# POLITECNICO DI MILANO

School of Industrial and Information Engineering Department of Management, Economics, and Industrial Engineering



## Master Thesis

## "Inefficiencies reduction in the Probe Head Productive Unit of Technoprobe"

Authors:

## HUSEYNLI GULNAR - 941342

BUSCAROLI ALESSANDRO - 947959

Supervisor: Alberto Portioli Staudacher Co-Supervisor: Ing. PhD Federica Costa

Academic Year 2020-2021

### Contents

Preface
Abstract
Semiconductor industry
Company Overview
Probe Card11
A3 Thinking
Productive Process
Laser processes
Manual processes in the department 20
A3 Framework
Problem Background22
Problem Breakdown24
Movements
Gluing inefficiency
Sandwich inefficiency
Idle time
Rework
TARGET
Gluing inefficiency
Sandwich inefficiency
Rework
Idle Time
Root cause analysis
The 5 Why's method
Management Type: Incremental Vs Radical Innovation46
Develop Countermeasures
Incremental Countermeasures
Rework Identification Tool
Laser Optimizer
New Gluing Workstation56
Radical Countermeasures
Final Washing Defect Identifier

New Layout of the Department
Implement Countermeasures
Rework Identification Tool72
Laser Optimizer Macro73
New Layout of the Department74
MONITOR RESULTS AND PROCESS77
Rework Identification Tool79
Laser Optimizer Macro81
New Gluing Workstation82
Defect Identifier
Standardize And Future Considerations83
Rework Identification Tool
Laser Optimizer Macro
New Gluing Workstation
Layout change consideration
Defect Identifier
Overview of Final Results
Conclusion
A3 89
Experience
References

Figure 1 Global semiconductor market	6
Figure 2 Sales in billion	7
Figure 3McKinsey prediction image 2021	7
Figure 4 Tecnoprobe in world	9
Figure 5 Technoprobe revenue chart	10
Figure 6 PDCA cycle developed by Deming (1990-1993)	16
Figure 7 A3 thinking template	17
Figure 8 Fundamental of GEMBA: Observe, Recognize and Communicate	24
Figure 9 Spaghetti Chart PH Front End Department	26
Figure 10 As-is Gluing Workstation Spaghetti	
Figure 11 Value Stream Map of the department	31
Figure 12 Pareto for technology	
Figure 13Technology variation monthly	34
Figure 14 Causes of Rework	35

Figure 15 Ishikawa diagram	
Figure 16 Different causes of rework	
Figure 18 Example of Excel sheet	
Figure 17 Main Window of the Tool	
Figure 19 Dashboard	
Figure 20 First version of the Tool	50
Figure 21 Message box of the program	51
Figure 22 Technical characteristics of the machine	51
Figure 23 Power Selection of machines, Actual Performance	52
Figure 24 All excels in one	
Figure 25 Final outcome	53
Figure 26 Case 1	54
Figure 27 Actual production sheet	56
Figure 28 Suggested hypotheses	57
Figure 29 Defect types	59
Figure 30 Defect Identifier Main Window	60
Figure 31 Examples of some selections	61
Figure 32 Email example	61
Figure 33 Actual layout configuration	62
Figure 34 Aldep relationships	67
Figure 35 Implementation of Tool	72
Figure 36 Manual for Macro	73
Figure 37 New addition to macro	74
Figure 38 Spaghetti Chart to be layout	76
Figure 41 New workstation for Gluing	85
Table 1 As-is Gluing Workstation Activities	29
Table 2 Sandwich VA & NVA time	
Table 3 Idle time no product	
Table 4 Rework numbers	35
Table 5 Impacts of each problem on LT	

Table 5 Impacts of each problem on LT	37
Table 6 Targets for each problem	
Table 7 Hypothesis descriptions	57
Table 8 Hypothesis 1 cost	58
Table 9 Hypothesis 2 cost	58
Table 10 Registered excel sheet	79
Table 11 Overall results of Tool	80
Table 12 Gluing final calculations	

## Preface

We are two students attending the Master of Science in Industrial Management track of Management Engineering at Politecnico di Milano.

This Thesis comes with full sphere of our experience at University, introducing us to the labor market for which we have been assigned to a company and a specific project.

We carried out this project in Technoprobe, a multinational company operating in the semiconductor industry, Probe Cards being the final product of the company.

The project is the result of 550 hours of work in the Company some parts being carried out remotely because of the ongoing pandemic.

In the development of the Thesis, we capitalize on the help of our Company Tutor Diego Fumagalli, our Methodological Tutor Federica Costa, and our Professor Alberto Portioli Staudacher. We thank them for the knowledge and availability they have provided to us and for the eagerness and willingness they have shown towards us over the period of the project.

Furthermore, we thank our families for their endless support both moral and economic, which allowed us to study and get to this point.

Finally, we thank everyone who were there for us in the difficult and sometimes pressured times within the duration of whole project.

Gulnar Huseynli

X

Alessandro Buscaroli

## Abstract

The thesis aims to describe the path that our team has completed over the last few months to carry out a project that is about using the tools and theoretical knowledge that we obtained during our master studies in Industrial Management/Management Engineering at Politecnico di Milano. In particular it regards the application of Lean principles to reduce the inefficiencies in the "Probe Head Productive Unit" in Technoprobe.

We held the kick-off meeting on 28<sup>th</sup> of October; due to the pandemic we have started a month later after attending the training in all the departments alternately. We finished the project on 26<sup>th</sup> of February.

To develop the project, we exploited the A3 Thinking, Microsoft Excel, Visual Basic, Windows Presentation Foundation, Value Stream Map, Gemba Walk, Pareto Analysis, Minitab, Variability Analysis, expertise of the company and methodological tutor, professor of the Industrial Management course and eventually the knowledge and experience of the operators in the Probe Head Front End department.

The project is developed in the A3 framework structure.

The result is a reduction of lead time by 3.18% and labor cost reduction of  $101,000 \in$  in a year considering only the incremental countermeasures, while these numbers are expected to become a lot more after the implementation and continuous usage of the radical countermeasures as one of them is a structural change that will need rather considerable amount of investment.

The company tutor and head of the department was very happy with the results since the countermeasures introduced have been considered quite useful for their day-to-day operations. Apart from these, it is noteworthy to mention that through the regular implementation of the tools Technoprobe will be able to win more customer orders since the tools will help to reduce the possible delays and problems in the production.

## Semiconductor industry

The field in which Technoprobe has to compete is wide and highly variable. Semiconductor industry took advantages of a world phenomenon that include the utilization of electronic equipment and technological instruments as Artificial Intelligence, Machine Learning and Internet of things that are in exponential growth.

The graphs below show the continuous improvement and expansion of the semiconductor market, demonstrating the incredible importance it has assumed over the years with the advancement of technology. As anticipated, it is possible to see how it has increased considerably from 2017 in the following years.



Figure 1 Global semiconductor market

Semiconductor companies play a primary role in the development and research of new technologies, field of utilization are numerous, all characteristics suited to attracting investment. Figure 2 shows the billions of sales of the major players in the semiconductor field in recent years in order to understand how the market share varies in different years.

÷	Intel (U.S.)	Samsung (South 🗘 Korea)	TSMC (Taiwan)* <sup>‡</sup>	SK Hynix (South Korea)	Micron (U.S.)	Qualcomm <sub>\$\overline{T}}</sub> (U.S.)**
2012	49.11	32.25	16.95	9.06	8	13.18
2013	48.32	33.59	19.8	13.04	10.55	17.15
2014	51.4	37.81	24.98	16.29	16.72	19.29
2015	52.14	42.04	26.44	16.65	14.48	16.01
2016	56.31	43.54	29.32	14.23	12.84	15.44
2017	61.72	65.88	26.72	8.31	32.16	17.8
2018	69.9	78.5	34.2	36.8	31	16.4
2019	70.8	55.71	34.67	23.19	22.41	14.39
2020	73.89	60.48	45.42	26.47	21.66	19.37

#### Figure 2 Sales in billion

As we can see from these numbers representing the sales of the major players in the semiconductor market, the environment is highly unstable. Even industry giants such as Samsung recorded a decrement in sales from 78 billion in 2018 up to 55 billion in 2019. The changes are difficult to predict and so some companies, like in this case, lose market share for not being quick in the change, remaining on market sectors generating less sales.



Figure 3McKinsey prediction image 2021

These variations are determined by global technological changes, as in the case of the personal computer which in recent years has recorded a decline in favor of other products such as smartphones, tablets, smart TVs, and automotive devices. For example, the automotive sector (where growth from 28 to 36 per cent is expected for 2021) are favored as the government will incentivize the purchase of cars, as in the case for example of electric cars.

The criticality for these companies lies in the fact that they compete in increasing number of sectors and what is required is not only a greater production capacity to meet the demand but at the same time also a certain technological advancement to remain in the market. In this perspective for example characteristics important for the chip correspond to size and performance. A constant evaluation of the investments is a fundamental aspect for these companies because increasing capacity requires investments as it happens for interventions that are required in the different steps of the supply chain.

## **Company Overview**

Technoprobe is a leading company in the semiconductor industry providing the most advanced wafer testing solutions. The company manufactures leading-edge wafer probe cards offering design and development.

Technoprobe was born in a small garage in 1993 in Merate near Milan, Italy. Their vice president in one of his interviews said that in the garage they had installed a cutter, a welder, two microscopes and a small oven for heat treatments, all of them being recycled equipment and have been recovered from the other companies without being charged. They started to make their first products - electronic boards which was quite simple compared to today's sophisticated ones. He also said that his dad, suffering from insomnia, spent nights in the garage designing and making these cards with a passion. Afterwards some collaborators and employees arrived. After some time while they were growing, in 1999 they decided to buy a shed of nearly 1000 square meters in Cernusco, near Lecco. Therefore, Technoprobe evolved to be one of the major players in the industry working for the high-tech giants.



Figure 4 Tecnoprobe in world

Nowadays Technoprobe is operating in many countries worldwide. In 2001 Technoprobe has opened its first expansion outside Italy, Technoprobe France located in Rousset (Provence, South France). Then in 2002 taking the opportunity formed in Asia Pacific region, being strategically important for the microelectronic industry it launched its expansion in Singapore, which was the second largest Technoprobe site with 120 employees at the end of 2019.

In 2007 Technoprobe introduced first Vertical MEMS technology Probe Head ever sold to the market and it has been awarded for "Most Innovative Technology" at Semiconductor Wafer Test Conference in San Diego as they presented a revolutionary manufacturing approach for Probe Head construction, based on MEMS needles assembled in a vertical configuration. Later, the year 2008 had been especially successful year for Technoprobe as they expanded into United States which is the primary market for technological research and development. Not to mention all, Technoprobe followed a quite successful path throughout the years and has been astonishingly achieved a number of milestones; recent this year, in 2020, it has inaugurated its China Center to service the world's biggest market by providing local support. In the same year Technoprobe jumped to be 2<sup>nd</sup> worldwide probe card manufacturer with an annual revenue of USD 264M and 1000 employees.

Looking at its revenue chart illustrated, we can observe its huge success throughout the years by increasing its revenue every year. In 2017 Technoprobe becomes the 3<sup>rd</sup> largest probe card manufacturer worldwide with an annual revenue of USD 180M. Eventually, in 2020 it has skyrocketed to its highest



value raising the company's ranking to the second place among the probe card manufacturers worldwide.

#### **Technoprobe Highlights**

- Technoprobe nowadays has 850 employees worldwide, 650 of them being in Italy which is the headquarters.
- Technoprobe has planned an investment of more than 100M Euros in the period of 2019/20
- It has 500+ active patents, about 40 new deposits per year.
- Company has been awarded several times with:
  - o Industrial Felix
  - Financial Attractiveness
  - o Best Semiconductor Test Supplier
- Technoprobe serves many companies most of them being the high-tech giants



Looking at Technoprobe's values and its business strategy it is undeniable that customer satisfaction and product quality are at the center of their operations. We have made a small research and found an approval of Technoprobe's customer satisfaction which is embedded in high quality according to VSLI Research Inc. They also claim that Technoprobe's customers reveal high levels of support and trust with growing market share. Customer's honor Technoprobe with 5 VLSI Stars

according to VLSI research made in 2020. It has obtained exceptional 9.9 points out of 10 in the Field Engineering Support rating.

Technoprobe has carried out some diversification and expansion strategies as well. First of all, in 2017 it acquired DA-TOR for 18M Euros which is the Italian company specialized in manufacturing fittings and nuts for the automotive industry. Later, in April 2019 it has signed a definitive agreement to acquire Microfabrica Inc for USD 100M. M&A deal with Microfabrica Inc. being the leader in high-volume production, microscale additive manufacturing marked a strategic step in Technoprobe's growth plans according to the CEO Stefano Felici. He also said: "As technological leaders in our fields, joining forces will accelerate both organizations' development efforts, so we can launch a variety of breakthrough products aimed at the SOC and memory market segments. Our plan to further invest in Microfabrica will help the company expand its capabilities and achieve its global market potential."

Taking a glance at the company's management system we can also see that they place a huge importance in respect, protection, and improvement of the environment in which it operates as a part of their business responsibility. All the operating processes and facilities are constantly reexamined to identify all possible improvements that would reduce environmental impact.

Just as importantly, Technoprobe perceives the significance of its role in the community and hence is committed to development of charitable projects.

## Probe Card

A probe card is a device used for electrical testing of a large-scale integrated circuit chip on a wafer test system, verifying chip functionality. In order to understand the possible utilization of the PCs, it is better to explain some essential phases of the chip process. Chip production is divided in 2 steps:

- Construction of a multi-layer silicon wafer chip where all the chips are together
- Chip cutting and consequent packaging

Also, the testing phase, as in the case of production is divided into two stages:

- A first test is performed when the chip is not separated, and chip is still on the silicon wafer.
   In this case an electrical impulse is given, and you check how it responds.
- A second step when the chip is already assembled.

Considering these two phases, the probe card is used to control and test the chip when are still at the wafer level, so the first type of test.

The wafer test system is made by 3 different parts:

- The **prober**, this disposal has the task of moving the structural wafer and brings it into contact with the probe card.
- The **probe card**, that is electrically connect to the chip is positioned on the wafer that change many times the position in order to test all chips. The number of chips tested in a given time interval will depend on the type of probe cart used and characteristics of the chip as the technology and size.
- The **tester**, that is connected with a computer and a software that is used to do the different test routine depending on the type of chip.



The probe cards must be very resistant; in fact they can work from -40 degrees up to 200 degrees and must also guarantee the customer one million touches, i.e., contacts with the wafer.

#### Typology of probe card

The main typology of probe cards produced by the company corresponds to:

#### Cantilever probe card composed by:

- Main PCB
- Mechanics that uses a spider that is directly soldered in the main PCB



This solution responds to the need of the semiconductor market that requires a more performing product with reduced dimensions and it is less affected by the high variations in temperature during the tests.

#### Vertical Probe Card is composed by:

- Probe head
- PCB
- Interconnection



In this solution having short needles and vertical contact with the wafer, this type of probe card is used to test very small chips and its sensitivity is more suitable for the measurement of small pads and high frequency devices. The interconnections can be of different types according to the needs and the types of chips to be tested, so they can be customized according to the customer's requests.

In general, there are 5 main types of interconnections:

- Space transformer
- Interposer
- Hybrid interposer
- Direct attach
- MLO/MLC

The probe card market now corresponds to a mature market, therefore new entrants are struggling to overtake companies that have been operating in the sector for some time both in terms of design and reputation. In a general perspective, the major drivers for this market that lead to growth perspectives is an increasing demand in integrated circuit market that correspond directly to an increase in the wafer size, in order to test more products at the same time.

#### **Probe head**

The probe head is the part that remains more external in the probe card, the one that goes to contact the chip directly. The probe head is very delicate and requires attention in handling and exposing critical temperatures. The material is a ceramic layer, but inside the probe head also metal parts (housing) and spacer frames are positioned between layers. This is because the probe head must have certain dimensions and weight, so it is not possible to fill the entire volume of ceramic layers.



In the department all these processes are carried out with a margin of error at the micron level, which is why the machines present in the department are highly precise and operators are highly specialized. Represented here the internal structure of a probe head, including components just mentioned.



As it can be seen from the figure, precision is highly important because the needle must be inserted manually or automatically inside, so the holes must have the right trajectory for the insertion. An important thing to take into consideration is the fact that within the company not all needles are inserted in the probe head back-end department, most needles are assembled directly by the end customer once the probe head is received.

## A3 Thinking

The project of Industrial Management Lab focuses on the Probe Head Front End department, following the company direction that has already approached the lean direction. Under this perspective the project to which we are assigned has been addressed following the A3 thinking. The A3 thinking is a methodology used in companies to support problem setting and problem solving. It underlies the basis of the lean methodology and its popularity made it even today one of the most widely used methods. Focusing on the method, the robustness of it is given by the fact that its output is objective and rational, so it is possible to share results and interpretations among people affected, without the influence of who wrote it and with no risk of misinterpretation.

The reason behind this fact stays within the approach, the method is profoundly scientific because it is based on direct observations and data collected on the field to understand the problem addressed, with the help of visual charts and tools, for the purpose of developing countermeasures with solid foundations. The A3 takes inspiration from the previous PDCA cycle that shares the idea of the continuous improvement of the processes following this cycle.



*Figure 6 PDCA cycle developed by Deming* (1990-1993)

The model is based on the essential phases of:

- Plan: in this phase you have to understand the nature of the problem, understand which resources you have and what it is needed in order to solve the problem. It corresponds to a critic phase because it requires the involvement of people with different roles in the department. Because usually problems comprise processes that require technical knowledge, people that it is more dedicated to a specific phase is also more aware of the problematic that are addressed daily.
- Do: this is the phase to put in practice what has been defined in the plan phase, sometimes something unconsidered can occur for this reason an implementation in a small environment is in some case preferable, where you can better control the different variable. In fact, it is the phase where you can practice the method and make adjustments where needed and also measure the response variables of the action taken.
- *Check:* this is the phase where you have to check the result achieved in the previous phase, understanding what is working and what's need some corrective action.
- *Act:* this is the final phase, if everything seems correctly developed in this phase it is required to implement the solution but the important aspect to keep in mind is that it is not a point of end, but the improved process becomes the starting point for new actions.

The PDCA cycle is just the logic that stands behind the A3 thinking because the sections of A3 thinking are:

- 1. Problem background
- 2. Problem background-current situation
- 3. Target
- 4. Analysis of Root Causes
- 5. Develop Countermeasures
- 6. Implement Countermeasures
- 7. Monitor Result and Process
- 8. Standardize and Share Success



Figure 7 A3 thinking template

The important elements that are part of A3 thinking are:

- 1. *Logical Thinking Process*, it promotes the way of thinking typical of scientific approach, it requires to not jump to the solution driven by intuition but to think in a cause-effect logic.
- 2. *Objectivity*, the process has to be supported by data, take measure on site when it is required and understanding through analysis quantitative data, in few words, it is required to be more objective as possible.
- 3. *Result and Process*, the focus of the A3 thinking embodies also the process followed not only the result, in order to have a more schematic setting in solving actual problem. In this

way paying attention to the process, allow to avoid the risk of facing similar problems again in future.

- 4. *Synthesis, Visual, Distillation* the graphical communication and the utilization of visual tool is encouraged because correspond to a direct communicative method that remark instantly the problem more than texts and long lists of details described in words.
- 5. Alignment, it highlights the importance of the collaboration and sharing of information between various employee with different background and knowledge from different areas. It underscores the importance of different point of view in the evaluation of problematics and in the way to develop solutions.
- 6. *Coherency and consistency:* the different sections are not separated one from another, the element and the facts reported in a determinate section are directly link to what is reported in the previous section.
- 7. *System viewpoint:* it is not related to a single function in the company but includes in its preparation connection of different processes till the big picture that is comprehensive of dynamics in it.

## **Productive Process**

#### Laser processes

The production process of the department Probe Head Front End represents different operations in sequence where the final product can be very different depending on customer requirements. The biggest differentiation that is possible to consider in this manufacturing area is the one relative on Machine and the Manual one. The Laser part is not completely automatic, and it is essential the presence of operators to accomplish programming operations on the machine, the piece positioning on the machine and in addition other intermediate operations.



1. The first step corresponds to the selection of the raw material, there are two warehouses of raw material, the biggest one is downstairs and the other is positioned in the department near laser machines. The larger has the function of warehouse for the smaller one and an

operator has the task to refill the one in the department, usually this operation is accomplished in the morning. Before drilling, the operator goes to the warehouse, select a new layer of ceramic material or one with some parts already consumed in other projects. In order to avoid problems after other operations in the later stages, the operator measures the width and the thickness of the plate using a microscope that is shared also with other areas of the department.

- 2. The second step consists of lowering the plate using a dedicated machine, it is not an operation that is always necessary for all types of plates, but the majority of customers requires it. We have considered the forecasted data that we have which is around 60% of the total corresponding to lowered plates. In this case the height of the plate is not the same but it is lowered in some part, so the surface is not completely uniform, the operation is quite fast, and operators are only partially dedicated to this operation.
- **3.** The laser drilling operation corresponds to the operation that requires more specialization because product and process is very variable. This phase represents also the phase with higher time required in the entire department. The operator in this case, takes the plate manually and positions it in an auxiliary metallic tool which is called GIG. After the plate is inserted in the laser machine and the technical parameters are set in the machine with respect to the sheet model run, the machine can start its operation by using the drilling file present in the computer near Laser machines. The process requires a high number of hours, given the average performance of the laser machine (2100 holes/hours) and plate with number of holes in some case is superior to 50000 holes. Laser machine also performs the cutting operation before the drilling, in this case the time required is less but not only plate are cut in the department. For this reason, it is possible to find 2 machines in the department entirely dedicated to the operations of cutting the frames, in this case the pool of lasers can be more flexible in case of a last-minute customer requirement. At the end of the laser operation the operator is required to perform the unloading of the operation by positioning the plate outside the machine another time on a specific jig positioned on a cart to take it to the next step.
- 4. The following operation is consisted of the washing of the plate coming out from the laser machine. In this process water and ultrasound is used in sequence in order to remove particulates of the ceramic material residue of the drilling process. Operators are not fully

dedicated to this process, often an operator waits for the end of some steps of process from different laser machines, so plates are accumulated, and operator can make the cleaning and the drying of more plates in single time.

5. The final step of the process related to the laser side of the department includes a detailed checking regarding the quality and the size of the holes in the plate. Plates are positioned on a machine with a precise microscope because of the low tolerance in the measure of holes. At the moment it is possible to find 4 measurement machines in the department, 3 of these machines are positioned side by side and the other one occupies an arbitrary position in the department.

The microscope check is automatic, but it is required at the same time the presence of operators that control the machine during the process. Operators have to control the proper functioning of the microscope and it is important to be ready to intervene in case something is detected. In addition, he performs the placement and the setup of the machine. The control is based on a system of cartesian axes so the plate during the process, thanks to mechanical devices, plates can change position different times compared to the initial position. In case the data of the control process for the plates respects specifications for the typology of probe head, plates can go forward to the next step.

#### Manual processes in the department

As we have already mentioned it before, there is also a set of processes in the department which is mostly manual. This set of processes consists of acid washing, gluing, sandblasting, and chemical washing, parylene and sandwich phase.

#### Acid Wash

After measurement and control there is another washing phase which is acid wash that is performed with hydrofluoric acid solution. This process is done in order to remove the residual impurities through acid-based washings. Moreover, the air can enter the holes during the drilling, and this can cause the decrease of energy by some oxygen molecules and if not removed, it can lead to short-circuits or leakages. It can take several seconds or maybe sometimes a couple of minutes depending on the material of the probe head. Then another washing with demineralized water and ultrasound machine is performed. Later the drying of the plates and manual measurement of the thickness of the plates that make up the probe head is done.

#### Gluing

Gluing is the most critical process in the PH FE department as it is 100% manual. This process is yet to be automatic too as it is already in the test phase and will be installed soon. In this part of the process operator glues the plates which make the upper and lower package according to the technology. There is a working station where the pieces are put on the working pallet near the operator, and he/she takes the corresponding document to make the packages aligned with the specifications. The gluing takes nearly 20-30 minutes per sandwich, but this can take even longer or shorter according to the size and type of the sandwich. After having glued the plates, the operator inserts a jig on it and he uses a striker that applies 1 Newton force on the plates. After this step, the sandwiches are put in an oven for 2-3 hours with a temperature of 200 degrees Celsius. Currently there are 4 ovens in the department with two of them having a capacity of 12 PH at one time, one with 8 and one with 4 PH.

#### Sandblasting

Depending on the type of ceramic, for some of them sandblasting process is realized. This process is executed by means of the appropriate machine and it is done in order to remove the extra glue that can come out of the edges after the gluing process. The sandblasting cleans this extra glue and helps to avoid aesthetics issues applying pressure with bicarbonates on the piece. Later the pieces are washed in demineralized water with the ultrasound machine to remove the bicarbonate residuals. After this point all the pieces have to undergo some activities depending on some points:

- The thickness of the different pieces is measured with a measuring tool and if the thickness is not within specifications, it is sent to the engineering department to define whether to register them as scrap or to move it forward.
- It is needed to check if the holes are closed or if they have some dirt inside the holes. This is done by means of an optical tool.
- The lineup of 4 reference holes has to be verified by means of W\*\*\*\* control as these holes are used to assemble different pieces together which is carried out in sandwich phase.
- The pieces are washed with an ultrasound machine and then are dried in the oven.

#### Parylene

The next and the last phase before the sandwich, is parylene. Parylene is a thin film that is applied to lower and intermediate layers to facilitate the smoothness of the needles and to avoid short circuits between the needles as they have to pass through the holes of probe head. This process is quite a delicate process and takes a fixed 90-120 minutes that varies considering whether the machine goes empty or not.

#### Sandwich

The last activity before sending the set to probe head backend department to insert the needles is sandwich phase where the set is assembled together with housing that comes from the mechanical shop. After measuring the thickness of collected parylene on the surface it goes to sandwich phase if everything is according to the specifications. Normally there are two operators working on making sandwiches in the department. They deal with assembling lower and upper layers with housing. The operator takes the document from the shelves and uses the respective run-sheet to make them aligned with specifications. After putting all parts together operator checks the final thickness of the sandwich to see if everything is under specifications or not. When everything is under control and met with specifications it goes to backend department and initially 5 needles test is performed to understand the showdown and running characteristics of the needles. If there is a problem with sandwich when performing this test, the set has to go back to the frontend department. After the 5 needles test, the insertion of needles has to be realized. If the number of needles is less than 5000 then this process is manual, otherwise automatic, but only in Technoprobe Italy worldwide. Following the insertion of needles lapping is done for the needles to have the same height. After that probe head is completely ready to be assembled with PCB.

#### A3 Framework

#### Problem Background

Our project focus was Probe Head Productive Unit which consists of two departments: Probe Head Front End and Probe Head Back End. In front end department the sandwiches are made and in back-end department needles are inserted onto them. After discussions with our company tutor, we have decided to select Probe Head Front End department as the main area of our focus because the optimization of the back-end department depends on the performance of the front-end department since only less than 20% of what front end produces continue to back end, 80-90% of them go directly to the customer as most of the clients prefer to insert the needles themselves.

However, we will show some radical implementations where we have taken into consideration also the back-end department.

Element	Description
Tutor	D. Fumagalli
Statement	The Probe Head is the core component of the probe card; a set of ceramic laser drilled plates assembled on mechanic housing allows to micro metrically guide the probes that contact the pads of the chips under test on the wafer. Probe Heads are different in size, number and type of probes. The Probe Head Unit is the manufacturing line that drills ceramics, prepares the head and assemblies the probes; the assembly process can be both automatic (high pin count) or manual (low pin count), both internal and overseas.
Target	Define the best flow and organization that improve productivity and reduce the delivery time
Scope	<ol> <li>Identify the present inefficiencies</li> <li>Define the best manufacturing area flow and organization taking into account the present and future product variability</li> <li>Define an implementation plan</li> </ol>

The project we have been assigned is as the following:

Looking at this and taking into consideration some necessary points we have to define the problem statement.

First of all, the main thing that the company cares about is the application of lean practices within departments. Another point is that the problem that we focus on should be in a size that is manageable in a time period we have available which has been affected by the ongoing pandemic. Instead of starting in October we have started in mid-November which was due by mid-February.

Taking into consideration the abovementioned point we have decided to select the following to be the main ones among 7 wastes of Lean having impact on high lead time and also the ones that we can deal with by implementing some countermeasures.

- Motion the kind of waste encompassing the movements of employees which are unnecessary as a result of which some injuries and damages can occur leading to extended production time.
- Waiting the waste occurred whenever tasks are not moving. It is the easiest waste to identify.

• Defects – the kind of waste that causes rework or scrap which in turn leads to need of production again or from any point in production flow and this certainly comes with additional labor and machine hours.

According to all abovementioned, we can define the problem statement:

There are some inefficiencies in PH FE department of Technoprobe in terms of motion, waiting and defect and the lead time is high in the department.

#### Problem Breakdown

In order to understand the problems that are present in the department, two different methods were used:

- I. Inefficiencies detected through the use of GEMBA walk inside the department, observing an everyday situation and talking with operators taking notes on the details detected.
- II. Inefficiencies detected through the use and interpretation of the Value Stream Map

#### Gemba Walk

The term "Gemba" comes from a Japanese term used in Lean Manufacturing and its meaning is simply "*the real place*", this is to emphasize the reference to the most important place, the department, because it is the place where the work is physically done.



Figure 8 Fundamental of GEMBA: Observe, Recognize and Communicate

#### **Movements**

The first thing observed in the department was the redundancies of movement carried out by operators, the direct consequence is a waste in terms of time. However, the impact of movements is not only time related but also it has consequences in the quality of the finished product.

In fact, holding a plate makes you realize the delicacy of the material, for this reason handling the ceramic plates around the department as well as climbing and descending stairs can bring to qualitative problems. Moreover, in the transfer from one area to another the change in temperature may have an impact on the final quality of the product. Firstly, we performed a quantification of the time waste as a consequence of redundancies in movements. Consequently, we decided to follow an entire process from the beginning so from the first phase (incoming material warehouse) till the end corresponding to the Final Assembly of plates (Sandwich Phase). The department actually is organized on two different floors, this organization was considered addressing safety reasons as well as space constrain. For analyzing the redundancies in movements, we used a visual tool very frequent in mapping processes in manufacturing areas: The Spaghetti Chart.



A spaghetti chart uses the layout of the department where activities are carried out and it is used in order to map a path followed by the material in the different steps of a process. The first floor where the greater part of the department is situated, includes both processes performed with machinery and the manual ones and in the ground floor there is the sand phase and the acid phase. We decided to make a distinction based on the critical level of the track walked by the operator

**Black movements:** the movement takes place in the same floor, time required for it that remains lower than a minute and a not elevated handling of the ceramic plate.

**Red movements:** different floors, the operators use stairs in order to accomplish the task of acid attack and the sandblasting phase after the gluing process, time spent is greater than a minute and the handling also is critical. In this case, additional instruments are also used for transportation as trolley and cases for the material.

Initial	Arrival	Time required	
Incoming material	Set Up	27	sec
Set Up	Lowering	13	sec
Lowering	Laser	10	sec (avg
Laser	Clean and dry	15	sec
Clean and dry	Acid phase	75	sec
Acid phase	Measurement and control	85	sec
Measurement and control	Gluing	12	sec
Gluing	Oven cycle	10	sec
Oven cycle	Sand phase	66	sec
Sand phase	Measurements	67	sec
Measurements	Parylene phase	5	sec
Parylene	Sandwich	8	sec
	Total seconds	393	
	Total minutes	6.55	

Figure 9 Spaghett	i Chart PH	l Front End	Department
-------------------	------------	-------------	------------

The result shows us that on average for an entire process 6.55 minutes of operators are required, this value corresponds to movements accomplished for only one sandwich. The time indicated is

not charged on a single operator because the tasks are not assigned to the same operator because everyone is only partially dedicated considering the entire process.

Based on the actual data received by the company we estimate a daily production around 24.4 sandwiches daily. A number that can only increase in the future taking into consideration the positive trend in demand for the department.

It is also important to consider that the represented one is an optimal situation because it represents the case that an operator accomplishes each line only one time. On the contrary, the availability of equipment (es. microscope, documentation), instruments that are not duplicated increases the incidence of this type of waste, as sometimes the movements are performed only to check if the equipment is occupied.

Based on the previously defined output rate and the number of minutes waste in movements that have been calculating with the Spaghetti Chart it is possible to find the overall value in a day of activities:

$$T = t\left(\frac{minutes}{sandwich}\right) * n\left(\frac{sandwich}{daily}\right) = 6,55 \frac{min}{sandwich} * 24,4 \frac{sandwich}{day} = 159,82 min/dayTotal amount of movement time/day159,82min/dayHours waste in the movement/monthly79,91hour/month3,329583333days/month40days/year$$

In a yearly perspective, a total around 40 days corresponds only in movements of operators.

#### Gluing inefficiency

As we have already mentioned before, gluing is one of the most critical processes in the department as it is mostly manual. The company already bought an automatic gluing machine, but currently only one of them is in use and it is located on the ground floor. However, as the process is mostly manual for the moment and the layout of the area is not well-structured, there are a lot of not valueadded activities during the full procedure. We have made direct observation to understand the overall process and movements within the area better that is not value added on an average basis and we have built a spaghetti chart to be able to see it visually.



Two colors used represent both operators, the black line shows the movements completed by the manual gluing operator and the red one shows the operator dedicated to the automatic one in the bottom floor. We have observed and recorded the time for every activity that takes to finish up only one set for both of the processes together. Results can be seen here in this table:

Manual:	Time in seconds
from station to incoming material	15
from incoming material to drawer	7
from drawer to station	11
from station to material out	27
from material out to station	9
from station to pressure	10
from pressure to carrello	34
from carrello to oven	90
from oven to pressure (disassembly)	75
from pressure to drawer	14
from drawer to station	14
Automatic:	
from first floor to pressure	125

rotar (minutes)	12.42
Total (minutos)	12/2
from drawer to first floor	130
from pressure to drawer	12
from oven to pressure	75
from pressure to oven	97

Table 1 As-is (	Gluing	Workstation	Activities
-----------------	--------	-------------	------------

We have also calculated the average cycle time of the gluing process and it resulted to be 24 minutes. This means that 12.42 minutes and thus about 52% of the overall cycle time consists of not value-added activities<sup>1</sup>.

Apart from this, we have been told by the operators that there can happen some damages during the gluing phase and that can increase the rework cases. These reworks/repairs in the gluing are mainly caused by the critical handling of the plates and the manual operation itself.

Following this, to understand the impact of these redundant activities in gluing phase we decided to calculate corresponding labor cost. To do that, we have used the target plan for next year (from October 2020 to December 2021) where we have the data of the target sandwiches out weekly. We have found the monthly numbers of product out from there. Then we have calculated the time wasted in gluing phase by multiplying the monthly number of sandwiches by 12.42 which is the not-value added time we calculated for one sandwich in gluing phase. Following this, considering 30 Euros of hourly labor cost we have estimated monthly cost and then found the average of all months to be around 5,600 Euros monthly.

#### Sandwich inefficiency

One of the critical areas in the department is sandwich as the process is fully manual and everything has to be done attentively based on the specifications that operator read from a paper. In order to analyze the current situation in this phase we have again performed a direct observation which enabled us to witness the process closely and to notice the inefficiencies. We have made the observations for 4 different sandwiches from the beginning of the phase till the end. We have listed this time all the not value-added times happened during the operations of each set. These activities were:

<sup>&</sup>lt;sup>1</sup> This percentage has been assumed to be the NVA percentage of only manual operations (for one sandwich) since in the direct observations of manual gluing we have measured quite variable percentage of NVA, in some observations being higher than 60%.

- Going for the control microscope and back
- Searching for the name of technology in the dimensional specifications table (sometimes, especially when it is a rare technology, it takes some time to find it)
- Registration of the data on the paper manually
- ➤ Waiting
- Clarifying the problem occurred with other operators etc.

As we have recorded all these times, we have then calculated the average time that these redundant activities take and estimated the percentage of NVA time over average total time spent for all 4 sandwiches.

Average NVA	Average VA	% of NVA over Total time spent
23.40	16.10	59.23

#### Table 2 Sandwich VA & NVA time

It resulted to be around 60% of the total time, which is quite an important number to consider. Taking into account the daily sandwiches we can estimate monthly approximate wasted time due to the redundant activities in sandwich phase:

$$23.4 * 24.4 * \frac{30}{60} = 285.48 \text{ hours/month}$$

Therefore, building a direct correlation between the wasted hours and monthly demand we have estimated the numbers for each month from November 2020 to August 2021 and considering 30 Euros of manhour cost we calculated the labor cost impact of this phase in the department to be nearly 10,000 Euros per month.

#### VALUE STREAM MAP

With regards to the second methodology that we have mentioned before, first thing we did was to understand which type of technology is to consider. The evaluation of technology is a critical step because since the product is highly customizable, the department produces more than 78 technologies in terms of production processes. Having the table with the characteristics of all technologies, in order to choose one of those we have taken into account technologies where the process phases are shared because some technology has less stages. We also decided to take into account a product highly required and a technology that is critical because the number of holes is considerable (51,000 holes) for each plate. The different WIP before the laser was represented. After asking the daily WIP to send every day the planning to the department with all processes that have to be made during the day.

Regarding the cycle time of the different phase the measures have been taken directly from us in the department, asking to the various operators to signal us in the moment that they had to perform the task on technology earlier mentioned.

C	Colors in WIP								
	Prj measurement done, ready for gluing								
	Prj ready for drilling								
	Prj drilling under way								
	Prj already drilled ready to be measured								
	Prj On-Hold								
	Prj Engeen Group								

The time for the lowering was taken directly from the data

present in the computer that is next to the machine that records the different time regarding products worked within the machine.



Figure 11 Value Stream Map of the department

From the Value Stream Map, it is possible to observe that a high WIP is present in some stages, for example: directly before the drilling process carried out by laser machines, that corresponds to

the same time to the most burdensome procedures in term of cycle time for the high number of holes in the plate.

#### Idle time<sup>2</sup>

An important component that directly affects the WIP before the laser machines is stand-by time of the machines. The laser machines are provided with a computer that can monitor and store data about performance which are periodically controlled.

There are different situations where the idle time can be manifested in the area for laser machines. We will only talk about the following ones:

**Stand-by No product:** in this case the laser machine is in stand-by because there is not any technology to process or just because of the lack of demand. Laser machines are not all the same, characteristics are different and also the internal instrumentation can be different. Example of this fact is that in the current situation 5 laser machines in the actual pool of machines because of lack of long axles and cameras inside cannot work lowered plates. The demand of lowered plates corresponds also to the majority of plates in production; we can mention weekly production of 869 plates, 517 plates correspond to lowered plates, so around 60% of plates are lowered. Another aspect connected to technologies to consider is the fact that a specific technology is needed for calibration of the laser machine before being drilled so the action taken always is to allocate technologies to the same specific laser machines, but this can mean to increase the value of standby of other machines. In general, standby no product percentage is considered to be 14.5% after making some adjustments.

Considering the actual performance in terms of number of holes:

Actual Performance	Performance without no product	Number of operators	Total Operator Hours	Total cost of operators	Optimal Performance Cost	Actual Cost	Delta Difference	
19191212,00	21973937,74	15,99	2686,76968	80603,0904	€ 0,0037	€ 0,0042	€ 0,00053	

Table 3 Idle time no product

The delta difference in this case represents the difference in terms of a single hole that the department could reach in case of removing the idle time no product.

<sup>&</sup>lt;sup>2</sup> All the data used in this section has been extracted from a report of a specific week

Ideal labor cost saving related to this factor would be around 21,000€ monthly considering the future demand, however reducing this value by a considerable amount is not achievable given the difference in terms of technology of laser machines. That is why we can achieve to save only some part of this cost.

#### **Pareto of technologies**

In order to estimate the variation in demand we have been provided the forecasted data of sandwiches for technology. In fact, the standby values can be related to repercussion of the variability of the demand. As it is possible to see from the image, volume for technology does not have a fixed value monthly, this type of industry requires a high capacity for the department to satisfy the change in demand in a short time. In order to understand which technology impacts the most in the actual production of the department we decided to divide the products actually in production to 3 different categories: A, B and C. The A are the technology produced more considering the number of sandwiches out, followed by the B category and C. In order to divide the production in class we decided to implement the marginal approach technique, always using the forecasted trend data that we have been given by the company.

technol	sandwich	class	class2	
TECHN 1	671	А	А	
TECHN 2	151	А	А	
TECHN 3	130	А	А	
TECHN 4	86	А	А	
other 1	42,92	others	В	
other 2	42,92	others	В	
other 3	42,92	others	В	
other 4	42,92	others	В	
other 5	42,92	others	В	
other 6	42,92	others	В	
other 7	42,92	others	В	
other 8	42,92	others	В	
other 9	42,92	others	В	
other 10	42,92	others	В	
other 11	42,92	others	В	
other 12	42,92	others	В	
other 13	42,92	others	В	
other 14	42,92	others	В	
other 15	42,92	others	В	
TECHN 5	19	others	С	
TECHN 6	10	others	С	
average	81,466667		40	а. А

Figure 12 Pareto for technology

#### Variation of technology

The sandwich requests also considering the same customer is not uniform taking into consideration different months. Starting from the forecasted data, our team performed an analysis in order to estimate the impact as a percentage of the total production of the department. The variation connected to the period corresponds to an important factor to take into consideration for the department as the capacity and the characteristics of laser machines shall be in line with the variations. It is also possible to consider the purchase of new laser machines considered for example that the TECHN 1 shown in the table consists of lowered plates. For this reason, it is necessary to increase the drilling capacity of the laser machines provided with camera.

	TECHN 1	TECHN	TECHN 3	TECHN 4	other 1	other 2	other 3	other 4	other 5	other 6	other 7	other 8	other 9	other 10	other 11	other 1	2 other 13	other 1	4 other 15	TECHN 5	TECHN 6
nov	28%	12%	9%	6%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	30	6 39	6 39	6 3%	1%	1%
dic	28%	9%	12%	6%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	39	6 39	6 39	6 3%	1%	1%-
gen	44%	6%	6%	5%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	6 39	6 39	6 3%	1%	1%-
feb	43%	7%	7%	5%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	29	6 29	6 29	6 2%	1%	0%-
mar	42%	8%	7%	5%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	29	6 29	6 29	6 2%	1%	0%-
apr	42%	10%	7%	5%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	29	6 29	6 29	6 2%	1%	0%
mag	41%	10%	7%	5%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	29	6 29	6 29	6 2%	1%	1%-
giu	41%	10%	7%	5%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	20	6 29	6 29	6 2%	1%	1%-

Figure 13Technology variation monthly

#### Setup time

The performance of laser machines is affected also by the setup time in the department. As we have already mentioned the product is not standardized at all. So, also the parameters of the machine have to be set in relation to the type of technology to process.

The machines are not standardized and sometimes it could be that some machines are indicated more for a certain type of technology, the tendency therefore is to work with a higher frequency on a determinate laser machine for a particular technology. In case of a higher number of holes to perform on each plate, with drilling times that can pass 20 hours, it is also possible for example that the lower, middle, and higher plates are assigned singularly to different machines.

In fact, in case a machine works a specific technology in 2 months but in the following period does not perform the same technology, the setup on the machine has to be performed by the operators. A problematic situation emerges in case of wrong choice of laser machine to perform the drilling phase not considering the past production or the adaptability of laser-technology. Another case where a setup is required is after the machine has been maintained, but in this report, we will not focus on the setup from this aspect. Value of setup provided by machine corresponds to 1.9% of the total time available that corresponds to around 384 h/monthly used in setup. It is important also to consider the actual condition of the laser before planning the setup, in particular the actual power of the laser machine selected has to be higher than a determinate level.

Setup corresponds to the time required to set the characteristics of drilling, doing the calibration of the machines, performing some tests and check the outcome of the test with the microscope. The time related to the loading and unloading operation falls in idle time no operator category and it is related to the manual activity of positioning the plate on the jig before inserting it in the machine. We decided to evaluate the actual incidence of the setup, in order to evaluate the impact in monetary terms for a single hole.

By using the same calculation method, we have estimated the following:

```
Delta Difference = Actual Performance - Optimal performance (without setup) = 0,00008 \notin /hole
```

Considering trends for future months the set-up time will have a great impact, we have calculated the cost related to it and it resulted to be around 3,000€month.

#### Rework

Another main problem leading to high lead time is the number of reworks that should be redone from the certain phase of the production flow. We have decided to estimate the average time required for required by using a unique way since there was no data about the time of rework


Firstly, we have figured out that there are nearly 16 reworked plates per week (data is for Wk45) and it can be caused by different reasons shown in the pie-chart here.

As we have seen here the reasons can be:

- ➢ Run sheet mode error.
- ➢ Holes dimension out of specification.
- > Breaks
- Downloaded file error.
- ➢ Trajectory error
- ▶ Lower marking error etc.

We have been told by our company tutor and other engineers in the company that the average occurrence of rework and repair together in the production can be considered to be 10% considering the variability of demand. This will help us to calculate the average time needed for rework. Later to understand how much time rework takes on average, we have used the data about different reasons of rework that we had. Here we had also the number of each type of rework that have happened in the specific time duration. In order to get a reasonable estimate, we have divided the whole flow of production into three areas:

- From RS to Laser drilling (initial phase)
- From Plate washing to Gluing (intermediary phase)
- The rest till sandwich (final phase)

Thus, we have counted all the rework types and assigned them to the abovementioned phases to understand the incidence of rework in each phase, respectively.

	Initial phase	Intermediate phase	Final phase
Number of plates	12	16	53
Time from VSM (min)	2282.6	8163.3	12797.4
Percentage of occurrence	0.148	0.198	0.654

Table shows the number of reworked plates<sup>3</sup> in each phase and the respective time of those corresponding phases from VSM. As we see from the table most of the breaks/damages happen in

<sup>&</sup>lt;sup>3</sup> The number of reworks shown here covers a duration of more than one month – 5 weeks

the last phase percentage being about 65%, while that of intermediate and initial phase is nearly 20% and 15% respectively. From these numbers we can compute the approximate rework time that is needed taking into account all the percentages and times we have calculated:

$$0.148 * 2282.6 + 0.198 * 8163.3 + 0.654 * 12797.4 = 10324.3 min$$

Nevertheless, this time is not sufficiently accurate since not all the reworks occurred within any of the 3 phases happen in the end of the phase, some of them can happen in the middle of the flow, or maybe even in the beginning. Considering this fact, we have introduced a corrective factor to reduce the impact of this deviation and decided to set it as 1.5 also following the instructions of company tutor to get to more realistic result.

$$\frac{10324.3}{1.5} = 6882.85 \ min$$

Subsequently, as we have the average time needed for rework and the percentage of occurrence of rework, we can compute the overall approximate time needed:

$$0.1 * 6882.85 = 688.28 min$$

However, for calculating the labor cost of the extra time that this problem leads to, we decided to use the number of reworks per month which we had from the weekly report of week 45. Considering the capacity of operators being nearly 15 sandwiches per week per operator and applying direct correlation to the number of reworks with the total number of plates monthly we have calculated the average monthly labor cost of 1,500 Euros.

As there is also a substantial amount of material cost related to the broken/damaged pieces, we have also calculated that cost to be roughly 19,000 Euros per month. However, as this is a rough estimation and can be quite different for different scenarios, we have decided to focus on the labor cost merely.

As we have nearly estimated the excess time that is wasted as a result of each problem we have defined, we can build a summary table showing the impact of each one and that of total on the lead time:

Total impact	1550.3	12.11
Sandwich inefficiency	23.4	0.18
Gluing inefficiency	12.42	0.1
Idle Time	826.2	6.46
Rework	688.28	5.38
Current impact	Minutes	%

Table 5 Impacts of each problem on LT

### TARGET

After collecting all the information throughout direct observations, data collection and analysis, use of different tools, we have defined the targets of the project following the indications of our tutor who is working for the company for many years and has all the necessary information about all the KPIs of the department.

The design of target requires a goal for improvement which will be generated as a result of the further proposed changes. About the problems of Gluing and Sandwich that we have observed through Gemba walk to understand the value stream and its problems, we have set must have and nice to have targets and the former is expected to be achieved by means of the countermeasures implemented by mid-February. These countermeasures can be considered quick-wins or light interventions with minimum investment required. However, for the movement of operators a structural intervention is needed such as a layout change which is shown in the radical countermeasures part.

Regarding the inefficiencies found by means of Value Stream Map we have targeted to reduce the WIP before laser machines by applying some light interventions while the WIP before Sandwich phase is not something that can be solved by light interventions since most of them are connected to the Mech Shop for the provision of the Housing and needs structural interventions to be reduced. Thus, our target is to reduce the lead time by 1.37% as a must have and 1.77% as a nice to have target, trying to achieve the former by mid-February.

### Gluing inefficiency

In the gluing phase we have defined 12.42 min of NVA time, and it is 52% of the total time spent for the process. We have set a target to reduce this percentage to 39% as must have and 23% as nice to have target. As this reduction in the overall time needed for gluing process, cycle time of gluing phase in VSM and thus the lead time will be reduced. This reduction can be seen small considering the high lead time, however if we consider the approximate daily demand of 24.4 sandwiches, must have target of 122 minutes and nice to have 220 minutes per day can be deemed considerable.

Achieving must have target means nearly 1500 Euros monthly cost saving for the department.

	LT	LT reduction%
AS IS	12797.4	
MUST HAVE	12792.4	0.04
NICE TO HAVE	12788.4	0.07

### Sandwich inefficiency

When we have made direct observations in the sandwich phase, we have defined nearly 60% of NVA time in the overall process of sandwich which is quite a significant amount of time. We aimed to reduce this percentage to 35% as must have, and to 30% as nice to have target. As this inefficiency has direct impact on lead time, and current cycle time for sandwich phase in our VSM is 55 minutes, we target to reduce this time to 49 minutes and 44 minutes, respectively. Therefore, this is 0.04% reduction in lead time as a must have target. We aim to achieve this reduction by decreasing the time the operators spend to identify the problem and register it on the paper, about which we will talk about in the countermeasures section.

		LT reduction
LT actual	12797.4	
Lt must have	12791.9	0.043%
Lt nice to have	12786.95	0.082%

#### Rework

For the rework problem we have calculated the time of the rework and repair 10324.3 minutes, corrective factor of 1.5 and the occurrence of them in the department to be 0.1 and we have set a target of changing the corrective factor to 1.7 as a must have and 1.9 as a nice to have by being able to detect the problems in advance.

Later, considering the same occurrence of the rework, but this time new corrective factors we have calculated the impact of each on the lead time and therefore computed 0.633% of must have and 1.132% nice to have target of reduction in LT.

	As-is	must have	nice to have
rework% on LT	5.38	4.75	4.25
Lead time	12797.4	12716.4	12652.5
Lead time reduction%		0.633	1.132

#### Idle Time

Since we have focused on the idle time problem starting from the WIP before the laser machines we have set a target of reducing the WIP by 13% as a must have and 20% as a nice to have target. We have followed the instructions of our company tutor as well in order not to set an unrealistic target. Thus, the numbers we have set are reasonable and achievable by means of the countermeasure we will introduce. Therefore, starting with a direct correlation between the number of inventories before the laser machines and the percentage of idle time for each component (no product, no operator, setup & maintenance) we have identified new reduced idle time percentage of laser machines to no product 12.615% (was 14.5% before), no operator 13.137% (was 15.1% before), setup 1.653% (was 1.9% before). Thus, the calculation taking into account the WIP reduction targets have been made and 1.29% of must have reduction in LT has been identified.

	as-is	must have	nice to have
time inventory	826.2	660.96	619.65
LT	12797.4	12632.16	12590.85
LT reduction %		1.29	1.61

Consequently, after having identified specific targets for each problem we can build a summary table to understand the overall target on lead time reduction:

TARGET	Must have	Nice to have
Rework	0.633	1.132
Idle Time	1.291	1.614
Gluing inefficiency	0.039	0.07
Sandwich inefficiency	0.039	0.082
Total reduction %	1.369	1.766
Final LT	12622.2	12571.4

#### Table 6 Targets for each problem

As it is depicted from the table the overall target reduction in LT is nearly 1.4% must have and 1.8% nice to have. This is 175 minutes of saving as must have target.

## Root cause analysis

Root-cause analysis is often used in proactive management to identify the root causes of a problem, that are factors that correspond to the main cause of that problem.

It is customary to refer to the root cause in singular form, but one or several factors may in fact constitute the root cause(s) of the problem under study. In order to go more in detail in the understanding of the different root causes we decide to implement the Ishikawa diagram, it is a typical diagram used in manufacture to show the causes of an event.

**Ishikawa diagram:** in the diagram here presented the main problem is stated on the head at right side and the different causes in the left side of the diagram. The causes are in the left side but there is some order that it is used to group the different causes of the problem and it is represented by the 4M, the different problematics are analyzed under 4 categories:

- Machine: this section includes the entire group of machines, facilities, and tools that we find in the department, sometimes the management and the disposition of this type of equipment is not aligned to reach the desired output.

- Man: this regards the incidence of managing people inside the department, the man is the element that performs the operations, programs the machines, and checks the products. The final output depends on the experience of operators and the problem can emerge by actions of operator not performed correctly.

- Method: the section related to method contain procedures, documentations and specifications used in the department to accomplish the job. It refers to the degree of the clearness and functionality of the type of documentation considering the type of job specified. This section take account also the procedures followed for performing manual process.

- Material: the section regards the components and consumables used to satisfy the production; the root cause can regard the adequacy of the lots in terms of conformity. Moreover, it is considered also the choice of material occurred during the design phase and the conditions of storage of material.



Figure 15 Ishikawa diagram

### The 5 Why's method

In order to go more in detail to the different causes of the problem we decided to perform the *5 whys method* methodology. This method was introduced by Sakichi Toyoda, a Japanese that following the age of innovations in the field of lean manufacturing developed this technique in order to make a well-informed decision. It is important that these questions are done to people with practical experience on the field. The tool is effective in finding the root cause of a specific problem by asking a series of why one after the other, the number of why it is not fixed in fact could be a number even different from 5. In this section we analyzed each principal branch that is part of the method, however, not all the problems are here analyzed but anyone that requires a superior analysis to get to the root cause.

### Material

The material is another critical issue because measure and condition of the plate must respect standard and also without any error from operator, it is possible that the plate present damage that finally is reflected in a case of noncompliance and the customer send it back again:

- *Why?* the material is very delicate, and its characteristics and dimension may vary along the process.
- *Why?* the process is characterized by a transportation of the plate though different area and it face different temperature that directly affect the final output.
- *Why?* the space organization of the area does not take into account that some process has to be performed in a precise temperature and as an open space it is not possible to regulate temperature to the exact value considering the type of process.

### Man

The man section is really important because although the drilling and cutting are performed entirely in the laser machine, other activities are entirely manual, and it is possible to find inefficiencies resulting from operator activities. The high number of redundant movements of operators inside the department it is critical because it does not represent only a waste in terms of time, but it affects the output quality of the product because it is delicate, and it can suffer a great handling of the plate. It is important in this sense to analyze and find the root cause of movements.

- *Why?* operators in charge of some plates in order to follow the entire process has to cover a great area of the department as well as changing the floor to accomplish mandatory operations for each plate.
- *Why?* machines are distributed randomly in the department, without a correlation with the flow of the probe head and the change of floor is due to safety reasons for some specific phase of the process.
- *Why?* operators are not specialized in some specific technology of plates and each one follows his flow without any restricted area and moving in the department perform only some operations. The consequence is that one single plate can switch several hands covering a lot of space of the department till the end of the process.
- *Why?* the actual distribution of the machine is the result of limitation in space.

## Machine

In the downtime of the machine a higher percentage of the time is constituted by the standby time no operator

- Why? the operator is not there to accomplish the load and unload operations
- *Why?* the personal of the area in doing different type of tasks and the operator does not notice that laser has finished to work
- *Why?* the personal of the area is not dedicated to some technologies so they have to manage the entire area of laser machine, lasers are positioned randomly so it is difficult know in advance where to perform the load and unload operation.

	Meth	nod	Machine			
WHY?	The space dedicated to this task and its organization make it difficult to find and reach the right set to accomplish the operation.	The reporting system is not appropriate to identify and collect detailed information of problematics faced.	A single laser machine in the department has to perform different technologies.	The machine remains stopped without any plate to perform		
WHY?	The operator accomplishes movements without knowing before how to find the right instruments and plate. Essential tools have the pressure system accessible only by getting up off the chair each time a set of plates is glued, and they are reachable only by walking.	The registration is done by operators responsible for the identification of Rework in the department, but the timing and the frequency of the registration do not allow us to intervene quickly.	From the planning plates that rely on different technologies to perform daily, different technologies are assigned in sequence to the same laser machine.	The reason can come from both a lack of demand from the planning phase, because they receive daily the plates to perform and the number is not fixed. Another reason could be also the fact that there are no laser machines with characteristics adapted to work on the plate.		
WHY?	The shelves organization does not follow the flow of the process and are organized without a logical order.	Operators record the date manually and they do not follow a fixed scheme that permit a collection of data for analyze what is happening to act quickly to solve the problem before operator faces it again	The selection of machines is not regularly based on past production that could in the case of recent operations on the same technology avoid the hole test.	In the planning phase of the drilling, operation customer specifications are not considered relation of the actual technical characteristics of laser machines in an overall view of the department at the moment of assignment of the laser.		
WHY?		The description relative to the type of defects is very simple, it is not detailed and not aligned with the process		The operator has in this sense to understand which laser is better to use for the task without losing sight on the sequence of processes to perform on a single loser to avoid leaving the machine unload.		
WHY?				The laser machines were bought in different times and also the advancement in terms of technology is different, for example the length of mechanical axes inside or the presence of a camera and the operator need to know which tasks it is possible to shift in these machines in order to avoid undesirable machine stoppage.		
Root causes	Reaching the plates and tools	Reporting system	Set up time	Standby time		

## Management Type: Incremental Vs Radical Innovation

In this chapter, before addressing singularly the different countermeasure, it is possible to understand the different approach considered in the moment of a proposal of change inside the department. First of all, it is important to make clear the distinction between incremental and radical innovation. Incremental changes take place gradually in the company, it refers for the major part of the case to adjustments and do not require an alteration of the company structure or the strategy followed. These types of changes include for instance modifications in procedures, tools and in the technology used in the production environment. This type of change occurs more frequently than the radical ones. The implementation of changes of this category it is not sufficient to have a radical shift in the performance because the effect is limited. However, through the frequent implementation of incremental improvement permit to the effect of this type of changes to lead the department in a perspective of a continuous improvement. Starting from this point our team has developed firstly tools moving on this direction, which have as starting point technologies and resources already available in the department.

The radical changes are also considered by our team, in order to suggest a direction for the company for future reconfigurations of the department as the demand will grow in the coming months and customer will require process more complicated.



The radical change, for its nature can concern all the company so all the departments, a similar case can happen in the moment that a new product is introduced, or a new technology is introduced. In this case structure and connections inside the company have to change in the same direction.

This is because all the phases of the process are strictly connected and therefore changes in the product require interventions at different steps of the process in the department. In other context the radical change can refer to a single area as in this case the PH FE department. In this case it is easy to observe that some innovations as the incremental one is related to some modifications in the process are applicable in reduced terms. Radical changes, for the level of investment required and technical changes to be made require a greater effort at several company levels.

# Develop Countermeasures Incremental Countermeasures

After having defined the root causes of the problem, we will implement some countermeasures acting on the most important ones taking the project scope and time constraints into the considerations as well. We tried to avoid the wrong approach of selecting the countermeasure, focusing on the real root cause of the problems which is something that is the part of daily routine in the department.

Three countermeasures have been developed with the support of methodological and company tutors.

## Rework Identification Tool

Taking as a reference the Fishbone diagram, we have developed a single countermeasure for three different root causes in the Method branch:

- Data collection
- Identification of problems
- Manual registration

As noticed during the direct observations we have made, there are a lot of redundant activities within the completion of each process, especially in the sandwich and gluing phases, most of them are related to the understanding of the type of problem and registering it manually. To tackle this issue and reduce the impact to the lower level, we have decided to build a digital tool where a list of possible types of problems is shown according to the previous records. Firstly, we have collected

all possible types of rework and repair that can happen in the department throughout all the processes as shown in the table below.

phase 1	L	phase	2	phase 3						
					Operatore laser	rottura in fase di scarico	note	Processo Glueing	incollaggio critico	note
						rottura in fase di pulizia\lavaqqio	note		allinemento incollaggio critico	note
	repair					rottura accidentale	note		attacco acido crítico	note
						errata compilazione RS MODE	note			
						errata compilazione Plate MODE	note : plate posizionata male sul batch	Processo Lavaggio	rottura durante il lavaggio	note
						errata caricamento traiettoria	note		foro toppo	note
						rottura in fase di misurazione (VERTH)	note			
						marcatura errata	note	Impianti	temperatura interna laser	note
									blackout	note
					Operatore incollaggio	rottura in fase incollaggio	note		idraulico	note
		-	Operatore Laser			rottura accidentale	note		elettrico	note
			Operatore Glueing			parylene fuori specifica	note			
			Sistema Laser			colla sui fori	note	area design	dxf errati	note
	rework		Processo Laser			graffio su plate	note			
			Processo Glueing			rottura durante la sabbiatura	note	area progettazione	fori align errati	note
			Processo Lavaggio			rottura in fase di sandwich	note		forature errate	note
			Impianti						criticità processo	note
			Area Design		Sistema Laser	software ko	note		progettazione errata	note
			Area Processi/R&D			CBIT	note			
			Area Planning			INVOKE NODE	note	Area processi\B&D	note operative errate	note
						PIEZO KO	note		progettazione errata	note
						SENSORE Planarità KO	note			
						ASSIKO	note	Altre Aree Produzione	rottura plate	note
						Telecamera K0	note		rottura ph	note
						Freeze PC	note			
								Area Planning	pianificazione errata	note
					Processo Laser Forat	dimensioni fori	note		Bun Sheet errato	note
						traslazioni fuori specifica	note			
						asola o boccola fuori specifica	note			
						allineamento telecamera errato	note			
						abbassamento fuori specifica	note			
						qualitá fori	note			
						pareti fori rotte	note			
						taglio non eseguito	note			
						fori non eseguiti	note			

Figure 16 Different causes of rework

Then by using WPF (Windows Presentation Foundation), an interface has been built to insert the input data such as type of rework, plate type, ID code, PH name, number of holes and the windows for possible options of reworks to select among, as well as a window to insert notes and finally name and surname of the operator in charge.



Figure 18 Main Window of the Tool

			-							
	IDcode	Date	FullName	PHName	Prima/Dopo	PlateType	HolesNumber	Туре	Job	Problem
	IT67890	2/4/2021 7:22:06 PM	Gulnar Huseynli	CPPU	Prima di incollaggio	U2	40000	Rework	Operatore Laser	Rottura accidentale
Fi	gure 17	Example of Exce	el sheet							

All the inserted data is saved in the database each time an operator registers a new problem through the application. (By means of "Generate Excel File" button). SQLite has been selected as the database. The example of a list of problems in an Excel sheet will be in the following way:

By means of this tool it is possible to decrease the amount of time required to identify and register the problem in gluing, sandwich, and laser drilling operations. Apart from this, *the main benefit* of the tool is reducing the cost of poor quality in terms of number of plates needed to be reworked, as it provides a good record of previous problems which helps to understand the most problematic activities in the department and act mostly on them to reduce the occurrence.

Another additional feature of the tool shown in the figure below, is a dashboard which is developed by means of Pivot tables through the medium of Excel. It is a very practical element to give an overall view of the recorded data for further uses, especially to provide a quick visual situation analysis for the head of department and top management. The graphics in the dashboard are automatically updated once the operator presses the button in Excel "update pivot tables", precisely showing the current situation. It is possible to easily understand what the most occurring type of problem in the department is as it is connected to the data that is generated with the help



Figure 19 Dashboard

of tool. It is also possible to see the most relevant technology that corresponds to the problem occurrence as well as showing the area which should be focused on more.

#### Laser Optimizer

### 1<sup>st</sup> version

Laser Optimizer consists of an instrument that in an automatic way guides the operator in the choice of the laser machine to process a specific technology of plates and at the same time gives to the operator a quick overview of the process scheduling in the department. As we analyzed in the root cause analysis section, the selection of the laser machine impacts both the quality of drilling as in the obligation to perform or not the hole test before starting the process. Since it represents a fundamental test to ensure a good quality, for each technology that works in the department it has been conducted at least once the hole test in each laser machine used for its production. However, some machines that are usually used for the production of other type of technologies that never processed this type of plate have to accomplish this test before starting the drilling. The test has a quite relevant time because it includes not only the time required to drill the plate but also the time for checking the results of the test under the microscope and also the hole test washing. It is also important to understand in this sense when the hole test was done, because in the case of a technology has been worked in a date more than 2 months before, it is not necessary to perform it again by using the same laser machine. Considering this, a first version of the program was implemented only taking into consideration the past production file already used in the department.



Figure 20 First version of the Tool

In this version the functioning of the macro is quite simple because the data used is part of the same file, also the format was maintained unchanged because the laser operators are already used to it. In this case the operator inserts manually the name of the technology and the program will show directly on the green table the identification number of the last laser that performed a plate of the same technology also providing the exact date. The identification of the laser works singularly, in fact not all the time it is required to work all plates for a technology, for this reason



Figure 21 Message box of the program

it is possible to narrow the search only to some plate, confirming or refusing the selection: In this case for example the choice is related only to the *medium (MDM)* plate of the inserted technology. From the outcome of the program, considering the difference in days from the actual date it is possible to understand instantly if the hole test is required or not.

## **Final Version**

After receiving great feedbacks from the company side for the logic of the functioning we decided after a comparison in the department to make the program more functional. In order to make the right choice of the laser machine, not only the time is a constraint, but the laser machine also has to be aligned in terms of technology and current performance with the plate to work. For this

reason, we decided to include two other sources of data in the program:

#### Technical characteristics of the laser machine

As we have already mentioned the presence of camera inside the laser machines corresponds to an important factor to take into consideration in the choice of laser. Lowered plates correspond to the typology more processed in the department and it is not possible to perform the drilling operation in a laser without a camera. We decided to include in the tool a simple table that resumes the presence of the camera inside the machine. The

Laser di foratura 🔻	Status of lase 🔻	Telecamer 🔻
L1	UP	No
L3	UP	No
L5	UP	No
L6	UP	No
L7	UP	No
L8	UP	Si
L9	UP	Si
L10	UP	Si
L11	UP	Si
L12	UP	Si
L13	UP	Si
L14	UP	Si
L16	UP	Si
L17	UP	Si
L18	UP	Si
L19	UP	Si
L20	UP	Si
L21	UP	Si
122	110	с:

 $\frac{d}{dt}$ Figure 22 Technical characteristics of the machine

presence of camera is identified considering the 3<sup>rd</sup> column and like the previous file it is possible to add new laser machines that the tool will work in the same way.



### **Actual Performance Data**

Figure 23 Power Selection of machines, Actual Performance

The performance of laser machines in the department does not remain stable at all, it is important to always monitor the actual performance.

A plate drilled with low power of the laser machine will probably achieve a low quality of the output. In addition to this, a quality in the drilling phase that does not comply with specifications required to perform again all the phases before the drilling. The table above represents the actual power for each identification code that represent a laser

machine. The operators in charge of the registration takes the data directly from the computer to the side of the laser machine and collect it in a sheet that is shared with all the department.

Finally, we decided to put together all sources of data in the same excel file in a way to link those with the main functioning of the program.



Figure 24 All excels in one

## FINAL OUTCOME

The team developed the final version of the program that can be used by opening just a single file in Excel; the interface of the program is represented here:

technology: number of holes: lowered:	uata morne	08/02/21 18:16 lat XLT 5000 si	TI (selezione si no	at XLT		-	
limite potenz	<b>a</b> 3,90						
		LOWER	MEDIUM	UPPER 1	UPPER 2		
	laser:	L8	L26	L8	L27		
	power:	4,12	4,31	4,12	6,1		
	data:	09/01/20	09/11/20	09/12/20	09/01/21		
	time required:	2,4	2,4	2,4	2,4		
	hole test:	da fare	da fare	da fare	già fatto		
	Dif.giorni	396	91	61	30		
	Stato Laser:	В	В	В	MB		

Figure 25 Final outcome

## Input

The program has a simple and understandable interface, the information to insert manually is limited and familiar for all operators of the area. In fact, the program requires as input:

- *TECHNOLOGY:* the name of the technology is easily selectable from a dropdown menu that contains all the technology present in the historical data.
- NUMBER OF HOLES: it is required to insert the number of holes that are required in each plate of this technology.
- LOWERED: the operators indicate if it is a case of lowered plate or not.
- LIMITE POTENZA: in this field it is possible to customize the value relative to the power of laser that is acceptable to assign working on the laser machine.

## Output

The program works as the first version, but in searching the laser machine it takes in account both technical characteristics and the actual performance of the laser machine. It shows in a graphical way the characteristics of the laser found and in case a laser machine does not respect one of the two condition the selection goes directly to the second choice in date order.

The indication relative to the need to perform or not the hole test is given directly considering the difference in day from the last process in the laser machine and the actual data.

## **Actual Production Scheduling Data**

Once finished the final version of the Laser optimized, concerning the root cause of the stand-by, considering the percentage relative to no product, we decided to complete it with an upgrade that



will help operators in charge of the planning phase to have an overview and to improve the scheduling activity. Maintaining the same interface of the Laser Optimizer, we upgraded it by adding 4 buttons that permit once you find the laser to confirm the selection and having immediately an overview of the production active in the department with the relative finishing time. In the same program, once the operators press the confirmation button relative to the different plates, all the data will go directly in the sheet in the same file called "Actual Production", in order to have an overview of the scheduling for laser machines. The program also shows the estimated end date taking into account the actual date and current time and starting from these the hours that are necessary to the drilling process are added, considering a rate of 2100 holes/hour for machine.

In the case just presented once the operator presses the "upper" button, the following message will appear:



In this case, the answering the question "do you want to substitute?" was "no", so in the "actual production" sheet the row will contain both types of plates. Considering that there are two operations in series on the same laser machine, the end date will include the drilling time of both plates. In this case each operator will be always informed on the sequence of product to perform, having at hand the distribution of production in the area, decreasing the incidence of standby of the machine. In fact, knowing that a machine is going to stop, it is possible through the program to understand if another technology in the daily WIP can be loaded on the laser machine, otherwise it is possible to dedicate one operator for the hole test on that machine to decrease the time of standby for the lack of product.

#### CASE 2:

	Availability	Technology	Holes	Plate	data e ora inizio	tempo di fine
laser1						
laser2						
laser3						
laser5						
laser6						
laser?						
laser8	Si	The are the take and	32000	HG1	02/09/21 15:49	02/10/21 06:49
laser9						
laser10						
laser11						
laser12						
laser13						
laser14						
laser15						
laser16						
laser17						
laser18						
laser19						
laser20						
laser21						
laser22						
1000122						
laser26	Si	Theo remember	32000	MDM	02/09/21 14:48	02/10/21 05:48
laser27	Si	TROOM TO CONTRACT	32000	HG2	02/09/21 14:48	02/10/21 05:48
laser28						
laser29						
laser30						
laser31						
laser32						
laser33						

Here on the contrary to the previous one, the answer selected by the operator is "si" and it is possible to observe as in the column relative to the "laser8" the lower already confirmed has been replaced by the higher 1, so in this case the laser will perform only the upper1 plate by removing from the line the plate previously selected with the program.

Figure 27 Actual production sheet

#### New Gluing Workstation

The goal in this is case is to understand and analyze the activities that are redundant and try to remove them. Our countermeasure in fact includes a modification of the actual layout of the area to reorganize the area and reduce the movements. In addition to modifying the current configuration of the area, it is important to consider the possibility of adding instrumentation inside the work cell to reduce non-value-added activities and reduce the possibility of error on the part of operators. In this perspective, the gluing area will be independent from the other processes as the integration of the automatic gluing machine will be required in it. An arbitrary position was considered for the position of the oven because in the future development of the area these elements will be positioned in the same plane. Taking into account this condition we have decided to propose 2 alternative layouts.



## Figure 28 Suggested hypotheses

Hypothesis (1)	Time needed	Hyopthesis (2)	Time needed (sec)
	(sec)		
Automatic:		Manual:	
from machine to in/out	11	from station to incoming material	4
from in/out to drawer	4	from incoming material to WH	4
from drawer to pressure	14	from WH to station	6
from pressure to working desk	6	from station to working table	6
from working desk to machine	5		
from machine to working desk	9	Automatic:	
Manual:		from station to incoming material	4
from station to in/out	7	from incoming material to WH	4
from in/out to drawer	8	from WH to machine	5
from drawer to station	15	from machine to working table	5
from station to pressure	8		
from pressure to working desk	12	3rd operator:	
Combined:		from closing process to WH	4
from working desk to oven	70	from WH to other WH	6
from oven to pressure	100	from WH to closing process	4
from pressure to working desk (disassembly)	15	from closing process to working table	4
from wroking desk to drawer	7	from working table to closing process	4
from drawer to working desk	5	from closing process to carrello	9
		from carrello to oven	50
		from oven to disassembly	40
		from disassembly to WH	4
		from WH to closing process	5

Table 7 Hypothesis descriptions

In the first hypothesis the layout of the cell is a typical u-shaped cell, the two operators in this case share the same working table. In this case the input material warehouse and the dresser for the jig remains in common. The layout in this case allows to combine the trip to the oven station, because considering the cycle time of the automatic machine that is considerably lower than the manual process, the operator of the automatic machine can do the travel to the oven also taking the plate of the other one. In a situation like this the number of plates performed by the automatic one will be higher so considering a daily production of 14 sandwich for the automatic and 10 for the manual, the cost will be:

manual	0.83 second/sandwich	10 sandwich/daily
automatic	0.82 minutes/sandwich	14 sandwich(daily
combined	3.28 minutes/travel	4 trips/daily
manual	130 €/monthly	1560€/yearly
automatic	371 €/monthly	4705.4€yearly
yearly cost		6021.4€

Table 8 Hypothesis 1 cost

## Hypothesis 2

In this second configuration is considered in the area additional equipment to make the two type of gluing process separated and independent. In addition, in this case it is considered a third operator that does not perform the gluing operation but only take the glued plate from the other two operators and perform the montage of plates on the jig, closing the pressure system and after getting the trolley to arrive to the ovens. It is considered also the disassembly operation after the trip to the oven in order to put the tools utilized for the gluing as the jig and the pressure system in the initial position, making them available for the following process.

Manual	0.33 minutes/sandwich	10.4
Automatic	0.30 minutes/sandwich	14
third operator	2.16 minutes/sandwich	4.1 number of travel
Manual cost	52 €/monthly	
Automatic cost	63 €/monthly	
Third operator cost	132.16 €/monthly	
Total and total yearly cost	249.97 €/monthly	2999.6 <b>∉</b> yearly

Table 9 Hypothesis 2 cost

# Radical Countermeasures

## Final Washing Defect Identifier

Starting from the root causes of referring to another operator about a problem and hard identification of responsible person we have come up with another countermeasure which is actually for the use of back-end department in final washing phase, but the benefit of the tool is expected directly in the front-end department.

Firstly, we have collected all types of problems happened till today while doing the final washing in back-end department. The example of that is shown here on excel sheet:

Assembled	Inserire: Nome progetto	Inserire: ID code	UD1	Тор	Parylene	Parylene: no	Parylene: Rifare parylene
Kit			UD2	Bottom	Graffio	Graffio: inserire le misure (x)	Graffio: (<5) La piastra è adatta per passare alla fase successiva, (>5) Contatta ingegnere di processo)
			LD		Macchia	Macchia: Inserire lungezza massima (x) e distanza area attiva (y)	Macchia: (x<5, y>5) La piastra è adatta per passare alla fase successiva, (else) Contatta ingegnere di processo
					Sbeccatura	Sbeccatura: Inserire posizione (x)	Sbeccatura: Contatta ingegnere di processo (inserire la foto) (e-mail: alessandro.bonetto@technoprobe.com)
					Gap	Gap: Inserire la misura (x)	Gap: (x<10, 10 <x<20) (="" adatta="" alla="" fase="" la="" passare="" per="" piastra="" successiva,="" è="">20) Rifare l'incollaggio</x<20)>
					Altri	Altri:	Contatta ingegnere di processo (inserire la foto) (e-mail: alessandro.bonetto@technoprobe.com)
							Ciao Alessandro, (table, picture) Il seguente difetto è derogabile? Grazie! (borderline)
							Ciao Alessandro, (picture) Il seguente difetto non è presente nel CP, che recovery plan possiamo attuare? Grazie!
							Ciao Alessandro, (picture) (table) Il seguente difetto non è derogabile, procediamo con il rework. Grazie!

### Figure 29 Defect types

The interface of the tool has been developed by the use of WPF (Windows Presentation Foundation) and it is possible to fill some information such as:

- ✓ Type of set: Assembled/Kit
- ✓ Name of project
- ✓ ID code
- ✓ Type of defect:
  - o Parylene
  - o Graffio
  - o Macchia
  - o Sbeccatura
  - o Gap
  - o Others
- $\checkmark$  The dimension(s) of the defect
- $\checkmark$  Type of layer (changes according to the first selection)
- ✓ Top/Bottom Layer
- ✓ Image of the defect (if needed)

✓ Set limits of dimensions (for engineers)

According to the limits set by engineers beforehand and the data input by operators, the tool either decides that the set is appropriate to move to the next stage, or in case of some specific cases shows directly the next needed operation to proceed, or it automatically sends an email to the engineer including all the input data.

Defect Identifier			_		×
Tipo di set	Tipo di layer				
~	~				
Nome progetto	Top/Bottom				
	~				
ID code					7
	Select Image				
Tipo di difetto	·,		•	•	
~	Set Limits				
Send	email	]			
		-			

Figure 30 Defect Identifier Main Window

This email either can be related to the borderline cases where it has to be decided by engineers to proceed or not, or it can also be some cases that have never happened before, or even the cases that was not present in CP.

Defect Identifier			×	Defect Identifier		_	×
Tipo di set	Tipo di layer			Tipo di set	Tipo di layer		
Assembled ~	v .			Kit ~	UD2 ~		
Nome progetto	Top/Bottom			Nome progetto	Top/Bottom		
ТРРН				ТРРТ	Bottom ~		
ID code				ID code			
TP12345	Select Image			TP1233	Select Image	V	
Tipo di difetto		•		Tipo di difetto		•	
Macchia ~	Set Limits			Parylene ~	Set Limits		
Inserire lungezza ma:	Distanza area attiva			-			
3	9						
La piastra è adatta fase successiva	per passare alla			Rifare parylene			
Send	Email			Save	To DB		

Below there are shown two types of response example provided by the tool.

Figure 31 Examples of some selections

Here it is also shown the example of automatic email generated by the tool, this time being about the problem that has to be reworked. By means of this tool it is possible to proceed immediately without waiting for the instructions of responsible person in some certain cases.

Difetto Inbox ×	Ð	Ľ
technoprobe.finalwash@gmail.com © Wed, Feb 10, 9:41 PM	*	:
Ciao Alessandro, Il seguente difetto non è derogabile, procediamo con il rework. Grazie!		
Nome - Gulnar		
IDCode - juz7		
Topi di Layer - UD1		
Top/Bottom - Bottom		
Difetto - Gap		
Misura - 4		
Decisione - La piastra è adatta per passare alla fase successiva		
Data - 2/10/2021 9:41:56 PM		



Figure 32 Email example

## New Layout of the Department

The layout corresponds to a radical change for the company as it takes a long time to implement as well as a large investment and the involvement of operators and personnel from different areas. In addition to this, technical assessments must be made to determine the exact location of machinery and equipment in the department, as the machinery uses facilities that are not available on the entire department. An example of that fact is that laser machines must be powered by pipes that cannot reach the whole area but only in specific positions, the same happens with the parylene machine that must be able to exchange the internal liquid after completing the operation and it is possible only in determined areas. What we have noticed from the initial situation is that the current position of the areas within the department does not respect the production flow of the probe head, many movements are overlapped and without added value. For this reason, having soon available new space for the department, we thought of a reconfiguration of the present areas using the **ALDEP** method. This method is used to make a layout starting from scratch.

As a starting situation, **ALDEP** uses as data:

Manual

- the measure of the department which is converted into blocks \_
- the size of the various areas within the department
- the width to be used in the filling process when implementing the method \_
- the relationships between the various areas present



Figure 33 Actual layout configuration

## **Determination of Number of Blocks Available**

The size of the department and the areas inside it are expressed in blocks, so the first operation to do was to measure the exact square meters of the current area in the department. We did not do the same with machines present in the department because the space occupied by laser, lowering and kapton machines depends on the number and this will be determined by considerations regarding the production capacity to be achieved in future. The percentages shown here refer to the meters occupied by the different areas within the manual part of the department.

	Actual proportion in the area	Area
Control and measurament	16,4%	16,3692308
Laser Drilling		
Kapton Cutting		
Ultrasound Washing	3,0%	2,3232
Assembly	11,0%	10,9846154
Gluing	10,9%	10,8923077
Oven	18,5%	18,4615385
Parylene	10,5%	10,4615385
Acid	Not move	
Sandbllasting	Not move	

Understanding what the relationships between the areas in terms of size are we can determine what will be the space to be allocated in the future layout. In addition to this, during the first visit to the department, we took steps to take an inventory of all the tables and equipment in the department, in the part relating to gluing that will be transferred together with the workstations in the new layout. It is important to identify this type of equipment as all the manual processes will be place

in another area, so it is relevant to allocate some space in the consideration for the layout for positioning the equipment that are used by operators as desks and inventories for the department.

Name	Number	Notes
Small desk	8	
Regular desk	41	
Big desk	4	
Big oven	2	
Small oven	3	on desks
Washing station		
(ultrasound station)	3	1 strange near s***
Plasma	1	on a small desk
Inventory shelf	17	1 outside
Drawer	4	
Small inventory shelf	3	
S***	1	

The equipment actually present in the department is listed here:

Starting from a possible space available for the department, we have reproduced the layout proposal by calculating the number of blocks destined for the new layout. Therefore, starting from the elements required by the ALDEP, we represent here the space available for the new layout to be filled. In general, what matters the most is not the exact area but the logic of the method that can be applied to different shapes without any constraint. The one represented here therefore represents a company area but can also be considered taking into account other spaces.



Listening to the suggestions given by the operators and company tutor having two separate areas available, we have assigned one of these to laser machines, some of which have already been bought but not yet positioned and the other part, the lower one, to manual processes.

Having more space available for the manual department, i.e. the lower part of the layout shown in the figure, we have decided to relate the current situation to the growth in demand expected for the next few months so that the manual departments also have a related capacity to this. In this way we have come to estimate the square meters to be used for each manual area in the new layout and subsequently convert this into number of blocks.

		Actual Area	New Area	Number of blocks
Control and measurament	16,4%	16,3692308	22,91692308	187
Laser Drilling				0
Laser Lowering				0
Cutting Frames				0
Kapton Cutting				0
Ultrasound Washing	3,0%	2,3	3,22	26
Assembly	11,0%	10,9846154	15,37846154	126
Gluing	10,9%	10,8923077	15,24923077	124
Oven	18,5%	18,4615385	25,84615385	151
Parylene	10,5%	10,4615385	14,64615385	120
Incoming material				30
Final Washing				52

For the other elements present in the department we have not considered a direct correlation as in this case because the evaluation of the number of machines to be placed in the department includes technical evaluations by the company.

## **Determination of Relation Of Different Areas**

After having determined the number of blocks, in order to proceed with the positioning, the ALDEP algorithm requires to calculate the relationships existing between the various areas and each of these relationships will be classified with a letter indicating the importance of the proximity between two areas. The type of relationship is subsequently assigned to a score, which added together for each relationship present in the "to be" layout will determine the total score for the proposed layout.

RELATION	DESCRIPTION	POINTS
Α	<ul><li>Flow related</li><li>Need to stay in the same area (in contact)</li></ul>	64
Е	<ul> <li>Flow related</li> <li>Highly liked</li> <li>Also in a different area (not in contact)</li> </ul>	16
I	<ul><li>Flow related</li><li>Closeness not so important</li></ul>	4
U	<ul><li>The closeness it's not important</li><li>No flow connection</li></ul>	0
X	<ul><li>Undesirable</li><li>Process constrain to stay in different areas</li></ul>	-1024

Based on the relationship between a generic department x and department y, this proximity will be evaluated in points which will contribute to the total score of the layout. In order to move forward to the evaluation of the relations present in the layout, with the help of the company tutor and the operators specialized in specific phases of the process, we have assigned a score for each possible combination; These relationships can be observed in the diagram below, where the relationship of each area is compared with all the other areas present in the department:



Figure 34 Aldep relationships

In this diagram there are all the possible relationships within the department, to interpret it just follow the diagram up to the corresponding box, for example the "A" present at the crossing point between laser drilling and lowering means that it is very important that these two elements are close together from a layout perspective because the two process are highly related. Contrary to this, in the case of the relation "x" it is important to keep the two areas apart, as happens in the case of the oven area which due to the heat emitted is important not to be positioned near areas which are sensitive to temperature variations.

### Legend of The Areas

In order to easily identify the areas that will be present in the layout to be, we have created a legend where each area will have associated a certain color and a letter. These colors will be used in the "to be" layout to fill the area of the new available space, in order to make more evident the distinction of the areas present in the layout.

#### **Insertion process and various hypotheses**

The insertion method consists in choosing the first department to be inserted randomly and always starting to insert from the same side of the layout. After entering the first department we must go and consider the department that has the highest score ratio and place it next to it. For positioning, a predetermined width of two blocks has been considered in the layout, so from top to bottom the layout will always be filled with two blocks in two, once you get to the bottom of the layout at the bottom you go back to the top always keeping the width of two blocks. In these cases, starting from different initial situations, the algorithm can therefore generate different solutions depending on the initial choice. The number of combination possible is high and each one of the combination generated will have a different score.

Legend	
С	Control and measurament
D	Laser Drilling
L	Laser Lowering
F	Cutting Frames
К	Kapton Cutting
U	Ultrasound Washing
S	Assembly
G	Gluing
0	Oven
Р	Parylene
А	Acid
В	Sandbllasting
Ι	Final Washing
М	Incoming Material

In hypothesis 1 we started the insertion starting from the "parylene" department on the left. The following department that will be positioned corresponds to the one with the best relationship with the "parylene" and so on proceeding, always taking into account the last department inserted.



## **Calculation of relations hypothesis 1**

Once the entire layout has been filled, we proceed to calculate the score of the considered layout, counting the points relating to the upper (laser machines) and lower (manual area).

DEPARTMENTS	CODE	RELATIONS	ALDEP POIN
D-L		64	А
D-M		16	E
D-F		64	А
D-U		16	E
D-K		64	А
P-S		16	E
S-0		4	1
0-G		16	E
G-I		0	U
I-C		4	1
K-L		64	А
L-M		16	E
M-F		16	E
F-U		16	E
total		376	
14		26,85714286	

Once the total points generated by the layout have been added, we divide by the number of present relationships to get the average score of the present relationships in the layout. In this case the average value of relationship presents in the layout is equal to 26.



The second hypothesis instead considers the area of the ovens as a starting point, consequently completing the lower part of the layout in this one, we will have in the upper part the microscopes in the same area of the laser machines.

## **Calculation hypothesis 2**

DEPARTMENTS	CODE	RELATIONS	ALDEP POINT
D-C		4	1
D-M		16	E
U-M		0	U
U-F		16	E
G-C		0	U
G-I		0	U
I-P		4	1
S-P		16	E
S-K		64	A
K-L		64	A
L-F		64	Α
D-U		16	E
D-F		64	Α
0-G		16	E
total		344	
14		24,57142857	

The score in this case is lower than the previous case with an average value of 24 points and also in this considerations is possible to detect a negative effect on temperature by the part relative to the oven that is positioned near the area related to microscope, where conditions must be stable.



## **Calculation hypothesis 3**

	HEDELLOUI
16	E
16	E
64	А
64	А
64	А
0	U
16	E
64	А
64	А
16	E
0	U
432	
30,85714286	
	16 16 64 64 0 16 64 64 64 16 16 16 16 16 43 432

In this case we achieve the higher average value, considering 14 relationships present in the layout the average value is 30. It corresponds to the higher value achieved using the ALDEP method. This value assures us that within the department the different areas have a good relationship of proximity and this favors the flow both in terms of movements and from a qualitative point of view. This is because in the calculation of the final score the letters take into account both positional and qualitative aspects.
#### Implement Countermeasures

#### **Rework Identification Tool**

After having the tool ready we have decided to implement it in order to see its benefits in the identification and registration part and then later to calculate its long-term impacts. Firstly, we showed the tool to our company tutor and asked his opinion about the tool's applicability. He seemed very enthusiastic since the tool seemed to be very effective and easy to use. Therefore, to begin with, we have explained the tool and each step of it to one operator who was the main person

to identify and register the problems when there are some. In the beginning he did not seem very happy as the operators do not like changes a lot since they think that it would be hard to get used to new operations. However, after explaining all the steps and showing also the excel file automatically generated, he was very surprised and satisfied with the result. Because now it was possible to register the problem by only making some selections which have already been listed without typing the problems manually.

We have also showed the tool to the head of the department displaying the excel file and the



Figure 35 Implementation of Tool

automatic dashboard on the screen as well. He was very happy with the tool; since the excel file that is generated changes each time there is a new insertion of the problem and the dashboard is updated automatically it will help to manager and the engineers to visualize the problematic areas quickly which in turn will help them to intervene immediately and win the customer order increasing the customer satisfaction by reducing the possible delays as well as saving cost.

Following this, we have installed the tool to the PC of the operator, and we have organized a small training to explain the usage of the tool in order to avoid possible mistakes and answer the questions that may arise during the utilization. The operator understood the procedure and noted that he could explain the tool for the other operators too, since it is quite simple and easy to use.

#### Laser Optimizer Macro

The implementation phase was carried out directly in the department, because for this program the only equipment required corresponds to a PC and all those that are present in the department. There is no cost of implementation because additional software of equipment is not required. The only effort to implement this countermeasure is in terms of time, in fact for understanding the functioning of the program we have carried out the training activity. In order to facilitate the learning of the Laser Optimizer we have also built a quick manual where the principal functions of the program are listed with the operations to do.

Figure 36 Manual for Macro

After some tests, a problem occurred in the program, in fact, in doing the searching activities the identification code of the laser shown in the table corresponded to laser assigned to other productions. In this case, it is not possible to interrupt the process so the program is no longer usable for this technology because it will always show the same result.

We decided to upgrade the program by also inserting the possibility to set the different laser machines as "free" or in "busy" before performing the searching activity in a very easy way.

In this way setting a laser as "busy" before pressing the button "search" will exclude the lasers that are processing other plates and in this case all the laser machines found in the program are definitely available machines ready to start the drilling process.

Wafer Probing Technologies	OCCUPA				
CONF.LOW1 CONF.MEDIU CONF.HIGH 1 CONF.HIGH 2	UBERA				
Ļ					
Microsoft Excel Laser da Renare Laser da Renar					

Figure 37 New addition to macro

After the finalization, we showed the program developed to the head of the department and he was very enthusiastic because by having added this last function it is possible to use the program in the department maintaining the status of the laser updated. In the concern of operators, the program will help not only in the searching activity, but it is a forward step to the optimal scheduling of operations to assign the laser machine considering the daily WIP of the planning phase in the department.

## New Layout of the Department

After showing the layout from a graphic point of view using the ALDEP, our team decided to show the layout found considering also the arrangement of the equipment. This was done to understand if there is enough space in the dedicated space to introduce the necessary equipment such as the presence in the same work cell of the manual and automatic gluing machine.

Inside the layout, the flow is indicated with arrows of different colors relating to the process with the machines and the manual one. We decided to represent the two solutions with the highest score from the ALDEP relationships calculation.

### Layout hypothesis 1



In this first hypothesis all the machines are positioned in the upper part of the layout while the manual areas in the lower one, this layout also allows to keep separate the part relating to the microscopes which, not being affected by the influence of the machining of the machines, can make more precise measurements not altered by temperature changes that modify the structure of the ceramic inside the probe head. It is also possible to dedicate one area to the oven and to positioning a microscope in a strategic position because in this case can be used by operators of the sandwich phase without having to go to opposite side of the department.



#### Layout hypothesis 3

In this case, as in the previous, the area relating to the laser machines is separate from the manual one. The area of the ovens that affects the temperature is positioned at the end of the layout, thus

positively impacting the quality. In this case the flow respects the phases of the probe head without having to cover unnecessary movements. In this case having obtained a higher score through ALDEP, we have decided to also analyze the movements that are made for an entire process in the case of this disposition. For doing that we decided to follow the same method used for the actual situation, the spaghetti chart, representing movements with traits with similar dimension to be able to compare them.



## Analysis of movements

Figure 38 Spaghetti Chart to be layout

## Monitor Results and Process

Starting from the layout that emerged from hypothesis 3, taking into account the square footage of the new available space, start from the evaluation of movements present in the Spaghetti Chart, we estimated the movement times for the entire process.

As regards the times, we considered the same reference table used in the analysis of the spaghetti chart in the current situation chapter. In the tables are estimated times for an entire process respectively for the current situation and for the "to be" situation found with the ALDEP method.

Incoming material	Setup Progetto	27
Setup Progetto	Lowering	13
Lowering	Laser	10
Laser	Lavaggio e asciug	15
Lavaggio e asciug	Attacco Acido	75
Attacco Acido	Controllo Werth	85
Controllo Werth	Glueing	12
Glueing	Ciclo Stufa	10
Ciclo Stufa	Sabbiatura e lavag	66
Sabbiatura e lavag	Controllo Werth	67
Controllo Werth	Parylene	5
Parylene	Sandwich	8



TOTAL: 6,55 min

	N
	>

Incoming material	Setup Progetto	3
Setup Progetto	Lowering	18
Lowering	Laser	8
Laser	Lavaggio e asciugatura	18
Lavaggio e asciugatura	Attacco Acido	25
Attacco Acido	Controllo Werth	25
Controllo Werth	Glueing	18
Glueing	Ciclo Stufa	15
Ciclo Stufa	Sabbiatura e lavaggio	30
Sabbiatura e lavaggio	Controllo Werth	20
Controllo Werth	Parylene	10
Parylene	Sandwich	13

Figure 40 To be layout times

TOTAL: 3,3 min

Considering the table, obtaining a reduction of 3,2 minutes, taking into account the current output of the department, which has already mentioned is estimated to increase for this year, the number of hours we would save in a year has a value equal to 470 hours.

Assuming, as for the other calculations, an average hourly cost per operator of  $30 \in it$  is possible to achieve a cost saving of  $14127 \in in$  a year only considering movements. This number is significantly larger if we also consider the impact from a qualitative point of view, as the reworks

have a huge impact on costs as the extra time required and additional material, that being so delicate and precise has an high price for layer.

## Qualitative consideration

We will have enormous positive impacts also in terms of quality as the handling of ceramics will decrease and the area divided in a different way. For this reason, it is useful to highlight the benefits of the layout also from a qualitative point of view.

## BENEFIT

- Less motion
- Less leadtime
- Less rework connected to handling
- Better control parameters (temperature)
- Control Machine in a separate area
- Better scheduling of process
- Less setup time of machines (dedication laser machine to customer)
- Less WIP inside the department
- **Higher dedication** of operators (laser areagluing area)

## DRAWBACKS

- High cost of implementation
- Additional workforce
- Additional equipment
- Need of adaptation
- Need of coordination

### STRUCTURAL CHANGES

- Automatic-manual gluing machine work cell
- Machine arrangement according to strategic customer
- The control area (microscope) in a dedicated spaced without any interferences from others areas in the department
- Sandwich area dedicated only to this operations

#### **Rework Identification Tool**

As we have installed and explained the procedure of using the tool to the operator, we have asked him to use the tool for the next 14 days instead of their conventional method in order to see the results of the tool. He agreed and started to use the tool for the problems arising within the department. We would be observing and measuring the time each time he registers the problem. In the first day of implementation, it took nearly 84 seconds to register the problem which was certainly higher than what we have estimated before. As it was the first day of the implementation, it was hard to get used to it immediately since they have to experience it more to find the right description of the problem which is written in the list and to find the excel file in the PC which is automatically generated.

We could measure the usage of tool only for three days within 14 days' time frame as it is not every day that there occurs a problem in the department. However, even for three days we achieved to see the result we were expecting as the operator was a fast-learner and found it very easy to use it.

Since we were able to reduce identification the and registration time to 55 seconds, we can now calculate the time and therefore the cost





we are saving by this method. For doing so, we have estimated the average time needed to identify and register the problem in sandwich phase which we have observed during the current situation analysis. We have found the average of two most relevant observations considering only the time taken for the abovementioned activities. This resulted to be 6.24 minutes. This means 6.24 \* 60 -

Day 1	84 seconds
Day 2	62 seconds
Day 3	55 seconds

55 = 5.33 minutes of saving per rework/repair and this means nearly 83% reduction in the activity. Starting from here we can calculate the lead time reduction of 0.08% considering the usage of tool in both Gluing & Sandwich and Laser Drilling operations and this is very close to our nice to have target of sandwich inefficiency problem which

was 0.082%. The saved time can later be translated into 5.69 days in a month and the average number of rework/repairs saved can be taken as 4 per month. Therefore, we can estimate the benefit of the tool both considering the cost of labor and cost of poor-quality saving. The former resulted to be 49,000 Euros/year and the latter 14,400 Euros/year.

As the tool, especially the dashboard helps to focus on the problematic areas and detect the problems beforehand we expect to increase the corrective factor that we have introduced before to 2 from 1.5, since the engineers found the tool to be very useful to do so. This means that the overall time that rework/repair takes to be worked on, will decrease substantially from 6882.85 minutes to 5162.14 minutes which means 25% of reduction. As the rework time decreases this will definitely have the impact on lead time considering the occurrence of rework in the normal production. However, as it is mentioned before, tool will also help to reduce the occurrence of rework/repairs since it is possible to detect the focus area and prevent some of the possible problems thanks to the well-structured and organized records of previous problems. With small projection and also following the instructions of our company tutor we have defined the saving in the number of rework/repairs 4 in one month. This means that the new occurrence of the rework in the department will be 0.09 which was 0.1 previously. Therefore, we can calculate the impact of the tool on the lead time. Considering the new corrective factor and the occurrence of

rework/repairs the lead time can be reduced to 1.60% by reducing the impact of rework/repair problem to 3.78% from 5.38%. Since we have developed this countermeasure for reducing the occurrence of rework/repairs and solving the problem of manual operations in identification and registration of the problems this countermeasure addresses the problems of



Table 11 Overall results of Tool

rework and sandwich together that we have identified during the current situation analysis. Nice to have target for them together was 1.214% and this means that by means of Rework Identification Tool we are able to reach and even surpass our nice to have target by having 1.68% of reduction in lead time. Furthermore, it is possible to see the productivity increase of 11% (30 sandwiches more in a month) in sandwich process with the same number of resources.

Summing the achieved (A) and expected (E) benefits of the tool up, we can see the results in the figure shown here.

#### Laser Optimizer Macro

The benefit of the program developed by our team consists of the reduction of the idle time of laser machines. The operator after an initial training can start to use the program in an autonomous way because the type of data needed in the macro is simple and easy to get.

In this consideration the starting point present in the data provided by the computer near laser machine that shows the percentages related to different states of the laser machines. The hours related to the setup that are fully about the hole test operation are 96.86 h, that corresponds to 387.44h/monthly. In total for the month that we decided to take in consideration 774 minutes/daily are used for the set-up activity consists of the hole test, without taking into account the unloading and loading operation of the operator on the machine. Performing the implementation activity in the department with the operators dedicated to the allocation of the plate to the laser machine, by using the daily WIP as a reference we realized that the number of new technologies required each month is highly variable depending on customer requests.

On average, the operator searches for the laser machine 6 times a day.

The previous method for understanding if the laser machine needs the hole test operation requires the operators to check visually row by row in the past production of the laser machine and to check in additional file for assuring the power and the characteristics of the laser machine.

These operations are required every time that a plate is assigned, and it is inevitable to make a mistake.

The average number of minutes to search for the laser that corresponds to the non-value-added time is on average 11.6 minutes/sandwich. In doing some test with the Laser Optimizer program the time required decreases to 1.9 minutes/sandwich because only few information has to be inserted.

Considering the time saved every day in the searching operation for the laser machine, taking  $30 \notin h$  as hourly cost for the operator, the yearly saving corresponds to  $10476 \notin$ 

Considering the idle time of the machine, the decrement comes from the fact that from the "actual production" sheet it is possible to immediately understand at which times machines will end the process. In case a machine is not working because technologies available in the WIP require hole test on that machine and they can notice from using the program that the next machines that will end require the hole test as well, it is possible to dedicate an operator in advance to perform the

hole test on that laser machine and not waiting for the other machines finishing. After the hole test the machine will be usable for the production, decreasing the previous standby time.

According to operators and also following the instructions of our company tutor, we can say that standby no product for each laser machine decreases from a value estimated as 26.2 h/weekly to 24.4h/weekly on average. In this way, impacting the time required for the set up and the standby time of the machine it is possible to have a higher production capacity in the laser machines, decreasing the WIP of plate waiting for the laser machines to be processed. Considering an initial WIP of 14 plates and adding the production capacity in the laser machine, the WIP before laser machines decreases by 3.1 units, thus the impact is 1.42% reduction on the lead time.

#### New Gluing Workstation

Having selected the second hypothesis it is expected to reduce the NVA activities by nearly 77% which can be translated into 0.08% of lead time reduction and mainly 65% increase of productivity in gluing process meaning about 390 sets more in a month.

NVA before	12.42	min
NVA after	2.8	min
Extra time saving	9.62	min
CT before	24	min
CT now	14.38	min
1 shift production before	20	sandwiches
1 shift production now	33	sandwiches
Productivity increase	65.00%	
Labor cost saving	3520.92	Euros/month
	42251.04	Euros/year

Table 12 Gluing final calculations

In this case considering the actual demand for sandwich it is possible to increase the capacity of 13 sandwiches in a shift, instead maintaining it at the same level it is possible to have a save in a year equivalent to more than 40.000€considering only labor cost saving.

#### Defect Identifier

As we have already mentioned before, this tool will be implemented in the backend department while the main benefits are expected to be seen in the frontend department. It is quite difficult to measure the lead time reduction without implementing the tool and using it repetitively and regularly. However, we have identified a bunch of expected benefits of the tool even if not qualitatively. These are:

- ✓ Reduction of lead time
- ✓ Reduction of rework time
- ✓ Easier identification of problem/the way to proceed
- ✓ Customer delay reduction
- ✓ Customer satisfaction
- ✓ More reactive approach to reworks
- ✓ Reduction in human reworks (more automatic process of procedure)
- ✓ Reduction in time for training the operators of final washing
- ✓ Elimination of need of learning CP (control plan) for the operators
- ✓ Standardization of process
- ✓ Making the unit department more independent from process engineers

## Standardize And Future Considerations

## Rework Identification Tool

In order to achieve more benefits, it is fundamental to keep regular use of the tool and communicate the changes within the department as well as sharing the advantages that is provided through the medium of the tool. Since the tool contains the list of possible problems embedded into the program it will be needed to change the list adding the type of problems that have never occurred before and will happen more frequently due to the new configuration or new habits of the operators etc. or removing the ones that does not occur very frequently anymore in order to improve the applicability of the tool as well as reducing the time it takes to fill all the needed gaps to register the problem.

#### Laser Optimizer Macro

The solution proposed for the choice of the laser machine represents a new direction for the planning regarding the technology to assign to the laser machine. The idle time of the machines increase also depending on the availability of other equipment in the department as the control machines. The operation of hole test requires in fact a following check in the control machine. Actually, the control machines in the department are 3 but operating on the whole production of the PH FE department, their capacity is always saturated and in case it is testing another plate the waiting time can be considerable. In this case the machine that was doing the hole test has to wait for the plate being checked in microscope, losing in this way useful production capacity.

The solution will be improving the tool for the selection of the laser machine taking into consideration also the present situation of control machines. In this direction it might be useful to assign the products to check the control machines depending on the technology or the pin count, taking a machine ready in a short time in case of a check required for the hole test. In case for example a control machine only performs plates with a lower pin count, the time interval between one control and another decreases, this machine will be ready in less time to check the plate of the hole test. Another direction that could be possible to follow in order to maximize the effect of the macro is to put the system connected in a direct way with the present state of the laser machine because in the program the actual presented status of the machine requires to be updated manually by the operator. This constitutes a limit because it needs an additional check by the operators to ensure the actual status of the machine.

#### New Gluing Workstation

This layout takes in account three operators that are only partially dedicated to the gluing phase. In this case movements of two operators dedicated to the gluing are confined to a small area because the third operator performs the other operations that require longer movements. Some important considerations were made together with the operator that has a long experience in the gluing activity.

1	The table serves as support for both the operators, the one of the manual gluing processes and the one of the automatic machines. In the table made by iron material are positioned the glued plates, they slide directly to the closing process and jig insertion table where there is the other operator.
2	One operator that it is only partially dedicated to this operation, the other 2 operators don't have to change their position
3	It is considered a table with two shelves, so the operator does not have to move to take the pressure system. The most used pressure systems are positioned in this shelf and the other one in the secondary pressure system warehouse. The operator can take the pressure systems from the upper shelf and start working.
4	The operator dedicated to the assembly operation and the pressure system, after the oven phase can be positioned here for disassembly and put the gig again in the right warehouse.
5	It is possible to put two incoming material warehouses, because the automatic process and the manual one work on different technology, in order to not have to search in the incoming material, the operators can easily access to this one

In this new layout it is possible to highlight some noticeable variation that is suggested in order to optimize the process in the gluing area, the equipment features are summarized as in the table.



Figure 39 New workstation for Gluing

#### Layout change consideration

The layout configuration in a new perspective will have to change taking into account the advancement of current processing technologies currently present. Some operations will have to be integrated into the production flow while others will be removed. Starting from the set of laser machines, the pool of laser will have to be modified also taking into account the integration of different machines because the required technologies have changed. Operations such as sandblasting, on the other hand, will gradually decrease, considering that the precision obtained by automatic gluing will allow to avoid the sandblasting process. By reducing internal handling through the layout proposal, it is also easier to delimit operators in certain areas, increasing their level of specialization. Another direction recommended for the company consists, once the available space will make it possible to integrate the machines already purchased, to dedicate a part of the machines to mass production and some others for particular technologies, for tests by the engineering team or for last minute orders. As regards the laser machines and microscopes area, it will be possible to dedicate some of these to specific customers, in order to increase the volumes by reducing the machine calibrations and to be more flexible in the event of an order or a specific requirement of this customers.

#### Defect Identifier

After having discussed with engineers and responsible operators for final washing/check phase, we have suggested some further suggestions in order to keep the beneficial use of the tool for better future results. In order to see the considerable result, it is suggested to utilize the tool regularly by filling all the needed information. "Set limits" button on the window is for the sole use of engineers to set the acceptable boundaries of the measures of each kind of defect. These boundaries help the tool to define and demonstrate the correct and necessary order to proceed accordingly. Moreover, it is also possible to set the tolerance limit for the defects to be accepted to proceed or to send to rework. Right now, it is set to 0.2, but according to the operations and demand requests it is possible to change it respectively.

# Overview of Final Results

These results are only based on the incremental countermeasures. More benefits are expected with the implementation of radical countermeasures as well.

Root Cause	Countermeasure	Before Countermeasure	After Countermeasure	Reduction
Random selection of	Laser Optimizer Macro	6.46% on LT	5.03% on LT	22.07%
machines		0.57 days	0.44 days	
Poor scheduling				
Manual registration	Rework Identification	5.56% on LT	3.92% on LT	29.46%
Data collection	Tool	0.49 days	0.35 days	
• Identification of problems				
Workstation organization	New Gluing	0.1% on LT	0.02% on LT	77.46%
Shelves in disorder	Workstation	12.42 minutes	2.8 minutes	

	Achieved		Expected		TOTAL
LT reduction	1.68%	215	+1.5%	+190	3.18%
		minutes		minutes	(6.8 hours)
Productivity increase in			65%	390 sets	
Gluing				more/month	
Productivity increase in	11%	30 sandwiches			
Sandwich		more/month			
«Rework LT» reduction			25%	29 hours	
Yearly labour cost			101,000€		
reduction					
Yearly cost of poor-			14,400€		
quality reduction					

## Conclusion

To sum up, it was very stimulating project with a lot of challenges and milestones. The results were quite substantial on a large scale considering the industry company operates in and the extremely expensive and time-consuming production even if it seems not very high looking at the numbers. Throughout the project we have encountered a lot of peaks and troughs and all of them motivated us to push our boundaries to achieve a significant result in the end. The outcomes have been positively accepted by the company and the applicability of the suggested countermeasures have been approved. We have grasped the true importance of teamwork, cooperation, communication with company members and university staff as well as acquiring a lot of professional and interpersonal skills that will definitely help us in our future endeavors.

A3



## Experience

In order to describe our experience, we have decided to a use a metaphor. Metaphor that we chose is the relationship between Sherlock Holmes and Dr. John Watson which imitates our team spirit and their way of solving the criminal cases replicates our approach to the handling of our project. The most outstanding part in how they solve the cases is the situational analysis Sherlock does which brings out the clues that plays a significant role in finding the solution. By means of this analysis and key points, Sherlock and John come up with possible ways to explain the incident and select the best and most accurate one that is the ultimate outcome. Likewise, in order to come up with potential countermeasures we have performed the current situation analysis to understand and solve the problem in the most logical and efficient way. To describe the metaphor, we chose in a better way, we are going to compare it with the specific case named "A Study in Pink".

When we started the project, the first task in front of us was to define the problem statement and perform the corresponding current situation analysis with the help of all the data that we have been provided. As how detectives did react, we analyzed the problem background which directed us to a number of problems causing the main issue of our project. This resembles the act of collecting all the clues in the crime scene and coming up with the explanation that Sherlock and John deals with a serial killer.

As the target for the detective and the doctor was to prevent the next crime in the chain, we set our goal of decreasing high lead time to a reasonable amount. In order to reach the objective, we have performed a root cause analysis and currently we are working on suggesting and implementing countermeasures that will aid us in successfully completing our project. "A study in Pink" case represents the successful handling of a tricky case. Achieving the ultimate goal despite all the complexities and obstacles inspires us to implement our countermeasures to deal with the problem that we have defined in the very beginning of the project.

Most of the detectives are capable of solving the cases if independent of time constraints, but the trick is to find the solution most effectively and in no time. This skill becomes more necessary in case of industrial management problems like our project as the soonest and most efficient response is desired from financial and operational point of view in practice. Therefore, successful handling of the project requires a number of skills that should not be underestimated:

Teamwork, reading emotions and motivations effectively

- Critical thinking
- > Attention to details
- > Prioritization

Albeit the communication issues i.e., being based in different cities, sharing very distinct cultures and languages we are succeeding in managing the project as how Sherlock and John always support and back each other. Overcoming this challenge enhances our soft and hard skills which will assist us in the further steps of our project to tackle and deliver it on time and with excellence.

## References

- 1. <u>https://www.technoprobe.com/company/who-we-are/</u>
- 2. https://www.technoprobe.com/company/management-system/
- 3. <u>https://www.vlsiresearch.com/customer-satisfaction-survey/technoprobe-top-probe-card-supplier#page1</u>
- 4. <u>https://lecconotizie.com/economia/merate-economia/nuovo-accordo-alla-da-tor-premio-di-risultato-da-1-500-euro/</u>
- 5. <u>https://www.technoprobe.com/technoprobe-to-acquire-microfabrica/</u>
- 6. <u>https://www.technoprobe.com/company/management-system/</u>
- 7. <u>www.statista.com</u>
- 8. <u>www.absolutereport.com</u>
- 9. <u>www.mckinsey.com</u>
- 10. Data and documents provided by company such as, weekly reports, department presentations, planning reports, demand reports etc.