
Piccolo	47x40 30x60 36x42 60x24 36x34 D36 22x29 D22	**Can be realized on already processed plate**

Figure 33: Grande, Medio, Piccolo classes

This subdivision reflects the analyzes carried out so far, in fact the "Grande" PH class encloses all those dimensions that can be made 1 or a maximum 2 times per plate, while the "Piccolo" class mainly indicates the dimensions made on the ceramic leftovers (figure 33). Such a subdivision will be very useful later when explaining the re-design of the warehouse and re-classification of semi-finished products.

Customers Analysis

Thanks to the department manager Valentino, the team could also work on a very important Excel file in which are listed all the projects realized in the PH FE department relating to the years 2019 and 2020 (obviously until May) with the corresponding customers.

Just like for “Prometeo”, even with these data the team focused only on the last year, carrying out a Pareto analysis of the projects requested by each Technoprobe’s customer. From the list of customers (figure 34), here called with letters or codes for privacy reasons, it is possible to see that the first 8 clients represent 80% of the total demand.

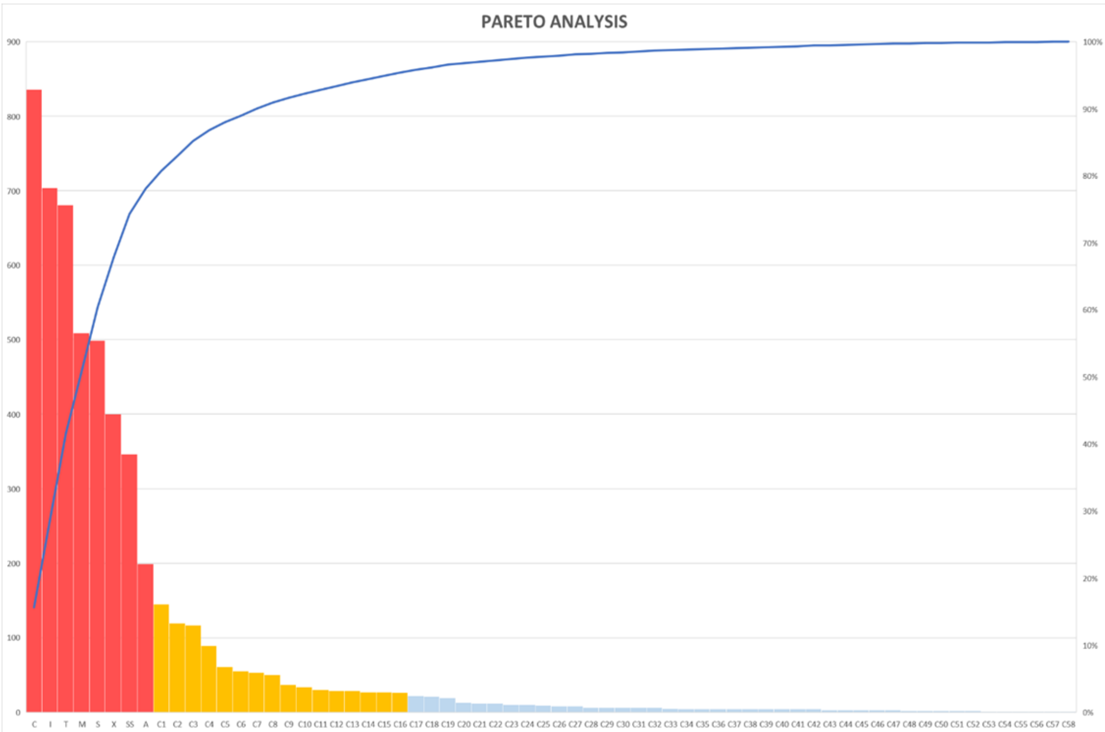
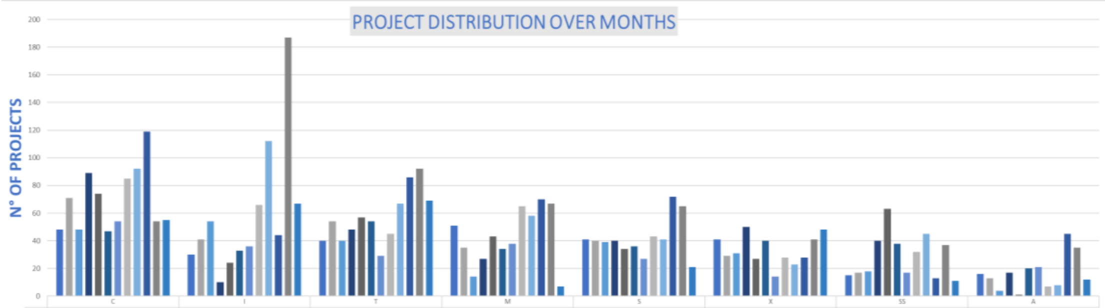


Figure 34: Pareto analysis of customers

From this moment on, the analysis will focus, for obvious reasons only, on the first 8 customers, who have proved to be by far the most representative and with the greatest impact on the total demand. Our team, therefore, decided to observe how these requests were distributed over the months and the graph representing the result is shown below (figure 35).



	C	I	T	M	S	X	SS	A
giu	48	30	40	51	41	41	15	16
lug	71	41	54	35	40	29	17	13
ago	48	54	40	14	39	31	18	4
set	89	10	48	27	40	50	40	17
ott	74	24	57	43	34	27	63	1
nov	47	33	54	34	36	40	38	20
dic	54	36	29	38	27	14	17	21
gen	85	66	45	65	43	28	32	7
feb	92	112	67	58	41	23	45	8
mar	119	44	86	70	72	28	13	45
apr	54	187	92	67	65	41	37	35
mag	55	67	69	7	21	48	11	12

Figure 35: Demand distribution of principal customers

The graph shows no particular trends for any of the main customers; not even the lockdown caused by the COVID-19 pandemic has homogeneously altered demand creating drops in requests. These data make the team understand how variable and constantly changing this sector is and how the demand does not present seasonality, making production flexibility and speed of response two fundamental weapons to challenge competitors.

Correlation Dimension-Customers

The last analysis made on past data was possible thanks to all the information collected so far, which allowed the team to investigate the available data more in-depth.

Based on the latest customer analysis just carried out in the previous chapter, the team extracted from Prometeo all the dimensions required by the main 8 customers of Technoprobe.

As anticipated in the chapter "Data Selection", among the main customers it should be noted that customer C does not specify the size of any PH format, because in Prometeo they are all saved as "Custom Size", not allowing the team to know the real dimensions and then to carry out all the previous analysis. Excluding this customer, all the remaining are used to order a great diversity of PHs, belonging to all the three macro-families "Grande", "Medio" and "Piccolo" defined.

Customer	Value	Priorità
A	36x34	A3
A	36x42	A3
A	D22	A3
I	36x34	A3
I	91x91	A1
I	98x98	C1
I	GRANDISSIMA SUPER SPECIAL	A1
M	36x34	A3
M	47x40	C2
M	91x91	A1
M	GRANDE	A2
SS	36x34	A3
SS	91x91	A1
SS	GRANDISSIMA SPECIAL	B2
SS	GRANDISSIMA SUPER SPECIAL	A1
SS	INTERMEDIA	B2
S	22x29	C3
S	36x34	A3
S	36x42	A3
S	60x24	C3
S	91x91	A1
S	96x76	B1
S	96x80	C1
S	D22	A3
S	GRANDE	A2
S	GRANDISSIMA	B2
S	GRANDISSIMA SPECIAL	B2
S	GRANDISSIMA SUPER SPECIAL	A1
S	INTERMEDIA	B2
S	ø172	CS
S	PICCOLA	B3
T	110x110	C1
T	36x34	A3
T	36x42	A3
T	91x91	A1
T	FLIP CHIP (UPPER Ø59)	C2
T	GRANDE	A2
T	GRANDISSIMA SPECIAL	B2
T	GRANDISSIMA SUPER SPECIAL	A1
T	INTERMEDIA	B2
T	PICCOLA	B3
X	22x29	C3
X	36x34	A3
X	36x42	A3
X	96x76	B1
X	D22	A3
X	GRANDE	A2
X	GRANDISSIMA	B2
X	GRANDISSIMA SUPER SPECIAL	A1
X	INTERMEDIA	B2
X	PICCOLA	B3
C	CUSTOM SIZE	-

Figure 36: PHs required by main customers

Subsequently, the relative priorities calculated a few chapters ago, were assigned to each dimension requested by the customer (figure 36). Our team has focused only on them to solve problems and to optimize the production process.

By filtering the table, considering only critical projects, the team obtained this second table (figure 37) in which the customers are reduced to 6 and where are computed the percentages of critical orders (high priority or criticality) on total orders issued for each customer. From the analysis of these percentages it's possible to understand even more in detail which are the most critical customers among all; in particular the percentages of customers I, SS and M are particularly relevant.

Customer	Value	Ordini critici/Totale Ordini
I	91x91 98x98 GRANDISSIMA SUPER SPECIAL	87,0%
M	91x91	40,0%
SS	91x91 GRANDISSIMA SUPER SPECIAL	53,8%
S	91x91 96x76 96x80 GRANDISSIMA SUPER SPECIAL	16,1%
T	110x110 91x91 GRANDISSIMA SUPER SPECIAL	17,8%
X	96x76 GRANDISSIMA SUPER SPECIAL	1,7%

Figure 37: % of critical order of the main customers

A special note for the client I, who not only requests high priority projects but also the trendiest formats of this period, becoming the most interesting client for possible optimization.

ON-SITE WORKING

Starting from May 2020 our team had the opportunity to go to the company initially with only one member at time. In the company, the team was able to see the whole process with its problems and risks. The current production is based on 2 full shifts, morning and afternoon, and the presence of only a few operators at night and during the weekend. There are currently 40 operators in the PH FE department, 20 workers dedicated to the laser machines and 20 to manual assembly, control and washing processes. The current machine base is 40 laser machines with the same characteristics and one of them is dedicated to cut frames.

As Technoprobe is a constantly expanding company, the number of laser machines is constantly growing, which has resulted in a not optimal disposition of the department. There are 10 lasers in one room of the department, another 20 in the main room and another 10 divided into other rooms. Inside the department, there is also a small warehouse that provides a sample of all the raw materials available and ceramic residuals difficult to reuse. It is a small shelf consisting of various drawers, each of them contains materials with different thickness levels and shapes.

At present, the classification of these residuals in each drawer is based on the number of operations carried out on a single plate. The two classifications highlighted in red in figure 38 are present only for a few thickness levels.

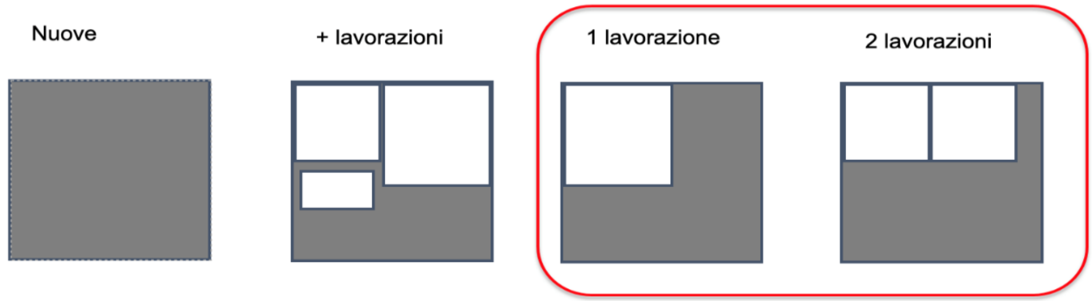


Figure 38: Warehouse classification

In the same building of the department PH FE there is an additional warehouse on the floor below, in which are stored not only most of the raw materials but also all the plates hardly re-usable accumulated over time.

Data Collection

On the days when the team went to the company, they collected the data directly from the laser machines. Each laser machine is controlled by its computer on which there is a specific program with which to define the processing parameters. The program requires in fact some main information such as the size, the finiture and the thickness level of the initial plate, the type of processes to be carried out with any downsizing (lowered parts of the plate, used to insert a different type of probes) and the number of holes to be realized.

This last parameter is fundamental to define the working time, all laser machines work at a speed of 2000 holes/hour. The main difficulty encountered by our team was to record the various formats in processing because in the program of the laser machine there are no dimensional indications of the project under machining but only an identification code. Through this code, thanks to the information contained in the runsheets, it was possible to link each process to the relative layer format.

During the month of June and July, 10 clusters of observations were collected at a distance of 2/3 days from each other, so that there was no bias due to repetitions of observations of the same project.

The cataloging of the data was done in a standardized way as depicted in figure 39:

					Performance attuali				
Layer	N° Layer	Finitura	Spessore	Tipologia	Plate	#plate	prezzo	Utilizzo	Residuo
74x76	2	opaco	A	Plate Forata	127x127	2	558,00 €	38%	347,16 €
74x76	3	liscio	A	Plate Forata	127x127	3	762,00 €	38%	474,07 €
74x76	3	liscio	B	Plate Forata	127x127	3	681,00 €	38%	423,68 €
89x89	9	liscio	B	Plate Forata	127x127	9	2.043,00 €	53%	955,75 €
91x91	2	lisico	A	Plate Forata	127x127	2	508,00 €	56%	225,36 €
98x98	1	liscio	B	Frame	127x127	1	227,00 €	65%	80,53 €
98x98	2	liscio	B	Plate Forata	127x127	2	454,00 €	65%	161,05 €
							5.233,00 €		2.667,61 €

Figure 39: Observations' classification

The various observations were grouped according to the common characteristics in order to make the analysis more effective. As shown in figure 26 for each class of observations have been defined the size of the layer to be made, the number of layers to be made, the finiture of the layer, the thickness level of the layer, the type of processing (perforated plate or frame), the plate on which these layers were made and the number of plates used. In addition to this information, our team has calculated thanks to the support of the purchasing office, in the figures of Dario Calvi and Davide Montini, the purchase price of the plates used obtained by multiplying the number of plates used by the relative price taken from the list.

The last two columns are related to the use of the plate; the first represents the percentage of plate used for processing, it is obtained considering only the workable part of the plate, (for example on a 127x127 plate the workable dimensions are 122x122) and the size of the layer made; the second is the economic value of the plate after processing which is difficult to reuse and, in most cases stored in the warehouse. This value is obtained from the price list of the plate multiplied by the percentage of unused plates. For each set of collected information, it was possible to calculate the current performance in terms of raw material cost and total residual value. By comparing the two data it is possible to define in a generic but still effective way the quality of the process in terms of the use of raw materials. The two parameters used to assess current performance are related to a number of working hours equal to 14, our team, therefore, had to transform these values into daily estimates, to standardize observations and to calculate monthly and annual projections.

A further parameter is represented by the operations, that is the time that an operator must devote not only to the physical operations of loading/unloading of the laser machine, the selection of the material and the jig and the operations of fixing the jig, but also to load the drilling file on the laser machine and time spent by the machine to control the planarity and centering before the start of the work task. These last two controls require a lot of time and are fundamental for the correct realization of the layer as even a minimal defect could affect the correct insertion of the probes in the appropriate hole and thus spoil the entire Probe Head.

To calculate this value, standard time values were used in relation to the jig used, for single-position jig the estimated time is 15 minutes, for double-position jig the estimated time is 25 minutes, for quadruple positioning jig is 45 minutes. In the table below (figure 40) there is the resume of all the calculations of the parameter depicted before, with the relative average and projection on the day, month and year; in the evaluation of the operation cost, the times needed by the operators are multiplied by 30 €/h, which is the average cost per hour for each operator.

	Attuali		
	Costi	Residuo	Operazioni
osservazone 1	5.233,00 €	2.667,61 €	254,17 €
osservazone 2	8.366,93 €	3.726,58 €	400,00 €
osservazone 3	9.928,10 €	4.529,49 €	425,00 €
osservazone 4	6.562,62 €	2.721,90 €	262,50 €
osservazone 5	9.917,21 €	3.950,38 €	450,00 €
osservazone 6	6.824,80 €	2.972,39 €	345,83 €
osservazone 7	7.678,44 €	3.356,95 €	316,67 €
Osservazione media	7.787,30 €	3.417,90 €	350,60 €
Proiezione giornaliera	13.350 €	5.859 €	601 €
Proiezione mensile	266.993 €	117.185 €	12.020 €
Proiezione annuale	3.203.918 €	1.406.221 €	144.245 €

Figure 40: Data projection

In most of the cases observed, in each plate a single layer is worked and the times just listed refer to the single processing on the plate. Instead, for the processing of 4 layers on the same plate, the times of the operations are equal to 30 minutes, as there is a single selection of the material, a single loading/unloading in the machine and a single fixing of the jig, also the time required for the centering and planarity control is shorter because they are done only for one plate, but more time is required to load the drilling file because it is heavier.

From the observations collected, our team has noted that there are some formats of layers particularly required in the last months, in particular 3 formats represent 80% of the processing carried out during the collection of data, as shown in the following table (figure 41).

Formati Plate	%
91x91	43%
98x98	23%
74x76	14%
Altro	20%

Figure 41: Layers required

Referring to the classification of layers' sizes taken from Prometeo's data, it is possible to observe that the three formats listed are classified as criticality 1, which are layers that require an entirely new plate for each of them. The "91x91" and "98x98" are critical for all plate formats currently available, 127x127 and 186x186, the format renamed "Grandissima Super Special" (74x76), could be downgraded to criticality 2 in case these are made on the plate of size 186x186, that from the collected observations is little used being preferred the 127x127 format.

TARGET DEFINITION

After collecting observations for a month, our team defined the targets of the project following the indications of Valentino Schiariti who has many years of experience in the sector and who has been monitoring all the KPIs of the department for years. In particular, given the significant amount of costs not only related to the purchase of raw materials but especially to the non-optimal use of them, the priority is to reduce the purchase cost of the plates to take advantage of a smaller amount of raw materials, lightening therefore also the warehouse.

Two objectives were then defined, a Must to Have objective equal to the reduction of the 3% of the raw materials' annual total cost, to be achieved by 30 September; a Nice to Have objective equal to the reduction of the 8 % of raw materials' total annual cost to be achieved by 30 September.

The two percentages of the two objectives already take into account a high percentage of processes that require particular technological needs, various urgencies and possible present defects of the raw materials that could affect the correct use of the entire plate.

Given the short duration of this project and the difficulty of applying possible countermeasures on a production process of this size, the analysis of the results will be complex. While presumably from the first use of these countermeasures it will be possible to observe some slight improvement in performance, to have a total view of the impact of these actions, it will be necessary to wait for the end of the current year. Carrying out an analysis within a few months could lead to biased results as they are strongly conditioned by the variability of demand and the size of some projects.

ANALYSIS OF THE ROOT CAUSE

To better identify where to act in the process and select the best possible countermeasures to implement, our team used two different techniques: Ishikawa Diagram and 5Whys Analysis.

Through the first technique called Ishikawa Diagram or Fishbone Diagram, our team has identified which are the main actors that participate in the production process and that can be the cause of the main problem : plates not optimized in terms of costs and utilization.

The main actors, that are the macro causes of the problem are the following (figure 42):

- Suppliers: due to the specificity of the raw material requested, Technoprobe has only two suppliers. In addition to this, these suppliers do not have as core competence the production of raw materials requested by Technoprobe, but they devote themselves to them only marginally. These suppliers present a high bargaining power that does not allow Technoprobe to be able to establish a partnership and a collaborative relationship to optimize not only the costs but also the residuals. This is fundamental to meet the production needs that are currently based on the use of raw materials with fixed dimensions and little variety that currently cause a significant waste of material.
- Operators: currently the operators do not follow any procedure for the positioning of the workings on the plate, they are based mainly on visual measurements and their own experience. Same procedure for the selection of raw materials already processed, the operator selects the first plate in which it is possible to create the required layer and not the optimal one. The operator focuses only on the single runsheet, he does not have a general view of the number of layers to be made with the same characteristics given the presence of multiple projects.
- Machines: the machines have a reduced autonomy due to the high number of setups required because they are often carried out single machining on the plate. This problem is also affected by the implementation of one project at a time.
- Customers: Customers are the most complex actor to analyze as it is not possible to act on them and their requests. The main feature of Technoprobe's products

is the high customization that makes each project or group of projects unique and not repeatable over time because often the product is made in co-design with the customer himself. Such high demand variability is due to the specific use of technologies and the distribution of orders in the time that does not follow any trend but only and exclusively the specific requests of the customer. Thus, in the face of almost total customization of the product, the customer requires also the shortest possible lead time as the technological market travels at very high speeds.

- Storage: although it is not a real actor, the warehouse and the logistics of the inventory represent one of the main macro causes. This is due to almost non-existent inventory traceability that makes difficult an effective use of materials already partially processed and a mode of inventory based on different scales: the raw materials are cataloged in pieces and the partially used materials are cataloged by weight, without specific classifications.

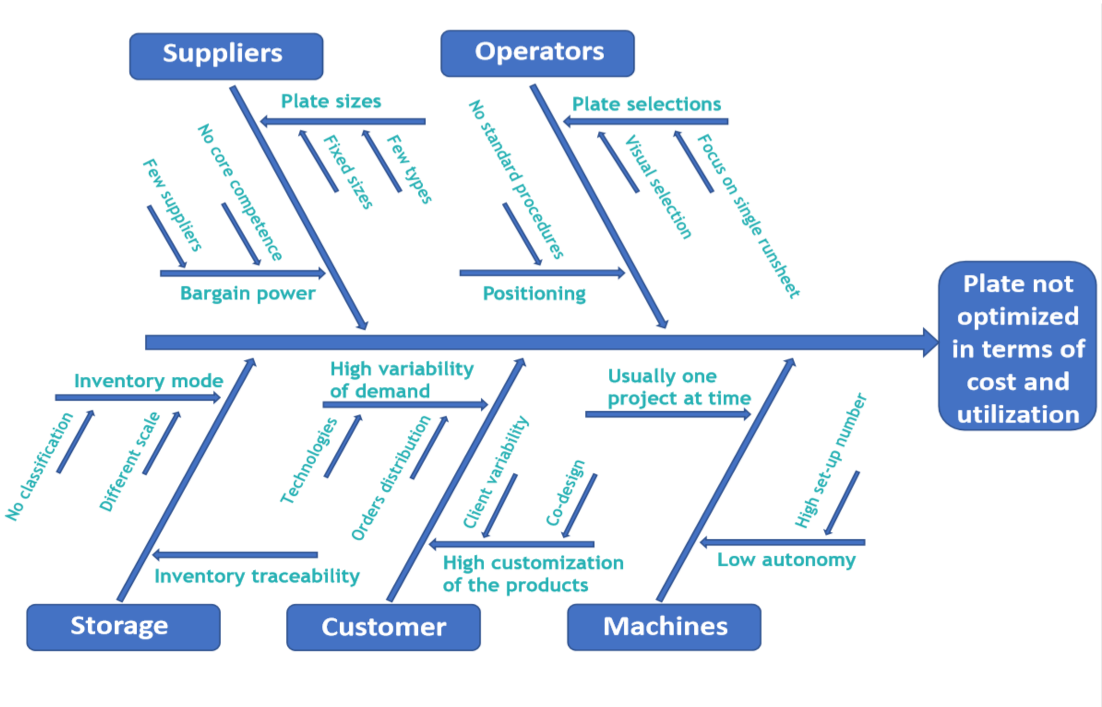


Figure 42: Ishiwaka Diagram

Subsequently, the team has carried out the 5Whys analysis (figure 43) in which they have been taken into consideration only the influent actors through the implementation of countermeasures that are the suppliers, the operators, the machines and the storage.

Through this technique, it was possible to identify the root cause of each actor through a series of "why?".

	Suppliers	Operators	Storage	Machines
WHY?	Plate size	Too many plate used	High inventory level	Low autonomy
WHY?	Fixed size and few typologies	Wrong plate selection	Difficulty in the re-usage	High number of set-up
WHY?	Low bargain power	Visual selection	Wrong inventory mode	Too many plate used
WHY?			Use of different scale	One project at time
WHY?				
ROOT CAUSES	Low collaboration	No optimal procedure	Non-homogeneous class	Lack of aggregation
Countermeasures	Increase plate size	Selection and positioning procedure	Re-classification of inventories	Different workload

Figure 43: 5Whys analysis

The main problem that involves the suppliers is the size of the plates that are of few and fixed typologies due to a low Technoprobe's bargaining power. It is therefore clear that the root cause is the lack of a collaborative relationship with the suppliers; the countermeasure identified by the team is the construction of a new partnership based on a new plate format with characteristics more congenial to Technoprobe.

For what concerns the operators, the main problem is related to the too high number of plates used, caused by the wrong selection of the plate done visually. The countermeasure on which our team will work will be the definition of an optimal procedure for the selection and positioning of the plate.

More complex is the analysis related to storage, characterized by a high inventory level due to a difficulty in re-using partially used materials, this is caused by a wrong classification of such materials which makes it impossible to find them quickly. The current classification is not based on the characteristics of the plate to be re-used but only on the weight of the plate.

The problem turns out to be the classification not homogenous of the inventory, our team will provide, therefor, to a reclassification of it with the aim to make more effective the selection of the material already used and to favor its disposal.

The last macro cause analyzed is that related to laser machines that have a reduced autonomy, this is caused by a high number of setups due to a high number of plates on which to realize a single machining. All this is caused by the working methodology of the operators that focus themselves on a single project at a time, this is caused by a little aggregation of projects that our team would like to address through a different workload.

The countermeasures of operators, storage and machines are directly applicable within the PH FE department and they represent the incremental changes developed by the team.
Regarding the countermeasure of the suppliers being this much more complex and involving external actors to the company, it will not only demand more time but it will involve more departments of the company, i.e the office purchases or the department design. They represent the radical changes proposed by the team. The difference between these two change management approaches are described in the following chapter.

CHANGE MANAGEMENT

After defining the context in which to operate and having defined the targets to be reached, the team must define not only the countermeasures to be implemented but also the process with which to implement an organizational change. Organizational change means a process through which an organization modifies its present condition, identifying new assets for its value creation system, in order to increase its effectiveness. Change management is a systematic approach to address the change of an organization as a whole and of the individuals that make it up. This consists of a set of processes, tools and techniques aimed at preparing the company to change, planning and controlling the change, and making it effective in the organizational context.

Based on the intensity of the change, how different the future state is from the current state of the organization, and the time within which these changes take place, two different types are identified: radical and incremental change.

Incremental change is gradual, progressive and meticulous. This type of change does not involve a drastic or sudden alteration of the fundamental characteristics of the organizational strategy, but continuous improvement of technologies to adapt to changes in the environment and to obtain limited improvements.

This type of change is also called continuous improvement or kaizen, which consists of the adoption of small, frequent and continuous improvements over time, in order to obtain significant results thanks to their cumulative effect.

In the case under consideration, our team will develop some improvements according to this modality of change, which is the countermeasures related to the macro causes of workers, machines and logistics.

The main advantages and limitations of continuous improvement concern low activation and implementation costs since these activities are entrusted to staff who already work for the company. In our case, these improvements will be used by the workers of the PH FE department.

In addition, it relies on the skills and availability of the operators concerned, enhancing their experience with an important motivational effect, it also facilitates the practical application of the solutions by reducing the introduction times from the moment.

Continuous improvement triggers a gradual and progressive development process that at the same time requires a long time to achieve results. Its success largely depends on the corporate culture, in an environment open to change, as in the case of Technoprobe, it is easier to implement the desired changes and improve the production process. In the past, the company has made incremental improvements such as the development of multi-position jigs (figure 44). The impact of countermeasures' implementation has gradually decreased over the time. As represented by the graph, in fact, the curve representing the relationship between benefits and efforts for implementation has flattened out with the introduction of more and more incremental improvements.

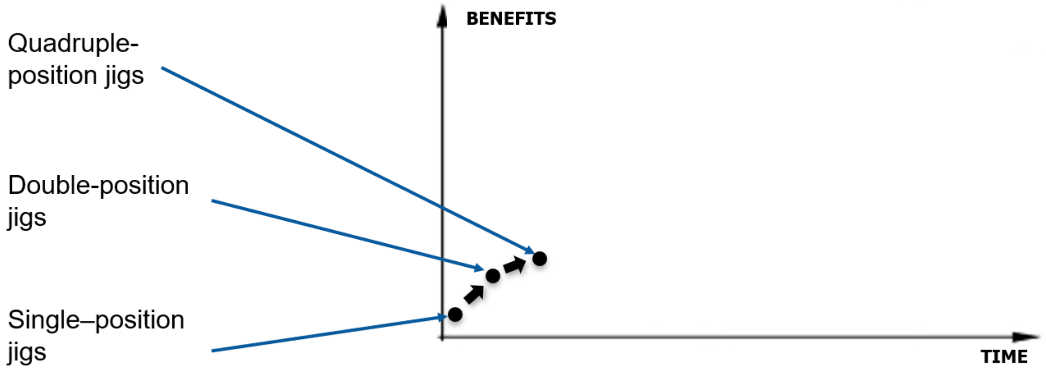


Figure 44: Impact of past incremental improvements

The radical change is drastic, rapid and far-reaching. It consists of a courageous attempt to quickly change one or more dimensions of the organization. This is a clear change from the customs of the past, new organizational structures or management models are created within the company or, in this case, revolutionary technologies or new products and services are introduced. This change can be related to a specific area, for example the implementation of a new process technology as in the case considered in the PH FE department, or to the whole company, such as the development of a new product or the entry in a new market. The radical change, therefore, constitutes a significant leap towards completely different organizational structures, models and logics compared to the current state of the company. This discontinuity from the past is often justified by the need to obtain radical improvements in company performance, in the face of performance that is no longer satisfactory for the market. These profound transformations generally have a systemic character; the radical change brings with it the need to review different areas of the organization and the involvement of other departments, in the case under consideration the Design Department and the Purchasing Office. These changes are therefore defined as multidisciplinary and they require the involvement of figures with different skills.

In this report, the team will propose and analyze the impact of two incremental changes, called Cost Optimizer and Residual Classifier, and two radical changes, called "new PH design" and "new plate format". The first two have the objective of improving the productivity performance of the current production process of the PH FE department to the maximum possible, the other two aim to make an important step in improving the process, bringing significant benefits from an economic and organizational point of view (figure 45).

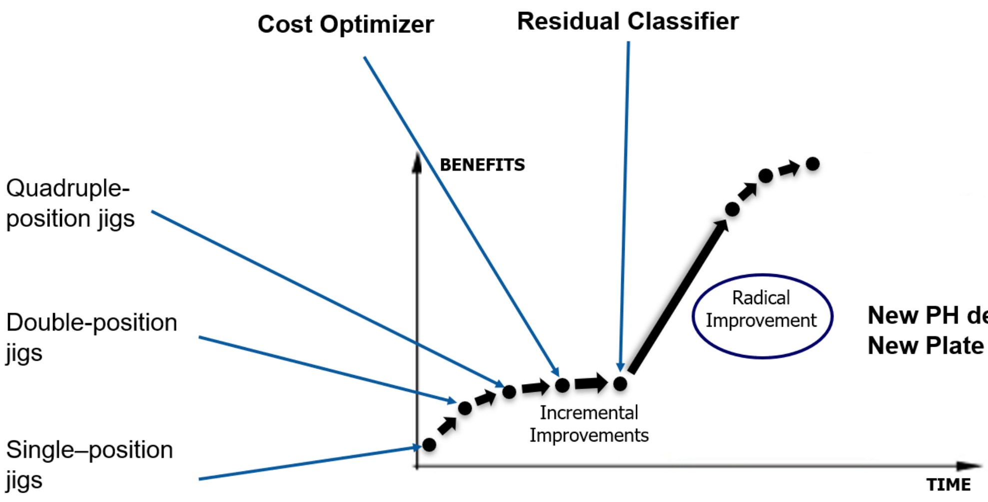


Figure 45: Incremental and radical improvements

DEVELOP COUNTERMEASURES

Once analyzed the causes and defined the possible countermeasures, our team has developed, thanks to the support of the two tutors, academic and company, some tools to improve the production process. The two incremental improvements tools developed by the team are programs made on Microsoft Excel that are called Cost Optimizer and Residual Classifier.

As for the countermeasures belonging to radical changes, the team hypothesized to create a relationship of greater collaboration with clients and suppliers, in order to meet the production needs of Technoprobe through the development of new design and the introduction of a new plate format.

The two approaches were developed simultaneously by the team, but being them completely different from a conceptual point of view and some of them requiring also the involvement of other departments or actors from the company will require different implementation times and different benefits. The analysis of these countermeasures will then follow the order in which they can be applied.

INCREMENTAL IMPROVEMENTS

As previously mentioned, as these improvements are easier to implement and require a low activation cost, they will be the first to be analyzed and subsequently implemented. Furthermore, these countermeasures also require standard technological support, so they can be effective immediately.

Cost Optimizer

Cost Optimizer is a spreadsheet that will automatically guide the operator in the selection of the plate suggesting the ideal format for three different parameters: for the optimal price, for the optimal use, the plate that best exploits the required area, or for the optimal residue, suggesting the plate whose residual part is of lower economic value than the others.

A first version of the program has been realized as in the following image (figure 46):

Dimensione	74X76
Finitura	lucido
Numero PH	1000

				127x127				186x186				d180			
	Spessore	Quantità	Tot	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo
Plate Forata	B	1	1000	1000	227.000,00 €	38%	141.226,82 €	250	113.000,00 €	69%	34.541,73 €	500	124.000,00 €	44%	69.161,91 €
Plate Forata	C	2	2000	2000	452.000,00 €	38%	281.209,35 €	500	222.000,00 €	69%	67.860,74 €	1000	247.000,00 €	44%	137.766,06 €
Frame	A	2	2000	2000	454.000,00 €	38%	282.453,64 €	-	-	-	-	1000	248.000,00 €	44%	138.323,82 €
Frame	C	2	2000	2000	452.000,00 €	38%	281.209,35 €	500	222.000,00 €	69%	67.860,74 €	1000	247.000,00 €	44%	137.766,06 €

Prezzi ottimali	FORMATO OTTIMALE
113.000,00 €	**186x186**
222.000,00 €	**186x186**
248.000,00 €	**d180**
222.000,00 €	**186x186**

Utilizzo ottimale	FORMATO OTTIMALE
69%	**186x186**
69%	**186x186**
44%	**d180**
69%	**186x186**

Residuo ottimale	FORMATO OTTIMALE
34.541,73 €	**186x186**
67.860,74 €	**186x186**
69.083,46 €	**186x186**
67.860,74 €	**186x186**

Figure 46: Cost Optimizer 1.0

At the top, the operator will enter the required layer size, the finiture and the number of PHs required. In the bottom part, four lines have been reported in which there are two lines dedicated to perforated plates and two to frames. Two rows have been dedicated because in almost all projects the layers required in the same PH can have at most two different thickness levels. The operator himself will enter the required thicknesses and quantities taking them from the runsheet. Automatically the program will calculate the total number of layers needed for the realization of all projects of this size.

In the lower part of the spreadsheet, three possible scenarios follow the three formats available. For each scenario will be calculated the number of plates needed, this value is obtained using tables built by our team in which there is the maximum number of layers achievable on the single plate. These tables have already been analyzed in the Smart working section, from the data taken from Prometeo. The price is calculated by multiplying the number of plates needed by the price list of the individual formats. The use is a percentage that represents the area of the plates used during the processing and the residue represents the economic value of the plate after the first processing.

Where there are no values in the table this means that this format is not available (i.e. in figure 45 the plate "186x186" with a thickness level A is not available). The output of this program is represented by three tables showing for each type of plate and thickness the optimal format in terms of price, use and residual. This output is obtained by comparing the above-calculated values; in most cases, the optimal format is the same. In case there are different outputs, the operator will decide which format to use following the guidelines of the management.

After a comparison, some operators came up with the need to simplify this program to speed up the plate selection operation. In this regard, the team has carried out a second version of the program as follows (figure 47):

				QUANTE VOLTE CI STA?		
Dimensione Layer	74x76	Dimensione da aggiungere		127x127	186x186	D180
Finitura	opaco	89	77	1	4	2
Numero PH da realizzare	1					

Dettagli PH	*Spessore*	*Quantità*	*Prezzi ottimali*	*FORMATO OTTIMALE*
Plate Forata	A	2	471,55 €	**186x186**
Plate Forata	B	2	392,96 €	**127x127**
Frame	A	2	471,55 €	**186x186**
Frame	B	2	392,96 €	**127x127**

AGGIUNGI

Figure 47: Cost Optimizer 2.0

The new graphic is much more compact, the information in the first box that the operator must insert is present in lists, in order to reduce the possible typos. The only value that the operator must enter manually is the number of PHs to be realized. Also the required thickness and the quantity of each layer are selectable from lists. The output represents the optimal format in terms of price since the main goal set by the team is to reduce the cost of purchasing the raw material.

In the upper-right part of the spreadsheet, a macro "Aggiungi" has been added which allows the operator to insert a new dimension into the Cost Optimizer. The possibility to add formats is very important as customers often require highly customized sizes that have never been created before and therefore are not present in the selection list. The operator must also enter the maximum number of layers that can be cut from each of the 3 types of virgin plates.

Such a program will be available for operators through a PC placed inside of the department and it will carry to remarkable benefits, not only economic. Faced with a clear reduction in the number of plates used and a consequent reduction in the cost of purchasing raw materials, there will also be advantages such as an increase in machine autonomy, a reduction in loading/ unloading operations, a reduction in incoming operations (due to less purchased materials) and an increase in working time and productivity in shifts in which there are fewer operators, i.e. during the night shifts and weekends.

Residual Classifier

The Residual Classifier is a spreadsheet that allows the classification of residues after the first processing. Contrary to what happened in the past where the plates used were classified according to how many workings had already been completed, with the new method the classification will be based on the number of formats still realizable on the plate. The idea of the team is to take advantage of the classification emerged from the data of Prometeo, that is the subdivision in "Grandi", "Medi", "Piccoli", to define for each plate used which other format of layer can be realized at least once. As shown in the following table (figure 48), the subdivision in the groups is based on the area of the layer. "Grandi" layers can be made once or twice on each plate. "Piccoli" layers are usually made on plates already partially worked.

Ø172	Grandi
128x101	
112x102	
110x110	
110x101	
121x91	
98x98	
91x91	
96x80	
96x76	
89x89	
80x80	
74x76	Medi
D76	
50x74	
44x74	
50x60	
D59	
47x40	Piccoli
30x60	
36x42	
60x24	
36x34	
D36	
22x29	
D22	

Figure 48: Classification of format

Such an instrument will necessarily involve a different organization of the warehouse present in the department. The current organization is ineffective because it does not differentiate the size of the work carried out, taking into account only the quantity. With the Residual Classifier, it will be instead appropriate to structure differently the drawers of the warehouse, maintaining however the subdivision based on the thickness and the dimension but grouping also the plates in base to the new classification.

As described in figure 49, in the new configuration, each drawer contains for the same thickness level all the three shapes/size of plates, and for each of them the subdivision is now in: new plate, plate that allow lavorations of at least one small PH (called “Piccoli”), plate that allows at least medium ones (“Medi”) and big ones (“Grandi”).

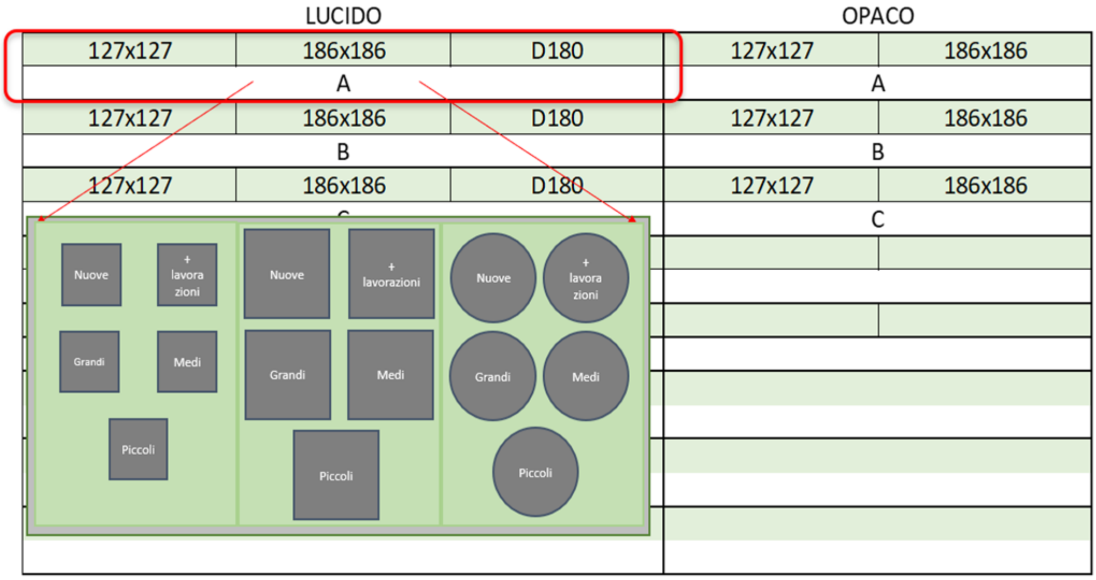


Figure 49: New warehouse layout

The Residual Classifier, as mentioned above, is an Excel sheet that, through the data entered by the operator, will classify the plate after processing. The final interface of the program is represented in figure 50.

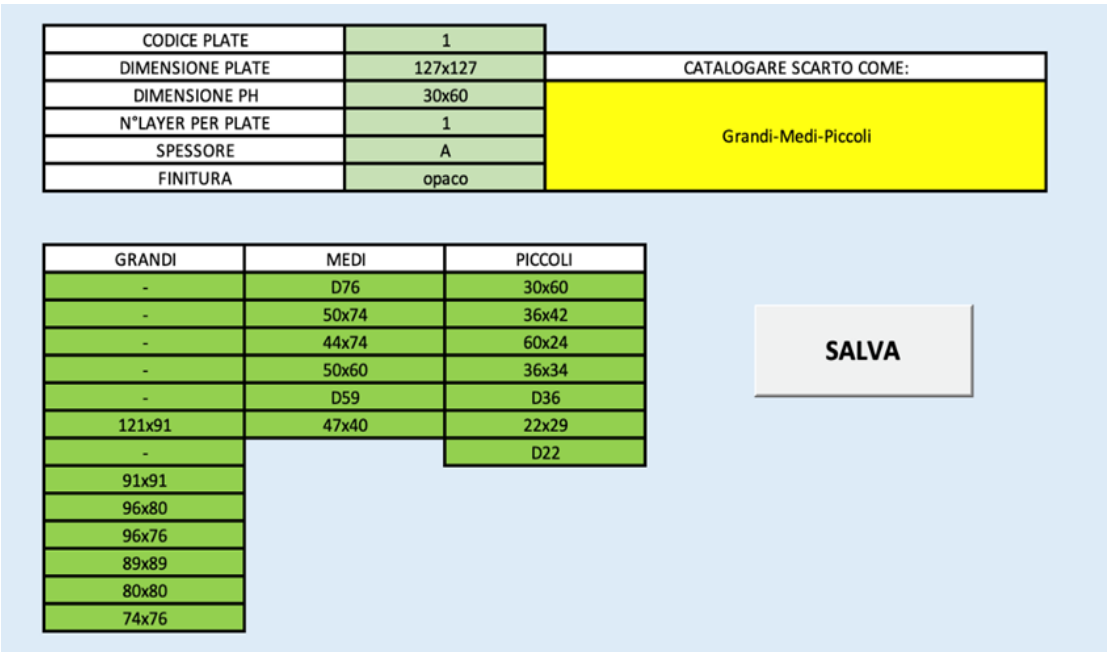


Figure 50: Residual Classifier

As shown in the picture, the information that the operator must enter is the plate code, the size of the plate to be used, the size of the layer realized, the number of layers required for each plate, the thickness level and the finiture.

Except for the plate code, all this information can be inserted through lists to avoid any typos. By inserting this data, automatically the class to which the waste belongs will be displayed in the yellow box. Below there are listed, divided into the respective size categories, all the dimensions that can be made on that particular waste. The calculations used to make this program work are explained in the following paragraph.

The Program

Currently, the program developed by our team allows the classification of plates on which have been cut at most two layers, this limit is due to the complexity of the calculations on which this program is based. Depending on this number, a different spreadsheet will be used.

The Residual Classifier is based on simple geometric calculations. Once the plate and layer dimensions are set, the program will automatically calculate the difference between these dimensions. These differences will then be compared with the sizes of all layers in the list and only the supported formats will be reported. More specifically for each layer format in the list, the program performs four different positionings (figure 51).

		Lato1	Lato2	Posizionamento1.1				Posizionamento1.2				Posizionamento2.1				Posizionamento2.2					Utilizzabile per
CUSTOM SIZE	Ø172	172	172	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	128x101	128	101	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	110x110	110	110	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	110x101	110	101	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	121x91	121	91	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	98x98	98	98	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	91x91	91	91	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	NO	OK	NOOK	FALSO	FALSO	-
CUSTOM SIZE	96x80	96	80	NO	OK	NOOK	FALSO	OK	OK	OKOK	VERO	NO	OK	NOOK	FALSO	OK	OK	OKOK	VERO	VERO	96x80
CUSTOM SIZE	96x76	96	76	NO	OK	NOOK	FALSO	OK	OK	OKOK	VERO	NO	OK	NOOK	FALSO	OK	OK	OKOK	VERO	VERO	96x76
GRANDISSIMA SUPER SPECIAL	74x76	74	76	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	74x76
STANDARD FLIP	D76	76	76	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	D76
GRANDISSIMA SPECIAL	50x74	50	74	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	50x74
GRANDISSIMA	44x74	44	74	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	44x74
INTERMEDIA	50x60	50	60	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	50x60
FLIP CHIP (UPPER Ø59)	D59	59	59	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	D59
CUSTOM SIZE	47x40	47	40	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	47x40
GRANDE	30x60	30	60	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	30x60
CUSTOM SIZE	36x42	36	42	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	36x42
CUSTOM SIZE	60x24	60	24	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	60x24
CUSTOM SIZE	36x34	36	34	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	36x34
PICCOLA	D36	36	36	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	D36
CUSTOM SIZE	22x29	22	29	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	22x29
CUSTOM SIZE	D22	22	22	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	OK	OK	OKOK	VERO	VERO	D22

Figure 51: Residual Classifier logic

The basic hypothesis is that the workmanship carried out is positioned in the upper left part of the plate, to leave a residue in an "L" shape. The first pair of positions inserts each layer format in the list next to the work already done, so at the top right part of the plate.

The output of the placement can be of four types, "NONO", "NOOK", "OKNO", "OKOK" and depends on two initial data (shown in figure 52) coming from two subtractions, the first between the horizontal side of the plate and the horizontal size of the layer already worked, the second between the vertical side of the plate and the vertical size of the layer already worked. In the first pair of positionings the program inserts each format of the layers in the list at the top right of the plate and evaluate two differences; the first one between the first initial data and the horizontal size of each layer format in the list, the second one between the vertical side of the plate and the vertical size of each layer in the list.

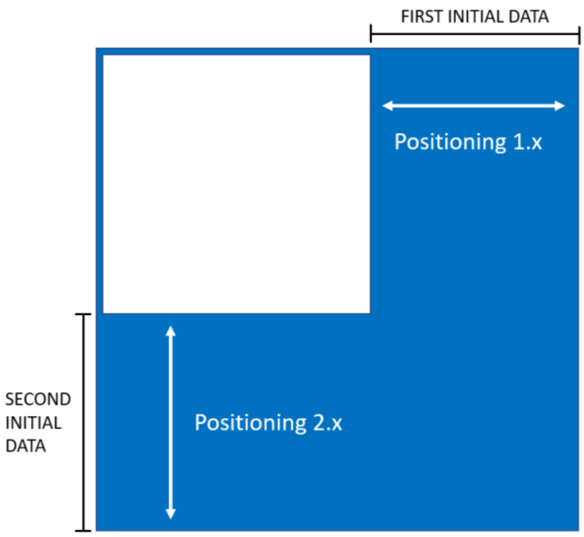


Figure 52: Positioning with 1 layer already done

The difference between positioning 1.1 and 1.2 is given by the positioning of the layer in the list, in the second case in fact the layer is rotated by 90°. The same difference exists between position 2.1 and 2.2. In the case of the second pair of positionings, the program inserts each format of the layers in the list at the bottom left of the plate, just under the work already carried out. The output of the placement will always be of four types and will depend on two subtractions, the first between the horizontal side of the plate and the horizontal dimension of the layer in the list, the second between the second initial data and the vertical size of the layer in the list.

Taking for example the case of output like "NOOK" in positioning 1.1, "NO" means that the first initial data is not enough to support the horizontal layer size in the list, while “OK” means that the vertical side of the plate can correctly support the vertical size of the layer in the list.

In the case at least one pair of positions gives as output the value "OKOK" the relative format will be copied in the rightmost cell of the table. The program will calculate how many formats are achievable on this plate and based on this number will catalog them. In case the number of workings carried out is less than 3 the plate is classified as "Da Scartare" because they could be used only for very small formats, the latter however is achievable on any residue. In the case where the number of workings carried out is less than or equal to 6 the residue would be classified as "Solo Piccoli", with a number of workings carried out less than or equal to 14 the classification is "Medi-Piccoli" (as shown in the example in figure 53), in all other cases, it will be classified as "Grandi-Medi-Piccoli”. In the case of the layer format not supported by the plate the output of the program will be “Errore”.

SI POSSONO REALIZZARE ANCORA	9	FORMATI DIVERSI
QUESTA PLATE è DA	CONSERVARE	
CATALOGARE COME CLASSE	Medi-Piccoli	

Figure 53: Residual Classifier output

In case the operator selects the option “2 operations” performed on the plate, the spreadsheet that the program will use is a little bit different in structure but similar in logic. Starting from the hypothesis that the worked layers will be positioned both in the upper part of the plate with the same rotation, a total of 8 placements will be carried out. The first group of 4 placements will take place with the layers worked with a rotation

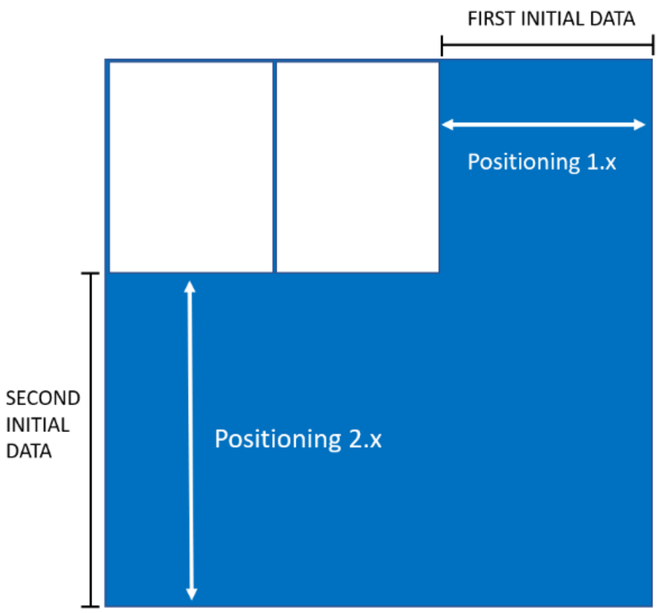


Figure 54: First 4 positioning with 2 layers

of 0° as depicted in figure 54 and then follow the same logic seen above; the second group of 4 placements will take place with the worked layers rotated by 90° like in figure 55 and then will follow again the same logic.

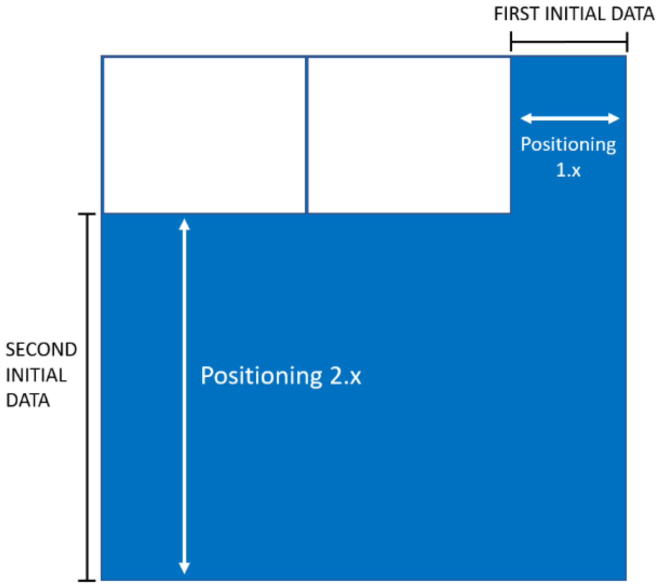
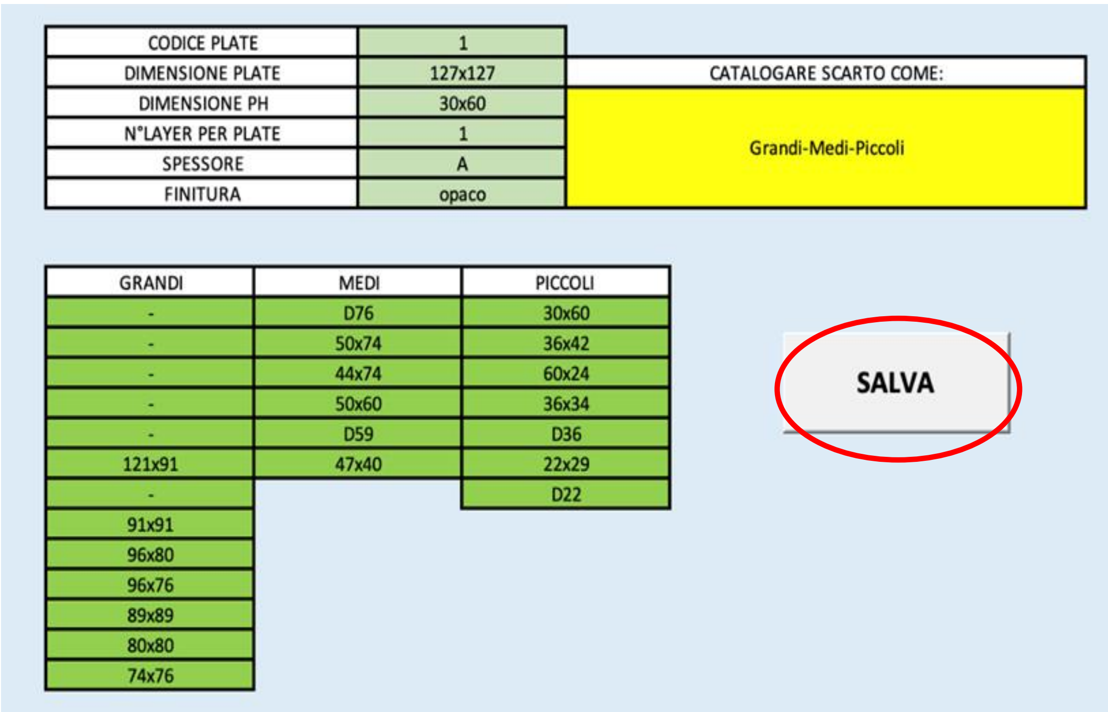


Figure 55: Last 4 positioning with 2 layers

The macros: Save, Search and Delate

The team added three Excel macros to the Residual Classifier through buttons, one of them, renamed "Save" is shown in the following figure 56.



CODICE PLATE	1	
DIMENSIONE PLATE	127x127	CATALOGARE SCARTO COME:
DIMENSIONE PH	30x60	Grandi-Medi-Piccoli
N°LAYER PER PLATE	1	
SPESSORE	A	
FINITURA	opaco	

GRANDI	MEDI	PICCOLI
-	D76	30x60
-	50x74	36x42
-	44x74	60x24
-	50x60	36x34
-	D59	D36
121x91	47x40	22x29
-		D22
91x91		
96x80		
96x76		
89x89		
80x80		
74x76		

Figure 56: "Salva" macro

Through this macro, the team created an automatic system capable of storing all the information entered by the operator that identifies a plate and outlines all its characteristics, such as the finiture, the thickness level, the category and all the layer sizes still suitable.

In the database that will be built automatically (figure 57) each row will represent a plate, that will locate it within the warehouse thanks to the category assigned by the Residual Classifier and it will record all the formats still achievable on this raw material. This implementation will speed up the picking times of the plates present in the warehouse and it will favor a more constant use of plates already worked. Currently, given the lack of a specific classification, the materials already partially processed are not stored based on their characteristics and this demotivates the operator, who instead of wasting time in finding a suitable plate for the required processing, prefers to use a new one.

A	B	C	D	E	F	G	H	I
Codice Plate	Dimensione	Spessore	Finitura	Categoria	Ø172	128x101	110x110	112x102
1	186x186	E	opaco	Grandi-Medi-Piccoli	-	-	-	-
2	186x186	E	opaco	Grandi-Medi-Piccoli	-	128x101	112x102	-
3	186x186	E	opaco	Grandi-Medi-Piccoli	-	-	-	-
1	127x127	B	lucido	Medi-Piccoli	-	-	-	-
2	127x127	B	lucido	Solo Piccoli	-	-	-	-
3	127x127	B	lucido	Medi-Piccoli	-	-	-	-
1	127x127	C	lucido	Medi-Piccoli	-	-	-	-
2	127x127	C	lucido	Grandi-Medi-Piccoli	-	-	-	-
1	186x186	B	opaco	Grandi-Medi-Piccoli	-	128x101	112x102	110x110

Figure 57: Database

Having a constantly updated information archive is essential for improving a production process, in fact, having such information available, it is possible to create specific KPIs to evaluate performance such as inventory rotation and the average stock of waste.

The team then concentrated on creating a second interface that could be complementary to the one created to save the stored plates. Through this interface (figure 58), the operator can verify the presence in the warehouse of plates capable of supporting the required processing. Also in this program, the operator will have to enter some information, such as the size of the layer to be created, the level of thickness and the required finish, through lists in order to avoid any typing errors.

The resulting output will be a list of plates suitable for the requests, in this list there is the information necessary to locate the plate within the warehouse, namely the code, size, thickness, finish and category.

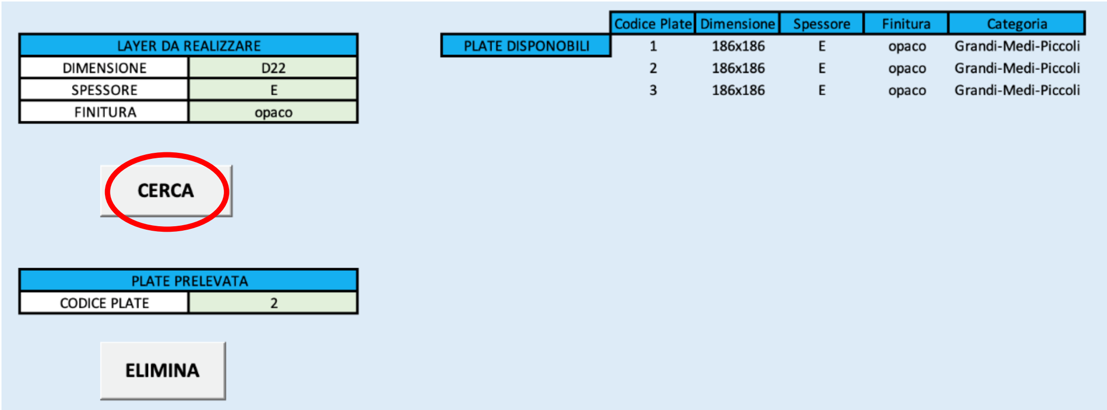


Figure 58: "Cerca" Macro

Also in this case, the team created a macro capable of filtering the database through the information entered by the operator and copying on the right-side of the spreadsheet all the plates with the required characteristics.

Once the plate has been identified, the operator will proceed with the picking phase and quality controls. If these checks are passed and the operator deems the plate taken suitable for the creation of the desired layer, this plate will be deleted from the database.

To carry out this operation, the team has programmed a third macro called "Elimina" (figure 59), capable of identifying the plate taken from the list in the database through the plate code, eliminating it to keep the file updated and consistent with what is present in stock and refreshing the list of available plates in the upper right part.

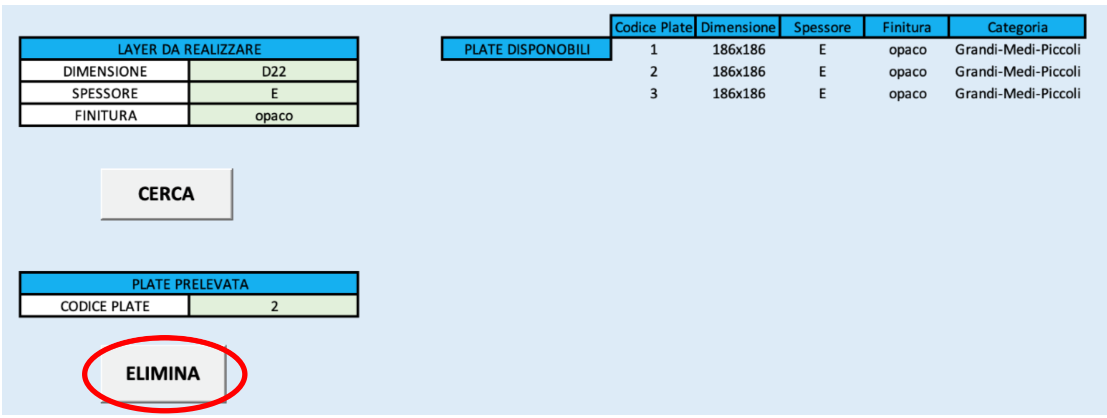


Figure 59: "Elimina" Macro

The use of macros has been widely supported by the team, since making these operations standardized and fully automatic, the operator will be focused only on a reduced number of operations, thus not only decreasing the stress's level of each of them but also increasing the quality and speed of the process.

Impact Simulation

By reporting the example represented in figure 40, it is possible to simulate the effects of introducing these two countermeasures from an economic point of view (figure 60).

The optimal costs are lower than the current ones as the Cost Optimizer has led the operator to choose more usable plates. The purchase of raw materials also decreased due to the Residual Classifier which allowed greater use of already partially processed plates. The second item represents the unexploited value of the plates that are stored, the reduction of this value is also due to both countermeasures. The cost optimizer, in fact, by choosing the optimal plate will limit the use of not very advantageous formats, while, the Residual Classifier will allow greater re-use of the plates already stored, thus lightening the warehouse. The last column represents the economic value of the machinery loading/unloading and setting operations. Through the procedure suggested by the Cost Optimizer, the choice of plates that can contain more than one format will be privileged.

	Attuali			**Ottimali**		
	Costi	**Residuo**	**Operazioni**	**Costi**	**Residuo**	**Operazioni**
osservazone 1	5.233,00 €	2.667,61 €	254,17 €	4.004,55 €	1.711,11 €	204,17 €
osservazone 2	8.366,93 €	3.726,58 €	400,00 €	7.916,93 €	3.274,97 €	320,83 €
osservazone 3	9.928,10 €	4.529,49 €	425,00 €	9.232,10 €	3.936,17 €	412,50 €
osservazone 4	6.562,62 €	2.721,90 €	262,50 €	6.106,62 €	2.295,16 €	275,00 €
osservazone 5	9.917,21 €	3.950,38 €	450,00 €	9.472,21 €	3.640,37 €	345,00 €
osservazone 6	6.824,80 €	2.972,39 €	345,83 €	6.734,35 €	2.967,04 €	320,83 €
osservazone 7	7.678,44 €	3.356,95 €	316,67 €	7.434,44 €	3.224,34 €	333,33 €
Osservazione media	7.787,30 €	3.417,90 €	350,60 €	7.271,60 €	3.007,02 €	315,95 €
Proiezione giornaliera	13.350 €	5.859 €	601 €	12.466 €	5.155 €	542 €
Proiezione mensile	266.993 €	117.185 €	12.020 €	249.312 €	103.098 €	10.833 €
Proiezione annuale	3.203.918 €	1.406.221 €	144.245 €	2.991.744 €	1.237.175 €	129.992 €
Miglioramenti percentuali				7%	12%	10%
Risparmio teorico annuale				212.174 €	169.047 €	14.253 €
Risparmio effettivo				***106.087 €***	***84.523 €***	***7.127 €***

Figure 60: Impact simulation of Cost Optimizer and Residual Classifier

It was considered that to load 4 processes on the same plate, 30 minutes are required and by comparing these times with the ones currently used, described in the "Data Collection" chapter, a saving has been foreseen considerable also of loading/unloading operations. Calculating the optimal scenario’s projections on one day, one month and one year, the team made a forecast of the savings that could be achieved. These values, however, have been halved due to very common technical problems of realization and urgencies, obliging operators to work in a non-optimal way.

RADICAL INNOVATIONS

As described above, radical change is something highly impacting which can lead to an initial drop in performance but in the long run leads to exceeding the limits that were reached with the previous settings. Following a meeting with Stefano Lazzari and Alessio Guerci, in which the team has presented part of their work, an interesting fact emerged concerning a client already highlighted in the previous chapters. In particular, one of the main customers of Technoprobe, client I, will increase its orders by approximately 350% in 2021. The peculiarity of these orders is that the requests are almost entirely Probe Head size “91x91” and “98x98" with the “opaco” finiture level. As highlighted in this report, both dimensions cannot be optimized with the plates and resources that the company currently has available. Both the two sizes are too large to be cut in multiple quantities on raw materials and therefore lead to a poor usage rate of virgin plates.

By focusing on these considerations, our team has decided to think about possible radical improvements (as not immediately feasible) to optimize this large slice of production scheduled for 2021, and which can bring widespread benefits to the whole department and the production processes of many other PHs requested by other customers. First of all, it should be noted that to simulate the possible radical improvements, some standard values and configurations have been decided in order to make it possible to calculate any economic advantages. In the next simulations, the PH under consideration is composed of 4 perforated layers of thickness B, 2 frames of thickness B and other 2 frames of A.

Another important feature is that all the layers will be cut from the material with "opaco" finiture, always requested by the customer I. From a direct on-site observation, currently, for the production of the customer I's products, Technoprobe uses a two-position jig to be loaded into laser machines (figure 61), thus having to realize the 4 perforated layers in two machine loads.

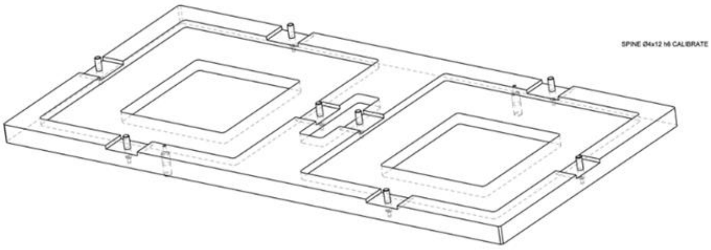


Figure 61: Double position jig

New PH Design

Analyzing the dimensions requested by the customer I, "91x91" and "98x98", there are two ways that have been identified to bring about a notable improvement in production, one of these concerns the design of the PH. Our team has noticed that in production there are "89x89" PHs that can make much better use of the raw materials available and this size is not very far from that requested by the customer I. As shown in the following figure 62, the "91x91" PHs do not fit 4 times on the 186x186 virgin plate for few millimeters, in fact the workable surface is of 180x180mm and the PH would require 182mm + 1mm in the middle, therefore 183 mm. Looking instead in figure 63, the 89x89mm PHs are perfectly suitable for the 186x186mm plate, going to fit perfectly and minimizing the ceramic residue.

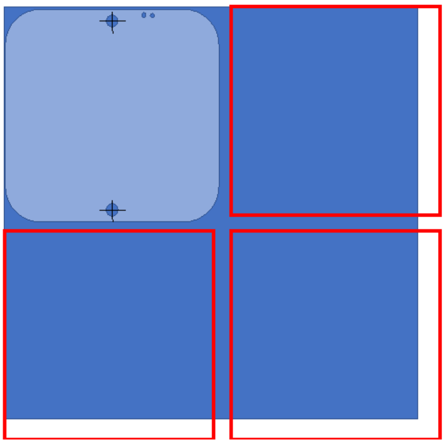


Figure 62: "91x91" on a 186x186 plate

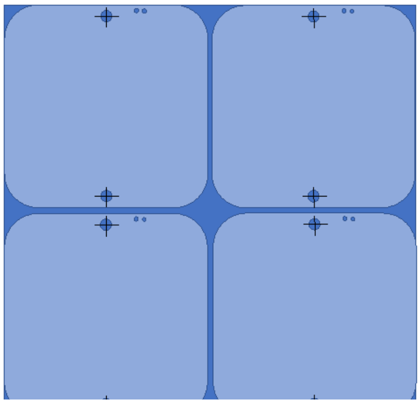


Figure 63: "89x89" on a 186x186 plate

The idea that follows is therefore to work in the preparation phase of the project, collaborating directly with the customer and the Design department to see if it is possible to reach a compromise and create the new "91x91" two millimeters shorter on each side, thus obtaining a new dimension 89x89mm that is much more manageable.

To simulate this scenario, our team used the Cost Optimizer, the spreadsheet on Excel developed that was described in the previous chapter regarding incremental changes. Thanks to this program and to the data and assumptions established, it was possible to calculate the realization's costs of the PH by entering the characteristics and the numbers of layers in the appropriate spaces of the sheet. In this first simulation, a hypothetical number of 1000 PHs has been inserted in order to see the costs coming from the production of the "91x91", this number will be the same used later in the second simulation.

As shown in figure 64, the Cost Optimizer highlights in yellow how currently the production on 127x127 plates is the best solution, for obvious reasons of space mentioned above. The table shows also that 8000 new plates are needed and the use of the plates is very low (56%), leaving a particularly high value in stock but as pointed out many times with a very low future usefulness for possible reuse.

Dimensione Layer	91X91
Finitura	opaco
Numero PH	1000

				127x127				186x186			
	Spessore	Quantità	Tot	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo
Plate Forata	B	4	4000	4000	785.920,00 €	56%	348.658,27 €	4000	1.829.600,00 €	26%	1.361.979,09 €
Frame	A	2	2000	2000	558.000,00 €	56%	247.545,96 €	2000	943.100,00 €	26%	702.056,45 €
Frame	B	2	2000	2000	392.960,00 €	56%	174.329,14 €	2000	914.800,00 €	26%	680.989,54 €

	127x127	186x186
COSTO DI 1000 PH	1.736.880,00 €	3.687.500,00 €
RESIDUO DI 1000 PH	770.533,37 €	2.745.025,08 €

Figure 64: Production simulation of 1000 91x91 PHs

In the second simulation, the production of 1000 PHs with the new design with sizes reduced to 89x89mm is calculated (figure 65). The Cost Optimizer has highlighted in yellow how in this case the convenience has shifted to the plate 186x186 as it would only take 2000 new plates, and very high use of the plate would be achieved, reaching 98%. Consequently, the residue in the warehouse would be useless and it would be directly discarded.

Dimensione Layer	89X89
Finitura	opaco
Numero PH	1000

				127x127				186x186			
	Spessore	Quantità	Tot	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo
Plate Forata	B	4	4000	4000	785.920,00 €	53%	367.667,36 €	1000	457.400,00 €	98%	10.107,98 €
Frame	A	2	2000	2000	558.000,00 €	53%	261.042,33 €	500	235.775,00 €	98%	5.210,34 €
Frame	B	2	2000	2000	392.960,00 €	53%	183.833,68 €	500	228.700,00 €	98%	5.053,99 €

COSTO DI 1000 PH	1.736.880,00 €	921.875,00 €
RESIDUO DI 1000 PH	812.543,36 €	20.372,30 €

Figure 65: Production simulation of 1000 89x89 PHs

The following table summarizes the savings derived from the production of 1, 100, 1000 or 2000 PHs with this new design (figure 66).

N° PH	Actual cost	Cost with new design	Savings €	Actual residual values	New residual values
1	1.737 €	1.386 €	351 €	771 €	485 €
100	173.688 €	92.188 €	81.501 €	77.053 €	2.037 €
1000	1.736.880 €	921.875 €	815.005 €	770.533 €	20.372 €
2000	3.473.760 €	1.843.750 €	1.630.010 €	1.541.067 €	40.745 €
			47%	44%	2%
			% of savings	% of not used plate Old	New

Figure 66: Cost and residual comparison

The purchase costs of raw material would be almost halved (-47%), and the residue would go from 44% of the raw material used to 2%, clearly explaining the perfect exploitation of the virgin plate. But analyzing the situation more in detail, other possible savings/improvements that derive from this solution are evident. Since the cutting times of the frames are not so relevant, and considering also that they are realized on a dedicated machine, they will be not analyzed.

Considering the 4 drilled layers instead, a lot of advantages can derive from a reduction in the necessary loading/unloading operations and an increased autonomy time of the machine.

Figure 67 summarizes the savings in terms of fewer operations required. Two operations are currently required to realize the 4 perforated layers, as mentioned in a few paragraphs above, and the times of these operations have already been discussed and they were around 25 minutes/operation. With the new dimension, the loading requires a single operation of about 30 minutes, gaining about 20 minutes at PH realized. Using 30 €/h as the hourly cost of the workers, for 1000 PHs realized the saving will be of about 10,000 €.

N° PH	Operation actually needed	Operation needed with new design	Savings €
1	2	1	10 €
100	200	100	1.000 €
1000	2000	1000	10.000 €
2000	4000	2000	20.000 €

Figure 67: Savings from operations

Regarding the second advantage that can be pursued, it is easy to imagine how by loading more processes in the same set-up, the machine can work for several hours consecutively without requiring the intervention of any operator. In this particular case, the number of machining operations would be doubled and consequently the autonomy time of the machine would double too. In figure 68, four cases are represented based on the number of holes to be made for each layer to see the time needed by the machine in complete autonomy, based on the data of 2000 holes/hour made by the laser machine.

N° holes	Old autonomy (hours)	New autonomy (hours)
5000	5	10
10000	10	20
15000	15	30
20000	20	40

Figure 68: The increasing of autonomy

The increase in autonomy has numerous consequences that can bring additional hidden advantages, such as better use of night shifts and weekends and a reduction in idle time, thus increasing productivity. These ones and other aspects will be analyzed in more detail later in the next chapter.

The solution of a new design seems to be convenient from innumerable points of view; however, these calculations and simulations do not take into account a difficult realization of this scenario. In fact, according to the opinion of Alessio Guerci, Stefano Lazzari and Valentino Schiariti, the requalification of the product by the customer and the validation phases of the new dimensions are quite complex. Moreover, the customer could request discounts going to cancel or reduce the possible savings. A solution of this type could be advantageous only in the case of a new project when the customer and the Design department of Technoprobe define the characteristics of the Probe Card from scratch.

New Plate Format

The reasoning that must be followed for the optimization of the "98x98" size machining is different from the one just explained, in fact it is unthinkable to reduce the size until reaching the limit value of 89x89mm. The path that must be pursued is relative to a new dimension of raw materials in order to apply more or less the same reasoning seen in the previous chapter.

The new minimum plate size that would allow placing multiple layers for each plate would be 210x210mm. This dimension would become about 200x200mm as it will be reduced at most by about 5 mm per side due to the locking jig. With this remaining effective size, it would be possible to position 4 "98x98" layers, optimizing the use of the plate similarly to as seen for the new design. The decision of the ideal size was made by the team thanks to the advice of Valentino, who knows very well the jigs and the spaces needed between one processing and the other, and also considering that even larger dimensions would have created the risk of flatness problems during processing due to warping, thus compromising the quality of the products.

Also for this improvement, the team calculated the possible benefits, always based on the starting hypotheses established at the beginning of the chapter of the incremental improvements, so based on PHs composed of 8 layers of which 4 perforated layers, 4 frames and with a method machine loading with double position jig.

Just like in the case of the new design, the positioning of 4 layers instead of one for each plate leads to gain in terms of necessary loading/unloading operations and the autonomy of the laser machines. The tables and calculations are the same as those made in the previous chapter, in fact for the realization of a PH with the current format two machine loads are needed each one of 25 minutes, instead with the new format single load is required and it would last 30 minutes, thus saving 20 minutes at PH.

Figure 69 represents the possible savings in monetary terms considering the cost of the operator equal to 30 €/hour. Also concerning the autonomy of the machine, the calculations made for the design are the same, the autonomy is doubled and in figure 70 the processing times are reported based on the holes to be made for each layer.

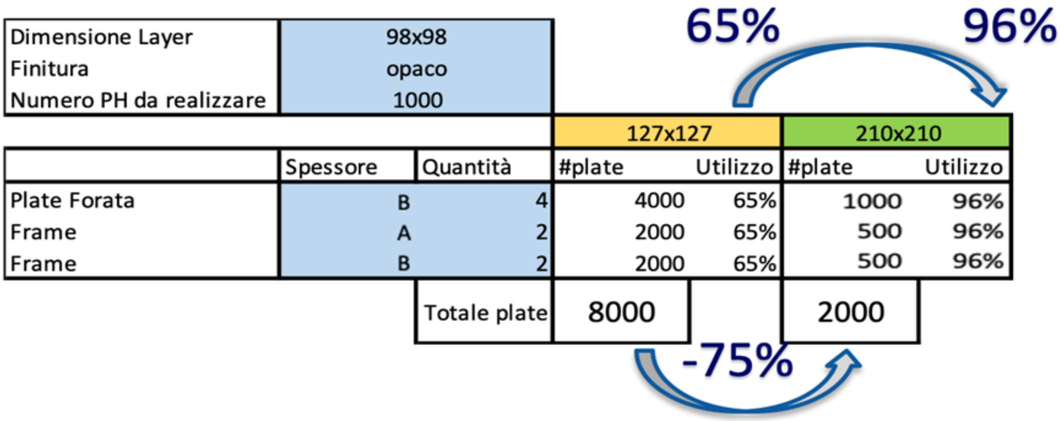
N° PH	Operation actually needed	Operation needed with new design	Savings €
1	2	1	10 €
100	200	100	1.000 €
1000	2000	1000	10.000 €
2000	4000	2000	20.000 €

Figure 69: Savings from operations

N° holes	Old autonomy (hours)	New autonomy (hours)
5000	5	10
10000	10	20
15000	15	30
20000	20	40

Figure 70: The increasing of autonomy

To quantify other additional benefits deriving from this new format, the team simulated production based on the features of Client I's requests. The simulation takes into account the production of 1000 PHs. The team was been able to evaluate 2 initial benefits thanks to the use of the Cost Optimizer. As shown in the simulation in figure 71, the number of "210x210" plates required for the realization of the entire group of projects would be 2000, against the 8000 virgin plates requests using the current 127x127 format, effectively reducing the number of plates to be purchased by 75%. The reduction of the necessary plates implies a simplification of the supply logistics, reducing the necessary incoming operations.



Dimensione Layer	98x98					
Finitura	opaco					
Numero PH da realizzare	1000					
			127x127		210x210	
	Spessore	Quantità	#plate	Utilizzo	#plate	Utilizzo
Plate Forata	B	4	4000	65%	1000	96%
Frame	A	2	2000	65%	500	96%
Frame	B	2	2000	65%	500	96%
		Totale plate	8000		2000	

Figure 71: New format advantages

Always as shown in figure 71, through the use of the Cost Optimizer, the team was also able to analyze the benefits in terms of use of the plate. With the current format, the plate is exploited to 65%, thus creating a significant residue from an economic point of view that is impossible to use for second processes. On the other hand, the new plate makes it possible to reach a utilization of 96%, making the most of the value of the plate.

To also calculate the impact of this improvement from an economic point of view, as the team did not have a list price available for these new dimensions, hypotheses were carried out. These values have been defined by proportionally following the size-price relationship observed in the actual price list. Looking at the increase in terms of dimension between the 127x127 and the 186x186 and the relative increase in economic terms, the team defined the two prices (one for each thickness level) of the 210x210 plates. Figure 72 represents the two scenarios assumed by the team, one optimistic and one pessimistic. For both scenarios, the relative purchase cost of the necessary plates was calculated. The cells highlighted in yellow represent the optimal choice from an economic point of view between the two formats. In the first scenario it can be observed that, due to the high prices, only for the production of A thick frames is convenient to use the new format. The economic advantage derived from processing these frames covers the losses due to a less advantageous price regarding the thickness B. In general, however, the pessimistic scenario would remain convenient in terms of economic savings.

In the most optimistic scenario (in the second table below), on the other hand, the assumed prices make the new format convenient for all processes regardless of thickness.

Finitura	Dimensior	Spessore	Prezzo
opaco	210x210	A	800,00 €
opaco	210x210	B	790,00 €

			127x127		210x210	
	Spessore	Quantità	#plate	prezzo	#plate	prezzo
Plate Forata	B	4	4000	785.920,00 €	1000	790.000,00 €
Frame	A	2	2000	558.000,00 €	500	400.000,00 €
Frame	B	2	2000	392.960,00 €	500	395.000,00 €

Finitura	Dimensior	Spessore	Prezzo
opaco	210x210	A	700,00 €
opaco	210x210	B	680,00 €

			127x127		210x210	
	Spessore	Quantità	#plate	prezzo	#plate	prezzo
Plate Forata	B	4	4000	785.920,00 €	1000	680.000,00 €
Frame	A	2	2000	558.000,00 €	500	350.000,00 €
Frame	B	2	2000	392.960,00 €	500	340.000,00 €

Figure 72: Price scenarios

At this point, the team asked to the purchasing department and more particularly to Dario Calvi and Davide Montini, if it was possible to ask directly to the supplier, what the price of a plate of new size would be, in order to make predictions and calculations more specific and detailed. After about a week a reply arrived and the purchasing department communicated the price quote proposed by the supplier.

The prices defined by the supplier are those shown in figure 73. These prices are much higher than those predicted by the team even in the pessimistic case.

Finitura	Dimensione	Spessore	Prezzo
opaco	210x210	A	1.246,00 €
opaco	210x210	B	1.012,00 €

Figure 73: Official prices

The difference in proportions between the various sizes and the relative prices is illustrated in figure 74 below.

Increase in size → x1.46 x1.12

		127x127	186x186	210x210
Opaco	A	279,00 €	471,55 €	1.246,00 €

Increase in price → x1.69 x2,64

		127x127	186x186	210x210
Opaco	B	196,48 €	457,40 €	1.012,00 €

Increase in price → x2,32 x2,21

Figure 74: Size-price comparison

Analyzing specifically the size-price relationships, it is visible that with an increase of about 150% in size, passing from a 127x127 to a 186x186, the relative price increase is different for the two thicknesses, + 169% for the thickness A and +232 % for thickness B, thus averaging + 200%. As for the new format, the dimensional increase is only 115% while the price increase is + 264% for the A thickness and + 221% for the B, thus increasing on average by + 240%. It is therefore evident that the price has been excessively increased at a minimum increase in size.

Immediate explanations were then requested from the supplier who explained the reasons for such a high price, based on much higher cutting and lapping times for the requested plates, the need for specific and dedicated machinery and above all as based on a possible sampling of a few pieces requested by Technoprobe.

Following these statements, the team began to calculate the new benefits in economic terms based on these new prices, but soon they realized that the main economic gain on the purchase of plates was no longer reachable due to the too high prices. For this reason, the team, first of all, concentrated on calculating specifically all the hidden benefits deriving from the use of this new format, also in economic terms; secondly, thanks to an analysis of the discounts that took place over the years following the increase in the 127x127 plates requested, the team hypothesized two levels of discounts on the price of the 210x210 plates and they calculated all the benefits based on this discount.

As highlighted by the Cost Optimizer, still set on the 1000 PHs defined for the execution of the simulations (figure 75), the new costs inserted cause an increase in the purchase cost of the 2000 210x210 plates, spending 2,141,000 €, against only 1,736,880 € necessary for the purchase of the current 8000 virgin plates 127x127.

Dimensione Layer	98x98
Finitura	opaco
Numero PH	1000

				127x127				186x186				210x210			
	Spessore	Quantità	Tot	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo
Plate Forata	B	4	4000	4000	785.920,00 €	65%	278.799,89 €	4000	1.829.600,00 €	30%	1.287.270,42 €	1000	1.012.000,00 €	96%	40.075,20 €
Frame	A	2	2000	2000	558.000,00 €	65%	197.946,79 €	2000	943.100,00 €	30%	663.546,53 €	500	623.000,00 €	96%	24.670,80 €
Frame	B	2	2000	2000	392.960,00 €	65%	139.399,95 €	2000	914.800,00 €	30%	643.635,21 €	500	506.000,00 €	96%	20.037,60 €

	127x127	186x186	210x210
COSTO DI 1000 PH	1.736.880,00 €	3.687.500,00 €	2.141.000,00 €
RESIDUO DI 1000 PH	616.146,63 €	2.594.452,16 €	84.783,60 €

Figure 75: Cost Optimizer updated with official prices of 210x210 plates

The only positive note that can be found in this table is the clear improvement in the use that can be pursued with the new format. As previously explained, a usage of 96% would be achieved against the current 65%, allowing to have as waste material with a value of only about 84,000 €, against the over 600,000 € deriving from the current format.

The team, therefore, researched how these residues could impact the benefits deriving from this new format. Starting from the assumption that both residues are to be considered as waste since even the processing of a "98x98" on a 127x127 creates an "L" shaped residue that cannot be used for future processing, the team wanted to investigate the cost of disposal of these particular materials.

First of all, the team calculated the weight in grams of the single virgin plate of the new format, thus establishing the price per gram. Later, being aware of the economic quantity of the waste, the team calculated the grams and subsequently the kg of waste material to be disposed of, obtaining the result of less than 10 kg of ceramic to be disposed of every 1000 PHs made. The same reasoning was followed for the calculation of the kg of material to be discarded following the production with the current format, and the result is considerably higher reaching over 40kg of material every 1000 PHs. By asking the company's EHS Department for the cost of disposing of this material, the team learned that the cost is less than 1 €/kg of material to be disposed of, making the resulting savings completely negligible.

The other aspect to be considered related to residues is the possibility of re-selling these to third parties or directly to the supplier to recover part of the costs. This would be a scenario that would go even further against the purchase of the new format, as the residue with the current format is very high and it would therefore allow a greater advantage to be taken from the re-sale. Through Dario Calvi and Davide Montini, it was possible to ask if the supplier was somehow interested in the waste material. Unfortunately, the supplier's response did not meet the team's expectations, in fact the supplier communicated that the residues are in no way re-usable and therefore there is no interest in buying them back.

Faced with this problem from the current purchase price of the plates, the team wanted to quantify each benefit in economic terms in order to have a final account of the convenience/inconvenience of this new format. Below it will be explained step by step the reasoning followed by the team and which allowed reaching the final conclusions.

First, the team decided to no longer rely on a simulation of 1000 PHs but to use more realistic data expected for 2021 to adjust and to be as precise as possible in the computation of the calculations. The request considered is 4000 PHs, which will be of "98x98" size with the composition already described above. The additional information and hypothesis to take into consideration are the number of average holes per layer required, which will be around 7000, and the productivity index, increased from the current 0.55 to the value of 0.7. This value is considered achievable thanks to the benefits explained above, relating to the halving of the necessary set-ups and the consequent doubling of the autonomy of the machines. Especially if exploited on weekends and during night shifts, these two factors can bring great advantages by considerably reducing the idle times of the machine, allowing to reach significantly higher productivity values.

Figure 76 shows the result of the Cost Optimizer based on new PHs' hypothesized demand.

Dimensione Layer	98x98
Finitura	opaco
Numero PH	4000

				127x127				186x186				210x210			
	Spessore	Quantità	Tot	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo	#plate	prezzo	Utilizzo	Residuo
Plate Forata	B	4	16000	16000	3.143.680,00 €	65%	1.115.199,57 €	16000	7.318.400,00 €	30%	5.149.081,68 €	4000	4.048.000,00 €	96%	160.300,80 €
Frame	A	2	8000	8000	2.232.000,00 €	65%	791.787,15 €	8000	3.772.400,00 €	30%	2.654.186,12 €	2000	2.492.000,00 €	96%	98.683,20 €
Frame	B	2	8000	8000	1.571.840,00 €	65%	557.599,79 €	8000	3.659.200,00 €	30%	2.574.540,84 €	2000	2.024.000,00 €	96%	80.150,40 €

	127x127	186x186	210x210
COSTO DI 4000 PH	6.947.520,00 €	14.750.000,00 €	8.564.000,00 €
RESIDUO DI 4000 PH	2.464.586,51 €	10.377.808,64 €	339.134,40 €

Figure 76: Cost Optimizer based on 4000 PHs

Based on the 2020's requests of "98x98" size for the customer I, the team calculated the number of PHs requests per month and therefore per week. They calculated the number of needles needed considering that each layer has about 7000 holes and multiplying by 4, obtaining the number of holes to be made per week (each probe pass through 4 perforated layers). Knowing that each machine makes 2000 holes/hour, the team has calculated the number of machine-hours needed per week to make the calculated number of holes. Each machine has a total of 168 theoretical hours per week

(24 h/day x 7 days/week, as the company works on three shifts and also on weekends) which multiplied by the productivity of 55% allows calculating the number of laser machines needed to cover the machine hours needed per week. Thanks to this series of calculations, the team has established that currently 4 machines are dedicated for the realization of the products of customer I. Following the same reasoning but considering the 2021 demand of 4000 PHs and the productivity achievable with the current format (55%), 13 lasers dedicated to customer I are needed, 9 more than this year. From the same calculation made with the productivity achievable with the new format (70%), it appears that only 10 lasers are needed, 6 more than in today's situation. All these calculations do not consider possible changes in the demand of other customers, and therefore considering all the other lasers in the department already occupied and not dedicated in the future to customer I.

The number of laser machines to be purchased to meet the new demand in the two cases of format used is shown in figure 77.

	Formato 127x127 (actual)	Formato 210x210 (new)
Productivity	***55%***	***70%***
New operators	***12***	***5***
New laser needed	***9***	***6***

Figure 77: Projections of needed operators and machines

The same table also highlights the operators who will need to be hired for the correct operation of the machines and the department in both cases. Currently it is considered to have an operator for each machine in the department, so as regards the production scenario with the 127x127, it has been calculated that buying 9 new lasers will need 9 new operators; in addition, given the huge amount of incoming material, to facilitate incoming and warehouse logistics, it will be necessary to hire 3 other people dedicated to those activities, to deal with the 32,000 plates purchased (in the scenario of 1000 PHs were needed 8000 plates, in the new scenario of 4000 PHs the plates needed are 32,000). In the case of the new format, on the other hand, the higher machines autonomy would make it possible to reduce the number of operators required to 5 instead of 6 and no more incoming operators are needed to manage the 8000 plates purchased (more or less the same number of plates actually managed).

All these calculations and the previous benefits are shown in monetary terms in the following table (figures 78):

		New 210x210 format		
	127x127 format	**full price**	**price discounted by 5%**	**price discounted by 20%**
PH Required	4000	4000	4000	4000
Necessary plates	32000	8000	8000	8000
Purchase cost	6.947.520,00 €	8.564.000,00 €	8.135.800,00 €	6.851.200,00 €
Operations cost	100.000,00 €	60.000,00 €	60.000,00 €	60.000,00 €
New laser needed	9	6	6	6
New laser cost	2.250.000,00 €	1.500.000,00 €	1.500.000,00 €	1.500.000,00 €
New workers cost	748.800,00 €	312.000,00 €	312.000,00 €	312.000,00 €
Total	10.046.320,00 €	10.436.000,00 €	10.007.800,00 €	8.723.200,00 €
Revenues / losses related to a productivity of 70%		**-389.680,00 €**	**38.520,00 €**	**1.323.120,00 €**

Figure 78: Final resume of the benefits

For both formats the following data are indicated: the requested plates, the actual purchase cost based on the price per plate, the cost of the set-up operations (which as shown a few paragraphs ago led to a saving of 10,000 € every 1000 PHs realized and in fact it can be noted that on 4000 PHs the difference between the two formats is 40,000 €), the new machines need with the relative cost (each machine costs about 250,000 €) and the cost of the new operators required. In the end, adding all the costs, despite the many benefits introduced, the currently even more convenient solution is that of the 127x127 format.

From the analysis of the discounts on the 127x127 mentioned previously, the team chose to first identify the percentage discount on the price per plate that would allow for profits, and secondly to calculate how much the benefit would be by reaching a larger discount of 20%. In the rightmost columns of figure 78 are described the result of such discounts. As shown in the table, all the items relating to the benefits of the 210x210 plate remain unchanged, only the purchase cost decreases with the discounts applied to the raw materials purchased. From a 5% discount onwards, the company would benefit greatly from the new format.

This new format was well received by the company despite the momentary economic disadvantage that derives from it, and in fact the purchasing department immediately became interested and carried out an order for the purchase of a sample to be tested. The qualification process is in fact of fundamental importance, through it, it is attested the ability to produce even on large material such as 210x210 layer in compliance with the technical specifications. If the specifications are met and there are no flatness and warping problems, production on the new plates will be approved and a larger order can be placed. In the case of larger orders, the team expects that the supplier will offer high discounts as they will be able to invest in machinery for a long-term supply with Technoprobe, and therefore they can amortize costs and grant a more accessible purchase price, allowing the company to achieve the exceptional savings highlighted in this chapter.

Unfortunately, the team will not be able to see this format implemented during this internship, as the order will take months to arrive and therefore the analysis was carried out only on the scenarios and simulations described previously. The team is however very optimistic believing that the calculations made are reliable, and therefore they hope that in the future the company will be able to rely on this new format for large-scale production.

COUNTERMEASURE IMPLEMENTATION

After defining the countermeasures to be applied to improve the process and verifying all the theoretical impacts of them, the next step is the implementation of these changes. This phase of the process is very delicate as it is first of all necessary to cancel any resistance to change as previously explained in the paragraph of the “Change Management”.

To make a change, it is in fact necessary to act both on the pushes to change and on the resistance to change in order to break the organizational balance in which the process currently finds itself and allows the organization to change. In particular, the team together with the management will have to act by emphasizing the pushes to change and by adopting actions that reduce resistance. In this regard, confrontation with operators will be fundamental, disavowing the current way of operating, making the effects of recurring problems evident, together with emphasizing the benefits of the new way of operating will be fundamental. In fact, it is very powerful to illustrate the advantages that can derive not only for the company but also for the staff, especially emphasizing the effects on the organizational climate and on the way of operating every day. With the improvements proposed by the team the operators will have a procedure to follow that will not only speed up some operations, but it will also limit the probability of making mistakes in the selection of the plate or in the positioning of the machining. Once awareness of the effectiveness of the change was spread, the team took steps to implement the countermeasures in practice.

To make both Excel programs usable by all operators, the team decided to install these programs inside a computer to be positioned next to the warehouse within the department. In the beginning, a computer already present in the department was used, waiting for the company to order a new dedicated PC for these programs.

This position is strategic as it is necessary to pass through the warehouse both in the plate selection operation and in the storage operation of the residues still usable after the first processing (figure 78).

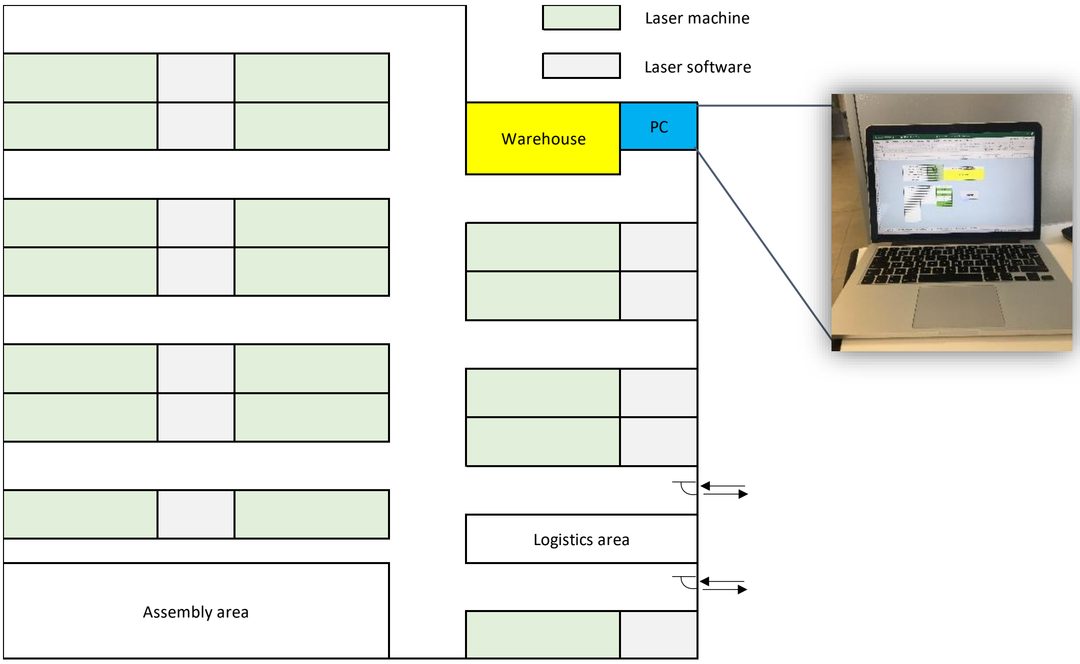


Figure 78: Countermeasure localization

During the development months of this project the team developed and subsequently tested two versions of the Cost Optimizer and one of the Residual Classifier, these processes were carried out in parallel starting in June 2020 and ending with the definition of the final version of both programs fully functional at the end of August 2020. Then, starting from September, the implementation phases in the department began, loading the programs first on a computer already present near the warehouse and then on a dedicated computer. As regards the re-organization of the warehouse, the implementation times were short, in fact only the storage method was changed, reorganizing the drawers with the relative labels that indicated the new division. This re-organization will be possible once the database of the "Residual Classifier" will begin to present a consistent number of plates to be stored with the new arrangement. The studies on the new design and the new format were simulated in the months of June/July and are still being evaluated by the management for a possible future implementation.

The schedule of the implementation of countermeasures and the current status are represented in figure 79.

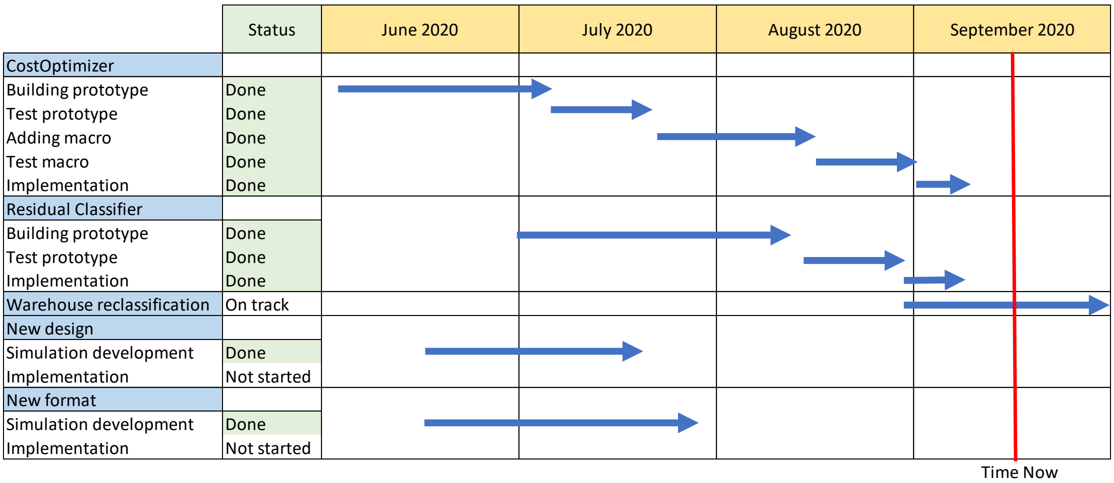


Figure 79: Status and scheduling of the implementation of the countermeasures

The Cost Optimizer was immediately available to everyone and it is usually used in the planning phase of production when a new project arrives to balance the workload based on the optimal plate format.

Regarding the Residual Classifier, initially, the program was used by a single operator, with greater experience, in order to check whether it was too time-consuming for the operators to use; once tested, the team updated the database with the information of the plates already in stock and they made it available to all operators. This program is used in the very first steps of the production process, when the operator takes the runsheet containing all the necessary information to be entered. This will optimize the operator's path and the future plate characteristics after machining are stored in the database. This choice of archiving the data in advance is due to the length of the drilling process, which often leads to the involvement of different operators for the loading and unloading operations. In fact, in most cases all the information necessary for the correct compilation of the database is not easily available during the unloading phase.

The programs were adjusted and corrected immediately during the first use thanks to the feedback of the operators, making them more comfortable and easier to use.

CONCLUSIONS

FUTURE STEPS

The countermeasures conceived by the team during this internship were implemented with fairly simple programs and software such as Excel and Visual Basic, which however allow a very wide and flexible range of applications in the field of calculation. Basing almost entirely on these programs and, in particular, thanks to macros that they allow to create, the team was able to realize the programs described above, called Cost Optimizer and Residual Classifier which with the insertion of a few data allows the operator to obtain as output a lot of information in an almost completely automated way. Although these programs work, they can undoubtedly be increased and improved over time thanks to the corrections that operators would recommend while using them, but also through the introduction of more specific management programs. There are management systems that unfortunately are not in the team's competences that could manage all the information contained in the Cost Optimizer and the Residual Classifier much better. In particular, the database that contains all the information of the already processed plates could be managed more safely and would be more easily manageable according to the needs; it would be available to multiple departments simultaneously, facilitating communication and sharing important information. Another advantage that would derive from the introduction of a management program would be the possibility to update prices and dimensions of plates and processes to be carried out more quickly and concisely, without having to modify the Excel program each time to make it functional again.

Closely connected to this purely technological aspect there is the idea of the electronic runsheet which was carried out by another team within Technoprobe. If the introduction of the electronic runsheet were possible, the team's countermeasures would also benefit from it. In fact, they could be used directly during the generation of the runsheet, adding some items and information useful to the operator. The operators would no longer have to go to the computer and enter the data to know how to proceed with the processing and how to storage the plates used in the warehouse but they would already find all the information on the runsheet, thus speeding up execution times and simplifying the procedures.

According to the team, a particularly interesting idea of a future step came from the observations and studies carried out on the new format of usable plates. As described in detail in this report, larger plate sizes would allow the optimization of many processes, but sometimes the too high price of these new plate sizes does not make the implementation of these orders profitable. The high prices are the consequence of a lack of interest of the supplier in contracting with Technoprobe, as the requested products do not represent the core business of them. The idea would be to bring the production process of plates inside the company, making the process more vertically integrated. This opportunity should be carefully studied as the necessary investment would be high, but the benefits that derived from it would be many. Currently the main problems with this supply strategy are lack of variety of virgin plates that can be used, long waiting times and unfavorable conditions for the introduction of new formats. Internal production would allow creating the most suitable dimensions for production, also adapting to the trend of demand, delivery times would be much faster and more flexible, and new dimensions could be designed and tested in a shorter time, allowing to maintain excellent levels in the degree of process's optimization.

FINAL CONSIDERATIONS

At the end of this path, it is necessary to thank all those who made this experience possible. On the one hand, the academic team of the Politecnico, including Professor Alberto Portioli Staudacher and our tutor Federica Costa, who have allowed us to live this opportunity to the fullest despite the difficulties due to the well-known events that have occurred in recent months and have supported us all along the way. This was an unmissable opportunity for us to be able to concretely apply all the teachings learned in this academic path.

On the other hand, necessary thanks to Technoprobe S.p.a and the Crippa family for the opportunity granted us to become part of one of the best manufacturing companies in Italy. Special thanks to the COO Alessio Guerci, to the Consultant in support of Operations in the implementation of processes Stefano Lazzari and to the WW Manufacturing Director Paolo Anghilieri who were immediately available to discuss and support our ideas, demonstrating how widespread the culture of continuous

improvement is within the company. We thank especially the Area Manager of the PH FE Department Valentino Schiariti for his availability and the constant support in these months in the company, probably without him this experience would not have been so positive and rich in teaching.

It was a unique opportunity that we hope to have made the most of despite some difficulties encountered, mainly related to the tight deadlines reserved for the development of this project and the constant changes that the company faces to support an ever-increasing demand. We will certainly treasure this experience and start building our working lives on it.

At the end of these months, we bring home not only the awareness of the potential of our ideas and our creativity but also the personal growth due to the improvement of some soft skills, including the relationship with people of different roles and the public speaking.

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