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MILANO 1863

# PRODUCTION SCHEDULING AND HEIJUNKA IMPLEMENTATION


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# 1. ABSTRACT

This project is the result of a work developed in Microelettrica Scientifica company. A company specialized in the production of electromechanical components. The main objective of this project was to improve the current on-time delivery performance through the implementation of Lean tools in the breaker segment of the company. We used the PDCA cycle as the basis for the development of the work in this project. The project began with the bibliographic review of the main lean methodologies and production scheduling case studies. Then the diagnoses were initiated through a detailed analysis of all the processes required for production in the company leading to the definition of the main root causes of the problem. Moving further, the possible countermeasures were developed, and the most effective ones were selected for implementation. The result of the implementation of such approach to the problem had positive impacts: 29% reduction of late orders to customers and 55% reduction of the WIP.

## 2. EXECUTIVE SUMMARY

Microelettrica Scientifica S.P.A. is an international company based in Buccinasco, Milan, Italy. The company has factories all over of the world like Germany, Brazil, and the USA. It is a global leader in state-of-the-art electromechanical and electronic components and systems for rail vehicles, traction power and energy & industry applications. It is a B2B company specialized in highly customized products to serve every client's need.

The project is developed in the breakers segment of the company. The breakers are automatically operated electrical switches designed to protect an electrical circuit from damage caused by excess current. They are one of the most difficult products to be produced by the company due to their complexity and customization. The competitive advantage of Microelettrica in this sector comes from its great flexibility in handling all the requests of its clients and in the great service level provided. Originally the number of breakers produced were limited and the company could handle with ease all the customers' orders but in recent years the demand had grown with a steady pace and the complexity of the products with it. The goal of the project is to improve the current on time delivery performance of the segment in the most effective way.

The PDCA[1] cycle was the chosen approach to analyze and reach a solution to the problems faced by the company. The first part of the project was dedicated to the collection of data from all functions related to the order processing: sales department, technical office, planning department, warehouse, and production department. Most of the initial work aimed at understanding the tasks carried out by each actor of the process and the type of communication between them. After this initial analysis, the attention focused on the production department as criticalities in all previous activities can influence the production phase. The analysis was carried out with several interviews to representatives from all the departments involved and with the collection of data right from the production process of the breaker segment. Furthermore, the production historical data was analyzed, and interviews performed with the operators of the production system.

The breaker's production system is organized in two major phases, the assembly lines, dedicated to four specific families of products and organized in three stations (sub assembly, final assembly and wiring) and the testing phase, composed by three testing rooms that can be considered as shared resources for all products. The bottleneck of the process is the testing phase and it is also the most fixed resource, since the number of testing rooms cannot be increased and only one operator at the time can work in them. BPMN diagram and value stream mapping are the techniques used to represent the overall process and visualize its criticalities. At the end of the first analysis the target of the project was set as a 15% decrease in the number of orders exceeding the delivery lead time by end of March 2020. A more optimistic nice to have target was set as a 30% reduction of the orders exceeding the delivery lead time. Furthermore, a nice to have target was

[1] Plan, do, check, act cycle

set as a 40% decrease of the WIP[2] level between assembly lines and testing phase by end of March 2020 because the current level is considered unacceptable and induced by an incorrect management of the process.

To represent all the causes of the problems encountered in the previous analysis, 4M Ishikawa Diagram was adopted for use a with the help of 5-way methodology to investigate the cause-effect relationships and determine the deep root causes of the delayed orders. The impact of each root cause was defined with the Process-FMEA[3] (P-FMEA) to better understand the level of risk it poses to the on-time delivery of an order considering frequency of occurrence and visibility. The main problems observed in the process are in the methods and materials criteria.

One of the major causes for the delay of orders is the missing material at the planned start of production, that can be related to four main root causes. The components coming from suppliers could have quality defects, the reorder lead time of components could be higher than expected and there could be delays in the warehouse due to peaks request for feeding of materials. Another important cluster of problems regard the methodology, in the estimation of the needed and available hours in the production planning phase, uncontrolled dispatching logic for the assignment of orders to the testing phase and product specifications and drawings revisions. The concentration of problems in materials and method is to be expected since the breakers require a huge variety of components coming from several suppliers and the segment is recently facing new methodological challenges caused by an increase in demand and higher saturation of the production resources.

Based on the results of the PFMEA analysis and suggested ideas for the solution of the root causes, several countermeasures were proposed. These countermeasures evaluations are based on their initial cost, the expected implementation time, impact on the on-time delivery (OTD) and easiness of implementation (a qualitative measure of how probable was the success of the countermeasure). Then, the AHP[4] method is used to compare the countermeasures based on their evaluation parameters and understand which one to implement. The process engineers of the company and representatives of the involved departments helped in the setting of the parameters of the AHP. Three countermeasures were chosen to be implemented:

1. Development of a production scheduling methodology and visual management support tool

The countermeasure targets the uncontrolled dispatching methodology in the testing phase and the imprecise the definition of the needed workload for the orders (the planning is done without considering some constraints of the testing rooms and with a high time granularity). It was the major focus of the project being the result of a rigorous analysis of the process. As a result, a software tool to help the segment leader and the operators in the planning and monitoring of the production system was built. The tool, realized in excel, is highly automated, easy to use and gives an accurate scheduling of the pieces in the different phases of

[2] Work in progress
[3] Process failure mode and effect analysis
[4] Analytical hierarchy process

production, following an order release logic aimed at the minimization of the late orders. Literature research was conducted to define the best scheduling logic with the objective of minimizing the late orders and the earliest due date logic was found the most fitting. The testing phase is set as the pacemaker of the system. The countermeasures also target the level of WIP in the production system, since in the new logic the assembly lines will produce following the scheduling of the testing room and the buffer between assembly and testing will be minimized.

Furthermore, a new visual tool for the organization of production will be introduced. It is a magnetic board that shows the planned scheduling of the testing rooms and assembly lines represented as stripes of magnetic stickers. The stickers represent the pieces that need to be produced and have different colors depending on the line of origin. Their length represents the average time it takes to finish the product. The operators can now look at the board and understand what needs to be produced in the future and what is the expected time to do so.

2. Improved methodology for updating of critical components lead time

For this countermeasure, the characteristics of components that have caused delays in the past were evaluated because their lead time in the MRP software of the company was incorrect. To tackle this issue, new guidelines for the purchase department to follow are proposed.

3. Improvement of the communication procedure between the sales and production departments for long-term orders in periods of high demand.

For this countermeasure, a solution for the miscommunication error between the sales and planning department was developed. For long-term orders, the order is not communicated immediately to production. In periods of high demand this can lead to an oversaturation of the production system and the delays. Therefore, a new methodology for the sales department was created to follow to help fix the problem.

The second and third countermeasures can be classified as easy to implement, low cost, low impact countermeasures. They were implemented in parallel with the first one and tackle simple problems in the sales and purchasing departments of the company.

The impact of these countermeasures can be measured in a quantitative and qualitative way. The major effect will be on the OTD level. It was not measured yet from real data because the physical implementation is still ongoing. From an analysis of the impacts of the developed countermeasures on the identified root causes, it was estimated and approved with the company that the overall effect will be a 29% reduction of late orders. It is a very good result because it is much higher than the minimum target fixed at 15% and just below the nice to have target of 30% deduction. Furthermore, the reduction on the level of WIP, even if it cannot be measured in the process yet, is estimated theoretically to be 55% which is above the targeted level of 40%. This reduction in WIP can also be translated in cost savings given by the reduced inventory cost and in a decrease of the space required by the buffer.

However, the improvements of the implemented countermeasures are not only limited to quantitative results. The reduction of WIP between testing phase and assembly phase gives more visibility over the problems and inefficiencies of the line. It is necessary for the introduction of a continuous improvement cycle. It will also help in the organization of the workforce since it will be possible to know several days in advance when and where to use overtime and where operators are going to be assigned. The visual management tool will increase the involvement of the operators in the production process, encouraging them to share ideas and feedback with the segment leader. The tool also saves time for the completion of activities that before were conducted with pen and paper by the segment leader. Time that he can invest in other more value adding activities.

A training was given to the process engineers of the company on how the software tool functions and how new assembly lines or testing rooms could be added to it. A standard for the modelling tool of the production system has been created, so that it serves as a base to help other departments in applying the same methodologies in the future as the tool could be modified to fit their specifications. Since changes in the process parameters are common in the breakers' department, an activity of maintenance of the tool is fundamental. The next step for the upgrade of the tool would be to integrate the reorder and feeding of the materials from the warehouse to the line with the scheduling of production. This would simplify the work of the segment leader and would help in the organization of the material feeding from the warehouse which is another criticality of the process.

## 3. INTRODUCTION

The project is developed in an industrial company called Microelettrica Scientifica, which is also part of an international group.

The project will be developed within the Industrial Engineering team. This department’s objective is to promote the same production standards and best practices between the different companies of the group, by applying Lean principles of continuous improvement to ensure that the most effective and efficient methods are applied in different departments of the company. Together with the I.E. team, our focus area will be the breakers segment which is characterized by bulky products that are highly customized and produced in small batch, by a limited and specialized number of people. This creates high fluctuations in cycle times and material supply. The main problem that we will be dealing with is the main delivery KPI below the expectations of the company.

## 4. PROBLEM DEFINITION

The project was born from the need of the company to continuously improve their processes, with a focus on production. The main problem associated with our project is the unsatisfactory percentage of orders exceeding the delivery lead time agreed with the client. This metric is important because it is an indication of the performance of the company in relation to satisfying the agreed deadline with its customers. The responsibility of this metric falls on the I.E. team even though all departments that have direct or indirect effect on the lead time of the orders influence this metric. Solving this problem will allow maintaining healthy customer relationships leading to more satisfied clients by providing a higher perception of value of the service delivered which corresponds to the company’s vision and values.

This problem has two main impacts: an impact on the customer and an economic impact. The impact on the customer can be seen in two aspects first the fidelity and reputation of the company and the creation of customer relationship issues which can lead to the customer dissatisfaction and loss of future opportunities.

As for the economic impact this stems from the fact that there are contractual penalties for late orders delivery. Another reason is the loss of revenues which could have come from the lost opportunities due damaged reputation. The penalty can reach from 5% of the value of the order per late week up to a 20%.

Moving on, it is necessary to define the stakeholders involved and what is their needs and expectations on the output of our project. We start by defining all main departments having an effect or affecting the processes that are related to our project: I.E. department, production department, purchasing department and sales department.

The I.E. department is responsible for the initiation of the project based on the fact of the need to improve the current process of the company due to the existence of inefficiencies which are leading to a delay in the delivery of orders to customers affecting the OTD metric. Their expectation from this project is the improvement of the process to gain a better value of this metric.

The production department is one of the most critical stakeholders of the project as it is responsible for crucial part of the process which has the greatest effect on the lead time of the orders. Their expectation from the initiative to improve the process is to help them improve the variations in the process which leads to higher amount of lead times than what was planned without major modifications on their processes as it would require a lot of effort to make these changes.

The purchasing and sales departments are responsible for managing relations with suppliers and clients to optimize the process of material supply and customer management. The interest of the purchasing and sales department is focused on the receival of input about new methods or process changes to define adequate procedures to optimize their tasks.

# 5. LITERATURE REVIEW

This part is divided into four main sections: First, a review on the lean principles and benefits is explained. Then, a deeper review is made on the lean concepts concerning the scheduling process and then, order release strategies. Finally, a review on several real-world case studies is provided to help get a realistic view from the field on what is relation between practice and theory and also, to have guidance through the process of developing a scheduling in practice.

## 5.1.Lean principles review

At the beginning of the manufacturing revolution, there was not a need for companies to be efficient as the supply was sufficient to meet the demand and there was an excess of labor. Henry Ford’s Model T emergence was the start of mass production concept in the manufacturing world and this had a radical effect on the business because it allowed achieving much lower production costs which, lead to better quality of products. European companies copied this model due to its beneficial effect on business.

Then in 1950 Toyoda receives an invitation to visit Ford’s factory. Through the visit he came to the fact that Ford’s model will not have the same success in Japan as it has a much smaller market with a huge demand for vehicle diversification (Saurin and Ferreira, 2009). Therefore, a need for a new model existed which was the flare that lead to the development of Toyota Production System (TPS) on the hands of the Toyota Motor Company. According to Ohno, the main objective of TPS is to increase production efficiency through elimination of wastes taking into consideration Just-in-Time (JIT) and automation as main pillars. Through time, Toyota’s methodologies developed to becoming today’s Lean Manufacturing (Ohno, 1988).

Lean Philosophy aims to reduce waste in organizations by improving the efficiency of their processes to have a continuous flow of production without interruption. Womack, J & Jones (Womack and Jones, 2003) define 5 principles that serve as a base to Lean. They are:

- Value: Represents the characteristics of a product from the customers perspective. It is paramount to determine the actual and latent needs of the customer. The levels of customer satisfaction and loyalty are higher as the value increases.
- Value Stream: Identifying and mapping all the activities from the planning to the commercialization of the product/service. In this step, the goal is using the customer’s values as a reference point to identify the activities that contribute to these values. Activities that do not add value are considered wastes and should be eliminated to reduce costs and maximize profit.
- Create flow: After removal of the wastes, the insurance that the flow of the process runs smoothly without any interruptions or delays should be maintained.
- Pull: The goal of applying this system is to limit the inventory and work in progress and producing based on real demand. This system allows to produce in small lots, to synchronize with the entire supply chain and to have shorter lead times.

- Continuous improvement: This principle seeks perfection by continuous improvement of the current state which makes lean thinking and continuous process improvement a part of the organizational culture.

Although these five principles are considered fundamental, some authors argue that they contain some weaknesses as they are based on the value chain without taking into consideration creation of value. This led to the proposal of two additional principles: “Know the Stakeholders” and “always innovate”.

According to Melton, the benefits of applying lean principles are reduction of lead time, inventory and costs, lower number of reworks are needed and the opportunity to understand the processes in a better way (Melton, 2005). Currently, there are several tools to represent the process flow, which help us to understand the flow and detect wastes such as Value Stream Mapping (VSM) or the Waste Identification Diagram (WID) (Rosa, Silva and Ferreira, 2017; Sousa *et al.*, 2018).

Alternatively, failure of implementing Lean in several companies lead to the rise of questioning its applicability in all sectors. Shah and Ward (Shah and Ward, 2003) state that aspects such as the maturity of the system has direct influence in the implementation of lean practices, Bamber and Dale (Bamber and Dale, 2000) argue that human factor is fundamental for success, Sawhney suggests that the implementation of lean represents a cultural change in the organization and that companies are not always prepared, Narang (Narang, 2008) mentions the lack of time available to understand the lean methodologies and Melton (Melton, 2005) defends that there is still much resistance in the organizations to change.

## 5.2.Lean concepts on the production scheduling

To get familiar with the production scheduling concepts, a research was led. Knowing that the lean theory generalizes on mainly two production systems, MTS[5] and MTO[6], in this phase the prevalence was given to theory regarding MTO. The research had the main queries: TITLE-ABS-KEY (pacemaker and lean and MTO) and TITLE-ABS-KEY (non-repetitive companies and lean):

According to the paper (Serrano Lasa, De Castro Vila and Goienetxea Uriarte, 2009), the key points on which the production control develops are identification of the order decoupling point, pacemaker, and bottleneck analysis.

The theory presented in this paper is referring to a linear MTO system, meaning that there is a unique and simple flow of products, different from our system in which flows are more complex. The order decoupling point is the point at which the system crosses the boundary between Made-To-Stock and Made-To-Order. The pacemaker is the process in the production system that should be the only scheduling point, giving the production rhythm for the rest of the system. According to the lean philosophy, upstream from this point there

[5] Make to stock
[6] Make to order

is a supermarket (managed through Kanban) while a pull system (for example a FIFO[7]) should be located downstream.

In every manufacturing system the bottleneck is defined as the most loaded resource or work center of the production system. For the choice of the PM, there is not a precise formula, but in linear MTO manufacturing systems, it is common knowledge that the pacemaker should be located in the first process, right after the order decoupling point. This schedule should be based on the maximum bottleneck capacity (Rother, 2004), meaning that the production sequence must be chosen considering the most utilized resource, that is not necessarily the pacemaker.

In general, the advantage of setting the pacemaker equal to the bottleneck is a better and simpler monitoring of the production limits, considering that the same process limits the system's productive capacity. Other general concepts about the pacemaker position is that the more the PM is set upstream the least is difficult to follow the customer's pace.

Pull systems are generally tailored for MTS companies and introduced to avoid wastes and to produce on the actual customers demand instead of forecast. Indeed, for MTO systems it is difficult to apply many of the lean concept, such as pacing production at the Takt time and Kanban since products are built on customers' requirements. Therefore, a pure supermarket system, with Kanban is difficult to apply to control production upstream the pacemaker.

The second paper (Portioli-Staudacher and Tantardini, 2012) describes a solution for the order release in MTO companies considering as non-linear system: the release of the orders is triggered by the Pre-Shop pull (PSP), which decouples the planning system from the shop floor: a storage area, usually a database, that consists of all the production orders already accepted, but not released yet to the shop floor. The major objectives of this logic are the control of WIP, allowing a reduction of the total throughput time of the order. The process to manage the PSP is composed by 3 main phases: order entry phase, pre-shop pull management phase and order release phase. Orders are stored there and sequenced and released based on predetermined logics.

Therefore, the timing of the release of customer order becomes crucial: releasing the order too in advance means introducing unnecessary queues in the system that block and increase in the order throughput, while releasing it too in delay means not meeting the due date. The paper compares two approaches present in literature, Balanced release, and Upper bound release; the first one performs better in terms of overall reduction of gross throughput time. In the PSP, an order is selected according to the minimization of the unbalance between different stations; the two approaches are compared.

[7] First in first out

## 5.3.Detail on Order Release strategies and scheduling logics

Following the theory of the last approach discussed (PSP), we found that this approach is widely developed and analyzed in literature.

According to the work of (Blocher, Chhajed and Leung, 1998), it was useful to know the advantages and disadvantages of each order dispatching logic on the main performances, among which the percentage of late orders. Five main classes of dispatching rules for orders are presented: arrival oriented, due date oriented, processing time oriented, job complexity oriented and ratio oriented. The study evaluates the performances in terms of flow time, average order tardiness and average late orders. Earliest due date should be the dispatching rule of choice for tardiness and seems to be the most robust of the rules.

The second paper (Bergamaschi *et al.*, 1997) was selected to decide the Order release strategy to be applied in a possible Pre-shop pull application. A key process is the choice of the technique to select orders from the PSP that should be released to the factory (priority and time or triggering event to release the subsequent order). Two main approaches were investigated: the load limiting, and the time based. In the load limiting approach, jobs are released to the shop floor provided that a set of constraints on the workload in the system are not exceeded: orders are released to the shop based on their distinctive features and the existing workload in the shop. The mechanism can work releasing orders with an upper bound, lower bound and ranges of the workload to be maintained on the shop floor. The time phased order release approach is centered on computing a release time for each order and then letting orders enter the shop when that predetermined time is reached, regardless of the shop load at that time. An alternative approach is to compute and control the workload for selected bottleneck work centers only. For instance, the OR policy introduced by Glassey and Resende (1988), called `starvation avoidance', focuses on these overloaded work centers.

The third one (Cigolini and Portioli-Staudacher, 2002) deepens the theory of the second, it focuses on the performances of the techniques for ORR through simulation. Among the techniques identified in literature, the workload balancing one was simulated and discussed. The result of this study shows that this last approach achieves better performances in terms of throughput, while the performances related to timeliness and delays are worst. It shows that the workload balancing system entails a strong risk of performance detriment on the due date-related indicators. In fact, jobs that do not balance well may be continuously delayed in the release phase, because less urgent jobs that balance the workload better are always preferred.

## 5.4.Case studies review

After the review of the lean principles and methodologies to provide help during the analysis of our problem, it is necessary to review existing case studies explaining the development of production scheduling in real life situation to serve as a guide in the progress of the project.

### 5.4.1. Case study 1: Optimal production scheduling of food process industries

According to (Georgiadis *et al.*, 2020), most industrial facilities production scheduling is manually generated by engineers or operators, based on set of rules or heuristics that result from their experience and of the process. The real scheduling problems are complex in nature which results to extremely difficult computational solutions. As real-world problems consist of many items and require the fast generation of schedules, researchers suggest heuristic and metaheuristic methods. These methods provide rapid and practical solutions if compared to the ones obtained by exact methods.

To better understand, they considered the scheduling problem of the Spanish industry Frinsa del Noroeste S.A., one of the largest canned fish producers in Europe. The studied facility can produce more than 400 product codes, that fulfills more than 100 orders every week. The production process is extremely complicated, comprising of batch and continuous processes. To simplify the description of the production process, we identify four major processing stages thawing, filling and sealing, sterilizing and packaging, each consisting of multiple parallel units.

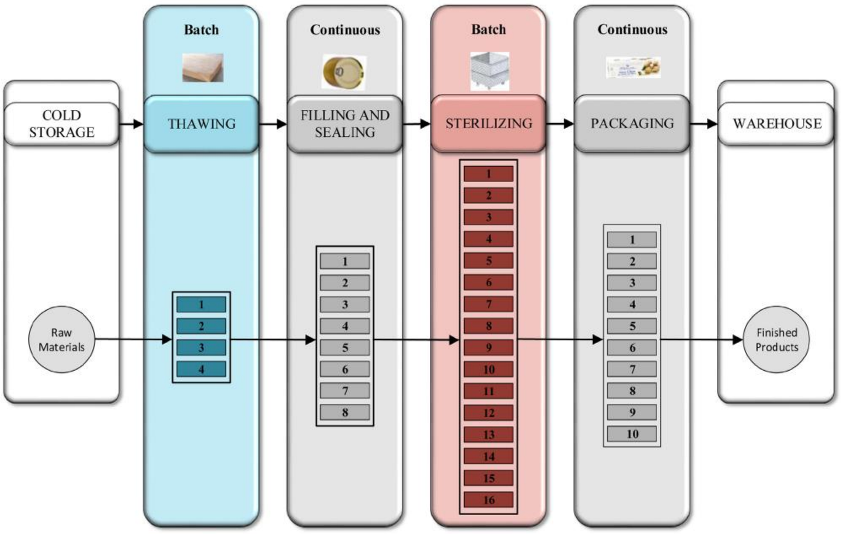


*Figure 1: Process description* (Georgiadis *et al.*, 2020)

Initially, the fish arrives in tracks in the form of frozen blocks, which are defrosted in the thawing stage. Then, the blocks are cut in the proper size and filled in cans along with other ingredients according to the product's recipe. In the same processing stage, the cans are sealed and transferred into carts. Afterward, the carts are manually inserted in the sterilization retorts. To avoid the growth of bacteria, the transfer between the filling and sealing lines and the sterilization retorts must guarantee a near zero-wait policy. Therefore, no more than 2 h must elapse between the completion of the filling and sealing process and the initiation of the sterilization process.

The sterilization process is critical for food safety and final product quality. The cans are heated at a temperature of around 110 °C, which is maintained for a specific time, that ensures the targeted bacteria lethality, and finally, they are cooled down to room temperature. After the completion of the sterilization process, the carts are manually extracted from the retorts and are transferred to the packaging stage, where the cans are packaged in the final product form (single, 6-pack, boxes etc.). An important operation of this stage is labeling. However, not all packaging lines have an individual labeler. Lines 1–2 and 5–6, share the same labeling machine, therefore they cannot operate simultaneously. Finally, after the completion of the packaging stage, the end products are stored in the warehouse, to be distributed in the market.

In the described plant four thawing chambers, eight filling and sealing lines, sixteen sterilizers and ten packaging lines exist, making up a total of 38 available units in the whole production process. with more than 100 products produced a week, the scheduling problem is complex. Large order sizes, which require their splitting into multiple batches increasing the number of items to be scheduled. Also, the plant has a high production flexibility. Each product can be processed by all batch units, but only specific continuous lines, which have different processing rates. Furthermore, the processing time of each stage significantly varies, thus making the efficient synchronization of all processes a difficult task. Consequently, the features of the plant combined with the absence of clear bottlenecks, result to a computationally exhaustive scheduling problem.

Production schedules are developed manually by engineers. As a result of the complexity of the problem, it is impossible to develop weekly integrated schedules for all the processing stages. Therefore, engineers decompose the decision-making process to try developing a feasible schedule. The plan for the filling and sealing stage is made first. Then, the packaging department checks the feasibility of that plan and there is back and forth communication till a final plan is agreed. Then the plan is developed for each day normally two days before the day under examination separately for each of the two previous stages. During this process, the sterilizers are neglected. As A Result, the actual schedule varies significantly from the planned one since they do not consider the synchronization of production between stages and the limitation enforced by the sterilization stage.

The main goal from their study is to find a solution that could be the core of a computer-aided tool that will automate the process and support production engineers into suggesting feasible and better schedules. Therefore, they developed an optimization-based approach that considers all involved stages and constraints that affect the efficiency of the produced schedules with the objective of minimizing the make span and total changeover time.

The solution they proposed was a mixed integer linear programming (MILP) mathematical model that consists of three pillars:

- A pre-processing algorithm that translates production orders into batches.
- The mathematical model describing the scheduling problem.
- A decomposition technique that splits the initial problem into tractable easily solvable sub-problems.

Due to the complexity of the problem and the requirement of using low computational times, their proposal was to simplify the overall process. After a thorough analysis, they concluded that first, the thawing stage can be omitted as the capacity of the thawing chambers is significantly larger than the rest of the processing stages, and the defrosted fish can be stored in the chambers for a significant amount of time. Also, the sterilization stage can be disregarded since it does not affect the quality of the products because all the sterilizers are identical and as such no sequence-dependent setups exist. Therefore, the process is reduced to a continuous one, consisting of two stages and several feasibility constraints for the batch stage in-between.

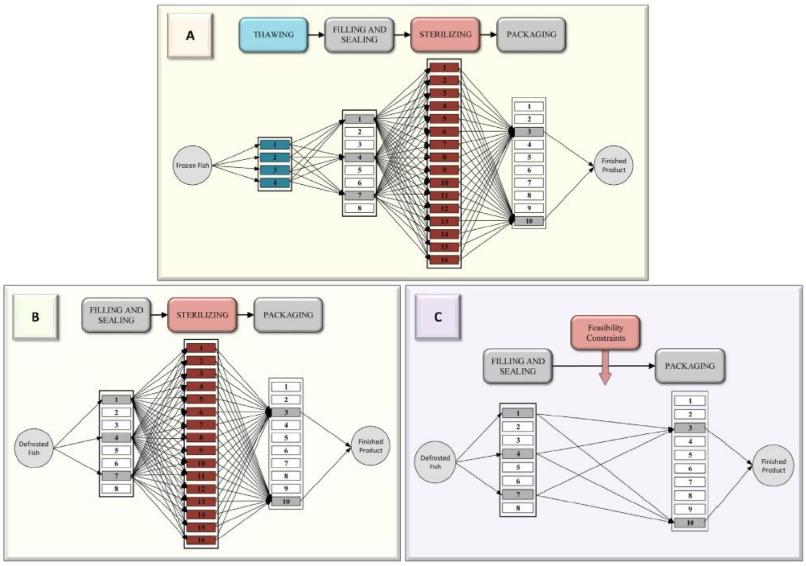


*Figure 2:Possible production routes of a single product when (a) considering the fully sized problem, (b) omitting the thawing stage and (c) explicitly modeling only the continuous stages.* (Georgiadis *et al.*, 2020)

A batching algorithm is used in the step before the model. The goal of this algorithm is to convert the product orders into batches in the sterilization stage to fully satisfy the given demand. Moreover, in this step, the processing time required for the first batch in the filling and sealing stage and the last batch in the packaging stage are calculated. These parameters are later required in the mathematical models. Also, a decomposition algorithm is used to split the initial problem into smaller sub-problems. The final schedule is generated iteratively. In each iteration, only a subset of the original set of product orders is scheduled. Therefore, the generated MILP models are smaller and can be solved much faster. Multiple possible sorting algorithms were studied to derive the best possible way to insert the data in the model. The best solutions were extracted when sorting from largest to smallest product order size was chosen. Then a mathematical model was developed to produce the schedule for the whole process.

This work illustrates the successful implementation of an optimization-based method for the production scheduling of a real industrial problem, which is a step towards the reduction of the existing gap between industrial reality and research.

### 5.4.2. Case study 2: Optimized rescheduling of multiple production lines for flow shop production of reinforced precast concrete components

The authors (Ma *et al.*, 2018) state that scheduling is crucial for production of precast components, which consists of master production scheduling, material requirement planning and shop floor scheduling. And since shop floor schedules should be coordinated with the assembly schedules of construction sites, precast production is sensitive to production emergencies that may result in delay in precast production process, such as resource shortage, machinery breakdown, etc.

The current operation procedure for the production emergency is described as follows: First, the emergency information is collected by site supervisors. Then, the operators and site supervisors try to eliminate its negative influence by using the over-assigned time of the corresponding workstation and slightly adjusting the production schedule of the workstation. If the order requirements can be fulfilled, the procedure ends, and production continues according to the new schedule. Otherwise, counterplans as outsourcing orders, or activating backup production lines, will be adopted by schedulers. Fifth, rescheduling is conducted based on the heuristic rules and then go back to the third step.

However, this procedure does not fulfil current production because the overtime allocated is not fully utilized as schedulers rely on counterplans to solve production emergencies. Also, the heuristic rule-based scheduling does not produce optimal schedules and it is influenced by the experience of the schedulers.

Therefore, this analysis proposes an approach for the optimized shop floor rescheduling of multiple production lines for flow shop precast production. The approach can not only consider the traditional ways for schedule adjustment, but also make use of the over assigned time of each production step to deal with serious production emergencies

The plant is equipped with several molds of various types, production pallets and production lines with fixed production routing. In each production line, precast components go through five production steps, namely molding, placing rebars and embedded parts, casting, curing, and demolding. Each production step is handled in a dedicated workstation (i.e. the curing room, in a production line can handle several precast components simultaneously) by a team. Precast components of multiple types are produced according to the original shop floor schedule and the shift work system that specifies the working hours of a day and the way the work team shifts before rescheduling is carried out when production emergencies occur.

The next step the authors did, was the definition of the optimization objectives and constraints. Then, the formulation of the mathematical model to solve the scheduling problem and a corresponding genetic algorithm-based solver to realize the optimized rescheduling. The proposed method can make use of the over-assigned time of multiple production steps in multiple precast components in the rescheduling process. Furthermore, a GA based solver is proposed to achieve the optimization. Compared to the existing approaches, the proposed one is less dependent on the experience of the schedulers. According to the authors, the proposed approach shows better performance in 76.3% of them and performs equally in the rest.

Optimization objectives.

| Item number | Optimization objective | Remark |
|---|---|---|
| 1 | Minimization of Workstation Idle time (WI) | – |
| 2 | Minimization of Contract penalty and Storage cost (CS) | – |
| 3 | Minimization of MakeSpan (MS) | – |
| 4 | Minimization of Type Change of precast components (TC) | – |
| 5 | Minimization of Material *Re*-dispatch complexity and workload (MR) | New |
| 6 | Using the minimum amount of Over-assigned time for production emergencies (UO) | New |

Optimization constraints.

| Number | Content | Remark |
|---|---|---|
| 1 | Constraint of workstation productivity | Revised |
| 2 | Constraint of the size of curing rooms | – |
| 3 | Constraint of the eight-hour day working | – |
| 4 | Constraint of the buffer size between workstations | – |
| 5 | Constraint of the quantity of moulds | – |
| 6 | Constraint of the quantity of production pallets | – |
| 7 | Constraint of the amount of resources | New |

*Figure 3: Optimization objectives and constraints* (Ma *et al.*, 2018)

### 5.4.3. Case study 3: An integrated production scheduling and delivery route planning with multi-purpose machines: A case study from a furniture manufacturing company

The next case study (Mohammadi, Al-e-Hashem and Rekik, 2020) analyzed is about a make to order manufacturing system that produces a wide variety of furniture for different customers. At the variety of furniture for different customers. At the beginning of the planning horizon, each customer places exactly one order, with a specified size and a time window within which the order should be delivered. The company is responsible for the delivery of finished products to the customers. As the products are customized, they must be delivered as soon as they are finished respecting the delivery date. However, on time delivery requires more resources, that will increase the manufacturer's total cost.

Therefore, the problem faced by the company is to optimize both production and distribution scheduling decisions, while ensuring the minimization of the total scheduling cost and respecting the on-time delivery of orders.

Production is performed in a flexible job shop manufacturing system. Each job comprises a fixed set of operations, where each can be processed by a different machine type with a different processing time. The company need is to determine which operation should be assigned to which machine, and how to schedule assigned operations on each machine. Moreover, transportation is performed with a limited number of heterogeneous vehicles having different capacities, and fixed and variable costs. From the distribution's side, the company should determine how many shipments of each vehicle type to use, which customer should be served in which trip, the sequence of orders in each trip, and schedule the time for the departure of each shipment from the production site.

The authors proposed to model the problem as a production-distribution scheduling framework and propose a novel bi-objective mixed integer model, trying to identify the best path and schedule of operations through machines, and the optimal arrangement of vehicles, routes, and the ideal departure time of vehicles from the production site. This is to simultaneously satisfy the two conflicting objectives: minimizing the production and distribution scheduling costs and minimizing the weighted sum of delivery earliness and tardiness. In the proposed model, the distribution cost involves a fixed and a variable charge for each of the vehicles used. Also, production costs may vary because a job can be done on different machines which vary in time and cost. Therefore, necessary to also consider the production cost as an important component of the total cost of system.

After developing and testing the required mathematical model for the solution of the problem and reaching an optimized schedule, the authors found that when production and distribution schedules are integrated, the weighted sum of delivery earliness and tardiness decreases, whereas the production and distribution scheduling costs are fixed. The improvement in the customer satisfaction with a minimum total scheduling cost means that the integration policy brings added value to the customers, while keeping the solution as economic as possible.

In conclusion, the study proposed to use a bi-objective mixed integer model that finds optimization between production and distribution decisions to optimize the tradeoff between operational costs and the weighted sum of the earliness and tardiness of delivery. This model is solved optimally with manufacturer, the proposed model is first optimally solved with the Ɛ-constraint method. Then, to address medium and large-sized problems in a reasonable time, an efficient HPSO algorithm is developed, and it is validated by solving an extensive set of test problems. The results showed that the used methodologies permit to create balance between conflicting criteria where integration policy not only improves the customer satisfaction through reducing the total completion times but also helps to keep the production and distribution scheduling costs at the minimum level possible.

### 5.5.Relation between case studies and project work

The case studies explained in the previous section were selected to help our team get a better picture on how scheduling is performed in real life situation. Also, they were useful giving us ideas to help tackle the problems we faced while developing the scheduling model. In the first case, the authors (Georgiadis *et al.*, 2020) mentioned that the variation in processing times between stages, the absence of clear bottlenecks and production flexibility results in computationally complex scheduling problem. This case is like the situation that we had on the breakers' segment.

Therefore, based on the authors' approach, we found that simplifying the process and trying to make it as continuous as possible makes it easier to solve. Also, the idea of the decomposition algorithm is very interesting as the splitting of the original problem into sub-problems reduces its complexity. And these ideas were formulated in the development of the scheduling model as it was split into two part: first the scheduling on the testing room at the beginning, then translating this schedule backwards to the assembly lines.

Moving on to the second case (Ma *et al.*, 2018), it explains the necessity of an easy optimized rescheduling process in the case of emergencies as in the reinforced precast concrete components sensitive to production emergencies that may result in delay in precast production process, such as resource shortage, machinery breakdown, rush orders, etc. This process was applied to our solution but in a different context, the team added the possibility of rescheduling in the model developed for different reasons (ex. new orders, change of due dates, overtime addition…etc.) as it was perceived of great use to the production engineers.

According to the final case (Mohammadi, Al-e-Hashem and Rekik, 2020), taking all factors and constraints affecting the process in consideration when doing the scheduling yields improved results. As seen in their approach, including the cost and distribution constraints along with the production ones, resulted in creating an optimized balance between cost and time of delivery. Similarly, we included the delivery date and assembly constraints in the scheduling which were not taken into consideration before.

Finally, in all cases mathematical models backed up with simulation tools were used to formulate the scheduling procedure. However, we decided not to follow this method and use excel instead as it would be easier to use and modify by the engineers in the company.

# 6. PROBLEM BREAKDOWN

The goal in this phase was divided into two parts.

The first was an introduction about the products, processes, and the segment itself, a Value Stream Mapping analysis with the aim to identify the bottleneck of the production process. An attention was given to the process of acquisition and processing of the order, with the aim to identify problems and the areas with major room for improvement.

Then the second phase was the analysis of the production planning and scheduling process finding inefficiencies and wastes and designing a reliable production scheduling concept that could be used by production.

To better understand the process, we started our analysis from the beginning of the process where the company receives the customer request for the order and moves on till, we reached the delivery of the order to the customer. We used two methods: the first one was to make as many interviews as possible with people from all different departments (planning, production, purchasing, logistics, quality and the I.E. team). The second method was to gather as much data we can to be the base for our analyzes. Based on the information and data gathered, we developed the BPMN[8] and Value Stream Mapping (VSM).

## 6.1.Business Process Modelling Notation

The customer order process was divided to three phases: Order feasibility study, administrative and replenishment, waiting and production. The process flow of the customer order is the following:

The customer sends the order request to the company which is received by the sales department. The sales then send the request to technical, production and purchasing departments for their review. The technical department checks the technical feasibility of the order and checks if the product is new or not, if it is a new product it creates a new part number (BOM, drawings, specifications) for it. The production department defines the amount of time required for the order production and, according to the expected available capacity, a proposal of feasible completion date. The purchasing department checks the feasibility of the order in terms of the required materials, including the material required in the "piano del fabbisogni". The feedback about the order request is sent to the sales department, which then formulates the order proposal and sends it to the customer for acceptance. The customer checks the proposal and either an acceptance is sent to the sales department or the proposal is rejected and sent back to the sales to review the modification required by the customer. This loop continues until the company and the customer agree on all the terms of the order. The next step is the administration phase which has a lead time of 6% of the overall process and replenishment phase which has a lead time of 12% of the overall process.

After the agreement on the order, the order information (delivery date, BOM) is uploaded on the MRP

[8] Business process model and notation

system of the company by the sales department. The MRP system includes the new order in the "portafoglio ordini" automatically. The MRP system checks the availability of the material required for the new order in the current inventory and creates a supply proposal for the missing material. The planning department checks the MRP proposal and verifies it. It also creates a purchase request based on the supply proposal and sends it to the purchasing department. The purchasing department checks the purchase request and then sends them to the corresponding suppliers. When the material arrives, the quality department performs the required quality checks on received materials from suppliers. The approved material is then stocked in the warehouse.

The production department waits until the planned date of production of the order arrives and until all the materials required for order production are available. The waiting time is 12% of the process lead time. Then the production of the order starts. Usually the lead time is 28% of the total lead time. When completed the order, products are put in stocks in the finished products warehouse. The packaging of the products is then finished there. The lead time for this process is around 5% of total lead time. Finally, the order is retrieved by the customer.

## 6.2.Value Stream Map

Before moving on to Value Stream Map, we have first to describe the layout of the breaker segment and the product families produced in it. As shown in Figure 4, there are 4 lines in this segment, each line is responsible for the production of specific product families as seen in Table 1. Each line is composed mainly of three stations in series, these stations are then followed by three test stations which serve the 4 lines simultaneously.

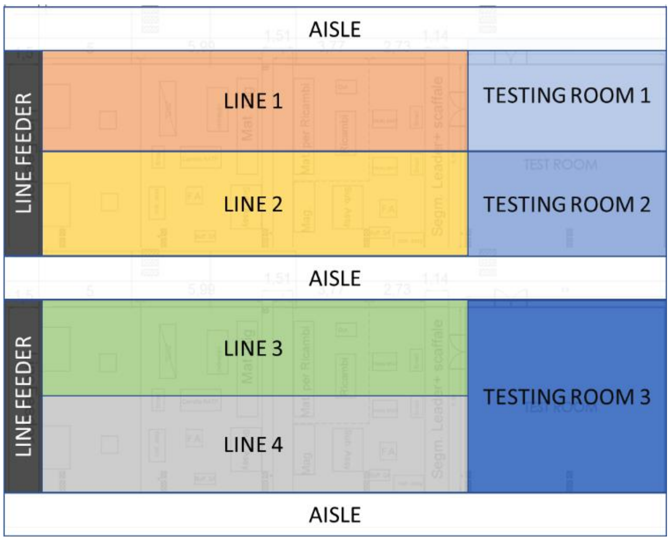


*Figure 4: Layout of the breakers segment*

*Table 1:Breakers product families*

| Line | Product family | N. of product codes | Demand Mix |
|---|---|---|---|
| L1 | T1 | 120 | 35% |
| L2 | T2 | 52 | 30% |
| L3 | T3 | 83 | 25% |
| L4 | T4 | 250 | 10% |

Since there was information missing about the cycle time of the different stations of the process and there was no information on the amount of WIP existing between the stations of the process, we adopted a Gemba walk approach. The objective was to gather enough information about the cycle times of the sub-assembly, assembly, wiring and testing stations and to know what the amount of WIP is existing in between them.

Another objective was to get more involved in the process by monitoring it by ourselves on the production line and ask the operators directly about any misconception that we had as they are the best source of information that we can talk to. Based on these objectives, we applied the Gemba approach for a period of two weeks. In these two weeks for simplicity we chose two products from two different lines to base our approach on them. First, we measured the cycle times needed to complete each product in each station of the process and then take the average of all our measurements as the final cycle time for the analysis.

Similarly, the amount of WIP between the station was measured at random times throughout the whole period of the analysis to get as many readings as possible, then the average of those readings was taken as the result of the analysis. At the end of this analysis, we compared the results we obtained with the existing information inside the company where we found an average variation of ±10%. Through this process we were guided by our company and academic tutors who have directed us in the right direction to achieve our target.

The assumptions that were taken to develop the value stream map:

- All products must pass through the same processes. One type of product was chosen as a representation for all the other for simplicity.
- Due to the variability in the cycle times of the process, we used the times we calculated during the Gemba walk as an approximation
- We assumed that there is only one supplier for all the materials
- We assumed that there is only one type of product in each family
- We assumed that the batch size is constant for all orders
- We simplified the part of the information flow as this part was explained in detail in the BPMN.

From the value stream map shown in Figure A- 28, we can see that the whole production process is composed of six steps to transform the raw materials to the final product. These steps are the following:

1) The first stage of production is the sub-assembly where many sub-assemblies are built
2) Final assembly in which the previously constructed sub-assemblies are put together to form the fully constructed product.
3) Wiring, in which all required internal and external wiring connections are added to the product
4) Final adjustment where the product is tuned to the required specifications
5) Completion
6) The final step is final testing where the final checks and tests are performed on each product to ensure its functionality and that it meets the standards of the company.

Based on the value stream map we found that there are buffers with a high level of WIP between stations. Also, we were able to calculate the average total production lead time and which of this time is value added time and which is waste as seen in Figure 5.

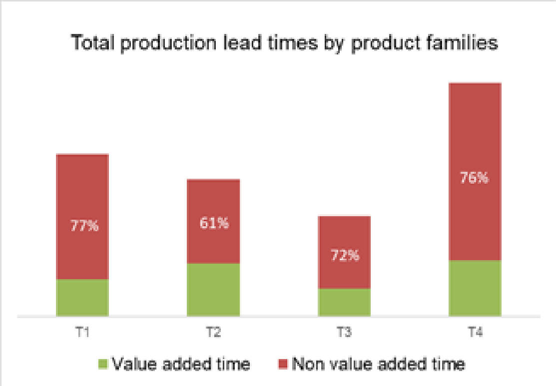

*Figure 5:Value adding and non-value adding times- average by product families*

## 6.3.Production scheduling and planning analysis

In this paragraph the main methodological steps related to the order due date definition the logics behind the order release in the production are explained.

As mentioned above, the sales department communicates with the production to propose a feasible due date to the customer. The production department, specifically the Segment leader and the Production Manager, establish a possible waiting and production lead time of the related order. The analysis is based mainly on the calculation of the available working hours in production for each line, the already assigned orders and relative workload (the total needed hours for production) and historical production lead times recorded for a similar (or equal) product code.

The available working hours are estimated monthly for the assembly, wiring stations and testing rooms by multiplying the monthly available working hours per operator and the number of operators.

As the orders are accepted, the monthly needed hours are computed by aggregating the expected workload of each order, assigned to the month in which it is expected its completion for each production phase, based on standard times. Even though the product family T4 can only be tested in one specific testing room, this constraint is not considered in this phase. The needed hours are then compared with the available hours and the gap between the two (if any) is corrected typically by overtime in the different production phases. This is the starting point for the production scheduling of the month.

These calculations are performed on an excel file by the segment leader, which is used in the order acceptance phase, when a completion date must be proposed to the customer. Generally, if there are still available hours in the month, the order due date is set in the month, with a date that considers the already set orders and the customer's requirements. Otherwise (based also on the urgency and importance of the customer) the due date is shifted in the following month. After the due date decision, the information system is also updated with the date.

After this monthly production planning is created, the production scheduling, meaning the decision on when to begin each order in production, is performed by the segment leader. The monthly production planning is regularly checked (in general weekly) and the orders are released in the assembly phase according to their due date (first the orders with the earliest due date are assembled). The release of the orders in the assembly is done continuously, products of the month are assembled whenever is possible to assemble on the lines (sub assembly, assembly and wiring are here considered a line since the sequence is the same, so a FIFO can be considered between these 3 phases), following an earliest due date logic. When the orders finish the wiring, the sequence in the testing phase is not clearly defined and does not follow a defined logic: it gives random priority to orders.

Therefore, the scheduling of the testing is separated from the assembly one: orders are rescheduled after the wiring is complete.

## 7. TARGET SETTING

After completing the previous analyzes and reaching a well-formulated problem definition and breakdown, the time has come to set our target. Given that we just had around 4 months to finish the project, we needed to concentrate our effort on a target which yields the best outcomes. So based on the meetings we had with our team and others, the experience we gained from working on the production line, the data we got though the project development and the analysis of the problem, the must to have target was defined as:

15% decrease in the number of orders exceeding the delivery lead time by end of March 2020.

In the event of the achievement of such a result we agreed to set with the company a nice to have target. It was included to understand how high the improvement of the project could be and to keep the focus of the team on the project also in the event of an early achievement of the first target.

The first nice to have target was defined as:

30% decrease in the number of orders exceeding the delivery lead time by end of March 2020.

Furthermore, a target regarding the level of WIP in the process was necessary to evaluate the performance of the new methodology. The high level of WIP shows a management problem in the process and reduces the visibility of methodological errors. Nonetheless the reduction of WIP is not the main concern of the company and we were asked to focus first on the OTD level.

The second nice to have target was defined as a 40% decrease of the WIP level between assembly lines and testing phase by end of March 2020.

*Table 2:Target setting*

| Type of target | Must have | Nice to have | Nice to have |
|---|---|---|---|
| Target | 15% decrease in the number of orders exceeding the delivery lead time by end of March 2020. | 30% decrease in the number of orders exceeding the delivery lead time by end of March 2020. | 40% decrease of the WIP level between assembly lines and testing rooms by end of March 2020 |

# 8. CAUSE ANALYSIS

After the definition of the target of our project, the root causes of the delayed orders in the breakers segment are analyzed to research which are the most critical issues for the low OTD, with particular attention to the causes of delays registered in September, October and November 2019. To do this, the focus kept is broad: the causes that are identified are related to all the departments that deal with the order processing process: production, planning, purchasing, sales, and technical department. This is for the nature of the problem and for avoiding missing significant measures of improvement. The identified causes cover also different organizational levels: operational, tactical and (few) strategic causes.

## 8.1.The methodology

The framework used for the analysis of root causes is the Ishikawa diagram, with the traditional 4M (man, machine, methods, materials). The 5 whys method was used in the interviews for the investigation of each problem identified to go deeper until the root cause. Indeed, the analysis develops from the major visible issues to the final root causes, with a series of cause-effect steps (Figure A- 26). The PFMEA (Process FMEA) framework was used to give a measure of the criticality of each root cause. Therefore, the frequency of occurrence and detectability of each one on the OTD was derived with the use of a scale appositely defined for the purpose.

The measure of occurrence considered is the frequency of each root cause causing a delayed order compared to the total number of delays on a given period. Regarding the impact on the OTD of each root cause, this could be considered not relevant for the analysis given the targeted measure: the OTD is by nature a proxy of the frequency of a certain event (delayed orders) and we are interested in decomposing it in other frequencies of the events that concur the final value (root causes); moreover, we are not focused in the days of delays as a measure of the impact. Instead detectability was considered as the relevant measure, which is defined as the likelihood to detect the problem leading to a delay before the delay happens. The ability to detect the issue indeed is an important capability to take precautionary actions on time. This will be assigned with a qualitative evaluation. In the appendix, it is possible to see the scales for the evaluation (Figure A- 33, Figure A- 34).

To define the occurrences of each root cause, data was collected from:

- Production documents: ERP records for each order upon completion (due date agreed with the client, confirmation of the work order closure), production reports related to the actual dates of assembly and testing of each order as well as the actual duration of each production stage with the corresponding problems if this exceeds the standard time;
- Gemba Walks in production area: Interviews with workers or/and responsible of the department under consideration (in case it was not possible to find any written documentation about that specific root cause)

From the above mentioned production documents, it was possible to identify the delayed orders of the period and match those orders (through the order code and line) with the actual time of production and testing start to identify if there was an actual unexpected waiting after production start or if the actual starting date was postponed due to other issues. The first case was assumed if the actual lead time was higher than the one identified in the value stream analysis for that order. The second case instead, if the starting date of assembly does not allow the product to be produced before its due date.

The underlying hypothesis is that most of the problems can manifest their impact on the OTD in the production phase. In this way it was possible to identify a first macro category of issues. Then, thanks to the interviews with the departments, it was possible to apply the 5 why procedure and reach a possible root cause of the identified delays and thanks to a discussion with them we were able to reach an estimation of the possible degree of occurrence and detectability. Then, a number ranging from 1 to 5 was assigned to each root cause (base on the computed quantitative measure for the occurrence and qualitative findings for the detectability). The products of the two is the final RPN, and from these the relative weight (that are shown in the Ishikawa diagram) were derived.

Then, the root causes were ranked and each one was given a relative weight of their criticality. The aim of the criticality analysis is to: both know which root cause to prioritize and, as a preventive analysis, to estimate the impact of a specific possible countermeasure on the reduction of the OTD. The last step is the identification of the most critical causes which must be targeted with specific countermeasures.

The following picture displays the result of the analysis. Each root cause is associated with percentages derived from the RPN of the PFMEA.

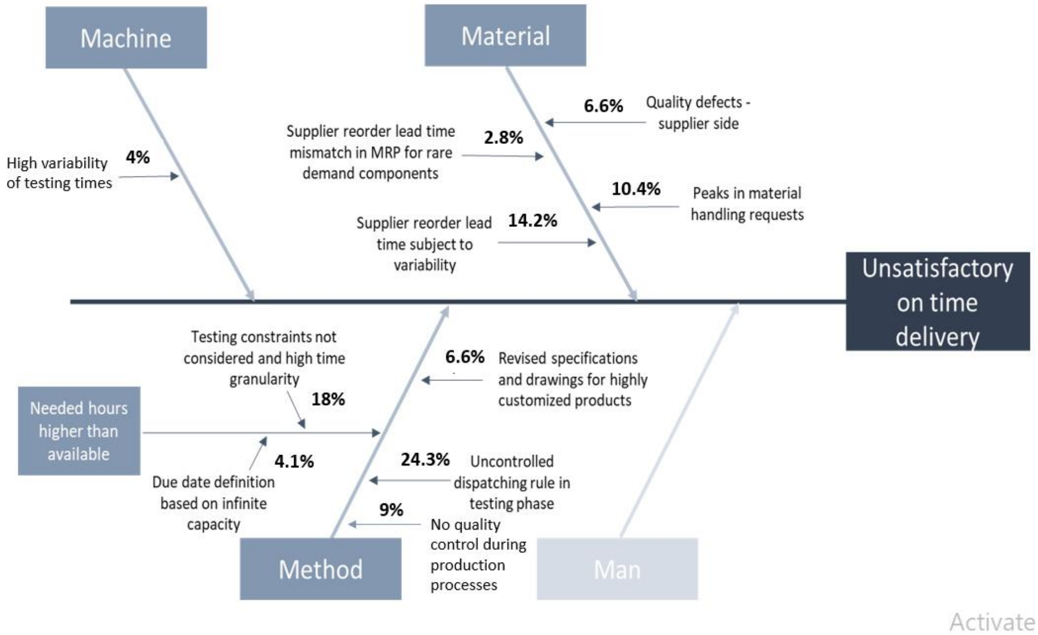


Figure 6: Ishikawa diagram

## 8.2. Materials

### 8.2.1. Components unavailability delays order's production start

The starting date of a portion of the delayed orders was postponed compared to the planned one, due to the unavailability of the components, causing a delay that affected the customer.

Among these orders, the root causes of the delays, that will be explained in the next paragraphs, were:

- Quality defects-supplier side
- Supplier reorder lead time variability
- Supplier reorder lead time mismatch in MRP
- Peaks in material handling requests

### 8.2.2. Quality defects-supplier side

The company sets high quality standards for its suppliers, moreover, all components are subject to the quality control either directly from the company or by the supplier. However, it can happen that quality defects and non- conformance issues are detected in this phase. These problems, despite being low frequency events, can create postponements of the production start of the order requiring the component. Since the production usually starts only after the availability of all the materials in the warehouse, this created a delay in the customer order and issues in the organization of the subsequent orders.

### 8.2.3. Supplier reorder lead time subject to variability

The availability of material highly depends on the reliability of the reorder lead times of suppliers. These times are the results of negotiations with the suppliers and contractual terms could also allow a defined variation of these, depending on the relationship and terms with the suppliers. However, sometimes those reorder lead times, due to disruption and issues on the supplier side, are higher than expected, leading to order delays.

### 8.2.4. Supplier reorder lead time mismatch in MRP

The purchasing department works with suppliers' reorder lead times recorded in the MRP that are reliable for most of the components. However, for very specific suppliers, such as those whose components have not been reordered in the last 6 months, the reorder lead time in the MRP could be different from the actual one.

### 8.2.5. Peaks in material handling requests

The warehouse is centralized for all the factory and is composed of one isle for the storing of high-volume components and several vertical carousels for smaller components. The material from the warehouse can be brought in the line with different systems: with Kanban (for small and general components) or through material handling orders to the internal warehouse. Those requests are coming often from the aggregation of the material needed for many subsequent orders, therefore a significant amount of material and relative workload to be processed in the warehouse. Given this current policy, the material request is done on average 2 days prior to the expected production date of an order today. In periods of demand peaks also for the other productive departments of the company, this policy causes an excessive workload in the warehouse, which can lead to disruptions and postponements of the starting date of the order.

## 8.3.Manpower

Human errors can for sure happen in all the activities of order processing. However, it was not found any significant cause related with manpower issues that can lead to a systematic OTD decrease.

## 8.4.Machine

For this branch of issues there was identified only one cause, related to two information tools used by two different departments. The only machines used in the process are the testing machines, the other processes are manual, therefore no root cause was identified related to production. The other equipment and tools did not show any criticality related to delayed orders.

### 8.4.1. Material software misalignment: MRP and WMS

This problem in the purchasing department deals with the postponement of production orders due to a mismatch in the availability of components in the MRP and the warehouse management system. The purchase department issues orders to the supplier starting from a proposal of the MRP system. It happened for some delayed orders, that the MRP worked with a non-updated availability of the component to be purchased. This can be related to the use of different software between warehouse and the other departments. In this case, the purchasing has to correct the purchase order with the right quantities. Sometimes this mistake is found after the receiving of the wrong quantities, causing a delay for the related order. The purchasing department knows the possibility of this misalignment and therefore often checks the real availability of components. Therefore, it is probable to detect this issue.

## 8.5.Method

The identified root causes lead to a discrepancy between the planned needed hours for production and the available ones in each period. Then, two other independent methodological causes were identified.

### 8.5.1. Production planning does not consider testing constraints and has high time granularity

The definition of the hours available in testing phase is done considering the available hours of all three of the testing rooms during the whole month. This type of estimation is necessary in the order due date proposal to the customer. Some products can only be tested in a specific testing room (T1) and aggregating the available hours of the overall month, concentration of orders in one period are not taken into consideration. Indeed, looking at the distribution of production orders over the month, it was found that for certain periods of time there was an uneven distribution of production orders to be tested. The lack of consideration of these constraints prevents an optimal estimation of the possible due date of new orders and leads to possible delays. Furthermore, the testing phase is not a flexible production department because the number of testing rooms cannot be modified and only one operator at the time can work in them.

### 8.5.2. Due date assignment based on infinite capacity for long-term orders

When the sales department receives a new order, the production is usually interviewed to define a feasible due date for that order. The production department checks the available production hours of the period and defines the earliest possible due date for the order. The sales department communicates with the customer and starts the negotiation based on this information. However, for long-term orders, infinite capacity of the production system of this segment is considered: the order is accepted without accurately checking the proposed due date with the future workload of the already confirmed orders foreseen for the specific period. The order is added to the "Portafoglio ordini" and communicated to the production in a time that in some cases creates problems in the organization of the orders on the line.

### 8.5.3. Uncontrolled dispatching logic in the testing phase

As was explained the problem breakdown phase, there is not a clear definition of what to be tested and in which sequence in the testing phase: the process does not follow a systematic and regular logic. We decided to analyze more in detail this issue, retrieving the sequence of release of the assembly and testing, from the production documents cited above and compared with the optimal testing sequence.

### 8.5.4. Waiting for the revised specifications and drawings for highly customized products

The last identified problem was the waiting in the production of an order due to issues in the drawings and specifications of highly customized products. Indeed, this problem relates only to rare and unusual customer orders that are not regularly produced by the company. The specifications and drawings of those orders require a high effort and knowledge and sometimes this created reprocessing and problems, discovered only in the production phase. In this case the production start must be postponed letting the technical department redefine the new specifications and drawings to guarantee the highest customer satisfaction.

From the results of our analysis, the most critical root causes and their relative impact were: Uncontrolled dispatching rule in testing phase; production planning does not consider testing constraints and has high time granularity; supplier reorder lead time variability and peaks in material handling request.

### 8.5.5. No quality control during the production process

The fact that there is not any sort of proper checking of the quality of activities performed on the product between each station and the one after it may result in the poor quality of the product and this can be shown when the product reaches the testing phase. The time it takes to test and adjust the settings of each product is subject to huge variation and in many times the products needs to be returned to one of the assembly stations to be reworked and solve the error caused which in many cases is unknown. This process of rework consumes additional wasted time which leads to extra delays in production. Another thing caused by the absence of the quality checks is the possibility of occurrence of defects in the product that can get out of production un-noticed.

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*Table 3:PFMEA- Unsatisfactory OTD*

| | |
|---|---|
| Process | Order entry and processing |
| Process Owner | Microelettrica scientifica |

| Process | Failure mode | Root cause | % identified delayed orders | Occurrence | Failure effects | Detectability | Risk priority number | Relative impact |
|---|---|---|---|---|---|---|---|---|
| Quality acceptance/Components request | Components defects detected in the quality control | Quality defects- supplier side | 7,2% | 2 | Time waste in inbound logistics, administrative costs (additional paperwork), production start delays | 3 | 6 | 7,6% |
| Purchasing order | Unexpected supplier reorder lead time increase | Supplier reorder lead time mismatch in MRP for rare demand components | 3,9% | 1 | Order lead time increases, administrative costs (additional paperwork), organizational issues | 3 | 3 | 3,8% |
| Purchasing order | In case of increase in supplier reorder lead time, postponement of the order starting date | Supplier reorder lead time subject to variability | 9,5% | 3 | Order lead time increases, administrative costs (additional paperwork), organizational issues | 4 | 12 | 15,2% |
| Material handling | Warehouse is not able to manage high peaks of material request, unavailable components to start assembly | Peaks in material handling requests | 11,1% | 3 | Assembly line stoppage, production start delays, organizational issues | 3 | 9 | 11,4% |
| Planning/Purchasing orders | Wrong quantity reordered to supplier | Material software misalignment: MRP and WMS | 8,8% | 2 | Order lead time increases, administrative costs (additional paperwork), organizational issues | 2 | 4 | 5,1% |
| Production planning/ order due date confirmation | Sales department notify the presence of long-term orders only 2 months before the due date, creating disruptions in workload and delays | Due date assignment based on infinite capacity for long-term orders | 3,9% | 1 | Workload increase, overtimes and Saturday hours planned; priority given to those new orders blocks the planned production | 4 | 4 | 5,1% |
| Production planning | Unoptimized estimation of the possible due date to be proposed to the customer | Production planning does not consider testing constraints and has high time granularity | 12,8% | 3 | Order lead time increases due to unexpected waiting times in production steps, unexpected overloading of one testing room/ assembly line | 5 | 15 | 19,0% |
| Order scheduling/production control | Priority is not given by order due date in testing room | Uncontrolled dispatching rule in testing phase | 19,3% | 5 | Priority in testing is not always given to the orders to be finished first, orders delayed due high waiting time in the queue before testing | 4 | 20 | 25,3% |
| Order technical customization/specificati on s definition | Reprocessing of the order drawings and specs leads to a delay | Waiting for the revised specifications and drawings for highly customized products | 19,5% | 3 | Order has to be reprocessed by technical department, drawings and specifications revised, production start delays | 2 | 6 | 7,6% |
| Production process | Time variability in the testing phase of the process | No quality control during production process | 14% | 4 | Production delays due to rework and variations from the original production schedule | 5 | 20 | 9% |

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# 9. COUNTERMEASURE DEVELOPMENT

After the identification of the root causes, some promising countermeasures were identified with their expected cost, easiness of implementation in the company, time, and estimated impact on the OTD. Moreover, the shareholders involvement in the projects is discussed. To assess these parameters, we have carried out estimates supported by the opinion of experienced personnel inside the company.

## 9.1. Development of a production scheduling methodology and visual management support tool

A production scheduling methodology can be defined as the allocation of orders over a period to perform the required production activities. The creation of a structured order scheduling methodology based on an appropriate order release logic has the potential to reduce the percentage of late orders, synchronizing the production stages and improving the control on the due dates of the orders. An indirect benefit is the reduction of the level of WIP in front of the testing rooms. The estimation of the available and needed hours in each period and production phase, can be improved with a proper scheduling system. The scheduling implemented on a proper tool could entail a more accurate definition of the available versus needed hours, to support the production department in the negotiation phase of the order due date and try to avoid delays due to overloading of one testing room or assembly line.

Based on our literature research and practical needs, the main principles of the scheduling methodology would be:

- The definition of an order release logic to improve the OTD performance: based on our literature research, the right order release logic with the highest control of the due dates and timeliness is the Earliest Due Date (EDD).
- The synchronization of the scheduling of the assembly and testing stages.
- The allocation of the orders based on the bottleneck capacity to avoid the accumulation of WIP in the system.

As it was found in our literature research, the lean principles imply the decision of a unique scheduling point that gives the pace to all the system. We evaluated the possibility to define only one pacemaker, that sets the rhythm to all the production. The possibilities were mainly to put it either in the assembly phase or in the testing. None of these options was however practically viable, since the first approach requires a FIFO logic in the testing room, and given that we have 3 common testing rooms, this would have created due dates problems. The second approach implies a supermarket with a Kanban system, and it is not practically possible. We know that a great simplification in accordance with lean principles would be to dedicate testing rooms to produce only certain families of products; however, the 100% dedication is not practically convenient for now, due to the great fluctuation of customer demands among families and therefore low utilization level of these fixed resources. For these reasons it is impossible for now to have a totally autonomous and pull system with the release of orders simply on one point. This will require the need to indicate a date and time to start the assembly phase and testing.

Furthermore, the order sequencing is done without a proper logic in the testing room (the last phase of production) and this has led to inefficiencies and a higher OTD, as we have seen in the root cause analysis. The new methodology must be supported by a tailor-made support tool. The excel environment was considered proper for the implementation, since it is already used in the production planning phase and does not require great effort for the training. Moreover, to make the most efficient use of the excel environment we thought it would be useful to make a tool to present the results of the scheduling process visually on the lines. This tool is important for many reasons, first it is an excellent method for communication with line operators which in turn fosters an environment of collaboration. Furthermore, it will prevent responsibility confusion between operators as all tasks are clearly outlined. Also, it provides superior monitoring as the segment leader can determine the status of the process at any time and arrange the production scheduling to efficiently enhance production capability and inventory levels.

Additionally, this tool will provide the operators with a way to monitor their performance and be challenged to outperform their previous results. Finally, after the introduction and use of this tool the decision-making process can be delegated to the operators which gives them more self-esteem and makes them feel involved in the process. The main characteristics of this tool are ease of use, clarity and fast to make and modify.

COST: The costs are related to the materials for the visual board (board, markers, magnetic tape); time spent for the seminars for the segment leader, operators and industrial engineers involved for the countermeasure introduction. Real costs: 100€ for the board materials + 3 hours dedicated to a seminar for the board introduction for each operator for 12 operators. Hidden costs: 1-day seminar to two industrial engineers and the segment leader.

EASINESS OF IMPLEMENTATION: medium. The initial change will be in the definition of a new methodology for the order planning. The stakeholders are limited to the production process and are all internal to the company. The main challenge in the implementation will be in making the segment leader and the operators understand the benefits of the new scheduling logic. For this reason, they must be involved in the design phase and feedback must be collected throughout the project.

TIME SPAN: 4 months.

ROOT CAUSE TARGETED: Uncontrolled dispatching logic in the testing phase; Production planning does not consider testing constraints and has high time granularity

IMPACT: The expected impact of this solution on the uncontrolled dispatching logic is considered 80% because the sequence of orders dispatched to the testing rooms in some cases could be altered from the optimal one because of the other causes of delay in the system. The impact on the imprecise capacity definition is considered 70% because in some cases the due date of a customer order cannot be renegotiated.

The total impact on the root cause is theoretically 28,9%.

STAKEHOLDERS: The definition and implementation of the improvements would be carried out by our team, with the counselling of the segment leader and the industrial engineers. The new scheduling will be used by the segment leader and industrial engineers to manage production flow and performances. The visual board will be designed by us and will be used by the industrial engineers to monitor the line. The operators of the segment need to be involved in the update of the board.

## 9.2. Improved methodology for updating of critical components lead time

The aim of this countermeasure is to keep the supply lead time inside of the MRP updated for the most critical components causing delays in production. To do this first, we would analyze the data of the orders delayed because of unexpected long reorder lead times of the components. We would make a list of the most critical components and their characteristics, like the average length period between two reorders of that part code or the type of product they are used in. We would create a list of part codes related to this problem and create new guidelines for their reorder by the purchase department. The methodology for the update of the lead time when the sales department receives the order request from the customer for a product made with those components could be improved. In this way possible changes in the lead time would not affect the OTD of the orders and the company could react in time.

COST: All the costs are hidden for this countermeasure because all activities are part of the tasks of the shareholders involved. However, it is required work for approximately 5 days for 2 people in the purchase department and 5 days for 2 industrial engineers that support us.

EASINESS OF IMPLEMENTATION: easy. The hardest part is the definition of a new methodology that the purchase department agrees with. The purchase department needs to understand the improvements of such a change in the purchase process.

TIME SPAN: 2 months.

ROOT CAUSE TARGETED: Supplier reorder lead time mismatch in MRP

IMPACT: The impact on the root cause is defined as 70% because not all critical components will be checked in every order, but just in the orders more at risk because have products that use many of them. Total impact is 3,4%.

STAKEHOLDERS: the team would manage the design of the new process methodology and would assist in the implementation of the project. The industrial engineers of the company and purchase department would help in the design and implementation phase and would manage the relationship with the suppliers. The purchase department will also be the final user of the system. Also, external suppliers could be involved in the project.

## 9.3.Improvement of the communication procedure between the sales and production departments for long-term orders in periods of high demand.

The communication process of new orders from the sales department to the segment leader is different between normal orders and short-term orders. Long-term orders are not communicated immediately to the segment leader and this can result in an incorrect estimation of the needed hours in periods of high demand. With an improvement in the communication process of long-term orders between the two departments an error in the scheduling of the orders would be less likely. The first step would be to analyze the type of orders that can create problems in the estimation of the needed hours of the period to define which are their characteristics. Then the methodology for their communication could be modified. The sales department could communicate with greater advance the long-term orders to the segment leader to be able to consider them more easily when defining the due date of the other orders. The sequence of activities and the proper process to follow in communication can be defined in a BPMN language.

COST: All the costs are hidden costs. The expected time required for the implementation will be 2 days for 2 process engineers and 1 day for 2 people in the sales department.

EASINESS OF IMPLEMENTATION: easy. The design of the new processes is limited to a very specific part of the work of these two departments. The team does not have high authority in the company to impose the best practices for the communication between 2 departments, so the active involvement of the industrial engineers of the company is necessary for the implementation and data collection phase.

TIME: 2 months.

ROOT CAUSE TARGETED: Due date assignment based on infinite capacity for long-term orders.

IMPACT: The impact on the targeted root cause is defined as 90% because mistakes in communication between sales and production department could still happen in the future. The total impact on the problem is 4%.

STAKEHOLDERS: the team will work on the collection of data, design of the new processes and their implementation. The sales department will provide the data and will be the final user of the solution. The industrial engineers of the company will help in the implementation phase of the project.

## 9.4.Improved supplier rating system based on the reliability of the reorder lead time

The company already has a supplier rating system that drives their decisions regarding the reorder policies. However, it is possible to improve it with a statistical analysis focused on the lead time variability of the suppliers. The first activity would be to collect all the needed data regarding the percentage of delayed shipment of materials to the company and which part code each supplier provides. The suppliers should then be ranked based on several parameters like strategic importance, number of part codes supplied, criticality of components supplied and variability of their lead time. They could then be clustered in groups based on their characteristics. The reorder policy for the most critical suppliers (the one that contributed to the highest number of delays) could then be revised based on their cluster and characteristics. Some changes to the reorder policy could be an increase in the expected reorder lead time used by the company to decide when to reorder, an increase in the warehouse safe stock inventory of components critical to production, or the renegotiation of penalties for late shipments.

COST: no real cost but there are hidden costs. Estimated 2 weeks of work for 2 workers in the purchase department and 2 workers in the legal department.

EASINESS OF IMPLEMENTATION: hard. The collection of the data will be challenging and time consuming. The complexity of the task is given by the high number of suppliers and very high number of components that would need to be considered in the analysis. Moreover, the definition of improved reorder policies will be done mainly by the purchase department that is the process owner while we would only offer consultation.

TIME SPAN: 4,5 months

ROOT CAUSE TARGETED: Supplier reorder lead time subject to variability

IMPACT: The impact defined for this countermeasure is 60% because even with a new rating system for suppliers the delays in the shipment of materials will still exist. The impact of this countermeasure will depend on the new policies that will be implemented based on its results. The total impact is 6,9 %.

STAKEHOLDERS: The collection of data and analysis would be done by us. We will also help the quality department in the definition of the improved reorder policies. The purchase department will be involved first in the collection of data and will be the decision maker for new reorder policies. The purchase and legal department would be involved in the negotiation phase.

## 9.5.Improvement of material feeding policies from warehouse to production lines

The introduction of a new material feeding policy based on the levelling of material requests throughout the period would reduce the number of delays in the retrieval activities. The aggregation of material requests for production orders creates peaks of requests in the warehouse that translates into higher material picking times. The first step would be the analysis of the operational parameters of the feeding activity. The time between two retrieval, the quantity of material retrieved for each request, the number of orders whose parts are collected on an average picking mission and the time required to perform the activity. Then, based on these parameters an improved material feeding policy could be defined. The aim would be to reduce the situations in which the request of a large volume of material at once creates delays in the feeding activities. This solution would be the starting point to gradually establish the best possible situation: have a balanced and even workload required from production along the week or even the day. The requests should be also synchronized with the production, in a JIT logic, as much as possible to minimize the space occupied by parts. This countermeasure also has some synergies with the first one, since a clear short-medium term scheduling of the pieces to be assembled on the lines will help in the definition of which materials should be retrieved and when.

COST: no real cost but there are hidden costs. Estimated 1 week of work for 2 industrial engineers of the company, 2 days of work for segment leader for the introduction of the new policies.

EASINESS OF IMPLEMENTATION: hard. The definition of the correct feeding policies for the lines will be based on trade-offs between many parameters like the use of warehouse throughput capacity, the picking time, the amount of inventory that can be placed on the line and the type of orders (number of pieces and parts to be assembled). The collection of the data will be challenging and time consuming.

TIME SPAN: 5 months

ROOT CAUSE TARGETED: Peaks in material handling requests

IMPACT: The impact defined for this countermeasure is 80% on the targeted root cause because even with a new retrieval policy of the materials there could still be specific situations that would require the batching of the retrieval of materials. The real impact of this countermeasure will depend on the new policies that will be implemented. The total impact on the problem is 10,5%.

STAKEHOLDERS: The collection of data and analysis would be done by us. We will also help the production department in the definition of the improved feeding policies. The production department will be involved first in the collection of data and will be the decision maker for new feeding policies. The industrial engineers of the company would also support the design of new feeding policies and their implementation.

### 9.6.Creation of proper quality control checks between production processes

The implementation of a quality control method in the production process would have a great impact. It will ensure that each product is corresponding to the required standards. Also, it limits the existence of any defects that may cause the discard of any component or even rework which matches the lean principles “do it right the first time”. It also gives the possibility to track where are the main sources causing waste or error in the process so that it can be easier to find a solution. Moreover, it can incentivize operators to do a better job. All the previous can lead to minimize any variation in the process.

To pursue this countermeasure an extensive analysis for the production process should be undertaken to understand the technical aspects of the products, their components and how are they assembled. Then, a standard for the important assembly steps should be defined and based on it, another standard is produced on the quality checks needed for every product and after which activity of the assembly should it be made. Then, a training on the new quality procedures should be given to the operators who will be responsible for quality and for the assembly operators.

COST: Estimated 2 months of work for 2 industrial engineers of the company and 2 technical. Cost of quality trainings and cost of quality operators if needed.

EASINESS OF IMPLEMENTATION: hard. The definition of the correct quality tests for the lines will be based on analysis done for the production process will be challenging as it will consume a lot of time and effort. Also, the implementation and adaptation of new procedures is costly and time consuming.

TIME SPAN: 4 months

ROOT CAUSE TARGETED: No quality control checks during the production process.

IMPACT: The impact defined for this countermeasure is 70% on the targeted root cause. The real impact of this countermeasure will depend on the new policies that will be implemented. The total impact on the problem is 15%.

STAKEHOLDERS: The quality, the industrial and technical departments are the main stakeholders in the implementation of this countermeasure.

However, as important as this countermeasure is, it will not be taken into consideration due to restrictions from the company. Therefore, it will not be considered for further analysis.

## 9.7.Analytical Hierarchical Processing

To evaluate the identified countermeasures, four relevant and heterogeneous criteria were used: cost, impact, time (quantitative) and easiness of implementation (qualitative). The ease of implementation is measured in a qualitative way considering the complexity of the challenges that need to be solved to have success in the implementation of the countermeasure. The AHP method was used for this purpose.

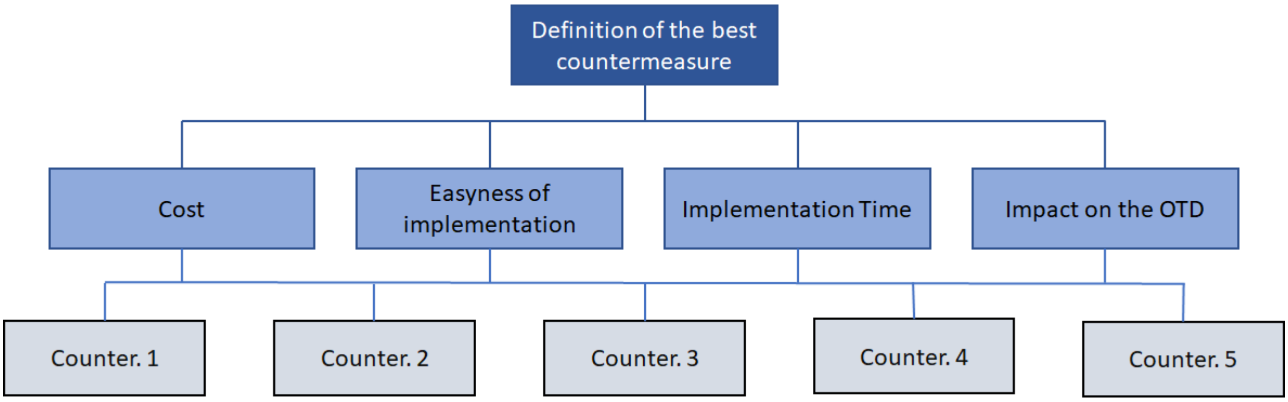



*Figure 7: AHP hierarchy*

The values of each parameter for each countermeasure have been estimated by us with the help of experts inside of the company (industrial engineers of the company and segment leader). The calculations are shown in the appendix Figure A- 32.

This is the final list with the correspondent scores:

*Table 4:AHP rank*

| **Countermeasure** | **Score** |
|---|---|
| Development of a production scheduling methodology and visual management support tool | 0,54 |
| Improved methodology for updating of critical components lead time | 0,31 |
| Improvement of the communication procedure between the sales and production departments for long-term orders in periods of high demand. | 0,29 |
| Improved supplier rating system based on the reliability of the reorder lead time | 0,12 |
| Improvement of material feeding policies from warehouse to production lines | 0,15 |

This result was consistent with the opinion of the company tutor that has accepted the implementation of the first three countermeasures by score.

# 10. IMPLEMENTATION OF THE COUNTERMEASURES

## 10.1. Countermeasure 1: Development of a production scheduling methodology and visual management support

The main decision of the new methodology is the order release policy and rules to implement. The application of the Pre shop pull system with the proper simplifications and assumptions derived by the practical application, was the starting point of our methodological decisions.

The PSP, in a full lean approach, should be a release of orders on the unique pacemaker. However, as it was discussed in the countermeasure selection, the impossibility to dedicate the testing rooms to product families constrained the choice to establish the production sequence on both the assembly and the testing phases.

Therefore, the orders will be released in the production starting from the testing phase, and then the sequence at the assembly phase is re-established to allow the feeding of the testing rooms, for these reasons:

- The testing rooms are the bottleneck for every product.
- It is easier to have a control on the OTD performance, controlling the release of orders on the last stage.
- The testing rooms are the only shared resources in the system.
- The decomposition of the process reduces its complexity and enables reaching a fast-feasible solution (Georgiadis *et al.*, 2020).

The approach for the order release in the testing phase is the Load Limiting one, with a lower bound limit: the workload of the orders is allocated to maintain a constant workload. This approach coupled with the EDD dispatching logic allows a better control on due-date performances and on the WIP level. Our workload measure was the hours for each order in the testing.

From the assignment of orders in the testing rooms, the scheduling of the assembly lines is derived. Starting from the scheduling of the assembly lines is possible to estimate an early date for the reorder of materials from the warehouse to the line. The scheduling concept therefore is divided into two main steps:

1- <u>Orders assignment in the Testing phase</u>

The "Portafoglio Ordini" provides the list of all the orders, arranged by increasing due date; it is our Pre shop pull in which the orders wait to be processed instead of waiting on the shop floor.

The scheduling works picking the orders in the pool from the most urgent to the least and allocating their expected workload (=the needed hours for that order) to the less loaded testing room among the available three as soon as the previous order in the selected testing room is finished. Referring to the assignment of one single order, three situations are possible:

1) The order can be assigned entirely to the station, finishing the testing before its due date

2) The pieces of the order need to be tested in different testing rooms to respect the due date

3) The workload of the order, even if divided among the testing rooms (parallelizing testing) does not allow to meet the due date.

In the situation 1 and 3 the order is entirely allocated to the least loaded testing room.

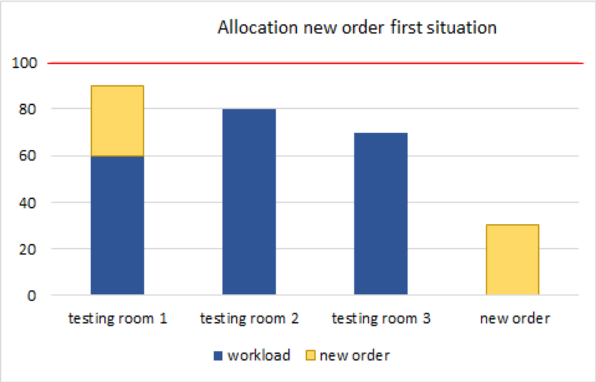



*Figure 8: Order allocation in testing rooms- case 1*

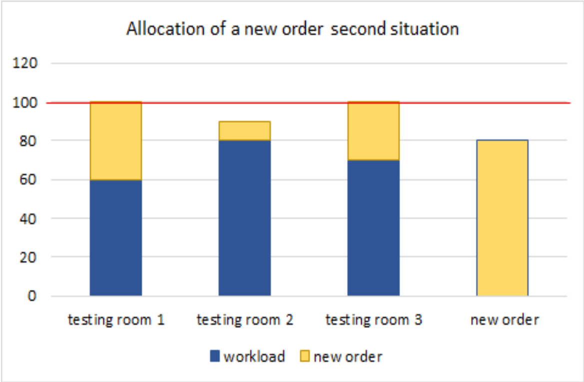



*Figure 9: Order allocation in testing rooms- case 2*

First it is evaluated how many products can be tested in the less loaded testing room before the due date, the remaining pieces then are allocated in the second less loaded testing room. If the available time before the due date is still not enough the remaining pieces are allocated to the third testing room. According to the amount of testing time allocated in each one of them, the finishing date of the order in the testing rooms is defined. This process is repeated for all orders up until the last one (the order with the latest due date) is allocated.

- $Tm$ = available time on the minimum
- $Ts$= starting time of the less loaded testing room
- $T2$ =time available in S2 $To$= time to test an order
- $To$= time to test an order

- $Tp$= time to test a piece
- $Np$= number of pieces in the order
- $T1$= time available in S1
- $T3$= time available in T1
- $Ta$ =time available in all 3-testing room
- $Nj$ = number of pieces allocated to testing room j
- $Tj$ =time available in testing room j
- $Tm = due\ date - Ts$
- $To = Tp * np$
- $Ta = T1 + T2 + T3$
- $Tj = \lfloor Nj\ /Tp \rfloor$

In case of equal starting date between two or three testing rooms at the moment of the allocation of a new order, the priority is to start the allocation on one of the two smaller testing rooms and only as a third choice the testing room with dedicated products.

At the end of the scheduling process the final date of working of each testing room is proposed. If the final date of the testing room with dedicated products is further away than the others, it means that at the end of the period there was a concentration of orders with products that could have been tested only there. To have a more balanced testing workload, some of the orders that were assigned to FL are reassigned to the other two. In this way the final date of work is similar between the three testing rooms and the scheduling spreads better the workload of the period.

This scheduling phase provides the starting and finishing time of each order in each testing room in which is tested. It also provides the number of pieces allocated to each testing room.

2- Synchronizing the Assembly lines

The assembly lines need to feed the testing rooms with assembled products. The cycle times of the products in the assembly lines and in the testing rooms are relatively similar, so when more than one testing room requires products from the same line at the same time it could be a problem. In these cases, the assembly of a piece must start in advance, before it is needed in the testing. To account for this situation we start the scheduling of the products in the assembly lines allocating the workload going backwards: we start the allocation of products to be assembled from the last product of the period and then we go back in time for the allocation of the other pieces.

To establish the assembly sequence in each line, the starting testing date of each single product within the order is defined. Their finishing time in the assembly line is defined equal to the minimum between its starting time at the testing room (minus a buffer period that can be set, initially decided at 3 days) and the starting assembly time of the piece assembled after it. The assembly lines are composed of 3 stations.

However, to simplify the scheduling (and not have to schedule 3 stations for 4 lines) we computed and showed on the visual tool only the scheduling of the first station. This is because the starting time of assembly of the product is the most useful information for the segment leader (because he can use it to know when to call the materials from the warehouse).

- $Ts_j$ = starting time of product j on the last station on the line
- $Tf_j$ = finishing time of product j on the line
- $CT_j$ = cycle time of the product j in the line
- $Tot_j$ = total time of product j on the line
- $Te_j$ = time of entrance of product j on the line
- $Tt_j$ =initial time of testing of product j
- B = buffer between line and testing
- $Tf_j = min\ (Ts_{j+1};\ Tt_j - B)$
- $Ts_j = Tf_j - CT_j$
- $Te_j = Tf_j - Tot_j$

### 10.1.1. Excel scheduler

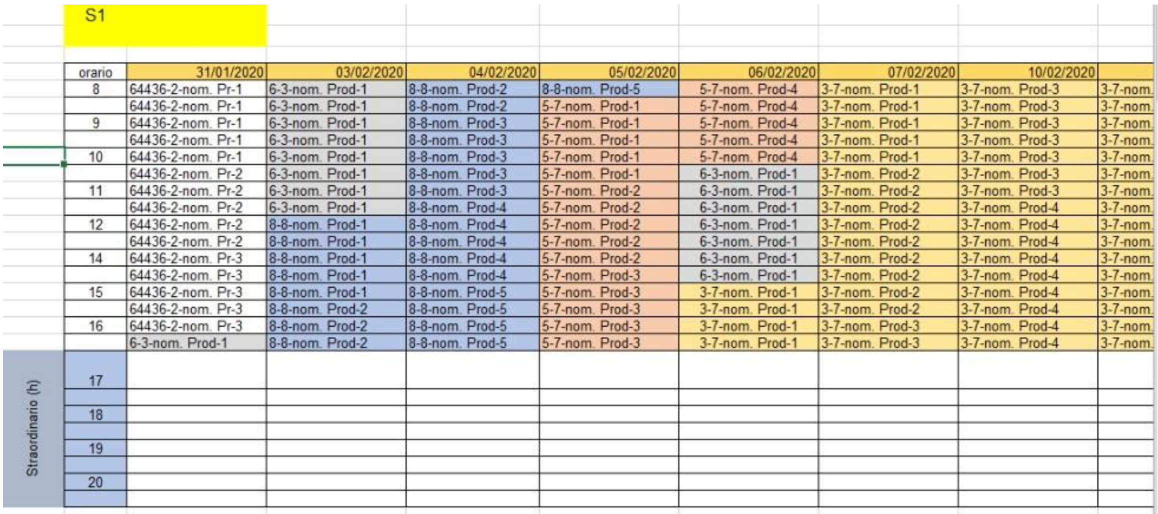
The Excel tool follows the logic and the constraints of the scheduling methodology explained in the previous two paragraphs with the usage of excel functions and macros. The excel tool develops in 15 excel sheets. It allows in few steps the automatic scheduling of the assembly lines and testing phase, considering as available working time 5 days per week, 8 hours per day, from 8.00 to 17.00 with a lunch break at noon. Consultations with industrial engineers of the company and the segment leader were useful to identify some practical characteristics of the tool, according to the needs of the future users. Some of the practical characteristics were:

- Rapid use and set-up phase
- Possibility to introduce overtime
- Possibility to introduce a double shift in the testing rooms
- It must be able to split the products in one order in several testing rooms
- It must provide KPIs
- It must be able to translate the scheduling of the testing phase to the assembly lines automatically
- Provide a visual representation of the scheduling on both testing rooms and assembly lines

- The possibility to do a rescheduling for the modelled period when its needed (Ma *et al.*, 2018).

The first sheet called “Collaudo" is dedicated to the scheduling of the testing phase. The lead times needed for the testing and assembly phases of the products are set in another separated sheet. A VLOOKUP function looks at the product type for each order and gives as a result the standard times, needed for the scheduling. However, for the great variety of products, it can happen that products of the same type require different assembly or testing times. Therefore, the table also has the information of those product codes: the information of the product code, if present in the table, has precedence over the product type one. To make the tool as robust as possible and avoid unfeasible scheduling, all the possible limit situations were evaluated in the excel functions. For example, it was modelled the situation of two or three equally loaded testing rooms. The scheduling system has the possibility to add planned or expected overtime, add the delay and anticipation of one order upon completion of it. In this way the scheduling can be more accurate also for orders at the end of the period and changes to the first plan can be recorded for the monitoring and the creation of KPIs. The scheduling gives a suggestion for a possible date for the overtime. The non-productive days (holidays and closure days that are not Saturdays and Sundays) can be added. There is also the possibility to leave a security time buffer between due date and end of testing.

The third sheet is dedicated to the visual representation of the testing scheduling, which is automatically displayed, taking as a reference the output of the sheet “Collaudo”. There is one visual representation for each testing room. The following figure represents one example of it.



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|---|---|---|---|---|---|---|---|---|---|
| | 8 | 64436-2-nom. Pr-1 | 6-3-nom. Prod-1 | 8-8-nom. Prod-2 | 8-8-nom. Prod-5 | 5-7-nom. Prod-4 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. |
| | | 64436-2-nom. Pr-1 | 6-3-nom. Prod-1 | 8-8-nom. Prod-2 | 5-7-nom. Prod-1 | 5-7-nom. Prod-4 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. |
| | 9 | 64436-2-nom. Pr-1 | 6-3-nom. Prod-1 | 8-8-nom. Prod-3 | 5-7-nom. Prod-1 | 5-7-nom. Prod-4 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. |
| | | 64436-2-nom. Pr-1 | 6-3-nom. Prod-1 | 8-8-nom. Prod-3 | 5-7-nom. Prod-1 | 5-7-nom. Prod-4 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. |
| | 10 | 64436-2-nom. Pr-1 | 6-3-nom. Prod-1 | 8-8-nom. Prod-3 | 5-7-nom. Prod-1 | 5-7-nom. Prod-4 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. |
| | | 64436-2-nom. Pr-2 | 6-3-nom. Prod-1 | 8-8-nom. Prod-3 | 5-7-nom. Prod-1 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-3 | 3-7-nom. |
| | 11 | 64436-2-nom. Pr-2 | 6-3-nom. Prod-1 | 8-8-nom. Prod-3 | 5-7-nom. Prod-2 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-3 | 3-7-nom. |
| | | 64436-2-nom. Pr-2 | 6-3-nom. Prod-1 | 8-8-nom. Prod-4 | 5-7-nom. Prod-2 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | 12 | 64436-2-nom. Pr-2 | 8-8-nom. Prod-1 | 8-8-nom. Prod-4 | 5-7-nom. Prod-2 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | | 64436-2-nom. Pr-2 | 8-8-nom. Prod-1 | 8-8-nom. Prod-4 | 5-7-nom. Prod-2 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | 14 | 64436-2-nom. Pr-3 | 8-8-nom. Prod-1 | 8-8-nom. Prod-4 | 5-7-nom. Prod-2 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | | 64436-2-nom. Pr-3 | 8-8-nom. Prod-1 | 8-8-nom. Prod-4 | 5-7-nom. Prod-3 | 6-3-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | 15 | 64436-2-nom. Pr-3 | 8-8-nom. Prod-1 | 8-8-nom. Prod-5 | 5-7-nom. Prod-3 | 3-7-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | | 64436-2-nom. Pr-3 | 8-8-nom. Prod-2 | 8-8-nom. Prod-5 | 5-7-nom. Prod-3 | 3-7-nom. Prod-1 | 3-7-nom. Prod-2 | 3-7-nom. Prod-4 | 3-7-nom. |
| | 16 | 64436-2-nom. Pr-3 | 8-8-nom. Prod-2 | 8-8-nom. Prod-5 | 5-7-nom. Prod-3 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. Prod-4 | 3-7-nom. |
| | | 6-3-nom. Prod-1 | 8-8-nom. Prod-2 | 8-8-nom. Prod-5 | 5-7-nom. Prod-3 | 3-7-nom. Prod-1 | 3-7-nom. Prod-3 | 3-7-nom. Prod-4 | 3-7-nom. |
| Straordinario (h) | 17 | | | | | | | | |
| | | | | | | | | | |
| | 18 | | | | | | | | |
| | | | | | | | | | |
| | 19 | | | | | | | | |
| | | | | | | | | | |
| | 20 | | | | | | | | |

*Figure 10: Visual representation of testing room on excel tool*

Each order has its own color and the information reported are the code of the order, the row number, the type of product and a progressive number for the products inside the order. Only working days are considered and, if overtime is inserted in the sheet “Collaudo”, it automatically displays the dedicated hours in the visual tool. This representation was created to support at the completion of the visual board, that should be based on similar information.

The fourth sheet is called “Dashboard” and shows the relevant KPIs. It gives useful information for the decision making at the beginning of the period and, if updated regularly, gives information on the actual production system. The first KPI is the expected OTD, that can be compared with the objective OTD of the period. If it is lower, the user can:

- plan overtime hours.
- start the testing of the orders in advance.

The second KPI is the expected average delay. It measures the time between due date and actual finishing of the late orders of the period. If it is low, it means that the addition of a small number of available hours (through overtime or starting the testing of the orders in advance) can highly increase the OTD of the period. The expected saturation of the testing rooms and the assembly lines are also computed. The saturation of the lines is important to keep track of the relative production mix. If too many products of the same type are produced in the same period, a specific line can become overloaded while the other will be underused. It gives a fast method to understand if the production mix is efficient or not and which lines should be prioritized in the allocation of resources (operators and overtime).

The fifth sheet is called “Scheduling -Collaudo” and it is a summary of the most useful information of the scheduling of the testing. It will be printed and distributed to the operators in the testing rooms to visualize the scheduling of the period. It gives information on the list of orders and type of products to be tested and the expected starting and finishing date in all testing rooms.

The sixth sheet is called “Scheduling-Assemblaggio” and contains all the initial calculations for the scheduling of the assembly lines (see appendix). A Macro on VBA groups the products to be tested based on their assembly line, so in four different columns. A second macro transfers the information related to those products in the next 4 excel sheets called “linea 1 assemblaggio”, “linea 2 assemblaggio”, “linea 3 assemblaggio” and “linea 4 assemblaggio”. Both the macros need to be activated by a button on this sheet.

At the end is created the list of products to be assembled on the line with relative starting and ending assembly times. A visual representation of the scheduling of the next 30 working days is also defined, as in for the testing phase.

The last excel sheet is called “visual testing 2 shift” and it shows a visual representation of the scheduling if 2 shifts were to be implemented in the testing phase. This is a real possibility in the future even if at least for now there are not enough operators to organize two shifts.

See Appendix for the step by step visualization of the tool.

### 10.1.2. Calculation of the production capacity

This scheduling system also provides a useful tool to define the actual production capacity of the system. It takes into consideration all the constraints that we have listed in the root cause analysis:

- Aggregation of available hours and needed hours by day and not by month
- Some products can only be tested in a specific testing room.
- The check of the capacity of the assembly lines.

If an order is immediately defined as late in the scheduling it means that there is not enough production capacity to finish it in time. Every time the sales department receives a new order it can be added to the list in the excel. If the order can be completed before its due date the sales department should accept it, otherwise if it becomes a late order in the scheduling its due date should be renegotiated with the customer or more overtime should be added. The excel sheet dedicated to the scheduling of the assembly is also useful for the check of the production capacity of the lines. If the starting date of assembly for the products of one line is too early in time it means that the line is overloaded, and the production mix is not optimal. Several decisions can be taken in this case:

- A new due date for orders assembled in that line could be shifted forward.
- The line could be prioritized in the scheduling of the resources (operators).
- More overtime could be assigned to the line.

### 10.1.3. Visual management tool

After reaching the final scheduling results of the excel tool, it is now time to present the results on the visual board as discussed previously. So, in the following section we explain how this board is constructed and how it functions. On the board the scheduling for all the testing rooms and assembly lines will be presented. Due to the constraint of size of the board, feasibility and clarity of information we decided that the span of time presented on the board would be one week in which each day will be divided into slots of the hours existing in the daily shift.

When a day of the week is finished the corresponding one of the next weeks is placed on the board instead of the existing one to continuously have a visibility of one week. A colored strip would mark which day we are at this moment. The products are presented on the board by magnetic strip where each strip represents only one product. The length of the strip represents the cycle time of its corresponding products as products from different families and even inside the same family can have different cycle times for each station of the process.

The color of the strip corresponds to the assembly line (each line has a unique color code) on which this product is manufactured to have visibility on the whole process and to see if a modification is made or a delay occurs where the process will be affected. Moreover, on this strip information related to the order number, product family and product number related to the order can be displayed if needed. This information can be added by an erasable marker to reuse these strips.

To construct this board, we take the information calculated in the scheduling excel file. Then, from the beginning of the first day of the first week of the month we start putting the magnetic stripes corresponding to product in the schedule till the end of the week is reached. Then, as each day passes the existing related strips are removed and replaced by the strips related to the products of the corresponding day in the next week.

Using this approach if a modification is done on the scheduling, it would be easy to make this modification on the visual board by just replacing the initial strip with the new ones of the new modified schedule. Also, when a delay occurs, it is translated on the board by shifting the magnetic strips by the amount of time corresponding to this delay. This means that it is easy to use, and it is easy to make a modification on this tool.

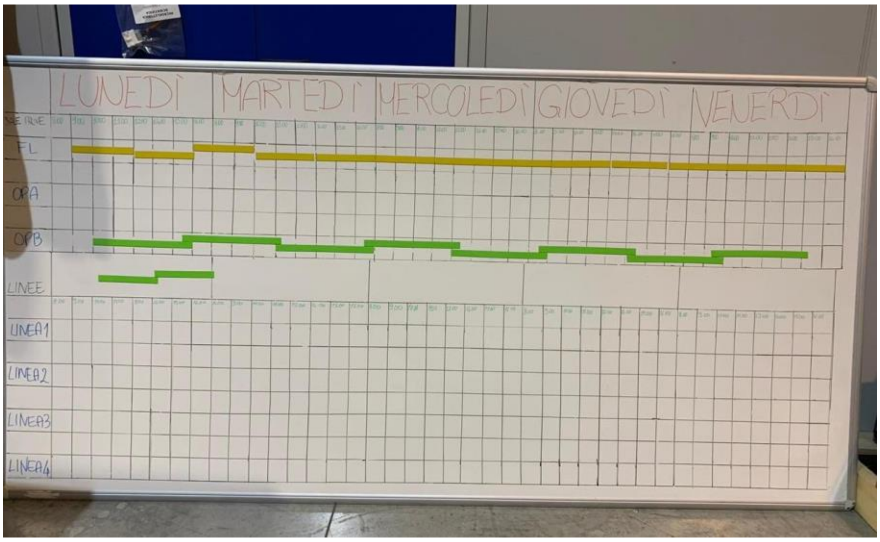


*Figure 11: Visual board and magnetic stickers*

### 10.1.4. Physical implementation phase

The tool was tested with the orders of January, during the construction of the tool, and February to test the robustness and performances of it. We have shown the logic, the excel functions and macros behind the tool so that in case of modifications to the production system it would be possible to modify it. This is aligned with the “check” and “act” principles of the PDCA cycle which state that the process of developing a solution should follow an iterative logic. Therefore, as it has been done, the proposed solution was examined and reviewed to discover any errors and act upon them as early as possible.

The shareholder involved in the project are the segment leader that will use the tool in its planning and everyday activities, the operators that will use it as a reference for their work and the industrial engineers of the company for the monitoring of the process performances and the maintenance of the tool after the end of the team's project in the company. The segment leader will use it mainly at the start of the month to plan the target production and have information on how it should be organized. The initial scheduling will give recommendations on how to assign the overtime and what materials will need to be moved on the lines every day.

The visual tool will be the starting point for the organization of the visual board. The team has involved the segment leader in the design of the tool, especially in the definition of the set-up activities to make him understand the ease and usefulness of the tool use. The segment leader will check daily the advance of production during the period and to have a more precise scheduling will add hours of delay or advance to the orders in the tool. The team also involved the operators in the project by asking them their opinion and interviewing them on what could be done to make their job easier and more effective. The visual board is an idea that was formulated after one of these interviews. The team also organized a meeting to explain the changes to the operators and how they are going to be affected by it and to try to convince them that the project would just simplify their work, without increasing their workload. The industrial engineers of the company that helped us always supported the project and they will oversee the implementation of the project after the end of the team's period in the company.

## 10.2. Countermeasure 2: Improved methodology for updating of critical components lead time

Given the results of the AHP analysis, we decided to develop a secondary countermeasure, involving the purchase department which is critical for the OTD performance in the company.

To solve the issue of unreliable components, lead time in the MRP, a new methodology has been defined. It was decided to first work on identifying the critical components, meaning those that could lead to orders delays for the mismatch between the actual lead time and the MRP's one. In the analysis of the root causes it was described why this influences the OTD level. Supported by the analysis conducted for the root cause and by the interview with the purchasing department, the components that fulfilled both the following requisites were considered critical:

- components sold by suppliers without a long-term contract.
- components not been reordered in the last 6 months.

Indeed, the suppliers that have a long-term contract are required to communicate changes in the delivery lead time of the components, so they are not part of the analysis. The most consistent characteristic for the critical components is the time between one reorder and the next one.

The improved methodology aims at reducing the probability of those events, while minimizing the additional work for the purchasing staff. The lead time for specific critical components was proposed to be asked as soon as the sales department receives the order request from the customer. In this way possible changes in the reorder lead time will be detected before the definition of a due date and would not impact the timeliness performances of the company.

The major challenge with the introduction of this countermeasure is in letting the purchase department staff understand the advantage of the new methodology. Since these critical components can be found mostly in special type of breakers (low percentage of orders a month) and they represent a limited part of the overall components (10%), the additional workload for the purchase department is very limited. Furthermore, the checking activity of the components reorder lead time is a task that the purchasing department would carry out regardless of the implementation of the countermeasure. The improved methodology only anticipates it. A meeting with the purchase department was carried on explaining the advantages of the solution.

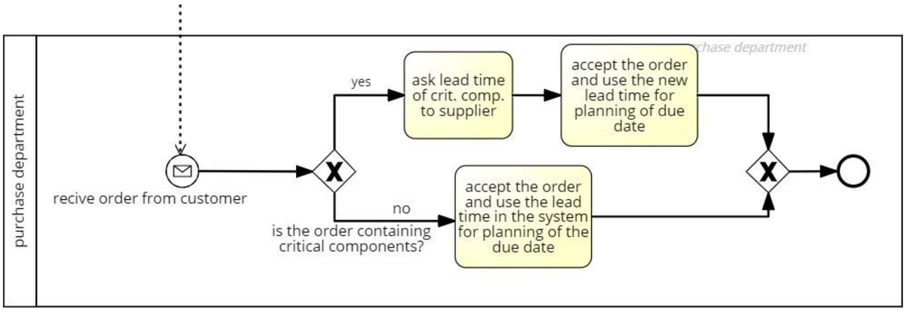

*Figure 12: Simplified visualization of the improved process in purchase department*

### 10.3. Countermeasure 3: Improvement of the communication procedure between the sales and production departments for long-term orders in periods of high demand.

When normal orders are accepted by the sales department, they are immediately communicated to the segment leader that defines the possible due date for the order and schedules production accordingly. Instead the due date of long-term orders (orders made by clients that require a fixed number of breakers every 6 months or every year) is scheduled on the assumption of infinite capacity and are communicated to the production department on average around 2 months before their due date. This can cause mismatches between needed hours and available hours if the period is experiencing an unpredicted high demand. The sales department does not need the authorization of the segment leader when accepting these orders because the production capacity on a time horizon of 6 months is considered always enough to make the order in time. In the past this delay in the communication was not a problem because of the lower demand of the segment, but with the recent increase in orders and in saturation sometimes a time horizon of 2 months is not sufficient for the segment leader.

The solution is to make the sales department communicate the order to the segment leader immediately after the customer confirmation. This is a minor change in the tasks of the sales worker and the workload would be unchanged. The main issue would be in making the sales department understand that even if the impact on the level of OTD of such a change would be quite small, it would still be relevant. To explain the changes in the methodology and their benefit we have organized a meeting with the sales department. For the implementation of this countermeasure we had the support of the industrial engineers of the company.

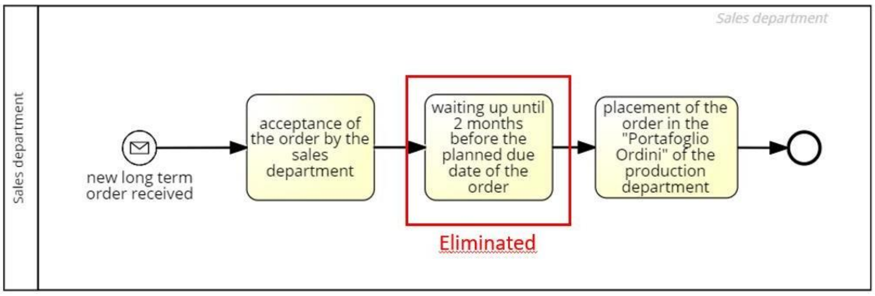


*Figure 13: Simplified visualization of the improved process in sales department*

# 11. MONITORING RESULTS AND PROCESS

## 11.1. Quantitative results

The qualitative results of the countermeasure that we have developed can be measured in percentage points of reduction of late orders and WIP reduction. The impact of the countermeasures on the must have target can be analyzed in 3 ways:

1- By multiplying the impacted root cause reduction for the effect of the root cause on the problem.

2- By recalculating the OTD of the last 3 months on our excel tool and comparing it to the real OTD measured in those months.

3- By measuring the OTD of the system after the implementation of the countermeasures

The first two ways are theoretical and used only in anticipation of the real target measurement.

### 11.1.1. The impact on the OTD

The first aim of our project was to increase the OTD of the breakers' segment. This does not translate immediately in a reduction of costs or an increase in revenues. However, the company and the team believe that in a b2b market like the one of Microelettrica Scientifica the customer service level is going to be more and more relevant in the future. Indeed, improving the OTD of the company will translate in the medium term in increasing revenues.

The excel tool has two functions: provide a clearer understanding of the production capacity to set a better due date with the client and provide a new way of scheduling to optimize the OTD with the existing production capacity. The first effect can be measured in practice only after 2 or 3 months after the first implementation, since the segment leader needs to be able to use the tool and understand when he can set the due date of the new orders. The impact of the second function could be measured 4 to 6 weeks after the first implementation of the tool because of the offset between production lines and testing rooms. The first real measures of success will then be collected from mid-March to late May.

To give a first estimation of the impact of the countermeasure we have used our scheduling tool on the "portafoglio ordini" of November and December and we have then compared the theoretical OTD with the OTD registered in reality. As it was explained before the change expected in the OTD does not consider the first function of the excel tool that enables to define more clearly the due date of the orders, because for past months the dates are already set and cannot be changed. Furthermore, the orders whose delay was attributable to other causes were not considered. To have a realistic analysis the starting time of the testing rooms was set the same date as in reality. Also, delays in production caused by other problems and the same number of overtimes were added in the excel tool. The total decrease in late orders was of 19%, quite in line with the expected result of 17%.

However, this first method cannot be used to evaluate the impact on the other root causes targeted by the implemented countermeasures. For the final analysis we have used the second method that estimates a reduction of 28,9% for the first countermeasure, 3,4% for the second one and 4% for the third one. The total reduction of late orders expected is then 35,7%. However, after a meeting with the company tutor, we have decided to be conservative and to reduce the expected impact by 20% because no real data have been collected yet. The total reduction of late orders agreed with the company is then 28,6%, just under our nice to have target, but well above the required one. The measurements on the real system after the physical implementation will give more precise data.

### 11.1.2. Impact of the first countermeasure on the WIP and space in the buffer between assembly phase and testing phase

The numbers regarding the WIP in the system and the economic calculations will not be shared explicitly to respect the privacy of the company. The impact of the first solution on the WIP right now can only be calculated theoretically since the real use of the tool in the company is ongoing and the transition period will last at least a month. The amount of WIP in the buffer was measured during the Gemba walk and used as a reference to calculate the amount of reduction induced by the implemented countermeasure. It is consistent with the information collected during the interviews with the segment leader that told us the offset time between assembly and scheduling before the introduction of the countermeasure and the amount of product produced on average in a month. To define the WIP necessary after the introduction of the new way of scheduling we have divided it into WIP created by misalignment between assembly throughput rate and testing rooms demand for breakers and WIP required to account for the variability of the processing times.

The first WIP can be calculated by using our scheduling tool on the Portafoglio ordini of the last 2 months and by measuring the average pieces finished by the assembly and waiting to be tested. In a perfect situation it could be 0 but for the measured months it was on average a number higher than 0 (mostly on line 2, because it was the one with more workload). The theoretical calculation for the second type of WIP was much harder because of the complexity of the system. A rough estimation with the probability of no completion theory gave us a buffer of 1-1,5 days. Put together the average theoretical buffer we were able to calculate the expected WIP after the introduction of the countermeasure. The expected reduction in WIP level of the buffer was then defined as 55%, above the target level of 40%.

This reduction in WIP has an impact on the immobilized capital of the company since the materials could be ordered later from the suppliers and this would postpone the actual payment of the components. From the average breaker material costs and the reduction in WIP we have then calculated an estimation of the economic savings. By comparing the reduction of inventory carrying costs and the initial investment the payback time can be calculated as around 1 month from the first implementation.

Since the amount of WIP will be reduced, also the space required by the buffer will go down. From the average space occupied by a breaker and the amount of WIP reduction we have calculated the savings in terms of space available for other activities.

## 11.2. Qualitative results

The reduction of WIP between testing phase and assembly phase gives more visibility over the inefficiencies of the line. Right now, many problems of the testing and assembly phase are hidden by the very high buffer between them. Only by reducing it the industrial engineers of the company and the segment leader can understand what should be improved and what should be changed, paving the way for the implementation of a continuous improvement approach.

It will also help in the organization of the workforce. Currently there is uncertainty in the assignment of the operators to the stations, for example they know only a few days in advance in which station they are going to work and if overtime is needed. With the new methodology, it will be possible to know several days in advance when and where to use overtime and where operators are going to be assigned.

The visual management tool will increase the involvement of the operators in the production process. They will not just receive instructions on what to produce every day, but they will be directly involved in the control of the production process, involving them in giving ideas and feedback to the segment leader.

New problems will be easier to solve because of a more structured and efficient monitoring of the performances of the process. Without high WIP and a short-medium term planning of production, delays and inefficiencies in the process will be spotted faster and solved.

The excel tool only requires a few minutes to be set up for use and it replaces all the activities for the calculations of the production capacity done every month by the segment leader. Before the introduction of the tool these activities were performed with paper and pen and it lasted between two and four hours. All this time is saved every month and can be used by the production leader to carry out other more useful activities.

The industrial engineers that supported us during the project will measure the effect of the developed countermeasures on the OTD and the amount of WIP in the buffer. They will measure the OTD KPI from the portafoglio ordini of March, April, and May to measure the medium-term effect and how and how the late orders will reduce over time. They will also perform the Gemba walks twice per week for the months of March and April to check if the WIP will be effectively reduced in line with the theoretical predictions.

## 12. STANDARDIZE AND SHARE SUCCESS

The project has shined light over the major problems of the production process. The excel tool has been developed in a modular way so that if changes were to be made to the production process it could still be used after little modifications. A fifth line and a fourth testing room could be added to the production system soon. The team has instructed the industrial engineers related to the project in the functioning of the excel and the way new assembly lines or testing rooms could be added to it. A standard for the modelling of production in excel has been created, so that if the need may arise for another department the tool could be modified to fit its specifications. Since changes in the process parameters are common in the breakers' department, an activity of maintenance of the tool is fundamental.

The next step for the upgrade of the tool would be to integrate the reorder and feeding of the materials from the warehouse to the line with the scheduling of production. Right now, the segment leader needs to send multiple material orders for each customer order to the warehouse at the right time to have the materials he needs to start production. Since now the starting times of assembly for each product can be defined in advance with greater accuracy, the excel tool could also handle the transmission of orders to the warehouse. This would simplify the work of the segment leader and would help in the organization of the material feeding from the warehouse, that is another criticality of the process.

Another activity that would reduce the uncertainty of production planning and increase the accuracy of the scheduling tool is the integration of standard times for each product code in the excel tool. Right now the standard times for most products are defined by the tool based on the type of product of the order. However, the inclusion of specific times for each one of the product codes would make the scheduling more accurate. This is an activity that can be performed continuously and in small steps by adding the specific standard times in the dedicated table in the excel every time a new code is produced.

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# 14. APPENDIX

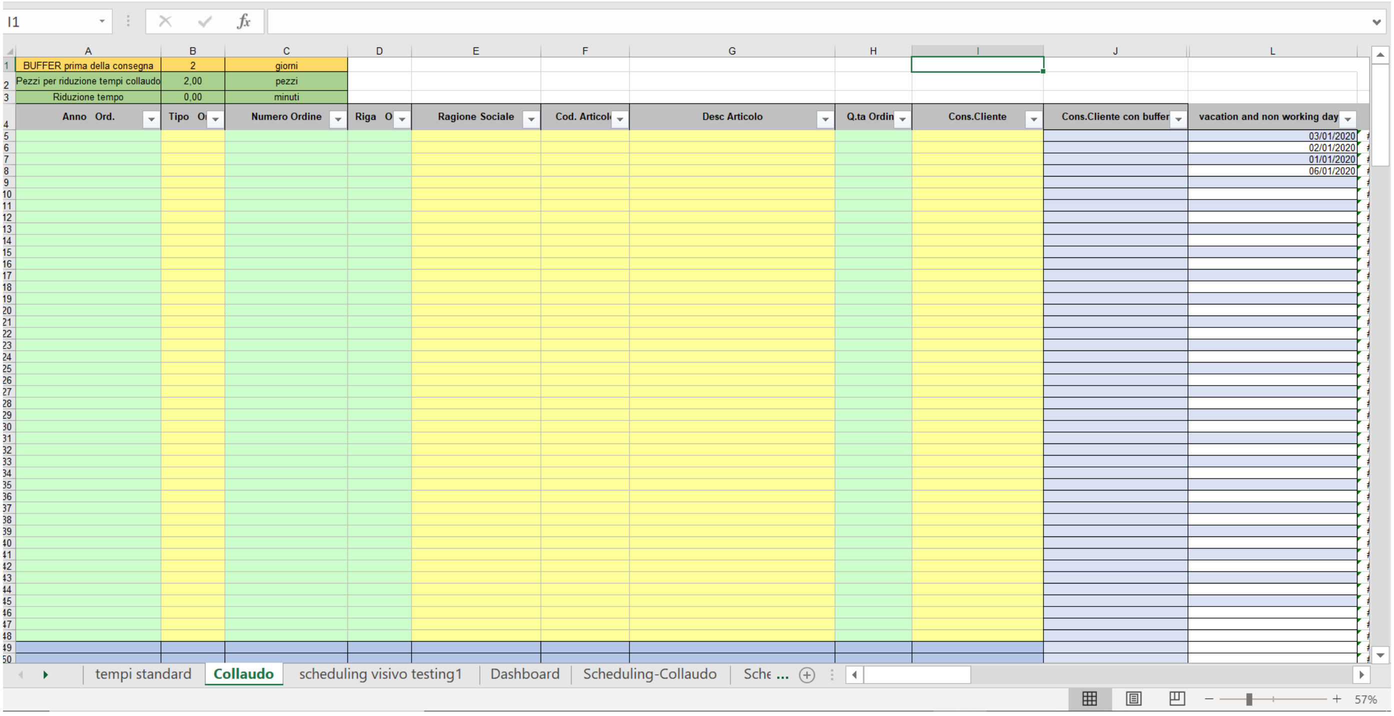
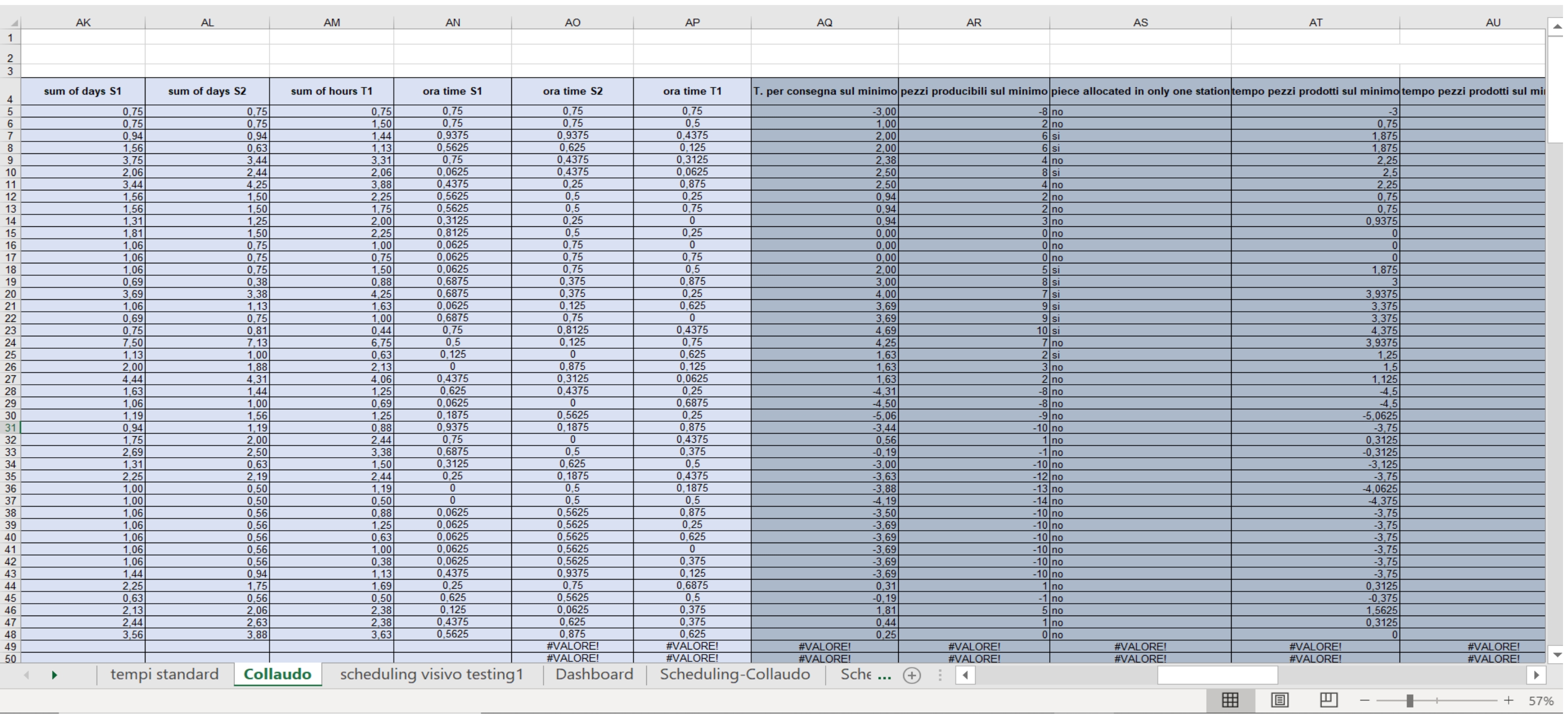



*Figure A- 1: first excel sheet with area for the copy pasting of the set-up information for the scheduling*



| | sum of days S1 | sum of days S2 | sum of hours T1 | ora time S1 | ora time S2 | ora time T1 | T. per consegna sul minimo | pezzi producibili sul minimo | piece allocated in only one station | tempo pezzi prodotti sul minimo | tempo pezzi prodotti sul mi |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0,75 | 0,75 | 0,75 | 0,75 | 0,75 | 0,75 | -3,00 | -8 | no | -3 | |
| 6 | 0,75 | 0,75 | 1,50 | 0,75 | 0,75 | 0,5 | 1,00 | 2 | no | 0,75 | |
| 7 | 0,94 | 0,94 | 1,44 | 0,9375 | 0,9375 | 0,4375 | 2,00 | 6 | si | 1,875 | |
| 8 | 1,56 | 0,63 | 1,13 | 0,5625 | 0,625 | 0,125 | 2,00 | 6 | si | 1,875 | |
| 9 | 3,75 | 3,44 | 3,31 | 0,75 | 0,4375 | 0,3125 | 2,38 | 4 | no | 2,25 | |
| 10 | 2,06 | 2,44 | 2,06 | 0,0625 | 0,4375 | 0,0625 | 2,50 | 8 | si | 2,5 | |
| 11 | 3,44 | 4,25 | 3,88 | 0,4375 | 0,25 | 0,875 | 2,50 | 4 | no | 2,25 | |
| 12 | 1,56 | 1,50 | 2,25 | 0,5625 | 0,5 | 0,25 | 0,94 | 2 | no | 0,75 | |
| 13 | 1,56 | 1,50 | 1,75 | 0,5625 | 0,5 | 0,75 | 0,94 | 2 | no | 0,75 | |
| 14 | 1,31 | 1,25 | 2,00 | 0,3125 | 0,25 | 0 | 0,94 | 3 | no | 0,9375 | |
| 15 | 1,81 | 1,50 | 2,25 | 0,8125 | 0,5 | 0,25 | 0,00 | 0 | no | 0 | |
| 16 | 1,06 | 0,75 | 1,00 | 0,0625 | 0,75 | 0 | 0,00 | 0 | no | 0 | |
| 17 | 1,06 | 0,75 | 0,75 | 0,0625 | 0,75 | 0,75 | 0,00 | 0 | no | 0 | |
| 18 | 1,06 | 0,75 | 1,50 | 0,0625 | 0,75 | 0,5 | 2,00 | 5 | si | 1,875 | |
| 19 | 0,69 | 0,38 | 0,88 | 0,6875 | 0,375 | 0,875 | 3,00 | 8 | si | 3 | |
| 20 | 3,69 | 3,38 | 4,25 | 0,6875 | 0,375 | 0,25 | 4,00 | 7 | si | 3,9375 | |
| 21 | 1,06 | 1,13 | 1,63 | 0,0625 | 0,125 | 0,625 | 3,69 | 9 | si | 3,375 | |
| 22 | 0,69 | 0,75 | 1,00 | 0,6875 | 0,75 | 0 | 3,69 | 9 | si | 3,375 | |
| 23 | 0,75 | 0,81 | 0,44 | 0,75 | 0,8125 | 0,4375 | 4,69 | 10 | si | 4,375 | |
| 24 | 7,50 | 7,13 | 6,75 | 0,5 | 0,125 | 0,75 | 4,25 | 7 | no | 3,9375 | |
| 25 | 1,13 | 1,00 | 0,63 | 0,125 | 0 | 0,625 | 1,63 | 2 | si | 1,25 | |
| 26 | 2,00 | 1,88 | 2,13 | 0 | 0,875 | 0,125 | 1,63 | 3 | no | 1,5 | |
| 27 | 4,44 | 4,31 | 4,06 | 0,4375 | 0,3125 | 0,0625 | 1,63 | 2 | no | 1,125 | |
| 28 | 1,63 | 1,44 | 1,25 | 0,625 | 0,4375 | 0,25 | -4,31 | -8 | no | -4,5 | |
| 29 | 1,06 | 1,00 | 0,69 | 0,0625 | 0 | 0,6875 | -4,50 | -8 | no | -4,5 | |
| 30 | 1,19 | 1,56 | 1,25 | 0,1875 | 0,5625 | 0,25 | -5,06 | -9 | no | -5,0625 | |
| 31 | 0,94 | 1,19 | 0,88 | 0,9375 | 0,1875 | 0,875 | -3,44 | -10 | no | -3,75 | |
| 32 | 1,75 | 2,00 | 2,44 | 0,75 | 0 | 0,4375 | 0,56 | 1 | no | 0,3125 | |
| 33 | 2,69 | 2,50 | 3,38 | 0,6875 | 0,5 | 0,375 | -0,19 | -1 | no | -0,3125 | |
| 34 | 1,31 | 0,63 | 1,50 | 0,3125 | 0,625 | 0,5 | -3,00 | -10 | no | -3,125 | |
| 35 | 2,25 | 2,19 | 2,44 | 0,25 | 0,1875 | 0,4375 | -3,63 | -12 | no | -3,75 | |
| 36 | 1,00 | 0,50 | 1,19 | 0 | 0,5 | 0,1875 | -3,88 | -13 | no | -4,0625 | |
| 37 | 1,00 | 0,50 | 0,50 | 0 | 0,5 | 0,5 | -4,19 | -14 | no | -4,375 | |
| 38 | 1,06 | 0,56 | 0,88 | 0,0625 | 0,5625 | 0,875 | -3,50 | -10 | no | -3,75 | |
| 39 | 1,06 | 0,56 | 1,25 | 0,0625 | 0,5625 | 0,25 | -3,69 | -10 | no | -3,75 | |
| 40 | 1,06 | 0,56 | 0,63 | 0,0625 | 0,5625 | 0,625 | -3,69 | -10 | no | -3,75 | |
| 41 | 1,06 | 0,56 | 1,00 | 0,0625 | 0,5625 | 0 | -3,69 | -10 | no | -3,75 | |
| 42 | 1,06 | 0,56 | 0,38 | 0,0625 | 0,5625 | 0,375 | -3,69 | -10 | no | -3,75 | |
| 43 | 1,44 | 0,94 | 1,13 | 0,4375 | 0,9375 | 0,125 | -3,69 | -10 | no | -3,75 | |
| 44 | 2,25 | 1,75 | 1,69 | 0,25 | 0,75 | 0,6875 | 0,31 | 1 | no | 0,3125 | |
| 45 | 0,63 | 0,56 | 0,50 | 0,625 | 0,5625 | 0,5 | -0,19 | -1 | no | -0,375 | |
| 46 | 2,13 | 2,06 | 2,38 | 0,125 | 0,0625 | 0,375 | 1,81 | 5 | no | 1,5625 | |
| 47 | 2,44 | 2,63 | 2,38 | 0,4375 | 0,625 | 0,375 | 0,44 | 1 | no | 0,3125 | |
| 48 | 3,56 | 3,88 | 3,63 | 0,5625 | 0,875 | 0,625 | 0,25 | 0 | no | 0 | |
| 49 | | | | | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! |
| 50 | | | | | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! |

*Figure A- 2: first part of the calculations for the scheduling of the testing rooms* step 2

| | AU | AV | AW | AX | AY | AZ | BA | BB | BC | BD |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | tempo pezzi prodotti sul minimo S1 | tempo pezzi prodotti sul minimo S2 | tempo pezzi prodotti sul minimo T1 | ore da aggiungere S1 | ore da aggiungere S2 | ore da aggiungere T1 | pezzi prodotti non sul minimo | tempo pezzi non sul minimo | EMPO PEZZI PRODOTTI SU NON MINIMO | EZZI PRODOTTI SU |
| 5 | -3,0000 | -3,0000 | -3,0000 | 0,0000 | 0,0000 | 0,0000 | 10 | 3,75 | 3,7500 | |
| 6 | 0,7500 | 0,7500 | 1,5000 | 0,7500 | 0,7500 | 0,5000 | 0 | 0 | 0,0000 | |
| 7 | 1,8750 | 1,8750 | 2,3750 | 0,8750 | 0,8750 | 0,3750 | 0 | 0 | 0,0000 | |
| 8 | 2,8125 | 1,8750 | 2,3750 | 0,8125 | 0,8750 | 0,3750 | 0 | 0 | 0,9375 | |
| 9 | 3,1875 | 2,8750 | 2,7500 | 0,1875 | 0,8750 | 0,7500 | 1 | 0,5625 | 1,5000 | |
| 10 | 3,0000 | 3,3750 | 3,0000 | 0,0000 | 0,3750 | 0,0000 | 0 | 0 | 0,5000 | |
| 11 | 2,3125 | 3,1250 | 2,7500 | 0,3125 | 0,1250 | 0,7500 | 2 | 1,125 | 1,1875 | |
| 12 | 0,8125 | 0,7500 | 1,5000 | 0,8125 | 0,7500 | 0,5000 | 2 | 0,75 | 0,8125 | |
| 13 | 0,8125 | 0,7500 | 1,0000 | 0,8125 | 0,7500 | 0,0000 | 2 | 0,75 | 0,8125 | |
| 14 | 1,0000 | 0,9375 | 1,6875 | 0,0000 | 0,9375 | 0,6875 | 1 | 0,3125 | 0,3750 | |
| 15 | 0,3125 | 0,0000 | 0,7500 | 0,3125 | 0,0000 | 0,7500 | 4 | 1,5 | 1,8125 | |
| 16 | 0,3125 | 0,0000 | 0,2500 | 0,3125 | 0,0000 | 0,2500 | 2 | 0,75 | 1,0625 | |
| 17 | 0,3125 | 0,0000 | 0,0000 | 0,3125 | 0,0000 | 0,0000 | 2 | 0,75 | 1,0625 | |
| 18 | 2,1875 | 1,8750 | 2,6250 | 0,1875 | 0,8750 | 0,6250 | 0 | 0 | 0,3125 | |
| 19 | 3,3125 | 3,0000 | 3,5000 | 0,3125 | 0,0000 | 0,5000 | 0 | 0 | 0,3125 | |
| 20 | 4,2500 | 3,9375 | 4,8125 | 0,2500 | 0,9375 | 0,8125 | 0 | 0 | 0,3125 | |
| 21 | 3,6875 | 3,7500 | 4,2500 | 0,6875 | 0,7500 | 0,2500 | 0 | 0 | 0,3125 | |
| 22 | 3,6875 | 3,7500 | 4,0000 | 0,6875 | 0,7500 | 0,0000 | 0 | 0 | 0,3125 | |
| 23 | 4,6875 | 4,7500 | 4,3750 | 0,6875 | 0,7500 | 0,3750 | 0 | 0 | 0,3125 | |
| 24 | 4,6875 | 4,3125 | 3,9375 | 0,6875 | 0,3125 | 0,9375 | 5 | 2,8125 | 3,5625 | |
| 25 | 1,7500 | 1,6250 | 1,2500 | 0,7500 | 0,6250 | 0,2500 | 0 | 0 | 0,5000 | |
| 26 | 2,0000 | 1,8750 | 2,1250 | 0,0000 | 0,8750 | 0,1250 | 0 | 0 | 0,5000 | |
| 27 | 1,6250 | 1,5000 | 1,2500 | 0,6250 | 0,5000 | 0,2500 | 5 | 2,8125 | 3,3125 | |
| 28 | -4,0000 | -4,1875 | -4,3750 | 0,0000 | 0,8125 | 0,6250 | 10 | 5,625 | 6,1250 | |
| 29 | -4,0000 | -4,0625 | -4,3750 | 0,0000 | 0,9375 | 0,6250 | 9 | 5,0625 | 5,5625 | |
| 30 | -5,0000 | -4,6250 | -4,9375 | 0,0000 | 0,3750 | 0,0625 | 11 | 6,1875 | 6,2500 | |
| 31 | -3,5625 | -3,3125 | -3,6250 | 0,4375 | 0,6875 | 0,3750 | 12 | 4,5 | 4,6875 | |
| 32 | 0,5000 | 0,7500 | 1,1875 | 0,5000 | 0,7500 | 0,1875 | 4 | 1,25 | 1,4375 | |
| 33 | -0,1250 | -0,3125 | 0,5625 | 0,8750 | 0,6875 | 0,5625 | 9 | 2,8125 | 3,0000 | |
| 34 | -2,4375 | -3,1250 | -2,2500 | 0,5625 | 0,8750 | 0,7500 | 12 | 3,75 | 4,4375 | |
| 35 | -3,0625 | -3,1250 | -2,8750 | 0,9375 | 0,8750 | 0,1250 | 17 | 5,3125 | 6,0000 | |
| 36 | -3,3750 | -3,8750 | -3,1875 | 0,6250 | 0,1250 | 0,8125 | 14 | 4,375 | 5,0625 | |
| 37 | -3,6875 | -4,1875 | -4,1875 | 0,3125 | 0,8125 | 0,8125 | 15 | 4,6875 | 5,3750 | |
| 38 | -3,0625 | -3,5625 | -3,2500 | 0,9375 | 0,4375 | 0,7500 | 11 | 4,125 | 4,8125 | |
| 39 | -3,0625 | -3,5625 | -2,8750 | 0,9375 | 0,4375 | 0,1250 | 11 | 4,125 | 4,8125 | |
| 40 | -3,0625 | -3,5625 | -3,5000 | 0,9375 | 0,4375 | 0,5000 | 11 | 4,125 | 4,8125 | |
| 41 | -3,0625 | -3,5625 | -3,1250 | 0,9375 | 0,4375 | 0,8750 | 11 | 4,125 | 4,8125 | |
| 42 | -3,0625 | -3,5625 | -3,7500 | 0,9375 | 0,4375 | 0,2500 | 11 | 4,125 | 4,8125 | |
| 43 | -3,0625 | -3,5625 | -3,3750 | 0,9375 | 0,4375 | 0,6250 | 12 | 4,5 | 5,1875 | |
| 44 | 1,0000 | 0,5000 | 0,4375 | 0,0000 | 0,5000 | 0,4375 | 4 | 1,25 | 1,9375 | |
| 45 | -0,1250 | -0,1875 | -0,2500 | 0,8750 | 0,8125 | 0,7500 | 2 | 0,75 | 1,0000 | |
| 46 | 1,8125 | 1,7500 | 2,0625 | 0,8125 | 0,7500 | 0,0625 | 1 | 0,3125 | 0,5625 | |
| 47 | 0,8750 | 1,0625 | 0,8125 | 0,8750 | 0,0625 | 0,8125 | 5 | 1,5625 | 2,1250 | |
| 48 | 0,4375 | 0,7500 | 0,5000 | 0,4375 | 0,7500 | 0,5000 | 10 | 3,125 | 3,5625 | |
| 49 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! |
| 50 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! |

tempi standard | Collaudo | scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Sche ... 57%

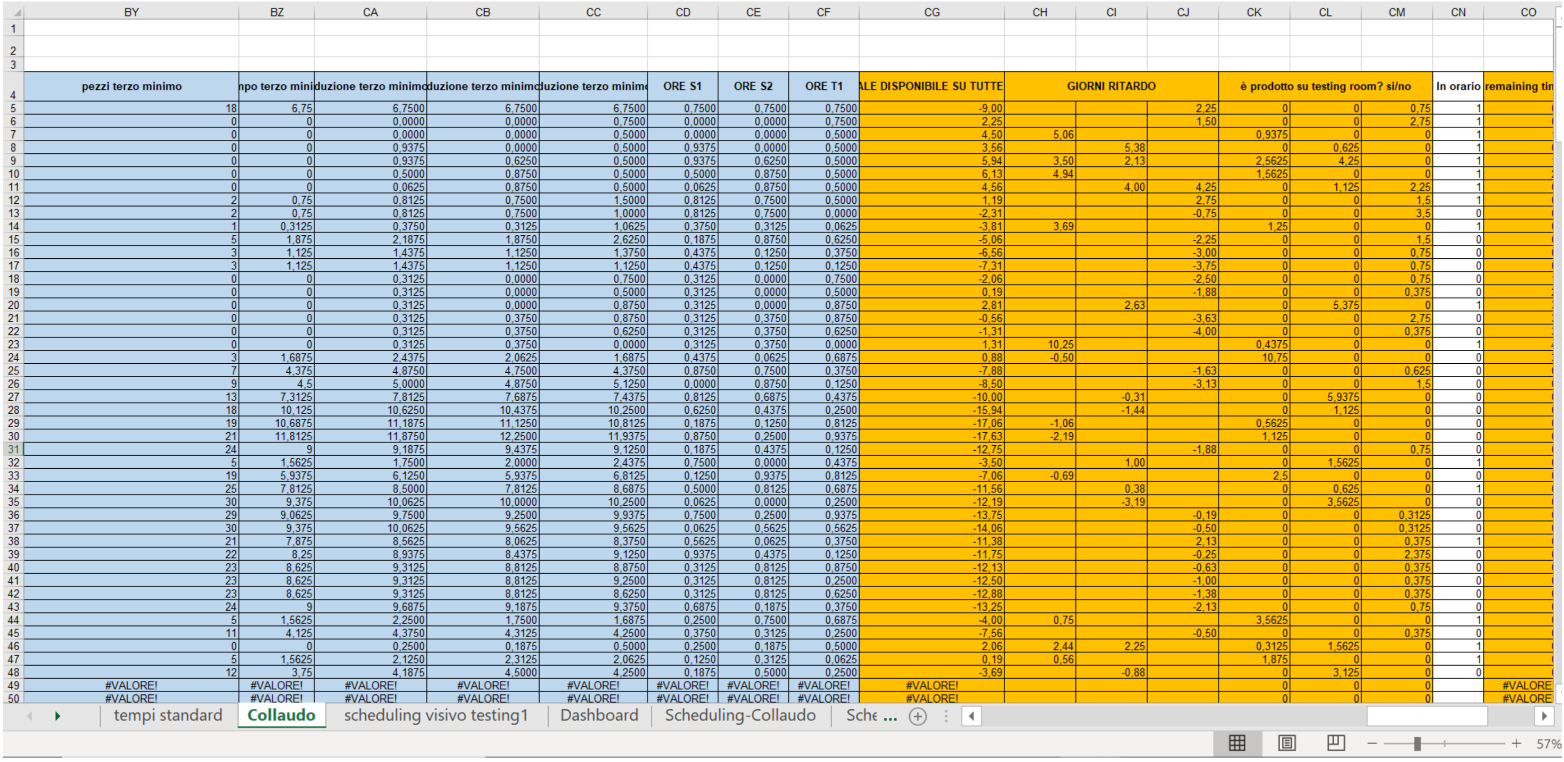
*Figure A- 3: calculations for the scheduling of the testing room part 2*

step 3

| | BD | BE | BF | BG | BH | BI | BJ | BK | BL | BM | BN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | EZZI PRODOTTI SU NON MI | EZZI PRODOTTI SU NON MI | ORE RIMANENTI S1 | ORE RIMANENTI S2 | ORE RIMANENTI T1 | T. per consegna secondo minimo | pezzi sul secondo minimo | empo pezzi producibili sul secondo minim | ZZI PRODOTTI SU SEC. I | ZZI PRODOTTI SU SEC. I | ZZI PRODOT |
| 5 | 3,7500 | 3,7500 | 0,7500 | 0,7500 | 0,7500 | -3,00 | -8 | -3 | -3,0000 | -3,0000 | |
| 6 | 0,0000 | 0,7500 | 0,0000 | 0,0000 | 0,7500 | 1,00 | 2 | 0,75 | 0,7500 | 0,7500 | |
| 7 | 0,0000 | 0,5000 | 0,0000 | 0,0000 | 0,5000 | 2,00 | 6 | 1,875 | 1,8750 | 1,8750 | |
| 8 | 0,0000 | 0,5000 | 0,9375 | 0,0000 | 0,5000 | 1,06 | 3 | 0,9375 | 1,8750 | 0,9375 | |
| 9 | 1,1875 | 1,0625 | 0,5000 | 0,1875 | 0,0625 | 2,06 | 3 | 1,6875 | 2,6250 | 2,3125 | |
| 10 | 0,8750 | 0,5000 | 0,5000 | 0,8750 | 0,5000 | 2,50 | 8 | 2,5 | 3,0000 | 3,3750 | |
| 11 | 2,0000 | 1,6250 | 0,1875 | 0,0000 | 0,6250 | 1,13 | 2 | 1,125 | 1,1875 | 2,0000 | |
| 12 | 0,7500 | 1,5000 | 0,8125 | 0,7500 | 0,5000 | 0,25 | 0 | 0 | 0,0625 | 0,0000 | |
| 13 | 0,7500 | 1,0000 | 0,8125 | 0,7500 | 0,0000 | 0,00 | 0 | 0 | 0,0625 | 0,0000 | |
| 14 | 0,3125 | 1,0625 | 0,3750 | 0,3125 | 0,0625 | 0,00 | 0 | 0 | 0,0625 | 0,0000 | |
| 15 | 1,5000 | 2,2500 | 0,8125 | 0,5000 | 0,2500 | -0,31 | -1 | -0,375 | -0,0625 | -0,3750 | |
| 16 | 0,7500 | 1,0000 | 0,0625 | 0,7500 | 0,0000 | -0,31 | -1 | -0,375 | -0,0625 | -0,3750 | |
| 17 | 0,7500 | 0,7500 | 0,0625 | 0,7500 | 0,7500 | -0,31 | -1 | -0,375 | -0,0625 | -0,3750 | |
| 18 | 0,0000 | 0,7500 | 0,3125 | 0,0000 | 0,7500 | 1,69 | 4 | 1,5 | 1,8125 | 1,5000 | |
| 19 | 0,0000 | 0,5000 | 0,3125 | 0,0000 | 0,5000 | 2,69 | 7 | 2,625 | 2,9375 | 2,6250 | |
| 20 | 0,0000 | 0,8750 | 0,3125 | 0,0000 | 0,8750 | 3,69 | 6 | 3,375 | 3,6875 | 3,3750 | |
| 21 | 0,3750 | 0,8750 | 0,3125 | 0,3750 | 0,8750 | 0,63 | 1 | 0,375 | 0,6875 | 0,7500 | |
| 22 | 0,3750 | 0,6250 | 0,3125 | 0,3750 | 0,6250 | 0,63 | 1 | 0,375 | 0,6875 | 0,7500 | |
| 23 | 0,3750 | 0,0000 | 0,3125 | 0,3750 | 0,0000 | 1,63 | 3 | 1,3125 | 1,6250 | 1,6875 | |
| 24 | 3,1875 | 2,8125 | 0,5625 | 0,1875 | 0,8125 | 1,63 | 2 | 1,125 | 1,8750 | 1,5000 | |
| 25 | 0,3750 | 0,0000 | 0,5000 | 0,3750 | 0,0000 | -4,50 | -8 | -5 | -4,5000 | -4,6250 | |
| 26 | 0,3750 | 0,6250 | 0,5000 | 0,3750 | 0,6250 | -4,50 | -9 | -4,5 | -4,0000 | -4,1250 | |
| 27 | 3,1875 | 2,9375 | 0,3125 | 0,1875 | 0,9375 | -4,50 | -8 | -4,5 | -4,0000 | -4,1250 | |
| 28 | 5,9375 | 5,7500 | 0,1250 | 0,9375 | 0,7500 | -4,50 | -8 | -4,5 | -4,0000 | -4,1875 | |
| 29 | 5,5000 | 5,1875 | 0,5625 | 0,5000 | 0,1875 | -5,44 | -10 | -5,625 | -5,1250 | -5,1875 | |
| 30 | 6,6250 | 6,3125 | 0,2500 | 0,6250 | 0,3125 | -5,44 | -10 | -5,625 | -5,5625 | -5,1875 | |
| 31 | 4,9375 | 4,6250 | 0,6875 | 0,9375 | 0,6250 | -4,19 | -12 | -4,5 | -4,3125 | -4,0625 | |
| 32 | 1,6875 | 2,1250 | 0,4375 | 0,6875 | 0,1250 | -0,19 | -1 | -0,3125 | -0,1250 | 0,1250 | |
| 33 | 2,8125 | 3,6875 | 0,0000 | 0,8125 | 0,6875 | -3,00 | -10 | -3,125 | -2,9375 | -3,1250 | |
| 34 | 3,7500 | 4,6250 | 0,4375 | 0,7500 | 0,6250 | -3,88 | -13 | -4,0625 | -3,3750 | -4,0625 | |
| 35 | 5,9375 | 6,1875 | 0,0000 | 0,9375 | 0,1875 | -3,88 | -13 | -4,0625 | -3,3750 | -3,4375 | |
| 36 | 4,5625 | 5,2500 | 0,0625 | 0,5625 | 0,2500 | -4,69 | -15 | -4,6875 | -4,0000 | -4,5000 | |
| 37 | 4,8750 | 4,8750 | 0,3750 | 0,8750 | 0,8750 | -4,69 | -15 | -4,6875 | -4,0000 | -4,5000 | |
| 38 | 4,3125 | 4,6250 | 0,8125 | 0,3125 | 0,6250 | -3,69 | -10 | -3,75 | -3,0625 | -3,5625 | |
| 39 | 4,3125 | 5,0000 | 0,8125 | 0,3125 | 0,0000 | -3,88 | -11 | -4,125 | -3,4375 | -3,9375 | |
| 40 | 4,3125 | 4,3750 | 0,8125 | 0,3125 | 0,3750 | -4,19 | -12 | -4,5 | -3,8125 | -4,3125 | |
| 41 | 4,3125 | 4,7500 | 0,8125 | 0,3125 | 0,7500 | -4,19 | -12 | -4,5 | -3,8125 | -4,3125 | |
| 42 | 4,3125 | 4,1250 | 0,8125 | 0,3125 | 0,1250 | -4,19 | -12 | -4,5 | -3,8125 | -4,3125 | |
| 43 | 4,6875 | 4,8750 | 0,1875 | 0,6875 | 0,8750 | -4,19 | -12 | -4,5 | -3,8125 | -4,3125 | |
| 44 | 1,4375 | 1,3750 | 0,9375 | 0,4375 | 0,3750 | -0,19 | -1 | -0,3125 | 0,3750 | -0,1250 | |
| 45 | 0,9375 | 0,8750 | 0,0000 | 0,9375 | 0,8750 | -3,25 | -9 | -3,375 | -3,1250 | -3,1875 | |
| 46 | 0,5000 | 0,8125 | 0,5625 | 0,5000 | 0,8125 | 0,75 | 2 | 0,625 | 0,8750 | 0,8125 | |
| 47 | 2,3125 | 2,0625 | 0,1250 | 0,3125 | 0,0625 | 0,25 | 0 | 0 | 0,5625 | 0,7500 | |
| 48 | 3,8750 | 3,6250 | 0,5625 | 0,8750 | 0,6250 | -0,50 | -2 | -0,625 | -0,1875 | 0,1250 | |
| 49 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VAL |
| 50 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VAL |

tempi standard | Collaudo | scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Sche ... 57

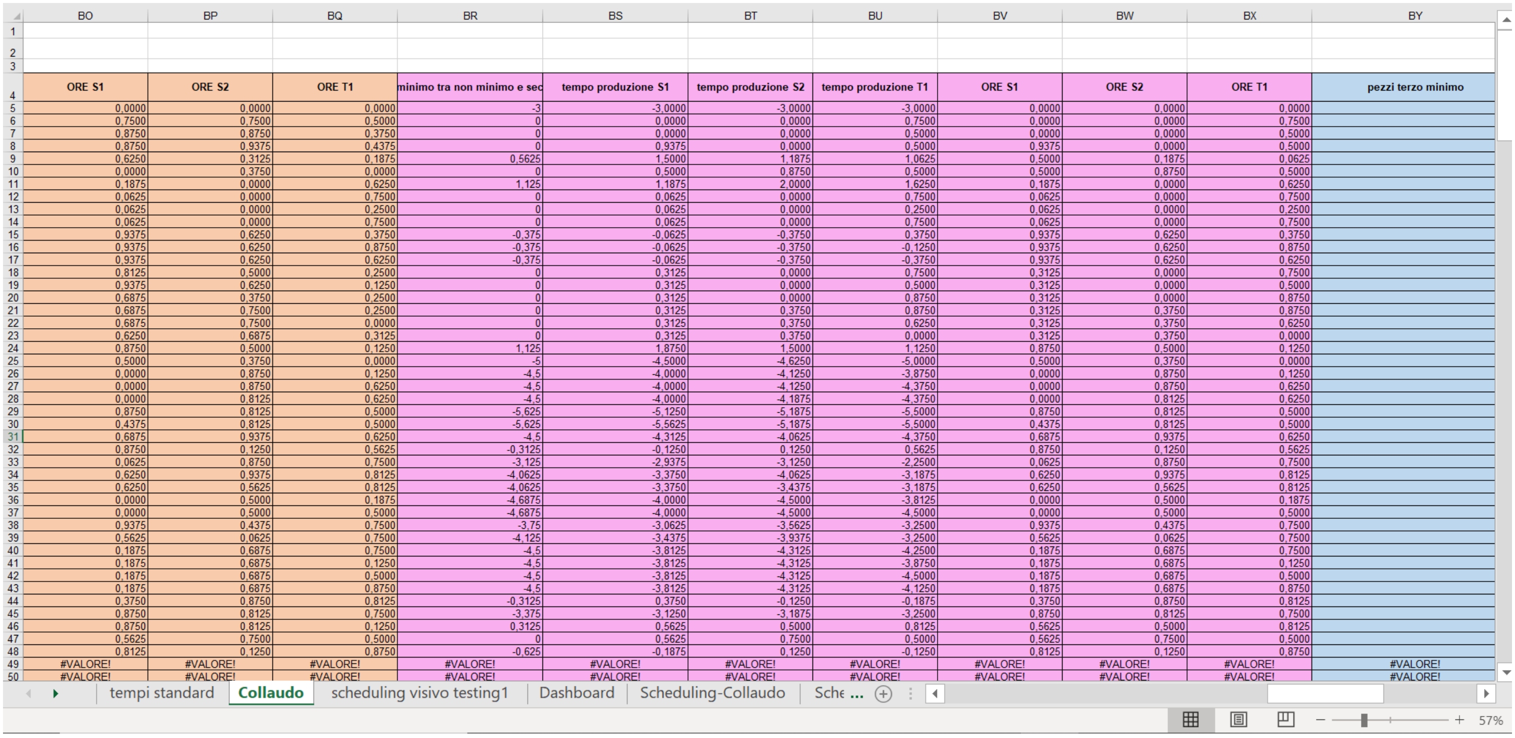
*Figure A- 4: calculations for scheduling of testing part 3*



| | BY | BZ | CA | CB | CC | CD | CE | CF | CG | CH | CI | CJ | CK | CL | CM | CN | CO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | pezzi terzo minimo | npo terzo mini | duzione terzo minimo | duzione terzo minimo | duzione terzo minim | ORE S1 | ORE S2 | ORE T1 | ALE DISPONIBILE SU TUTTE | GIORNI RITARDO | | | è prodotto su testing room? si/no | | | In orario | remaining tin |
| 5 | 18 | 6,75 | 6,7500 | 6,7500 | 6,7500 | 0,7500 | 0,7500 | 0,7500 | -9,00 | | | 2,25 | 0 | 0 | 0,75 | 1 | |
| 6 | 0 | 0 | 0,0000 | 0,0000 | 0,7500 | 0,0000 | 0,0000 | 0,7500 | 2,25 | | | 1,50 | 0 | 0 | 2,75 | 1 | |
| 7 | 0 | 0 | 0,0000 | 0,0000 | 0,5000 | 0,0000 | 0,0000 | 0,5000 | 4,50 | 5,06 | | | 0,9375 | 0 | 0 | 1 | |
| 8 | 0 | 0 | 0,9375 | 0,0000 | 0,5000 | 0,9375 | 0,0000 | 0,5000 | 3,56 | | 5,38 | | 0 | 0,625 | 0 | 1 | |
| 9 | 0 | 0 | 0,9375 | 0,6250 | 0,5000 | 0,9375 | 0,6250 | 0,5000 | 5,94 | 3,50 | 2,13 | | 2,5625 | 4,25 | 0 | 1 | |
| 10 | 0 | 0 | 0,5000 | 0,8750 | 0,5000 | 0,5000 | 0,8750 | 0,5000 | 6,13 | 4,94 | | | 1,5625 | 0 | 0 | 1 | |
| 11 | 0 | 0 | 0,0625 | 0,8750 | 0,5000 | 0,0625 | 0,8750 | 0,5000 | 4,56 | | 4,00 | 4,25 | 0 | 1,125 | 2,25 | 1 | |
| 12 | 2 | 0,75 | 0,8125 | 0,7500 | 1,5000 | 0,8125 | 0,7500 | 0,5000 | 1,19 | | | 2,75 | 0 | 0 | 1,5 | 1 | |
| 13 | 2 | 0,75 | 0,8125 | 0,7500 | 1,0000 | 0,8125 | 0,7500 | 0,0000 | -2,31 | | | -0,75 | 0 | 0 | 3,5 | 0 | |
| 14 | 1 | 0,3125 | 0,3750 | 0,3125 | 1,0625 | 0,3750 | 0,3125 | 0,0625 | -3,81 | 3,69 | | | 1,25 | 0 | 0 | 1 | |
| 15 | 5 | 1,875 | 2,1875 | 1,8750 | 2,6250 | 0,1875 | 0,8750 | 0,6250 | -5,06 | | | -2,25 | 0 | 0 | 1,5 | 0 | |
| 16 | 3 | 1,125 | 1,4375 | 1,1250 | 1,3750 | 0,4375 | 0,1250 | 0,3750 | -6,56 | | | -3,00 | 0 | 0 | 0,75 | 0 | |
| 17 | 3 | 1,125 | 1,4375 | 1,1250 | 1,1250 | 0,4375 | 0,1250 | 0,1250 | -7,31 | | | -3,75 | 0 | 0 | 0,75 | 0 | |
| 18 | 0 | 0 | 0,3125 | 0,0000 | 0,7500 | 0,3125 | 0,0000 | 0,7500 | -2,06 | | | -2,50 | 0 | 0 | 0,75 | 0 | |
| 19 | 0 | 0 | 0,3125 | 0,0000 | 0,5000 | 0,3125 | 0,0000 | 0,5000 | 0,19 | | | -1,88 | 0 | 0 | 0,375 | 0 | |
| 20 | 0 | 0 | 0,3125 | 0,0000 | 0,8750 | 0,3125 | 0,0000 | 0,8750 | 2,81 | | 2,63 | | 0 | 5,375 | 0 | 1 | |
| 21 | 0 | 0 | 0,3125 | 0,3750 | 0,8750 | 0,3125 | 0,3750 | 0,8750 | -0,56 | | | -3,63 | 0 | 0 | 2,75 | 0 | |
| 22 | 0 | 0 | 0,3125 | 0,3750 | 0,6250 | 0,3125 | 0,3750 | 0,6250 | -1,31 | | | -4,00 | 0 | 0 | 0,375 | 0 | |
| 23 | 0 | 0 | 0,3125 | 0,3750 | 0,0000 | 0,3125 | 0,3750 | 0,0000 | 1,31 | 10,25 | | | 0,4375 | 0 | 0 | 1 | |
| 24 | 3 | 1,6875 | 2,4375 | 2,0625 | 1,6875 | 0,4375 | 0,0625 | 0,6875 | 0,88 | -0,50 | | | 10,75 | 0 | 0 | 0 | |
| 25 | 7 | 4,375 | 4,8750 | 4,7500 | 4,3750 | 0,8750 | 0,7500 | 0,3750 | -7,88 | | | -1,63 | 0 | 0 | 0,625 | 0 | |
| 26 | 9 | 4,5 | 5,0000 | 4,8750 | 5,1250 | 0,0000 | 0,8750 | 0,1250 | -8,50 | | | -3,13 | 0 | 0 | 1,5 | 0 | |
| 27 | 13 | 7,3125 | 7,8125 | 7,6875 | 7,4375 | 0,8125 | 0,6875 | 0,4375 | -10,00 | | -0,31 | | 0 | 5,9375 | 0 | 0 | |
| 28 | 18 | 10,125 | 10,6250 | 10,4375 | 10,2500 | 0,6250 | 0,4375 | 0,2500 | -15,94 | | -1,44 | | 0 | 1,125 | 0 | 0 | |
| 29 | 19 | 10,6875 | 11,1875 | 11,1250 | 10,8125 | 0,1875 | 0,1250 | 0,8125 | -17,06 | -1,06 | | | 0,5625 | 0 | 0 | 0 | |
| 30 | 21 | 11,8125 | 11,8750 | 12,2500 | 11,9375 | 0,8750 | 0,2500 | 0,9375 | -17,63 | -2,19 | | | 1,125 | 0 | 0 | 0 | |
| 31 | 24 | 9 | 9,1875 | 9,4375 | 9,1250 | 0,1875 | 0,4375 | 0,1250 | -12,75 | | | -1,88 | 0 | 0 | 0,75 | 0 | |
| 32 | 5 | 1,5625 | 1,7500 | 2,0000 | 2,4375 | 0,7500 | 0,0000 | 0,4375 | -3,50 | | 1,00 | | 0 | 1,5625 | 0 | 1 | |
| 33 | 19 | 5,9375 | 6,1250 | 5,9375 | 6,8125 | 0,1250 | 0,9375 | 0,8125 | -7,06 | -0,69 | | | 2,5 | 0 | 0 | 0 | |
| 34 | 25 | 7,8125 | 8,5000 | 7,8125 | 8,6875 | 0,5000 | 0,8125 | 0,6875 | -11,56 | | 0,38 | | 0 | 0,625 | 0 | 1 | |
| 35 | 30 | 9,375 | 10,0625 | 10,0000 | 10,2500 | 0,0625 | 0,0000 | 0,2500 | -12,19 | | -3,19 | | 0 | 3,5625 | 0 | 0 | |
| 36 | 29 | 9,0625 | 9,7500 | 9,2500 | 9,9375 | 0,7500 | 0,2500 | 0,9375 | -13,75 | | | -0,19 | 0 | 0 | 0,3125 | 0 | |
| 37 | 30 | 9,375 | 10,0625 | 9,5625 | 9,5625 | 0,0625 | 0,5625 | 0,5625 | -14,06 | | | -0,50 | 0 | 0 | 0,3125 | 0 | |
| 38 | 21 | 7,875 | 8,5625 | 8,0625 | 8,3750 | 0,5625 | 0,0625 | 0,3750 | -11,38 | | | 2,13 | 0 | 0 | 0,375 | 1 | |
| 39 | 22 | 8,25 | 8,9375 | 8,4375 | 9,1250 | 0,9375 | 0,4375 | 0,1250 | -11,75 | | | -0,25 | 0 | 0 | 2,375 | 0 | |
| 40 | 23 | 8,625 | 9,3125 | 8,8125 | 8,8750 | 0,3125 | 0,8125 | 0,8750 | -12,13 | | | -0,63 | 0 | 0 | 0,375 | 0 | |
| 41 | 23 | 8,625 | 9,3125 | 8,8125 | 9,2500 | 0,3125 | 0,8125 | 0,2500 | -12,50 | | | -1,00 | 0 | 0 | 0,375 | 0 | |
| 42 | 23 | 8,625 | 9,3125 | 8,8125 | 8,6250 | 0,3125 | 0,8125 | 0,6250 | -12,88 | | | -1,38 | 0 | 0 | 0,375 | 0 | |
| 43 | 24 | 9 | 9,6875 | 9,1875 | 9,3750 | 0,6875 | 0,1875 | 0,3750 | -13,25 | | | -2,13 | 0 | 0 | 0,75 | 0 | |
| 44 | 5 | 1,5625 | 2,2500 | 1,7500 | 1,6875 | 0,2500 | 0,7500 | 0,6875 | -4,00 | 0,75 | | | 3,5625 | 0 | 0 | 1 | |
| 45 | 11 | 4,125 | 4,3750 | 4,3125 | 4,2500 | 0,3750 | 0,3125 | 0,2500 | -7,56 | | | -0,50 | 0 | 0 | 0,375 | 0 | |
| 46 | 0 | 0 | 0,2500 | 0,1875 | 0,5000 | 0,2500 | 0,1875 | 0,5000 | 2,06 | 2,44 | 2,25 | | 0,3125 | 1,5625 | 0 | 1 | |
| 47 | 5 | 1,5625 | 2,1250 | 2,3125 | 2,0625 | 0,1250 | 0,3125 | 0,0625 | 0,19 | 0,56 | | | 1,875 | 0 | 0 | 1 | |
| 48 | 12 | 3,75 | 4,1875 | 4,5000 | 4,2500 | 0,1875 | 0,5000 | 0,2500 | -3,69 | | -0,88 | | 0 | 3,125 | 0 | 0 | |
| 49 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | | | | 0 | 0 | 0 | | #VALORE |
| 50 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | | | | 0 | 0 | 0 | | #VALORE |



*Figure A- 5: Calculations for scheduling of testing part 4*



| | BO | BP | BQ | BR | BS | BT | BU | BV | BW | BX | BY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | ORE S1 | ORE S2 | ORE T1 | minimo tra non minimo e sec | tempo produzione S1 | tempo produzione S2 | tempo produzione T1 | ORE S1 | ORE S2 | ORE T1 | pezzi terzo minimo |
| 5 | 0,0000 | 0,0000 | 0,0000 | -3 | -3,0000 | -3,0000 | -3,0000 | 0,0000 | 0,0000 | 0,0000 | |
| 6 | 0,7500 | 0,7500 | 0,5000 | 0 | 0,0000 | 0,0000 | 0,7500 | 0,0000 | 0,0000 | 0,7500 | |
| 7 | 0,8750 | 0,8750 | 0,3750 | 0 | 0,0000 | 0,0000 | 0,5000 | 0,0000 | 0,0000 | 0,5000 | |
| 8 | 0,8750 | 0,9375 | 0,4375 | 0 | 0,9375 | 0,0000 | 0,5000 | 0,9375 | 0,0000 | 0,5000 | |
| 9 | 0,6250 | 0,3125 | 0,1875 | 0,5625 | 1,5000 | 1,1875 | 1,0625 | 0,5000 | 0,1875 | 0,0625 | |
| 10 | 0,0000 | 0,3750 | 0,0000 | 0 | 0,5000 | 0,8750 | 0,5000 | 0,5000 | 0,8750 | 0,5000 | |
| 11 | 0,1875 | 0,0000 | 0,6250 | 1,125 | 1,1875 | 2,0000 | 1,6250 | 0,1875 | 0,0000 | 0,6250 | |
| 12 | 0,0625 | 0,0000 | 0,7500 | 0 | 0,0625 | 0,0000 | 0,7500 | 0,0625 | 0,0000 | 0,7500 | |
| 13 | 0,0625 | 0,0000 | 0,2500 | 0 | 0,0625 | 0,0000 | 0,2500 | 0,0625 | 0,0000 | 0,2500 | |
| 14 | 0,0625 | 0,0000 | 0,7500 | 0 | 0,0625 | 0,0000 | 0,7500 | 0,0625 | 0,0000 | 0,7500 | |
| 15 | 0,9375 | 0,6250 | 0,3750 | -0,375 | -0,0625 | -0,3750 | 0,3750 | 0,9375 | 0,6250 | 0,3750 | |
| 16 | 0,9375 | 0,6250 | 0,8750 | -0,375 | -0,0625 | -0,3750 | -0,1250 | 0,9375 | 0,6250 | 0,8750 | |
| 17 | 0,9375 | 0,6250 | 0,6250 | -0,375 | -0,0625 | -0,3750 | -0,3750 | 0,9375 | 0,6250 | 0,6250 | |
| 18 | 0,8125 | 0,5000 | 0,2500 | 0 | 0,3125 | 0,0000 | 0,7500 | 0,3125 | 0,0000 | 0,7500 | |
| 19 | 0,9375 | 0,6250 | 0,1250 | 0 | 0,3125 | 0,0000 | 0,5000 | 0,3125 | 0,0000 | 0,5000 | |
| 20 | 0,6875 | 0,3750 | 0,2500 | 0 | 0,3125 | 0,0000 | 0,8750 | 0,3125 | 0,0000 | 0,8750 | |
| 21 | 0,6875 | 0,7500 | 0,2500 | 0 | 0,3125 | 0,3750 | 0,8750 | 0,3125 | 0,3750 | 0,8750 | |
| 22 | 0,6875 | 0,7500 | 0,0000 | 0 | 0,3125 | 0,3750 | 0,6250 | 0,3125 | 0,3750 | 0,6250 | |
| 23 | 0,6250 | 0,6875 | 0,3125 | 0 | 0,3125 | 0,3750 | 0,0000 | 0,3125 | 0,3750 | 0,0000 | |
| 24 | 0,8750 | 0,5000 | 0,1250 | 1,125 | 1,8750 | 1,5000 | 1,1250 | 0,8750 | 0,5000 | 0,1250 | |
| 25 | 0,5000 | 0,3750 | 0,0000 | -5 | -4,5000 | -4,6250 | -5,0000 | 0,5000 | 0,3750 | 0,0000 | |
| 26 | 0,0000 | 0,8750 | 0,1250 | -4,5 | -4,0000 | -4,1250 | -3,8750 | 0,0000 | 0,8750 | 0,1250 | |
| 27 | 0,0000 | 0,8750 | 0,6250 | -4,5 | -4,0000 | -4,1250 | -4,3750 | 0,0000 | 0,8750 | 0,6250 | |
| 28 | 0,0000 | 0,8125 | 0,6250 | -4,5 | -4,0000 | -4,1875 | -4,3750 | 0,0000 | 0,8125 | 0,6250 | |
| 29 | 0,8750 | 0,8125 | 0,5000 | -5,625 | -5,1250 | -5,1875 | -5,5000 | 0,8750 | 0,8125 | 0,5000 | |
| 30 | 0,4375 | 0,8125 | 0,5000 | -5,625 | -5,5625 | -5,1875 | -5,5000 | 0,4375 | 0,8125 | 0,5000 | |
| 31 | 0,6875 | 0,9375 | 0,6250 | -4,5 | -4,3125 | -4,0625 | -4,3750 | 0,6875 | 0,9375 | 0,6250 | |
| 32 | 0,8750 | 0,1250 | 0,5625 | -0,3125 | -0,1250 | 0,1250 | 0,5625 | 0,8750 | 0,1250 | 0,5625 | |
| 33 | 0,0625 | 0,8750 | 0,7500 | -3,125 | -2,9375 | -3,1250 | -2,2500 | 0,0625 | 0,8750 | 0,7500 | |
| 34 | 0,6250 | 0,9375 | 0,8125 | -4,0625 | -3,3750 | -4,0625 | -3,1875 | 0,6250 | 0,9375 | 0,8125 | |
| 35 | 0,6250 | 0,5625 | 0,8125 | -4,0625 | -3,3750 | -3,4375 | -3,1875 | 0,6250 | 0,5625 | 0,8125 | |
| 36 | 0,0000 | 0,5000 | 0,1875 | -4,6875 | -4,0000 | -4,5000 | -3,8125 | 0,0000 | 0,5000 | 0,1875 | |
| 37 | 0,0000 | 0,5000 | 0,5000 | -4,6875 | -4,0000 | -4,5000 | -4,5000 | 0,0000 | 0,5000 | 0,5000 | |
| 38 | 0,9375 | 0,4375 | 0,7500 | -3,75 | -3,0625 | -3,5625 | -3,2500 | 0,9375 | 0,4375 | 0,7500 | |
| 39 | 0,5625 | 0,0625 | 0,7500 | -4,125 | -3,4375 | -3,9375 | -3,2500 | 0,5625 | 0,0625 | 0,7500 | |
| 40 | 0,1875 | 0,6875 | 0,7500 | -4,5 | -3,8125 | -4,3125 | -4,2500 | 0,1875 | 0,6875 | 0,7500 | |
| 41 | 0,1875 | 0,6875 | 0,1250 | -4,5 | -3,8125 | -4,3125 | -3,8750 | 0,1875 | 0,6875 | 0,1250 | |
| 42 | 0,1875 | 0,6875 | 0,5000 | -4,5 | -3,8125 | -4,3125 | -4,5000 | 0,1875 | 0,6875 | 0,5000 | |
| 43 | 0,1875 | 0,6875 | 0,8750 | -4,5 | -3,8125 | -4,3125 | -4,1250 | 0,1875 | 0,6875 | 0,8750 | |
| 44 | 0,3750 | 0,8750 | 0,8125 | -0,3125 | 0,3750 | -0,1250 | -0,1875 | 0,3750 | 0,8750 | 0,8125 | |
| 45 | 0,8750 | 0,8125 | 0,7500 | -3,375 | -3,1250 | -3,1875 | -3,2500 | 0,8750 | 0,8125 | 0,7500 | |
| 46 | 0,8750 | 0,8125 | 0,1250 | 0,3125 | 0,5625 | 0,5000 | 0,8125 | 0,5625 | 0,5000 | 0,8125 | |
| 47 | 0,5625 | 0,7500 | 0,5000 | 0 | 0,5625 | 0,7500 | 0,5000 | 0,5625 | 0,7500 | 0,5000 | |
| 48 | 0,8125 | 0,1250 | 0,8750 | -0,625 | -0,1875 | 0,1250 | -0,1250 | 0,8125 | 0,1250 | 0,8750 | |
| 49 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! |
| 50 | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! | #VALORE! |



*Figure A- 6: Calculations for scheduling of testing part 5*

| CK | CL | CM | CN | CO | CP | CQ | CR |
|---|---|---|---|---|---|---|---|
| è prodotto su testing room? si/no | | | In orario | remaining time 1 | remaining time 2 | remaining time 3 | Ritardo (giorni) |
| 0 | 0 | 0,75 | 1 | 0,00 | 0,00 | 0,00 | |
| 0 | 0 | 2,75 | 1 | 0,75 | 0,75 | 0,00 | |
| 0,9375 | 0 | 0 | 1 | 1,88 | 1,88 | 0,31 | |
| 0 | 0,625 | 0 | 1 | 0,94 | 1,88 | 0,31 | |
| 2,5625 | 4,25 | 0 | 1 | 1,69 | 2,25 | 1,13 | |
| 1,5625 | 0 | 0 | 1 | 2,50 | 0,94 | 2,50 | |
| 0 | 1,125 | 2,25 | 1 | 0,56 | 1,13 | 2,25 | |
| 0 | 0 | 1,5 | 1 | 0,75 | 0,00 | 0,00 | |
| 0 | 0 | 3,5 | 0 | 0,75 | 0,00 | 0,00 | 0,75 |
| 1,25 | 0 | 0 | 1 | 0,94 | 0,00 | 0,00 | |
| 0 | 0 | 1,5 | 0 | 0,00 | 0,00 | 0,00 | 2,25 |
| 0 | 0 | 0,75 | 0 | 0,00 | 0,00 | 0,00 | 3 |
| 0 | 0 | 0,75 | 0 | 0,00 | 0,00 | 0,00 | 3,75 |
| 0 | 0 | 0,75 | 0 | 1,50 | 1,88 | 0,00 | 2,5 |
| 0 | 0 | 0,375 | 0 | 2,63 | 3,00 | 0,00 | 1,875 |
| 0 | 5,375 | 0 | 1 | 3,38 | 3,94 | 0,00 | |
| 0 | 0 | 2,75 | 0 | 3,38 | 0,38 | 0,00 | 3,625 |
| 0 | 0 | 0,375 | 0 | 3,38 | 0,38 | 0,00 | 4 |
| 0,4375 | 0 | 0 | 1 | 4,38 | 1,31 | 0,00 | |
| 10,75 | 0 | 0 | 0 | 3,94 | 1,13 | 0,00 | 0,5 |
| 0 | 0 | 0,625 | 0 | 0,00 | 1,25 | 0,00 | 1,625 |
| 0 | 0 | 1,5 | 0 | 0,00 | 1,50 | 0,00 | 3,125 |
| 0 | 5,9375 | 0 | 0 | 0,00 | 1,13 | 0,00 | 0,3125 |
| 0 | 1,125 | 0 | 0 | 0,00 | 0,00 | 0,00 | 1,4375 |
| 0,5625 | 0 | 0 | 0 | 0,00 | 0,00 | 0,00 | 1,0625 |
| 1,125 | 0 | 0 | 0 | 0,00 | 0,00 | 0,00 | 2,1875 |
| 0 | 0 | 0,75 | 0 | 0,00 | 0,00 | 0,00 | 1,875 |
| 0 | 1,5625 | 0 | 1 | 0,00 | 0,31 | 0,00 | |
| 2,5 | 0 | 0 | 0 | 0,00 | 0,00 | 0,00 | 0,6875 |
| 0 | 0,625 | 0 | 1 | 0,00 | 0,00 | 0,00 | |
| 0 | 3,5625 | 0 | 0 | 0,00 | 0,00 | 0,00 | 3,1875 |
| 0 | 0 | 0,3125 | 0 | 0,00 | 0,00 | 0,00 | 0,1875 |
| 0 | 0 | 0,3125 | 0 | 0,00 | 0,00 | 0,00 | 0,5 |
| 0 | 0 | 0,375 | 1 | 0,00 | 0,00 | 0,00 | |
| 0 | 0 | 2,375 | 0 | 0,00 | 0,00 | 0,00 | 0,25 |
| 0 | 0 | 0,375 | 0 | 0,00 | 0,00 | 0,00 | 0,625 |
| 0 | 0 | 0,375 | 0 | 0,00 | 0,00 | 0,00 | 1 |
| 0 | 0 | 0,375 | 0 | 0,00 | 0,00 | 0,00 | 1,375 |
| 0 | 0 | 0,75 | 0 | 0,00 | 0,00 | 0,00 | 2,125 |
| 3,5625 | 0 | 0 | 1 | 0,31 | 0,00 | 0,00 | |
| 0 | 0 | 0,375 | 0 | 0,00 | 0,00 | 0,00 | 0,5 |
| 0,3125 | 1,5625 | 0 | 1 | 0,63 | 1,56 | 0,00 | |
| 1,875 | 0 | 0 | 1 | 0,31 | 0,00 | 0,00 | |
| 0 | 3,125 | 0 | 0 | 0,00 | 0,00 | 0,00 | 0,875 |
| 0 | 0 | 0 | | #VALORE! | #VALORE! | #VALORE! | |
| 0 | 0 | 0 | | #VALORE! | #VALORE! | #VALORE! | |

Collaudo | scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Sc

*Figure A- 7: Calculations for scheduling of testing part 6*

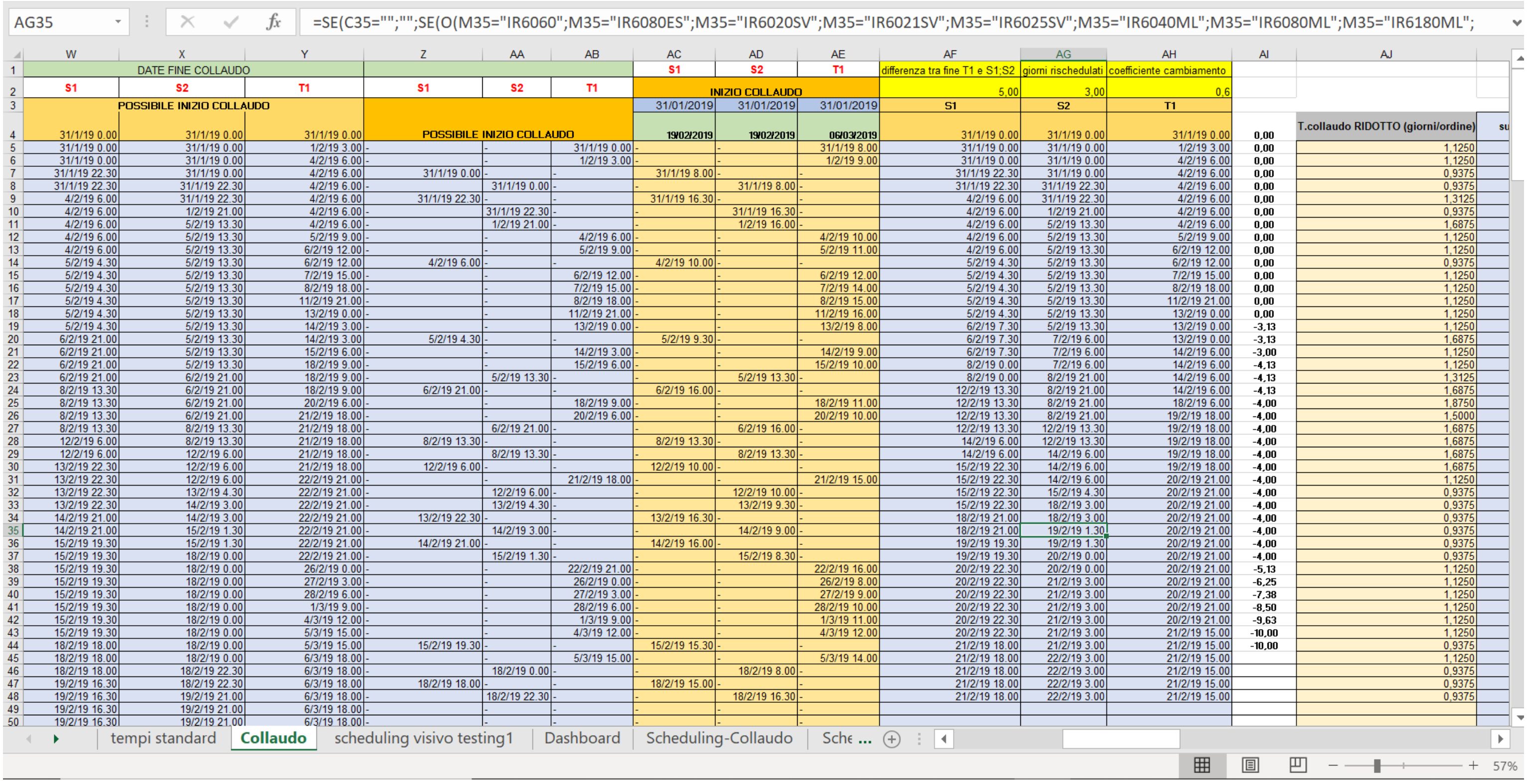



*Figure A- 8: Calculations on the dates for the scheduling of the testing*

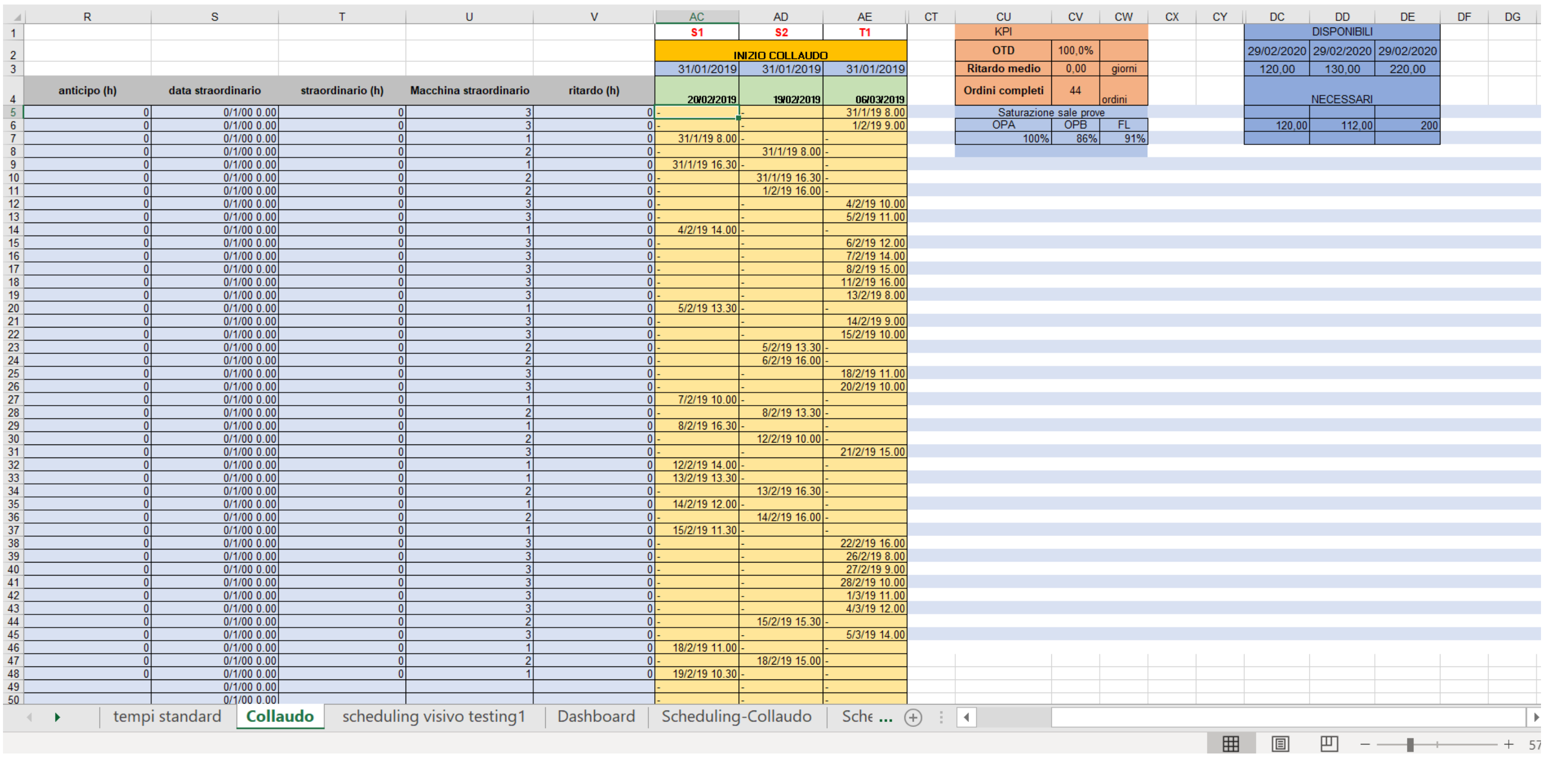
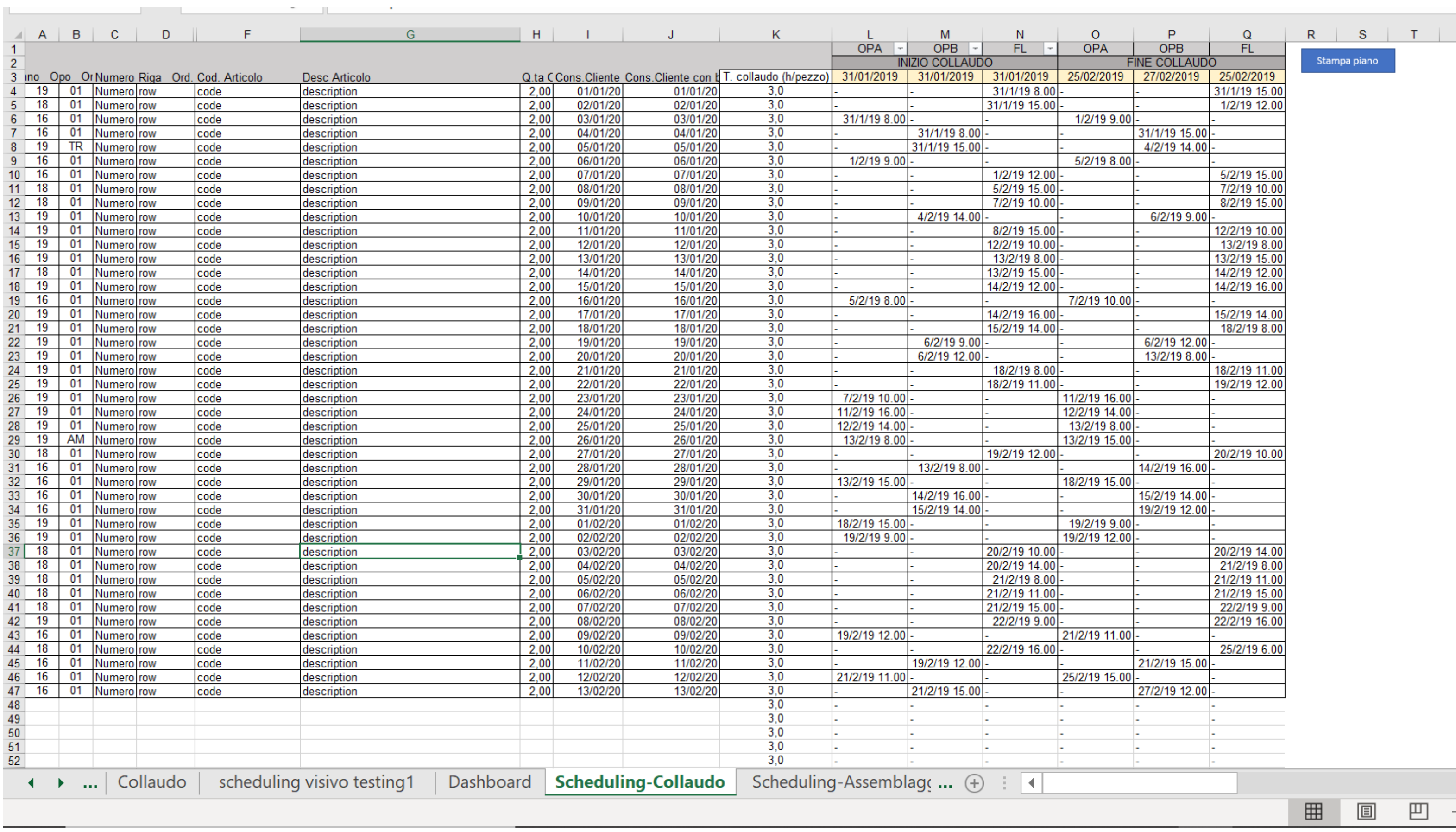


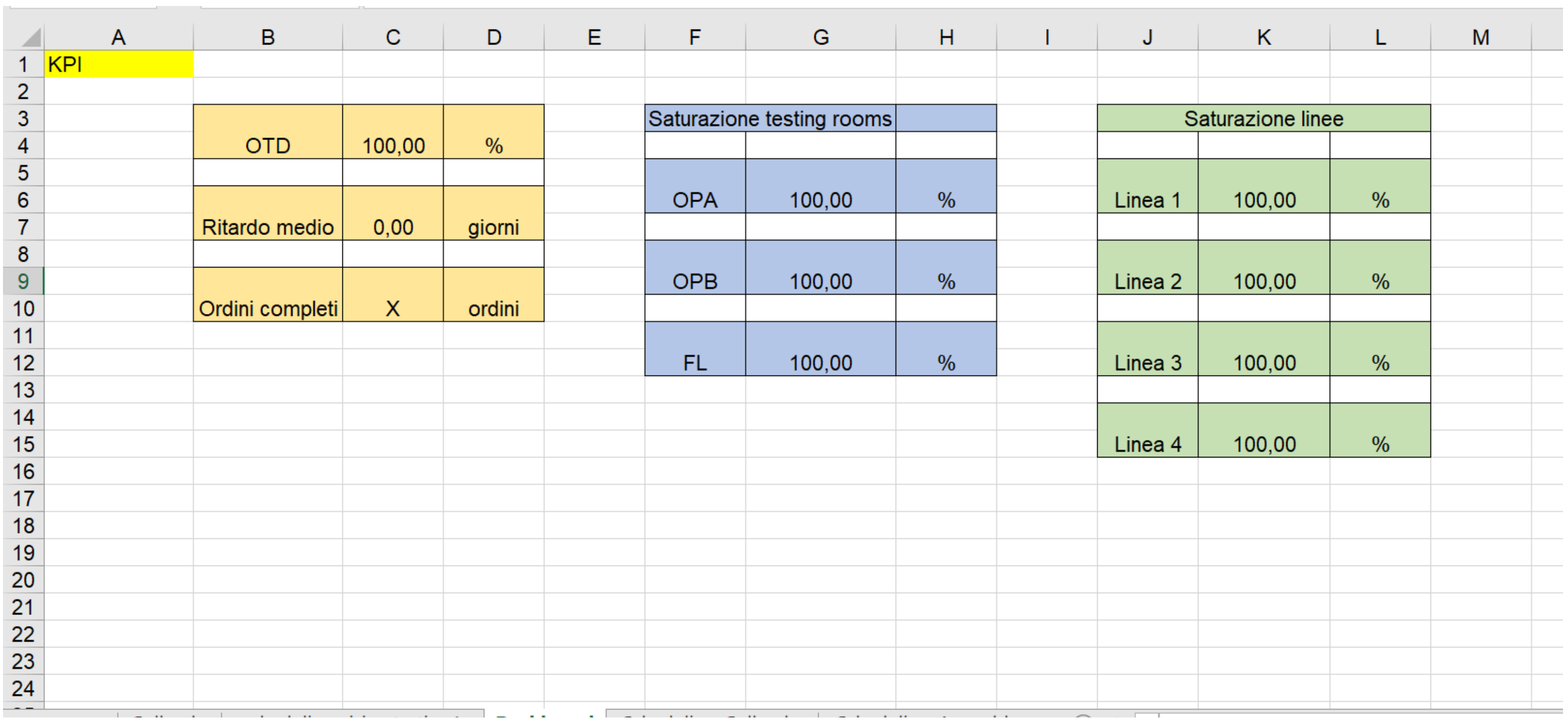

*Figure A- 9: Output scheduling of testing phase*



| | A | B | C | D | F | G | H | I | J | K | L | M | N | O | P | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | OPA | OPB | FL | OPA | OPB | FL |
| 2 | | | | | | | | | | | INIZIO COLLAUDO | | | FINE COLLAUDO | | |
| 3 | ino | Opo | Or Numero | Riga | Ord. Cod. Articolo | Desc Articolo | Q.ta C | Cons.Cliente | Cons.Cliente con b | T. collaudo (h/pezzo) | 31/01/2019 | 31/01/2019 | 31/01/2019 | 25/02/2019 | 27/02/2019 | 25/02/2019 |
| 4 | 19 | 01 | Numero | row | code | description | 2,00 | 01/01/20 | 01/01/20 | 3,0 | - | - | 31/1/19 8.00 | - | - | 31/1/19 15.00 |
| 5 | 18 | 01 | Numero | row | code | description | 2,00 | 02/01/20 | 02/01/20 | 3,0 | - | - | 31/1/19 15.00 | - | - | 1/2/19 12.00 |
| 6 | 16 | 01 | Numero | row | code | description | 2,00 | 03/01/20 | 03/01/20 | 3,0 | 31/1/19 8.00 | - | - | 1/2/19 9.00 | - | - |
| 7 | 16 | 01 | Numero | row | code | description | 2,00 | 04/01/20 | 04/01/20 | 3,0 | - | 31/1/19 8.00 | - | - | 31/1/19 15.00 | - |
| 8 | 19 | TR | Numero | row | code | description | 2,00 | 05/01/20 | 05/01/20 | 3,0 | - | 31/1/19 15.00 | - | - | 4/2/19 14.00 | - |
| 9 | 16 | 01 | Numero | row | code | description | 2,00 | 06/01/20 | 06/01/20 | 3,0 | 1/2/19 9.00 | - | - | 5/2/19 8.00 | - | - |
| 10 | 16 | 01 | Numero | row | code | description | 2,00 | 07/01/20 | 07/01/20 | 3,0 | - | - | 1/2/19 12.00 | - | - | 5/2/19 15.00 |
| 11 | 18 | 01 | Numero | row | code | description | 2,00 | 08/01/20 | 08/01/20 | 3,0 | - | - | 5/2/19 15.00 | - | - | 7/2/19 10.00 |
| 12 | 18 | 01 | Numero | row | code | description | 2,00 | 09/01/20 | 09/01/20 | 3,0 | - | - | 7/2/19 10.00 | - | - | 8/2/19 15.00 |
| 13 | 19 | 01 | Numero | row | code | description | 2,00 | 10/01/20 | 10/01/20 | 3,0 | - | 4/2/19 14.00 | - | - | 6/2/19 9.00 | - |
| 14 | 19 | 01 | Numero | row | code | description | 2,00 | 11/01/20 | 11/01/20 | 3,0 | - | - | 8/2/19 15.00 | - | - | 12/2/19 10.00 |
| 15 | 19 | 01 | Numero | row | code | description | 2,00 | 12/01/20 | 12/01/20 | 3,0 | - | - | 12/2/19 10.00 | - | - | 13/2/19 8.00 |
| 16 | 19 | 01 | Numero | row | code | description | 2,00 | 13/01/20 | 13/01/20 | 3,0 | - | - | 13/2/19 8.00 | - | - | 13/2/19 15.00 |
| 17 | 18 | 01 | Numero | row | code | description | 2,00 | 14/01/20 | 14/01/20 | 3,0 | - | - | 13/2/19 15.00 | - | - | 14/2/19 12.00 |
| 18 | 19 | 01 | Numero | row | code | description | 2,00 | 15/01/20 | 15/01/20 | 3,0 | - | - | 14/2/19 12.00 | - | - | 14/2/19 16.00 |
| 19 | 16 | 01 | Numero | row | code | description | 2,00 | 16/01/20 | 16/01/20 | 3,0 | 5/2/19 8.00 | - | - | 7/2/19 10.00 | - | - |
| 20 | 19 | 01 | Numero | row | code | description | 2,00 | 17/01/20 | 17/01/20 | 3,0 | - | - | 14/2/19 16.00 | - | - | 15/2/19 14.00 |
| 21 | 19 | 01 | Numero | row | code | description | 2,00 | 18/01/20 | 18/01/20 | 3,0 | - | - | 15/2/19 14.00 | - | - | 18/2/19 8.00 |
| 22 | 19 | 01 | Numero | row | code | description | 2,00 | 19/01/20 | 19/01/20 | 3,0 | - | 6/2/19 9.00 | - | - | 6/2/19 12.00 | - |
| 23 | 19 | 01 | Numero | row | code | description | 2,00 | 20/01/20 | 20/01/20 | 3,0 | - | 6/2/19 12.00 | - | - | 13/2/19 8.00 | - |
| 24 | 19 | 01 | Numero | row | code | description | 2,00 | 21/01/20 | 21/01/20 | 3,0 | - | - | 18/2/19 8.00 | - | - | 18/2/19 11.00 |
| 25 | 19 | 01 | Numero | row | code | description | 2,00 | 22/01/20 | 22/01/20 | 3,0 | - | - | 18/2/19 11.00 | - | - | 19/2/19 12.00 |
| 26 | 19 | 01 | Numero | row | code | description | 2,00 | 23/01/20 | 23/01/20 | 3,0 | 7/2/19 10.00 | - | - | 11/2/19 16.00 | - | - |
| 27 | 19 | 01 | Numero | row | code | description | 2,00 | 24/01/20 | 24/01/20 | 3,0 | 11/2/19 16.00 | - | - | 12/2/19 14.00 | - | - |
| 28 | 19 | 01 | Numero | row | code | description | 2,00 | 25/01/20 | 25/01/20 | 3,0 | 12/2/19 14.00 | - | - | 13/2/19 8.00 | - | - |
| 29 | 19 | AM | Numero | row | code | description | 2,00 | 26/01/20 | 26/01/20 | 3,0 | 13/2/19 8.00 | - | - | 13/2/19 15.00 | - | - |
| 30 | 18 | 01 | Numero | row | code | description | 2,00 | 27/01/20 | 27/01/20 | 3,0 | - | - | 19/2/19 12.00 | - | - | 20/2/19 10.00 |
| 31 | 16 | 01 | Numero | row | code | description | 2,00 | 28/01/20 | 28/01/20 | 3,0 | - | 13/2/19 8.00 | - | - | 14/2/19 16.00 | - |
| 32 | 16 | 01 | Numero | row | code | description | 2,00 | 29/01/20 | 29/01/20 | 3,0 | 13/2/19 15.00 | - | - | 18/2/19 15.00 | - | - |
| 33 | 16 | 01 | Numero | row | code | description | 2,00 | 30/01/20 | 30/01/20 | 3,0 | - | 14/2/19 16.00 | - | - | 15/2/19 14.00 | - |
| 34 | 16 | 01 | Numero | row | code | description | 2,00 | 31/01/20 | 31/01/20 | 3,0 | - | 15/2/19 14.00 | - | - | 19/2/19 12.00 | - |
| 35 | 19 | 01 | Numero | row | code | description | 2,00 | 01/02/20 | 01/02/20 | 3,0 | 18/2/19 15.00 | - | - | 19/2/19 9.00 | - | - |
| 36 | 19 | 01 | Numero | row | code | description | 2,00 | 02/02/20 | 02/02/20 | 3,0 | 19/2/19 9.00 | - | - | 19/2/19 12.00 | - | - |
| 37 | 18 | 01 | Numero | row | code | description | 2,00 | 03/02/20 | 03/02/20 | 3,0 | - | - | 20/2/19 10.00 | - | - | 20/2/19 14.00 |
| 38 | 18 | 01 | Numero | row | code | description | 2,00 | 04/02/20 | 04/02/20 | 3,0 | - | - | 20/2/19 14.00 | - | - | 21/2/19 8.00 |
| 39 | 18 | 01 | Numero | row | code | description | 2,00 | 05/02/20 | 05/02/20 | 3,0 | - | - | 21/2/19 8.00 | - | - | 21/2/19 11.00 |
| 40 | 18 | 01 | Numero | row | code | description | 2,00 | 06/02/20 | 06/02/20 | 3,0 | - | - | 21/2/19 11.00 | - | - | 21/2/19 15.00 |
| 41 | 18 | 01 | Numero | row | code | description | 2,00 | 07/02/20 | 07/02/20 | 3,0 | - | - | 21/2/19 15.00 | - | - | 22/2/19 9.00 |
| 42 | 19 | 01 | Numero | row | code | description | 2,00 | 08/02/20 | 08/02/20 | 3,0 | - | - | 22/2/19 9.00 | - | - | 22/2/19 16.00 |
| 43 | 16 | 01 | Numero | row | code | description | 2,00 | 09/02/20 | 09/02/20 | 3,0 | 19/2/19 12.00 | - | - | 21/2/19 11.00 | - | - |
| 44 | 18 | 01 | Numero | row | code | description | 2,00 | 10/02/20 | 10/02/20 | 3,0 | - | - | 22/2/19 16.00 | - | - | 25/2/19 6.00 |
| 45 | 16 | 01 | Numero | row | code | description | 2,00 | 11/02/20 | 11/02/20 | 3,0 | - | 19/2/19 12.00 | - | - | 21/2/19 15.00 | - |
| 46 | 16 | 01 | Numero | row | code | description | 2,00 | 12/02/20 | 12/02/20 | 3,0 | 21/2/19 11.00 | - | - | 25/2/19 15.00 | - | - |
| 47 | 16 | 01 | Numero | row | code | description | 2,00 | 13/02/20 | 13/02/20 | 3,0 | - | 21/2/19 15.00 | - | - | 27/2/19 12.00 | - |
| 48 | | | | | | | | | | 3,0 | - | - | - | - | - | - |
| 49 | | | | | | | | | | 3,0 | - | - | - | - | - | - |
| 50 | | | | | | | | | | 3,0 | - | - | - | - | - | - |
| 51 | | | | | | | | | | 3,0 | - | - | - | - | - | - |
| 52 | | | | | | | | | | 3,0 | - | - | - | - | - | - |



*Figure A- 10: A3 for the operators in the testing*



| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KPI | | | | | | | | | | | |
| 3 | | | | | | Saturazione testing rooms | | | | Saturazione linee | | |
| 4 | | OTD | 100,00 | % | | | | | | | | |
| 6 | | | | | | OPA | 100,00 | % | | Linea 1 | 100,00 | % |
| 7 | | Ritardo medio | 0,00 | giorni | | | | | | | | |
| 9 | | | | | | OPB | 100,00 | % | | Linea 2 | 100,00 | % |
| 10 | | Ordini completi | X | ordini | | | | | | | | |
| 12 | | | | | | FL | 100,00 | % | | Linea 3 | 100,00 | % |
| 15 | | | | | | | | | | Linea 4 | 100,00 | % |

*Figure A- 11: Dashboard*

POLITECNICO MILANO 1863

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Tipologia breaker | Codice articolo | T. collaudo (h/pezzo) | Linea | VINCOLO SU T1 | CT produzione (h/pezzo) | Tempo totale produzione |
| 2 | product type | | 3 | 1 | 0 | 3 | 10 |
| 3 | product type | | 3 | 1 | 0 | 3 | 10 |
| 4 | product type | | 3 | 1 | 0 | 3 | 10 |
| 5 | product type | | 3 | 1 | 0 | 3 | 10 |
| 6 | product type | | 3 | 1 | 0 | 3 | 10 |
| 7 | product type | | 3 | 1 | 0 | 3 | 10 |
| 8 | product type | | 3 | 1 | 0 | 3 | 10 |
| 9 | product type | | 3 | 1 | 0 | 3 | 10 |
| 10 | product type | | 3 | 1 | 0 | 3 | 10 |
| 11 | product type | | 3 | 1 | 0 | 3 | 10 |
| 12 | product type | | 3 | 1 | 0 | 3 | 10 |
| 13 | product type | | 3 | 1 | 0 | 3 | 10 |
| 14 | product type | | 3 | 1 | 0 | 3 | 10 |
| 15 | product type | | 3 | 1 | 0 | 3 | 10 |
| 16 | product type | | 3 | 1 | 0 | 3 | 10 |
| 17 | product type | | 3 | 1 | 0 | 3 | 10 |
| 18 | product type | | 3 | 1 | 0 | 3 | 10 |
| 19 | product type | | 3 | 1 | 0 | 3 | 10 |
| 20 | product type | | 3 | 1 | 0 | 3 | 10 |
| 21 | product type | | 3 | 1 | 0 | 3 | 10 |
| 22 | product type | | 3 | 1 | 0 | 3 | 10 |
| 23 | product type | | 3 | 1 | 0 | 3 | 10 |
| 24 | product type | | 3 | 1 | 0 | 3 | 10 |
| 25 | product type | | 3 | 1 | 0 | 3 | 10 |
| 26 | product type | | 3 | 1 | 0 | 3 | 10 |
| 27 | product type | | 3 | 1 | 0 | 3 | 10 |
| 28 | | | | | | | |
| 29 | | | | | | | |
| 30 | | | | | | | |
| 31 | | product code | 3 | 1 | 0 | 3 | 10 |
| 32 | | product code | 3 | 1 | 0 | 3 | 10 |
| 33 | | product code | 3 | 1 | 0 | 3 | 10 |
| 34 | | product code | 3 | 1 | 0 | 3 | 10 |
| 35 | | product code | 3 | 1 | 0 | 3 | 10 |
| 36 | | product code | 3 | 1 | 0 | 3 | 10 |
| 37 | | product code | 3 | 1 | 0 | 3 | 10 |
| 38 | | product code | 3 | 1 | 0 | 3 | 10 |

tempi standard | Collaudo | scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Sche ...

*Figure A- 12: Standard times in the excel tool*

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | tempi fine testing | | | | | S1 | | | |
| 2 | NUMERO ORDINE | riga ordine | descrizione | tipologia | etichetta tabella | CODICE CERCA VERT. | s1 | s2 | TESTING | TEMPO F | pezzi | CONTATORE | CODICE CONTATORE | CODICE TABELLA | CONTATORE INTERV |
| 3 | 1 | row | description | type | num.-row-type-num | 1-row-type | 31/1/19 0.00 | 31/1/19 0.00 | 31/1/19 18.00 | 9 | 2 | 31/1/19 0.00 | 3-row-type | 3-row-type-1 | |
| 4 | 2 | row | description | type | 2-row-type | 2-row-type | 31/1/19 0.00 | 31/1/19 0.00 | 1/2/19 12.00 | 9 | 2 | 31/1/19 1.30 | 3-row-type | 3-row-type-1 | |
| 5 | 3 | row | description | type | 3-row-type | 3-row-type | 1/2/19 3.00 | 31/1/19 0.00 | 1/2/19 12.00 | 9 | 3 | 31/1/19 3.00 | 3-row-type | 3-row-type-1 | |
| 6 | 4 | row | description | type | 4-row-type | 4-row-type | 1/2/19 3.00 | 31/1/19 18.00 | 1/2/19 12.00 | 9 | 2 | 31/1/19 4.30 | 3-row-type | 3-row-type-1 | |
| 7 | 5 | row | description | type | 5-row-type | 5-row-type | 1/2/19 3.00 | 4/2/19 15.00 | 1/2/19 12.00 | 9 | 5 | 31/1/19 6.00 | 3-row-type | 3-row-type-1 | |
| 8 | 6 | row | description | type | 6-row-type | 6-row-type | 5/2/19 0.00 | 4/2/19 15.00 | 1/2/19 12.00 | 9 | 5 | 31/1/19 7.30 | 3-row-type | 3-row-type-1 | |
| 9 | 7 | row | description | type | 7-row-type | 7-row-type | 5/2/19 0.00 | 4/2/19 15.00 | 5/2/19 18.00 | 9 | 6 | 31/1/19 9.00 | 3-row-type | 3-row-type-2 | |
| 10 | 8 | row | description | type | 8-row-type | 8-row-type | 5/2/19 0.00 | 4/2/19 15.00 | 7/2/19 6.00 | 9 | 4 | 31/1/19 10.30 | 3-row-type | 3-row-type-2 | |
| 11 | 9 | row | description | type | 9-row-type | 9-row-type | 5/2/19 0.00 | 4/2/19 15.00 | 8/2/19 18.00 | 9 | 4 | 31/1/19 12.00 | 3-row-type | 3-row-type-2 | |
| 12 | 0 | row | description | type | 0-row-type | 0-row-type | 5/2/19 0.00 | 6/2/19 3.00 | 8/2/19 18.00 | 9 | 4 | 31/1/19 13.30 | 3-row-type | 3-row-type-2 | |
| 13 | 1 | row | description | type | 1-row-type | 1-row-type | 5/2/19 0.00 | 6/2/19 3.00 | 12/2/19 6.00 | 9 | 4 | 31/1/19 15.00 | 3-row-type | 3-row-type-2 | |
| 14 | 2 | row | description | type | 2-row-type | 2-row-type | 5/2/19 0.00 | 6/2/19 3.00 | 13/2/19 0.00 | 9 | 2 | 31/1/19 16.30 | 3-row-type | 3-row-type-2 | |
| 15 | 3 | row | description | type | 3-row-type | 3-row-type | 5/2/19 0.00 | 6/2/19 3.00 | 13/2/19 18.00 | 9 | 2 | 31/1/19 18.00 | 3-row-type | 3-row-type-3 | |
| 16 | 4 | row | description | type | 4-row-type | 4-row-type | 5/2/19 0.00 | 6/2/19 3.00 | 14/2/19 12.00 | 9 | 2 | 31/1/19 19.30 | 3-row-type | 3-row-type-3 | |
| 17 | 5 | row | description | type | 5-row-type | 5-row-type | 5/2/19 0.00 | 6/2/19 3.00 | 14/2/19 21.00 | 9 | 1 | 31/1/19 21.00 | 3-row-type | 3-row-type-3 | |
| 18 | 6 | row | description | type | 6-row-type | 6-row-type | 7/2/19 6.00 | 6/2/19 3.00 | 14/2/19 21.00 | 9 | 6 | 31/1/19 22.30 | 3-row-type | 3-row-type-3 | |
| 19 | 7 | row | description | type | 7-row-type | 7-row-type | 7/2/19 6.00 | 6/2/19 3.00 | 15/2/19 15.00 | 9 | 2 | 1/2/19 0.00 | 3-row-type | 3-row-type-3 | |
| 20 | 89 | row | description | type | 89-row-type | 89-row-type | 7/2/19 6.00 | 6/2/19 3.00 | 18/2/19 0.00 | 9 | 1 | 1/2/19 1.30 | 3-row-type | 3-row-type-3 | |
| 21 | 0 | row | description | type | 0-row-type | 0-row-type | 7/2/19 6.00 | 6/2/19 12.00 | 18/2/19 0.00 | 9 | 1 | 1/2/19 3.00 | 6-row-type | 6-row-type-1 | |
| 22 | 1 | row | description | type | 1-row-type | 1-row-type | 7/2/19 6.00 | 13/2/19 0.00 | 18/2/19 0.00 | 9 | 12 | 1/2/19 4.30 | 6-row-type | 6-row-type-1 | |
| 23 | 2 | row | description | type | 2-row-type | 2-row-type | 7/2/19 6.00 | 13/2/19 0.00 | 18/2/19 9.00 | 9 | 1 | 1/2/19 6.00 | 6-row-type | 6-row-type-1 | |
| 24 | 3 | row | description | type | 3-row-type | 3-row-type | 7/2/19 6.00 | 13/2/19 0.00 | 19/2/19 12.00 | 9 | 3 | 1/2/19 7.30 | 6-row-type | 6-row-type-1 | |
| 25 | 4 | row | description | type | 4-row-type | 4-row-type | 11/2/19 21.00 | 13/2/19 0.00 | 19/2/19 12.00 | 9 | 7 | 1/2/19 9.00 | 6-row-type | 6-row-type-1 | |
| 26 | 5 | row | description | type | 5-row-type | 5-row-type | 12/2/19 15.00 | 13/2/19 0.00 | 19/2/19 12.00 | 9 | 2 | 1/2/19 10.30 | 6-row-type | 6-row-type-1 | |
| 27 | 6 | row | description | type | 6-row-type | 6-row-type | 13/2/19 0.00 | 13/2/19 0.00 | 19/2/19 12.00 | 9 | 1 | 1/2/19 12.00 | 6-row-type | 6-row-type-2 | |
| 28 | 7 | row | description | type | 7-row-type | 7-row-type | 13/2/19 18.00 | 13/2/19 0.00 | 19/2/19 12.00 | 9 | 2 | 1/2/19 13.30 | 6-row-type | 6-row-type-2 | |
| 29 | 8 | row | description | type | 8-row-type | 8-row-type | 13/2/19 18.00 | 13/2/19 0.00 | 20/2/19 6.00 | 9 | 2 | 1/2/19 15.00 | 6-row-type | 6-row-type-2 | |
| 30 | 9 | row | description | type | 9-row-type | 9-row-type | 13/2/19 18.00 | 14/2/19 21.00 | 20/2/19 6.00 | 9 | 5 | 1/2/19 16.30 | 6-row-type | 6-row-type-2 | |
| 31 | 1 | row | description | type | 1-row-type | 1-row-type | 18/2/19 18.00 | 14/2/19 21.00 | 20/2/19 6.00 | 9 | 8 | 1/2/19 18.00 | 6-row-type | 6-row-type-2 | |
| 32 | 2 | row | description | type | 2-row-type | 2-row-type | 18/2/19 18.00 | 15/2/19 15.00 | 20/2/19 6.00 | 9 | 2 | 1/2/19 19.30 | 6-row-type | 6-row-type-2 | |
| 33 | 3 | row | description | type | 3-row-type | 3-row-type | 18/2/19 18.00 | 19/2/19 12.00 | 20/2/19 6.00 | 9 | 5 | 1/2/19 21.00 | 6-row-type | 6-row-type-3 | |
| 34 | 4 | row | description | type | 4-row-type | 4-row-type | 19/2/19 3.00 | 19/2/19 12.00 | 20/2/19 6.00 | 9 | 1 | 1/2/19 22.30 | 6-row-type | 6-row-type-3 | |
| 35 | 5 | row | description | type | 5-row-type | 5-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 20/2/19 6.00 | 9 | 1 | 4/2/19 0.00 | 6-row-type | 6-row-type-3 | |
| 36 | 6 | row | description | type | 6-row-type | 6-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 20/2/19 15.00 | 9 | 1 | 4/2/19 1.30 | 6-row-type | 6-row-type-3 | |
| 37 | 7 | row | description | type | 7-row-type | 7-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 21/2/19 0.00 | 9 | 1 | 4/2/19 3.00 | 6-row-type | 6-row-type-3 | |
| 38 | 8 | row | description | type | 8-row-type | 8-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 21/2/19 9.00 | 9 | 1 | 4/2/19 4.30 | 6-row-type | 6-row-type-3 | |
| 39 | 9 | row | description | type | 9-row-type | 9-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 21/2/19 18.00 | 9 | 1 | 4/2/19 6.00 | 6-row-type | 6-row-type-4 | |
| 40 | 1 | row | description | type | 1-row-type | 1-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 22/2/19 3.00 | 9 | 1 | 4/2/19 7.30 | 6-row-type | 6-row-type-4 | |
| 41 | 2 | row | description | type | 2-row-type | 2-row-type | 19/2/19 12.00 | 19/2/19 12.00 | 22/2/19 21.00 | 9 | 2 | 4/2/19 9.00 | 6-row-type | 6-row-type-4 | |
| 42 | 3 | row | description | type | 3-row-type | 3-row-type | 21/2/19 9.00 | 19/2/19 12.00 | 22/2/19 21.00 | 9 | 5 | 4/2/19 10.30 | 6-row-type | 6-row-type-4 | |
| 43 | 4 | row | description | type | 4-row-type | 4-row-type | 21/2/19 9.00 | 19/2/19 12.00 | 25/2/19 6.00 | 9 | 1 | 4/2/19 12.00 | 6-row-type | 6-row-type-4 | |
| 44 | 5 | row | description | type | 5-row-type | 5-row-type | 21/2/19 9.00 | 21/2/19 18.00 | 25/2/19 6.00 | 9 | 6 | 4/2/19 13.30 | 6-row-type | 6-row-type-4 | |
| 45 | 6 | row | description | type | 6-row-type | 6-row-type | 25/2/19 15.00 | 21/2/19 18.00 | 25/2/19 6.00 | 9 | 6 | 4/2/19 15.00 | 6-row-type | 6-row-type-5 | |
| 46 | 7 | row | description | type | 7-row-type | 7-row-type | 25/2/19 15.00 | 27/2/19 12.00 | 25/2/19 6.00 | 9 | 10 | 4/2/19 16.30 | 6-row-type | 6-row-type-5 | |
| 47 | 8 | row | description | type | 8-row-type | 8-row-type | 25/2/19 15.00 | 27/2/19 12.00 | 25/2/19 6.00 | 9 | 0 | 4/2/19 18.00 | 6-row-type | 6-row-type-5 | |
| 48 | 9 | row | description | type | 9-row-type | 9-row-type | 25/2/19 15.00 | 27/2/19 12.00 | 25/2/19 6.00 | 9 | 0 | 4/2/19 19.30 | 6-row-type | 6-row-type-5 | |
| 49 | 1 | row | description | type | 1-row-type | 1-row-type | 25/2/19 15.00 | 27/2/19 12.00 | 25/2/19 6.00 | 9 | 0 | 4/2/19 21.00 | 6-row-type | 6-row-type-5 | |

... | Collaudo | scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Scheduling-Assemblag ...

Conteggio: 498 57%

*Figure A- 13: Calculations visual tool testing*

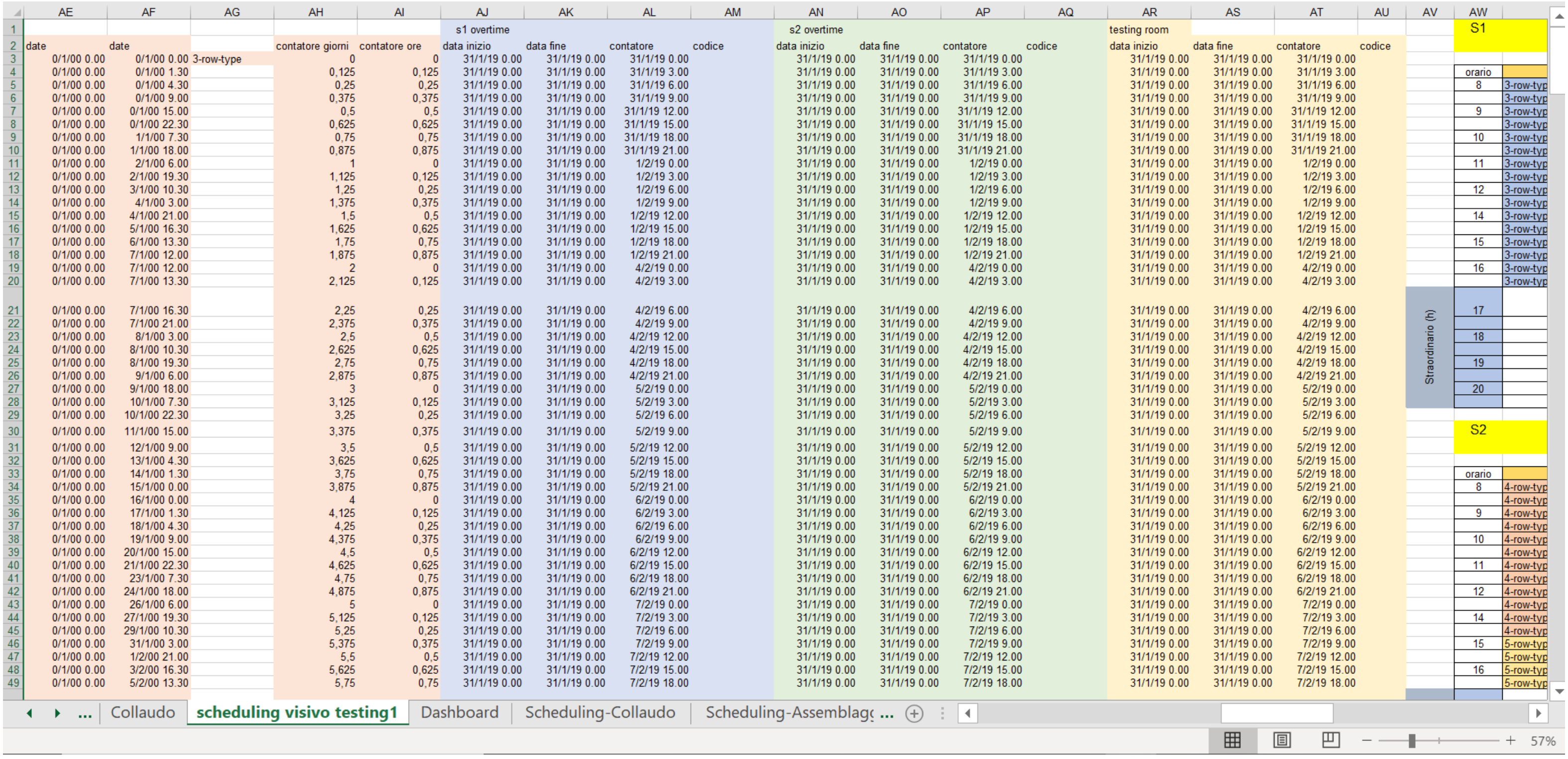



*Figure A- 14: Calculations visual tool testing part 2*

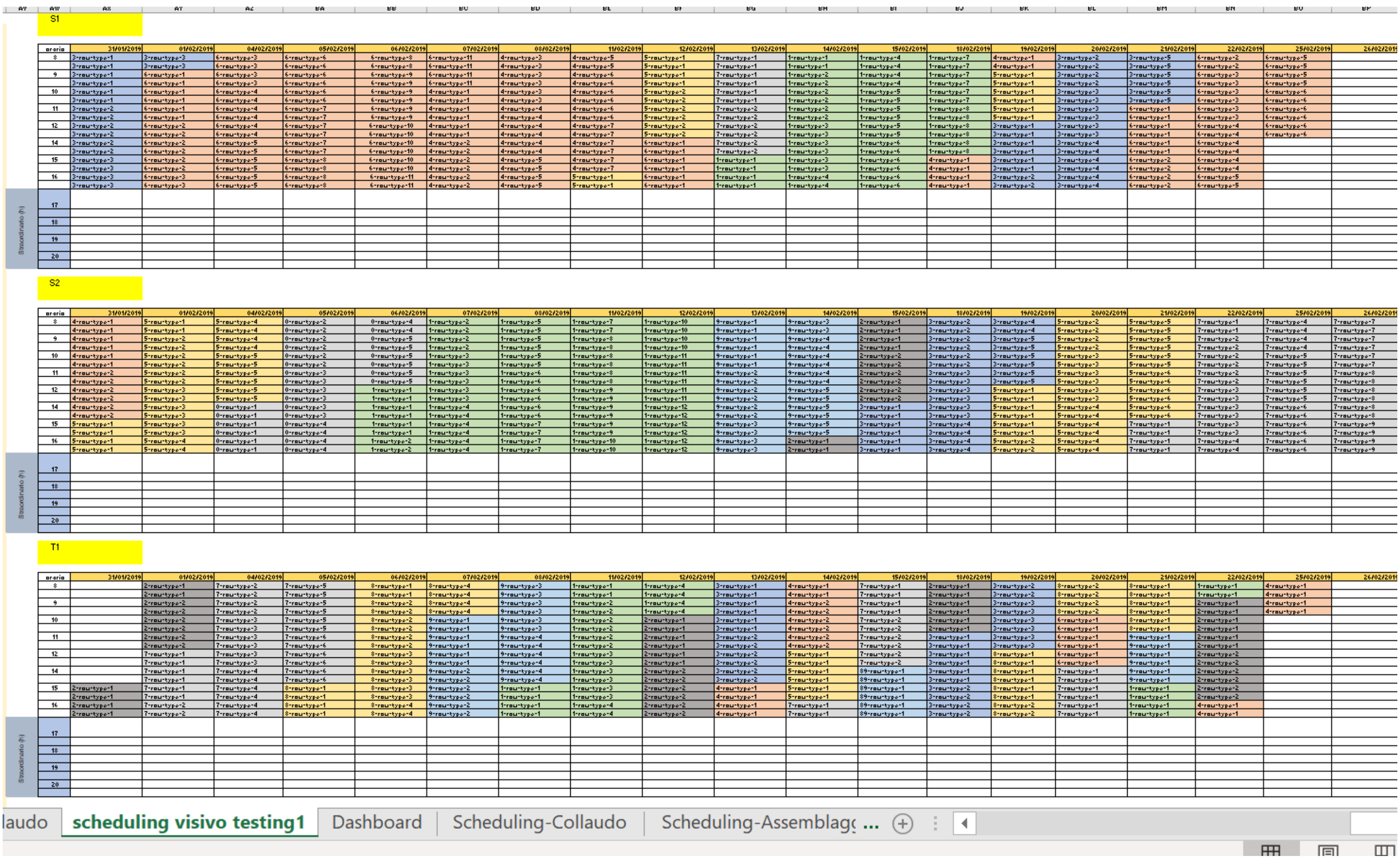



*Figure A- 15: Output visual tool testing rooms*

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Numero Ordine | Desc Articolo | tipologia | codice progressivo | T. collaudo (h/pezzo) | testing times su 24 | testing T | s1 | s2 | | Allocazion pezzi TR | | linea | |
| 2 | numero ordine | decsrizione articolo | tipologia | 44 | 3 | 9 | 1/2/19 3.00 | 31/1/19 0.00 | 31/1/19 0.00 | 0 | 31/1/19 0.00 | tipologia | 44 | |
| 3 | numero ordine | decsrizione articolo | tipologia | 43 | 2 | 6 | 4/2/19 6.00 | 31/1/19 0.00 | 31/1/19 0.00 | 0 | 31/1/19 1.30 | tipologia | 44 | |
| 4 | numero ordine | decsrizione articolo | tipologia | 42 | 4 | 12 | 4/2/19 6.00 | 31/1/19 22.30 | 31/1/19 0.00 | 3 | 31/1/19 3.00 | tipologia | 44 | |
| 5 | numero ordine | decsrizione articolo | tipologia | 41 | 6 | 18 | 4/2/19 6.00 | 31/1/19 22.30 | 31/1/19 22.30 | 2 | 31/1/19 4.30 | tipologia | 44 | |
| 6 | numero ordine | decsrizione articolo | tipologia | 40 | 2 | 6 | 4/2/19 6.00 | 4/2/19 15.00 | 31/1/19 22.30 | 0 | 31/1/19 6.00 | tipologia | 44 | |
| 7 | numero ordine | decsrizione articolo | tipologia | 39 | 4 | 12 | 4/2/19 6.00 | 4/2/19 15.00 | 1/2/19 21.00 | 5 | 31/1/19 7.30 | tipologia | 44 | |
| 8 | numero ordine | decsrizione articolo | tipologia | 38 | 3 | 9 | 4/2/19 6.00 | 4/2/19 15.00 | 5/2/19 13.30 | 0 | 31/1/19 9.00 | tipologia | 44 | |
| 9 | numero ordine | decsrizione articolo | tipologia | 37 | 2 | 6 | 5/2/19 9.00 | 4/2/19 15.00 | 5/2/19 13.30 | 0 | 31/1/19 10.30 | tipologia | 44 | |
| 10 | numero ordine | decsrizione articolo | tipologia | 36 | 4 | 12 | 6/2/19 12.00 | 4/2/19 15.00 | 5/2/19 13.30 | 0 | 31/1/19 12.00 | tipologia | 44 | |
| 11 | numero ordine | decsrizione articolo | tipologia | 35 | 6 | 18 | 6/2/19 12.00 | 5/2/19 13.30 | 5/2/19 13.30 | 4 | 31/1/19 13.30 | tipologia | 44 | |
| 12 | numero ordine | decsrizione articolo | tipologia | 34 | 2 | 6 | 7/2/19 15.00 | 5/2/19 13.30 | 5/2/19 13.30 | 0 | 31/1/19 15.00 | tipologia | 44 | |
| 13 | numero ordine | decsrizione articolo | tipologia | 33 | 4 | 12 | 8/2/19 18.00 | 5/2/19 13.30 | 5/2/19 13.30 | 0 | 31/1/19 16.30 | tipologia | 44 | |
| 14 | numero ordine | decsrizione articolo | tipologia | 32 | 3 | 9 | 11/2/19 21.00 | 5/2/19 13.30 | 5/2/19 13.30 | 0 | 31/1/19 18.00 | tipologia | 44 | |
| 15 | numero ordine | decsrizione articolo | tipologia | 31 | 2 | 6 | 13/2/19 0.00 | 5/2/19 13.30 | 5/2/19 13.30 | 0 | 31/1/19 19.30 | tipologia | 44 | |
| 16 | numero ordine | decsrizione articolo | tipologia | 30 | 4 | 12 | 14/2/19 3.00 | 5/2/19 13.30 | 5/2/19 13.30 | 0 | 31/1/19 21.00 | tipologia | 44 | |
| 17 | numero ordine | decsrizione articolo | tipologia | 29 | 6 | 18 | 14/2/19 3.00 | 7/2/19 6.00 | 5/2/19 13.30 | 0 | 31/1/19 22.30 | tipologia | 44 | |
| 18 | numero ordine | decsrizione articolo | tipologia | 28 | 2 | 6 | 15/2/19 6.00 | 7/2/19 6.00 | 5/2/19 13.30 | 0 | 1/2/19 0.00 | tipologia | 44 | |
| 19 | numero ordine | decsrizione articolo | tipologia | 27 | 4 | 12 | 18/2/19 9.00 | 7/2/19 6.00 | 5/2/19 13.30 | 0 | 1/2/19 1.30 | tipologia | 44 | |
| 20 | numero ordine | decsrizione articolo | tipologia | 26 | 3 | 9 | 18/2/19 9.00 | 7/2/19 6.00 | 6/2/19 21.00 | 1 | 1/2/19 3.00 | tipologia | 43 | |
| 21 | numero ordine | decsrizione articolo | tipologia | 25 | 2 | 6 | 18/2/19 9.00 | 7/2/19 6.00 | 8/2/19 13.30 | 0 | 1/2/19 4.30 | tipologia | 43 | |
| 22 | numero ordine | decsrizione articolo | tipologia | 24 | 4 | 12 | 20/2/19 6.00 | 7/2/19 6.00 | 8/2/19 13.30 | 0 | 1/2/19 6.00 | tipologia | 43 | |
| 23 | numero ordine | decsrizione articolo | tipologia | 23 | 6 | 18 | 21/2/19 18.00 | 7/2/19 6.00 | 8/2/19 13.30 | 0 | 1/2/19 7.30 | tipologia | 43 | |
| 24 | numero ordine | decsrizione articolo | tipologia | 22 | 2 | 6 | 21/2/19 18.00 | 8/2/19 22.30 | 8/2/19 13.30 | 0 | 1/2/19 9.00 | tipologia | 43 | |
| 25 | numero ordine | decsrizione articolo | tipologia | 21 | 4 | 12 | 21/2/19 18.00 | 8/2/19 22.30 | 12/2/19 6.00 | 0 | 1/2/19 10.30 | tipologia | 43 | |
| 26 | numero ordine | decsrizione articolo | tipologia | 20 | 3 | 9 | 21/2/19 18.00 | 12/2/19 15.00 | 12/2/19 6.00 | 0 | 1/2/19 12.00 | tipologia | 43 | |
| 27 | numero ordine | decsrizione articolo | tipologia | 19 | 2 | 6 | 21/2/19 18.00 | 12/2/19 15.00 | 13/2/19 22.30 | 0 | 1/2/19 13.30 | tipologia | 43 | |
| 28 | numero ordine | decsrizione articolo | tipologia | 18 | 4 | 12 | 22/2/19 21.00 | 12/2/19 15.00 | 13/2/19 22.30 | 0 | 1/2/19 15.00 | tipologia | 43 | |
| 29 | numero ordine | decsrizione articolo | tipologia | 17 | 6 | 18 | 22/2/19 21.00 | 13/2/19 13.30 | 13/2/19 22.30 | 5 | 1/2/19 16.30 | tipologia | 43 | |
| 30 | numero ordine | decsrizione articolo | tipologia | 16 | 2 | 6 | 22/2/19 21.00 | 14/2/19 12.00 | 13/2/19 22.30 | 8 | 1/2/19 18.00 | tipologia | 43 | |
| 31 | numero ordine | decsrizione articolo | tipologia | 15 | 4 | 12 | 22/2/19 21.00 | 14/2/19 12.00 | 14/2/19 21.00 | 2 | 1/2/19 19.30 | tipologia | 43 | |
| 32 | numero ordine | decsrizione articolo | tipologia | 14 | 3 | 9 | 22/2/19 21.00 | 15/2/19 10.30 | 14/2/19 21.00 | 5 | 1/2/19 21.00 | tipologia | 43 | |
| 33 | numero ordine | decsrizione articolo | tipologia | 13 | 2 | 6 | 22/2/19 21.00 | 15/2/19 10.30 | 15/2/19 19.30 | 1 | 1/2/19 22.30 | tipologia | 43 | |
| 34 | numero ordine | decsrizione articolo | tipologia | 12 | 4 | 12 | 22/2/19 21.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 0.00 | tipologia | 43 | |
| 35 | numero ordine | decsrizione articolo | tipologia | 11 | 6 | 18 | 26/2/19 0.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 1.30 | tipologia | 43 | |
| 36 | numero ordine | decsrizione articolo | tipologia | 10 | 2 | 6 | 27/2/19 3.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 3.00 | tipologia | 43 | |
| 37 | numero ordine | decsrizione articolo | tipologia | 9 | 4 | 12 | 28/2/19 6.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 4.30 | tipologia | 43 | |
| 38 | numero ordine | decsrizione articolo | tipologia | 8 | 3 | 9 | 1/3/19 9.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 6.00 | tipologia | 37 | |
| 39 | numero ordine | decsrizione articolo | tipologia | 7 | 2 | 6 | 4/3/19 12.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 7.30 | tipologia | 37 | |
| 40 | numero ordine | decsrizione articolo | tipologia | 6 | 4 | 12 | 5/3/19 15.00 | 18/2/19 9.00 | 15/2/19 19.30 | 0 | 4/2/19 9.00 | tipologia | 37 | |
| 41 | numero ordine | decsrizione articolo | tipologia | 5 | 6 | 18 | 5/3/19 15.00 | 18/2/19 9.00 | 15/2/19 19.30 | 5 | 4/2/19 10.30 | tipologia | 37 | |
| 42 | numero ordine | decsrizione articolo | tipologia | 4 | 2 | 6 | 6/3/19 18.00 | 18/2/19 9.00 | 18/2/19 18.00 | 0 | 4/2/19 12.00 | tipologia | 37 | |
| 43 | numero ordine | decsrizione articolo | tipologia | 3 | 4 | 12 | 6/3/19 18.00 | 19/2/19 7.30 | 18/2/19 18.00 | 6 | 4/2/19 13.30 | tipologia | 37 | |
| 44 | numero ordine | decsrizione articolo | tipologia | 2 | 3 | 9 | 6/3/19 18.00 | 19/2/19 7.30 | 19/2/19 16.30 | 6 | 4/2/19 15.00 | tipologia | 37 | |

scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Scheduling-Assemblaggio | LINEA ...

*Figure A- 16: Calculations scheduling assembly part 1*

| | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ezzi TR | linea | | TESTING TIME | | | | tempo inizio testing ro | s1 | linea | | TESTING TIME | | | | tempo inizio testing rooms | Allocazione pezzi s2 |
| 2 | tipologia | 44 | | 0,375 | 1,0625 | 3 | 0 | 31/1/19 0.00 | tipologia | 42 | | 0,5 | 0,875 | 2 | 0 | 31/1/19 0.00 | tipologia |
| 3 | tipologia | 44 | | 0,375 | 1 | 3 | 0 | | tipologia | 42 | | 0,5 | 0,8125 | 2 | 0 | | tipologia |
| 4 | tipologia | 44 | | 0,375 | 0,9375 | 3 | 0 | | tipologia | 42 | | 0,5 | 0,75 | 2 | 0 | | tipologia |
| 5 | tipologia | 44 | | 0,375 | 0,875 | 3 | 0 | | tipologia | 42 | | 0,5 | 0,6875 | 2 | 0 | | tipologia |
| 6 | tipologia | 44 | | 0,375 | 0,8125 | 3 | 0 | | tipologia | 42 | | 0,5 | 0,625 | 2 | 0 | | tipologia |
| 7 | tipologia | 44 | | 0,375 | 0,75 | 3 | 3 | | tipologia | 42 | | 0,5 | 0,5625 | 2 | 0 | | tipologia |
| 8 | tipologia | 44 | | 0,375 | 0,6875 | 2 | 0 | 31/1/19 9.00 | tipologia | 42 | | 0,5 | 0,5 | 2 | 2 | | tipologia |
| 9 | tipologia | 44 | | 0,375 | 0,625 | 2 | 0 | | tipologia | 42 | | 0,5 | 0,4375 | 1 | 0 | 31/1/19 10.30 | tipologia |
| 10 | tipologia | 44 | | 0,375 | 0,5625 | 2 | 0 | | tipologia | 42 | | 0,5 | 0,375 | 1 | 0 | | tipologia |
| 11 | tipologia | 44 | | 0,375 | 0,5 | 2 | 0 | | tipologia | 42 | | 0,5 | 0,3125 | 1 | 0 | | tipologia |
| 12 | tipologia | 44 | | 0,375 | 0,4375 | 2 | 0 | | tipologia | 42 | | 0,5 | 0,25 | 1 | 0 | | tipologia |
| 13 | tipologia | 44 | | 0,375 | 0,375 | 2 | 2 | | tipologia | 42 | | 0,5 | 0,1875 | 1 | 0 | | tipologia |
| 14 | tipologia | 44 | | 0,375 | 0,3125 | 1 | 0 | 31/1/19 18.00 | tipologia | 42 | | 0,5 | 0,125 | 1 | 0 | | tipologia |
| 15 | tipologia | 44 | | 0,375 | 0,25 | 1 | 0 | | tipologia | 42 | | 0,5 | 0,0625 | 1 | 0 | | tipologia |
| 16 | tipologia | 44 | | 0,375 | 0,1875 | 1 | 0 | | tipologia | 42 | | 0,5 | 0 | 1 | 1 | | tipologia |
| 17 | tipologia | 44 | | 0,375 | 0,125 | 1 | 0 | | tipologia | 40 | | 0,25 | 1,625 | 7 | 0 | 31/1/19 22.30 | tipologia |
| 18 | tipologia | 44 | | 0,375 | 0,0625 | 1 | 0 | | tipologia | 40 | | 0,25 | 1,5625 | 7 | 0 | | tipologia |
| 19 | tipologia | 44 | | 0,375 | 0 | 1 | 1 | | tipologia | 40 | | 0,25 | 1,5 | 7 | 7 | | tipologia |
| 20 | tipologia | 43 | | 0,25 | 1,0625 | 5 | 0 | 1/2/19 3.00 | tipologia | 40 | | 0,25 | 1,4375 | 6 | 0 | 1/2/19 3.00 | tipologia |
| 21 | tipologia | 43 | | 0,25 | 1 | 5 | 5 | | tipologia | 40 | | 0,25 | 1,375 | 6 | 0 | | tipologia |
| 22 | tipologia | 43 | | 0,25 | 0,9375 | 4 | 0 | 1/2/19 6.00 | tipologia | 40 | | 0,25 | 1,3125 | 6 | 0 | | tipologia |
| 23 | tipologia | 43 | | 0,25 | 0,875 | 4 | 0 | | tipologia | 40 | | 0,25 | 1,25 | 6 | 6 | | tipologia |
| 24 | tipologia | 43 | | 0,25 | 0,8125 | 4 | 0 | | tipologia | 40 | | 0,25 | 1,1875 | 5 | 0 | 1/2/19 9.00 | tipologia |
| 25 | tipologia | 43 | | 0,25 | 0,75 | 4 | 4 | | tipologia | 40 | | 0,25 | 1,125 | 5 | 0 | | tipologia |
| 26 | tipologia | 43 | | 0,25 | 0,6875 | 3 | 0 | 1/2/19 12.00 | tipologia | 40 | | 0,25 | 1,0625 | 5 | 0 | | tipologia |
| 27 | tipologia | 43 | | 0,25 | 0,625 | 3 | 0 | | tipologia | 40 | | 0,25 | 1 | 5 | 5 | | tipologia |
| 28 | tipologia | 43 | | 0,25 | 0,5625 | 3 | 0 | | tipologia | 40 | | 0,25 | 0,9375 | 4 | 0 | 1/2/19 15.00 | tipologia |
| 29 | tipologia | 43 | | 0,25 | 0,5 | 3 | 3 | | tipologia | 40 | | 0,25 | 0,875 | 4 | 0 | | tipologia |
| 30 | tipologia | 43 | | 0,25 | 0,4375 | 2 | 0 | 1/2/19 18.00 | tipologia | 40 | | 0,25 | 0,8125 | 4 | 0 | | tipologia |
| 31 | tipologia | 43 | | 0,25 | 0,375 | 2 | 0 | | tipologia | 40 | | 0,25 | 0,75 | 4 | 4 | | tipologia |
| 32 | tipologia | 43 | | 0,25 | 0,3125 | 2 | 0 | | tipologia | 40 | | 0,25 | 0,6875 | 3 | 0 | 1/2/19 21.00 | tipologia |
| 33 | tipologia | 43 | | 0,25 | 0,25 | 2 | 2 | | tipologia | 40 | | 0,25 | 0,625 | 3 | 0 | | tipologia |
| 34 | tipologia | 43 | | 0,25 | 0,1875 | 1 | 0 | 4/2/19 0.00 | tipologia | 40 | | 0,25 | 0,5625 | 3 | 0 | | tipologia |
| 35 | tipologia | 43 | | 0,25 | 0,125 | 1 | 0 | | tipologia | 40 | | 0,25 | 0,5 | 3 | 3 | | tipologia |
| 36 | tipologia | 43 | | 0,25 | 0,0625 | 1 | 0 | | tipologia | 40 | | 0,25 | 0,4375 | 2 | 0 | 4/2/19 3.00 | tipologia |
| 37 | tipologia | 43 | | 0,25 | 0 | 1 | 1 | | tipologia | 40 | | 0,25 | 0,375 | 2 | 0 | | tipologia |
| 38 | tipologia | 37 | | 0,25 | 1,0625 | 5 | 0 | 4/2/19 6.00 | tipologia | 40 | | 0,25 | 0,3125 | 2 | 0 | | tipologia |
| 39 | tipologia | 37 | | 0,25 | 1 | 5 | 5 | | tipologia | 40 | | 0,25 | 0,25 | 2 | 2 | | tipologia |
| 40 | tipologia | 37 | | 0,25 | 0,9375 | 4 | 0 | 4/2/19 9.00 | tipologia | 40 | | 0,25 | 0,1875 | 1 | 0 | 4/2/19 9.00 | tipologia |
| 41 | tipologia | 37 | | 0,25 | 0,875 | 4 | 0 | | tipologia | 40 | | 0,25 | 0,125 | 1 | 0 | | tipologia |
| 42 | tipologia | 37 | | 0,25 | 0,8125 | 4 | 0 | | tipologia | 40 | | 0,25 | 0,0625 | 1 | 0 | | tipologia |
| 43 | tipologia | 37 | | 0,25 | 0,75 | 4 | 4 | | tipologia | 40 | | 0,25 | 0 | 1 | 1 | | tipologia |
| 44 | tipologia | 37 | | 0,25 | 0,6875 | 3 | 0 | 4/2/19 15.00 | tipologia | 35 | | 0,75 | 0,875 | 2 | 0 | 4/2/19 15.00 | tipologia |

scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | Scheduling-Assemblaggio | LINEA ...

*Figure A- 17: Calculations scheduling assembly part 2*

POLITECNICO
MILANO 1863

| | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM | AN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | linea | TESTING TIME | | | 1 | tempo inizio testing rooms | Allocazione pezzi s2 | 41 | linea | | | | 0 | tempo inizio testing rooms | contatore gio | contatore ore | | | Linea 1 |
| 2 | | 0,5 | 0,875 | 2 | 0 | 31/1/19 0.00 | tipologia | 41 | | 0,75 | 0,875 | 2 | 0 | 31/1/19 0.00 | 0,00 | 0,00 | | 31/1/19 1.30 | Piece Type |
| 3 | | 0,5 | 0,8125 | 2 | 0 | | tipologia | 41 | | 0,75 | 0,8125 | 2 | 0 | | 0,0625 | 0,0625 | | 31/1/19 3.00 | Piece Type |
| 4 | | 0,5 | 0,75 | 2 | 0 | | tipologia | 41 | | 0,75 | 0,75 | 2 | 2 | | 0,125 | 0,125 | | 31/1/19 4.30 | Piece Type |
| 5 | | 0,5 | 0,6875 | 2 | 0 | | tipologia | 41 | | 0,75 | 0,6875 | 1 | 0 | 31/1/19 4.30 | 0,1875 | 0,1875 | | 31/1/19 6.00 | Piece Type |
| 6 | | 0,5 | 0,625 | 2 | 0 | | tipologia | 41 | | 0,75 | 0,625 | 1 | 0 | | 0,25 | 0,25 | | 31/1/19 7.30 | Piece Type |
| 7 | | 0,5 | 0,5625 | 2 | 0 | | tipologia | 41 | | 0,75 | 0,5625 | 1 | 0 | | 0,3125 | 0,3125 | | 31/1/19 9.00 | Piece Type |
| 8 | | 0,5 | 0,5 | 2 | 2 | | tipologia | 41 | | 0,75 | 0,5 | 1 | 0 | | 0,375 | 0,375 | | 31/1/19 10.30 | Piece Type |
| 9 | | 0,5 | 0,4375 | 1 | 0 | 31/1/19 10.30 | tipologia | 41 | | 0,75 | 0,4375 | 1 | 0 | | 0,4375 | 0,4375 | | 31/1/19 12.00 | Piece Type |
| 10 | | 0,5 | 0,375 | 1 | 0 | | tipologia | 41 | | 0,75 | 0,375 | 1 | 0 | | 0,5 | 0,5 | | 31/1/19 13.30 | Piece Type |
| 11 | | 0,5 | 0,3125 | 1 | 0 | | tipologia | 41 | | 0,75 | 0,3125 | 1 | 0 | | 0,5625 | 0,5625 | | 31/1/19 15.00 | Piece Type |
| 12 | | 0,5 | 0,25 | 1 | 0 | | tipologia | 41 | | 0,75 | 0,25 | 1 | 0 | | 0,625 | 0,625 | | 31/1/19 16.30 | Piece Type |
| 13 | | 0,5 | 0,1875 | 1 | 0 | | tipologia | 41 | | 0,75 | 0,1875 | 1 | 0 | | 0,6875 | 0,6875 | | 31/1/19 18.00 | Piece Type |
| 14 | | 0,5 | 0,125 | 1 | 0 | | tipologia | 41 | | 0,75 | 0,125 | 1 | 0 | | 0,75 | 0,75 | | 31/1/19 19.30 | Piece Type |
| 15 | | 0,5 | 0,0625 | 1 | 0 | | tipologia | 41 | | 0,75 | 0,0625 | 1 | 0 | | 0,8125 | 0,8125 | | 31/1/19 21.00 | Piece Type |
| 16 | | 0,5 | 0 | 1 | 1 | | tipologia | 41 | | 0,75 | 0 | 1 | 1 | | 0,875 | 0,875 | | 31/1/19 22.30 | Piece Type |
| 17 | | 0,25 | 1,625 | 7 | 0 | 31/1/19 22.30 | tipologia | 39 | | 0,5 | 0,875 | 2 | 0 | 31/1/19 22.30 | 0,9375 | 0,9375 | | 1/2/19 0.00 | Piece Type |
| 18 | | 0,25 | 1,5625 | 7 | 0 | | tipologia | 39 | | 0,5 | 0,8125 | 2 | 0 | | 1 | 0 | | 1/2/19 1.30 | Piece Type |
| 19 | | 0,25 | 1,5 | 7 | 7 | | tipologia | 39 | | 0,5 | 0,75 | 2 | 0 | | 1,0625 | 0,0625 | | 1/2/19 3.00 | Piece Type |
| 20 | | 0,25 | 1,4375 | 6 | 0 | 1/2/19 3.00 | tipologia | 39 | | 0,5 | 0,6875 | 2 | 0 | | 1,125 | 0,125 | | 1/2/19 4.30 | Piece Type |
| 21 | | 0,25 | 1,375 | 6 | 0 | | tipologia | 39 | | 0,5 | 0,625 | 2 | 0 | | 1,1875 | 0,1875 | | 1/2/19 6.00 | Piece Type |
| 22 | | 0,25 | 1,3125 | 6 | 0 | | tipologia | 39 | | 0,5 | 0,5625 | 2 | 0 | | 1,25 | 0,25 | | 1/2/19 7.30 | Piece Type |
| 23 | | 0,25 | 1,25 | 6 | 6 | | tipologia | 39 | | 0,5 | 0,5 | 2 | 2 | | 1,3125 | 0,3125 | | 1/2/19 9.00 | Piece Type |
| 24 | | 0,25 | 1,1875 | 5 | 0 | 1/2/19 9.00 | tipologia | 39 | | 0,5 | 0,4375 | 1 | 0 | 1/2/19 9.00 | 1,375 | 0,375 | | 1/2/19 10.30 | Piece Type |
| 25 | | 0,25 | 1,125 | 5 | 0 | | tipologia | 39 | | 0,5 | 0,375 | 1 | 0 | | 1,4375 | 0,4375 | | 1/2/19 12.00 | Piece Type |
| 26 | | 0,25 | 1,0625 | 5 | 0 | | tipologia | 39 | | 0,5 | 0,3125 | 1 | 0 | | 1,5 | 0,5 | | 1/2/19 13.30 | Piece Type |
| 27 | | 0,25 | 1 | 5 | 5 | | tipologia | 39 | | 0,5 | 0,25 | 1 | 0 | | 1,5625 | 0,5625 | | 1/2/19 15.00 | Piece Type |
| 28 | | 0,25 | 0,9375 | 4 | 0 | 1/2/19 15.00 | tipologia | 39 | | 0,5 | 0,1875 | 1 | 0 | | 1,625 | 0,625 | | 1/2/19 16.30 | Piece Type |
| 29 | | 0,25 | 0,875 | 4 | 0 | | tipologia | 39 | | 0,5 | 0,125 | 1 | 0 | | 1,6875 | 0,6875 | | 1/2/19 18.00 | Piece Type |
| 30 | | 0,25 | 0,8125 | 4 | 0 | | tipologia | 39 | | 0,5 | 0,0625 | 1 | 0 | | 1,75 | 0,75 | | 31/1/19 1.30 | Piece Type |
| 31 | | 0,25 | 0,75 | 4 | 4 | | tipologia | 39 | | 0,5 | 0 | 1 | 1 | | 1,8125 | 0,8125 | | 31/1/19 3.00 | Piece Type |
| 32 | | 0,25 | 0,6875 | 3 | 0 | 1/2/19 21.00 | tipologia | 38 | | 0,375 | 1,625 | 5 | 0 | 1/2/19 21.00 | 1,875 | 0,875 | | 31/1/19 4.30 | Piece Type |
| 33 | | 0,25 | 0,625 | 3 | 0 | | tipologia | 38 | | 0,375 | 1,5625 | 5 | 0 | | 1,9375 | 0,9375 | | 31/1/19 6.00 | Piece Type |
| 34 | | 0,25 | 0,5625 | 3 | 0 | | tipologia | 38 | | 0,375 | 1,5 | 5 | 5 | | 2 | 0 | | 31/1/19 7.30 | Piece Type |
| 35 | | 0,25 | 0,5 | 3 | 3 | | tipologia | 38 | | 0,375 | 1,4375 | 4 | 0 | 4/2/19 1.30 | 2,0625 | 0,0625 | | 31/1/19 9.00 | Piece Type |
| 36 | | 0,25 | 0,4375 | 2 | 0 | 4/2/19 3.00 | tipologia | 38 | | 0,375 | 1,375 | 4 | 0 | | 2,125 | 0,125 | | 31/1/19 10.30 | Piece Type |
| 37 | | 0,25 | 0,375 | 2 | 0 | | tipologia | 38 | | 0,375 | 1,3125 | 4 | 0 | | 2,1875 | 0,1875 | | 31/1/19 12.00 | Piece Type |
| 38 | | 0,25 | 0,3125 | 2 | 0 | | tipologia | 38 | | 0,375 | 1,25 | 4 | 0 | | 2,25 | 0,25 | | 31/1/19 13.30 | Piece Type |
| 39 | | 0,25 | 0,25 | 2 | 2 | | tipologia | 38 | | 0,375 | 1,1875 | 4 | 0 | | 2,3125 | 0,3125 | | 31/1/19 15.00 | Piece Type |
| 40 | | 0,25 | 0,1875 | 1 | 0 | 4/2/19 9.00 | tipologia | 38 | | 0,375 | 1,125 | 4 | 4 | | 2,375 | 0,375 | | 31/1/19 16.30 | Piece Type |
| 41 | | 0,25 | 0,125 | 1 | 0 | | tipologia | 38 | | 0,375 | 1,0625 | 3 | 0 | 4/2/19 10.30 | 2,4375 | 0,4375 | | 31/1/19 18.00 | Piece Type |
| 42 | | 0,25 | 0,0625 | 1 | 0 | | tipologia | 38 | | 0,375 | 1 | 3 | 0 | | 2,5 | 0,5 | | 31/1/19 19.30 | Piece Type |
| 43 | | 0,25 | 0 | 1 | 1 | | tipologia | 38 | | 0,375 | 0,9375 | 3 | 0 | | 2,5625 | 0,5625 | | 31/1/19 21.00 | Piece Type |
| 44 | | 0,75 | 0,875 | 2 | 0 | 4/2/19 15.00 | tipologia | 38 | | 0,375 | 0,875 | 3 | 0 | | 2,625 | 0,625 | | 31/1/19 22.30 | Piece Type |

scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | **Scheduling-Assemblaggio** | LINEA ...

62%

*Figure A- 18: Calculations scheduling assembly part 3*

| | AK | AL | AM | AN | AO | AP | AQ | AR | AS | AT | AU | AV | AW | AX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | contatore ore | | | Linea 1 | | | Linea 2 | | | Linea 3 | | | Linea 4 | |
| 2 | 0,00 | | 31/1/19 1.30 | Piece Type | 13 | 31/1/19 19.30 | Piece Type | 12 | 31/1/19 1.30 | Piece Type | 38 | 31/1/19 1.30 | Piece Type | 44 |
| 3 | 0,0625 | | 31/1/19 3.00 | Piece Type | 42 | 31/1/19 21.00 | Piece Type | 25 | 31/1/19 3.00 | Piece Type | 38 | 31/1/19 3.00 | Piece Type | 44 |
| 4 | 0,125 | | 31/1/19 4.30 | Piece Type | 42 | 31/1/19 22.30 | Piece Type | 25 | 31/1/19 4.30 | Piece Type | 38 | 31/1/19 4.30 | Piece Type | 43 |
| 5 | 0,1875 | | 31/1/19 6.00 | Piece Type | 42 | 1/2/19 0.00 | Piece Type | 25 | 31/1/19 6.00 | Piece Type | 38 | 31/1/19 6.00 | Piece Type | 43 |
| 6 | 0,25 | | 31/1/19 7.30 | Piece Type | 39 | 1/2/19 1.30 | Piece Type | 25 | 31/1/19 7.30 | Piece Type | 24 | 31/1/19 7.30 | Piece Type | 37 |
| 7 | 0,3125 | | 31/1/19 9.00 | Piece Type | 39 | 1/2/19 3.00 | Piece Type | 25 | 31/1/19 9.00 | Piece Type | 23 | 31/1/19 9.00 | Piece Type | 37 |
| 8 | 0,375 | | 31/1/19 10.30 | Piece Type | 39 | 1/2/19 4.30 | Piece Type | 25 | 31/1/19 10.30 | Piece Type | 23 | 31/1/19 10.30 | Piece Type | 37 |
| 9 | 0,4375 | | 31/1/19 12.00 | Piece Type | 39 | 1/2/19 6.00 | Piece Type | 25 | 31/1/19 12.00 | Piece Type | 23 | 31/1/19 12.00 | Piece Type | 37 |
| 10 | 0,5 | | 31/1/19 13.30 | Piece Type | 39 | 1/2/19 7.30 | Piece Type | 25 | 31/1/19 13.30 | Piece Type | 40 | 31/1/19 13.30 | Piece Type | 36 |
| 11 | 0,5625 | | 31/1/19 15.00 | Piece Type | 35 | 1/2/19 9.00 | Piece Type | 25 | 31/1/19 15.00 | Piece Type | 20 | 31/1/19 15.00 | Piece Type | 36 |
| 12 | 0,625 | | 31/1/19 16.30 | Piece Type | 35 | 1/2/19 10.30 | Piece Type | 25 | 31/1/19 16.30 | Piece Type | 19 | 31/1/19 16.30 | Piece Type | 36 |
| 13 | 0,6875 | | 31/1/19 18.00 | Piece Type | 35 | 1/2/19 12.00 | Piece Type | 25 | 31/1/19 18.00 | Piece Type | 19 | 31/1/19 18.00 | Piece Type | 36 |
| 14 | 0,75 | | 31/1/19 19.30 | Piece Type | 35 | 1/2/19 13.30 | Piece Type | 25 | 31/1/19 19.30 | Piece Type | 40 | 31/1/19 19.30 | Piece Type | 34 |
| 15 | 0,8125 | | 31/1/19 21.00 | Piece Type | 26 | 1/2/19 15.00 | Piece Type | 22 | 31/1/19 21.00 | Piece Type | 40 | 31/1/19 21.00 | Piece Type | 34 |
| 16 | 0,875 | | 31/1/19 22.30 | Piece Type | 16 | 1/2/19 16.30 | Piece Type | 22 | 31/1/19 22.30 | Piece Type | 40 | 31/1/19 22.30 | Piece Type | 34 |
| 17 | 0,9375 | | 1/2/19 0.00 | Piece Type | 16 | 1/2/19 18.00 | Piece Type | 22 | 1/2/19 0.00 | Piece Type | 40 | 1/2/19 0.00 | Piece Type | 34 |
| 18 | 0 | | 1/2/19 1.30 | Piece Type | 16 | 31/1/19 1.30 | Piece Type | 22 | 1/2/19 1.30 | Piece Type | 38 | 1/2/19 1.30 | Piece Type | 33 |
| 19 | 0,0625 | | 1/2/19 3.00 | Piece Type | 16 | 31/1/19 3.00 | Piece Type | 22 | 1/2/19 3.00 | Piece Type | 38 | 1/2/19 3.00 | Piece Type | 33 |
| 20 | 0,125 | | 1/2/19 4.30 | Piece Type | 16 | 31/1/19 4.30 | Piece Type | 22 | 1/2/19 4.30 | Piece Type | 29 | 1/2/19 4.30 | Piece Type | 32 |
| 21 | 0,1875 | | 1/2/19 6.00 | Piece Type | 16 | 1/2/19 4.30 | Piece Type | 22 | 1/2/19 6.00 | Piece Type | 29 | 1/2/19 6.00 | Piece Type | 32 |
| 22 | 0,25 | | 1/2/19 7.30 | Piece Type | 16 | | | | 1/2/19 7.30 | Piece Type | 29 | 1/2/19 7.30 | Piece Type | 31 |
| 23 | 0,3125 | | 1/2/19 9.00 | Piece Type | 16 | | | | 1/2/19 9.00 | Piece Type | 29 | 1/2/19 9.00 | Piece Type | 31 |
| 24 | 0,375 | | 1/2/19 10.30 | Piece Type | 5 | | | | 1/2/19 10.30 | Piece Type | 29 | 1/2/19 10.30 | Piece Type | 30 |
| 25 | 0,4375 | | 1/2/19 12.00 | Piece Type | 5 | | | | 1/2/19 12.00 | Piece Type | 29 | 1/2/19 12.00 | Piece Type | 28 |
| 26 | 0,5 | | 1/2/19 13.30 | Piece Type | 5 | | | | 1/2/19 13.30 | Piece Type | 21 | 1/2/19 13.30 | Piece Type | 28 |
| 27 | 0,5625 | | 1/2/19 15.00 | Piece Type | 5 | | | | 1/2/19 15.00 | Piece Type | 21 | 1/2/19 15.00 | Piece Type | 27 |
| 28 | 0,625 | | 1/2/19 16.30 | Piece Type | 5 | | | | | | | 1/2/19 16.30 | Piece Type | 18 |
| 29 | 0,6875 | | 1/2/19 18.00 | Piece Type | 3 | | | | | | | 1/2/19 18.00 | Piece Type | 18 |
| 30 | 0,75 | | 31/1/19 1.30 | Piece Type | 2 | | | | | | | 31/1/19 1.30 | Piece Type | 11 |
| 31 | 0,8125 | | 31/1/19 3.00 | Piece Type | 2 | | | | | | | 31/1/19 3.00 | Piece Type | 10 |
| 32 | 0,875 | | 31/1/19 4.30 | Piece Type | 2 | | | | | | | 31/1/19 4.30 | Piece Type | 9 |
| 33 | 0,9375 | | 31/1/19 6.00 | Piece Type | 2 | | | | | | | 31/1/19 6.00 | Piece Type | 8 |
| 34 | 0 | | 31/1/19 7.30 | Piece Type | 2 | | | | | | | 31/1/19 7.30 | Piece Type | 7 |
| 35 | 0,0625 | | 31/1/19 9.00 | Piece Type | 2 | | | | | | | 31/1/19 9.00 | Piece Type | 6 |
| 36 | 0,125 | | 31/1/19 10.30 | Piece Type | 41 | | | | | | | 31/1/19 10.30 | Piece Type | 6 |
| 37 | 0,1875 | | 31/1/19 12.00 | Piece Type | 41 | | | | | | | 31/1/19 12.00 | Piece Type | 4 |
| 38 | 0,25 | | 31/1/19 13.30 | Piece Type | 17 | | | | | | | | | |
| 39 | 0,3125 | | 31/1/19 15.00 | Piece Type | 17 | | | | | | | | | |
| 40 | 0,375 | | 31/1/19 16.30 | Piece Type | 17 | | | | | | | | | |
| 41 | 0,4375 | | 31/1/19 18.00 | Piece Type | 17 | | | | | | | | | |
| 42 | 0,5 | | 31/1/19 19.30 | Piece Type | 17 | | | | | | | | | |
| 43 | 0,5625 | | 31/1/19 21.00 | Piece Type | 15 | | | | | | | | | |
| 44 | 0,625 | | 31/1/19 22.30 | Piece Type | 15 | | | | | | | | | |

Raggruppa ordini per linea

Schedula linee

| BUFFER PRIMA DEL TESTING | | |
|---|---|---|
| LINEA 1 | 0 | giorni |
| LINEA 2 | 0 | giorni |
| LINEA 3 | 0 | giorni |
| LINEA 4 | 0 | giorni |

scheduling visivo testing1 | Dashboard | Scheduling-Collaudo | **Scheduling-Assemblaggio** | LINEA ...

62%

*Figure A- 19: Output scheduling assembly*

| | A | C | D | E | F | G | H | I | J | K | L | M | N | P | START TESTIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Buffer before testing | | | | | | | | | | | | | | |
| 2 | starting date at testing | serial number | START TESTING-TOT. ASSEMBLY TIME | WITH BUFFER | order number | CYCLE TIME | total assembly times | starting date at assembly | FINISHING DATE | MINIMUM | STARTING DATE | | starting date at testing | serial num | START TESTIN |
| 3 | 31/1/19 1.30 | 1 | 30/1/19 22.30 | 30/1/19 22.30 | num. Ord. | 3 | 12 | 30/1/19 13.30 | 30/1/19 22.30 | 30/1/19 13.30 | 30/1/19 13.30 | | 31/1/19 1.30 | 41 | |
| 4 | 31/1/19 3.00 | 1 | 31/1/19 0.00 | 31/1/19 0.00 | num. Ord. | 3 | 12 | 30/1/19 4.30 | 30/1/19 13.30 | 30/1/19 4.30 | 30/1/19 4.30 | | 31/1/19 3.00 | 42 | |
| 5 | 31/1/19 4.30 | 1 | 31/1/19 1.30 | 31/1/19 1.30 | num. Ord. | 3 | 12 | 29/1/19 19.30 | 30/1/19 4.30 | 29/1/19 19.30 | 29/1/19 19.30 | | 31/1/19 4.30 | 41 | |
| 6 | 31/1/19 6.00 | 1 | 31/1/19 3.00 | 31/1/19 3.00 | num. Ord. | 3 | 12 | 29/1/19 10.30 | 29/1/19 19.30 | 29/1/19 10.30 | 29/1/19 10.30 | | 31/1/19 6.00 | 42 | |
| 7 | 31/1/19 7.30 | 1 | 31/1/19 4.30 | 31/1/19 4.30 | num. Ord. | 3 | 12 | 29/1/19 1.30 | 29/1/19 10.30 | 29/1/19 1.30 | 29/1/19 1.30 | | 31/1/19 7.30 | 42 | |
| 8 | 31/1/19 9.00 | 2 | 31/1/19 6.00 | 31/1/19 6.00 | num. Ord. | 3 | 12 | 28/1/19 16.30 | 29/1/19 1.30 | 28/1/19 16.30 | 28/1/19 16.30 | | 31/1/19 9.00 | 39 | |
| 9 | 31/1/19 10.30 | 1 | 31/1/19 7.30 | 31/1/19 7.30 | num. Ord. | 3 | 12 | 28/1/19 7.30 | 28/1/19 16.30 | 28/1/19 7.30 | 28/1/19 7.30 | | 31/1/19 10.30 | 39 | |
| 10 | 31/1/19 12.00 | 2 | 31/1/19 9.00 | 31/1/19 9.00 | num. Ord. | 3 | 12 | 25/1/19 22.30 | 28/1/19 7.30 | 25/1/19 22.30 | 25/1/19 22.30 | | 31/1/19 12.00 | 39 | |
| 11 | 31/1/19 13.30 | 1 | 31/1/19 10.30 | 31/1/19 10.30 | num. Ord. | 3 | 12 | 25/1/19 13.30 | 25/1/19 22.30 | 25/1/19 13.30 | 25/1/19 13.30 | | 31/1/19 13.30 | 39 | |
| 12 | 31/1/19 15.00 | 2 | 31/1/19 12.00 | 31/1/19 12.00 | num. Ord. | 3 | 12 | 25/1/19 4.30 | 25/1/19 13.30 | 25/1/19 4.30 | 25/1/19 4.30 | | 31/1/19 15.00 | 39 | |
| 13 | 31/1/19 16.30 | 1 | 31/1/19 13.30 | 31/1/19 13.30 | num. Ord. | 3 | 12 | 24/1/19 19.30 | 25/1/19 4.30 | 24/1/19 19.30 | 24/1/19 19.30 | | 31/1/19 16.30 | 35 | |
| 14 | 31/1/19 18.00 | 2 | 31/1/19 15.00 | 31/1/19 15.00 | num. Ord. | 3 | 12 | 24/1/19 10.30 | 24/1/19 19.30 | 24/1/19 10.30 | 24/1/19 10.30 | | 31/1/19 18.00 | 35 | |
| 15 | 31/1/19 19.30 | 1 | 31/1/19 16.30 | 31/1/19 16.30 | num. Ord. | 3 | 12 | 24/1/19 1.30 | 24/1/19 10.30 | 24/1/19 1.30 | 24/1/19 1.30 | | 31/1/19 19.30 | 35 | |
| 16 | 31/1/19 21.00 | 2 | 31/1/19 18.00 | 31/1/19 18.00 | num. Ord. | 3 | 12 | 23/1/19 16.30 | 24/1/19 1.30 | 23/1/19 16.30 | 23/1/19 16.30 | | 31/1/19 21.00 | 35 | |
| 17 | 31/1/19 22.30 | 1 | 31/1/19 19.30 | 31/1/19 19.30 | num. Ord. | 3 | 12 | 23/1/19 7.30 | 23/1/19 16.30 | 23/1/19 7.30 | 23/1/19 7.30 | | 31/1/19 22.30 | 26 | |
| 18 | 1/2/19 0.00 | 2 | 31/1/19 21.00 | 31/1/19 21.00 | num. Ord. | 3 | 12 | 22/1/19 22.30 | 23/1/19 7.30 | 22/1/19 22.30 | 22/1/19 22.30 | | 1/2/19 0.00 | 17 | |
| 19 | 1/2/19 1.30 | 3 | 31/1/19 22.30 | 31/1/19 22.30 | num. Ord. | 3 | 12 | 22/1/19 13.30 | 22/1/19 22.30 | 22/1/19 13.30 | 22/1/19 13.30 | | 1/2/19 1.30 | 17 | |
| 20 | 1/2/19 3.00 | 3 | 1/2/19 0.00 | 1/2/19 0.00 | num. Ord. | 3 | 12 | 22/1/19 4.30 | 22/1/19 13.30 | 22/1/19 4.30 | 22/1/19 4.30 | | 1/2/19 3.00 | 17 | |
| 21 | 1/2/19 4.30 | 3 | 1/2/19 1.30 | 1/2/19 1.30 | num. Ord. | 3 | 12 | 21/1/19 19.30 | 22/1/19 4.30 | 21/1/19 19.30 | 21/1/19 19.30 | | 1/2/19 4.30 | 16 | |
| 22 | 1/2/19 6.00 | 5 | 1/2/19 3.00 | 1/2/19 3.00 | num. Ord. | 3 | 12 | 21/1/19 10.30 | 21/1/19 19.30 | 21/1/19 10.30 | 21/1/19 10.30 | | 1/2/19 6.00 | 17 | |
| 23 | 1/2/19 7.30 | 3 | 1/2/19 4.30 | 1/2/19 4.30 | num. Ord. | 3 | 12 | 21/1/19 1.30 | 21/1/19 10.30 | 21/1/19 1.30 | 21/1/19 1.30 | | 1/2/19 7.30 | 16 | |
| 24 | 1/2/19 9.00 | 5 | 1/2/19 6.00 | 1/2/19 6.00 | num. Ord. | 3 | 12 | 18/1/19 16.30 | 21/1/19 1.30 | 18/1/19 16.30 | 18/1/19 16.30 | | 1/2/19 9.00 | 17 | |
| 25 | 1/2/19 10.30 | 3 | 1/2/19 7.30 | 1/2/19 7.30 | num. Ord. | 3 | 12 | 18/1/19 7.30 | 18/1/19 16.30 | 18/1/19 7.30 | 18/1/19 7.30 | | 1/2/19 10.30 | 16 | |
| 26 | 1/2/19 12.00 | 5 | 1/2/19 9.00 | 1/2/19 9.00 | num. Ord. | 3 | 12 | 17/1/19 22.30 | 18/1/19 7.30 | 17/1/19 22.30 | 17/1/19 22.30 | | 1/2/19 12.00 | 15 | |
| 27 | 1/2/19 13.30 | 3 | 1/2/19 10.30 | 1/2/19 10.30 | num. Ord. | 3 | 12 | 17/1/19 13.30 | 17/1/19 22.30 | 17/1/19 13.30 | 17/1/19 13.30 | | 1/2/19 13.30 | 16 | |
| 28 | 1/2/19 15.00 | 5 | 1/2/19 12.00 | 1/2/19 12.00 | num. Ord. | 3 | 12 | 17/1/19 4.30 | 17/1/19 13.30 | 17/1/19 4.30 | 17/1/19 4.30 | | 1/2/19 15.00 | 15 | |
| 29 | 1/2/19 16.30 | 14 | 1/2/19 13.30 | 1/2/19 13.30 | num. Ord. | 3 | 12 | 16/1/19 19.30 | 17/1/19 4.30 | 16/1/19 19.30 | 16/1/19 19.30 | | 1/2/19 16.30 | 16 | |
| 30 | 1/2/19 18.00 | 5 | 1/2/19 15.00 | 1/2/19 15.00 | num. Ord. | 3 | 12 | 16/1/19 10.30 | 16/1/19 19.30 | 16/1/19 10.30 | 16/1/19 10.30 | | 1/2/19 18.00 | 14 | |
| 31 | 31/1/19 1.30 | 14 | 30/1/19 22.30 | 30/1/19 22.30 | num. Ord. | 3 | 12 | 16/1/19 1.30 | 16/1/19 10.30 | 16/1/19 1.30 | 16/1/19 1.30 | | 31/1/19 1.30 | 16 | |
| 32 | 31/1/19 3.00 | 16 | 31/1/19 0.00 | 31/1/19 0.00 | num. Ord. | 3 | 12 | 15/1/19 16.30 | 16/1/19 1.30 | 15/1/19 16.30 | 15/1/19 16.30 | | 31/1/19 3.00 | 13 | |
| 33 | 31/1/19 4.30 | 14 | 31/1/19 1.30 | 31/1/19 1.30 | num. Ord. | 3 | 12 | 15/1/19 7.30 | 15/1/19 16.30 | 15/1/19 7.30 | 15/1/19 7.30 | | 31/1/19 4.30 | 14 | |
| 34 | 31/1/19 6.00 | 16 | 31/1/19 3.00 | 31/1/19 3.00 | num. Ord. | 3 | 12 | 14/1/19 22.30 | 15/1/19 7.30 | 14/1/19 22.30 | 14/1/19 22.30 | | 31/1/19 6.00 | 16 | |
| 35 | 31/1/19 7.30 | 14 | 31/1/19 4.30 | 31/1/19 4.30 | num. Ord. | 3 | 12 | 14/1/19 13.30 | 14/1/19 22.30 | 14/1/19 13.30 | 14/1/19 13.30 | | 31/1/19 7.30 | 14 | |
| 36 | 31/1/19 9.00 | 13 | 31/1/19 6.00 | 31/1/19 6.00 | num. Ord. | 3 | 12 | 14/1/19 4.30 | 14/1/19 13.30 | 14/1/19 4.30 | 14/1/19 4.30 | | 31/1/19 9.00 | 16 | |
| 37 | 31/1/19 10.30 | 16 | 31/1/19 7.30 | 31/1/19 7.30 | num. Ord. | 3 | 12 | 11/1/19 19.30 | 14/1/19 4.30 | 11/1/19 19.30 | 11/1/19 19.30 | | 31/1/19 10.30 | 14 | |
| 38 | 31/1/19 12.00 | 14 | 31/1/19 9.00 | 31/1/19 9.00 | num. Ord. | 3 | 12 | 11/1/19 10.30 | 11/1/19 19.30 | 11/1/19 10.30 | 11/1/19 10.30 | | 31/1/19 12.00 | 5 | |
| 39 | 31/1/19 13.30 | 16 | 31/1/19 10.30 | 31/1/19 10.30 | num. Ord. | 3 | 12 | 11/1/19 1.30 | 11/1/19 10.30 | 11/1/19 1.30 | 11/1/19 1.30 | | 31/1/19 13.30 | 14 | |
| 40 | 31/1/19 15.00 | 15 | 31/1/19 12.00 | 31/1/19 12.00 | num. Ord. | 3 | 12 | 10/1/19 16.30 | 11/1/19 1.30 | 10/1/19 16.30 | 10/1/19 16.30 | | 31/1/19 15.00 | 5 | |
| 41 | 31/1/19 16.30 | 16 | 31/1/19 13.30 | 31/1/19 13.30 | num. Ord. | 3 | 12 | 10/1/19 7.30 | 10/1/19 16.30 | 10/1/19 7.30 | 10/1/19 7.30 | | 31/1/19 16.30 | 3 | |
| 42 | 31/1/19 18.00 | 15 | 31/1/19 15.00 | 31/1/19 15.00 | num. Ord. | 3 | 12 | 9/1/19 22.30 | 10/1/19 7.30 | 9/1/19 22.30 | 9/1/19 22.30 | | 31/1/19 18.00 | 5 | |
| 43 | 31/1/19 19.30 | 16 | 31/1/19 16.30 | 31/1/19 16.30 | num. Ord. | 3 | 12 | 9/1/19 13.30 | 9/1/19 22.30 | 9/1/19 13.30 | 9/1/19 13.30 | | 31/1/19 19.30 | 3 | |
| 44 | 31/1/19 21.00 | 17 | 31/1/19 18.00 | 31/1/19 18.00 | num. Ord. | 3 | 12 | 9/1/19 4.30 | 9/1/19 13.30 | 9/1/19 4.30 | 9/1/19 4.30 | | 31/1/19 21.00 | 5 | |
| 45 | 31/1/19 22.30 | 16 | 31/1/19 19.30 | 31/1/19 19.30 | num. Ord. | 3 | 12 | 8/1/19 19.30 | 9/1/19 4.30 | 8/1/19 19.30 | 8/1/19 19.30 | | 31/1/19 22.30 | 3 | |
| 46 | 1/2/19 0.00 | 17 | 31/1/19 21.00 | 31/1/19 21.00 | num. Ord. | 3 | 12 | 8/1/19 10.30 | 8/1/19 19.30 | 8/1/19 10.30 | 8/1/19 10.30 | | 1/2/19 0.00 | 5 | |
| 47 | 1/2/19 1.30 | 16 | 31/1/19 22.30 | 31/1/19 22.30 | num. Ord. | 3 | 12 | 8/1/19 1.30 | 8/1/19 10.30 | 8/1/19 1.30 | 8/1/19 1.30 | | 1/2/19 1.30 | 3 | |
| 48 | 1/2/19 3.00 | 17 | 1/2/19 0.00 | 1/2/19 0.00 | num. Ord. | 3 | 12 | 7/1/19 16.30 | 8/1/19 1.30 | 7/1/19 16.30 | 7/1/19 16.30 | | 1/2/19 3.00 | 3 | |
| 49 | 1/2/19 4.30 | 17 | 1/2/19 1.30 | 1/2/19 1.30 | num. Ord. | 3 | 12 | 7/1/19 7.30 | 7/1/19 16.30 | 7/1/19 7.30 | 7/1/19 7.30 | | 1/2/19 4.30 | 3 | |

*Figure A- 20: Calculations scheduling assembly line 1*

| | P | Q | R | T | U | V | W | X | Y | Z | AA | AB | AD | AE | AF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | |
| 2 | serial num | START TESTING-TOT. ASSEMBLY TIME | WITH BUFFE | CYCLE TIME | total assembly | starting date at assembly | FINISHING DATE | MINIMUM | STARTING DATE | contatore | contatore | Ordine-Riga-Tipologia-Progressivo pezzo | | CONTATORE | CODICE GRAF |
| 3 | 41 | 31/1/19 1.30 | 31/1/19 1.30 | 3 | 9 | 31/1/19 1.30 | 31/1/19 1.30 | 31/1/19 1.30 | 31/1/19 1.30 | 63 | 1 | num. Ord.-PT-63 | 63 | 28/12/18 0.00 | |
| 4 | 42 | 31/1/19 3.00 | 31/1/19 3.00 | 3 | 9 | 31/1/19 3.00 | 31/1/19 3.00 | 31/1/19 3.00 | 31/1/19 3.00 | 62 | 2 | num. Ord.-PT-62 | 62 | 28/12/18 1.30 | num. Ord.-PT-1 |
| 5 | 41 | 31/1/19 4.30 | 31/1/19 4.30 | 3 | 9 | 31/1/19 4.30 | 31/1/19 4.30 | 31/1/19 4.30 | 31/1/19 4.30 | 61 | 3 | num. Ord.-PT-61 | 61 | 28/12/18 3.00 | num. Ord.-PT-1 |
| 6 | 42 | 31/1/19 6.00 | 31/1/19 6.00 | 3 | 9 | 31/1/19 6.00 | 31/1/19 6.00 | 31/1/19 6.00 | 31/1/19 6.00 | 60 | 4 | num. Ord.-PT-60 | 60 | 28/12/18 4.30 | num. Ord.-PT-1 |
| 7 | 42 | 31/1/19 7.30 | 31/1/19 7.30 | 3 | 9 | 31/1/19 7.30 | 31/1/19 7.30 | 31/1/19 7.30 | 31/1/19 7.30 | 59 | 5 | num. Ord.-PT-59 | 59 | 28/12/18 6.00 | num. Ord.-PT-1 |
| 8 | 39 | 31/1/19 9.00 | 31/1/19 9.00 | 3 | 9 | 31/1/19 9.00 | 31/1/19 9.00 | 31/1/19 9.00 | 31/1/19 9.00 | 58 | 6 | num. Ord.-PT-58 | 58 | 28/12/18 7.30 | num. Ord.-PT-1 |
| 9 | 39 | 31/1/19 10.30 | 31/1/19 10.30 | 3 | 9 | 31/1/19 10.30 | 31/1/19 10.30 | 31/1/19 10.30 | 31/1/19 10.30 | 57 | 7 | num. Ord.-PT-57 | 57 | 28/12/18 9.00 | num. Ord.-PT-1 |
| 10 | 39 | 31/1/19 12.00 | 31/1/19 12.00 | 3 | 9 | 31/1/19 12.00 | 31/1/19 12.00 | 31/1/19 12.00 | 31/1/19 12.00 | 56 | 8 | num. Ord.-PT-56 | 56 | 28/12/18 10.30 | num. Ord.-PT-2 |
| 11 | 39 | 31/1/19 13.30 | 31/1/19 13.30 | 3 | 9 | 31/1/19 13.30 | 31/1/19 13.30 | 31/1/19 13.30 | 31/1/19 13.30 | 55 | 9 | num. Ord.-PT-55 | 55 | 28/12/18 12.00 | num. Ord.-PT-2 |
| 12 | 39 | 31/1/19 15.00 | 31/1/19 15.00 | 3 | 9 | 31/1/19 15.00 | 31/1/19 15.00 | 31/1/19 15.00 | 31/1/19 15.00 | 54 | 10 | num. Ord.-PT-54 | 54 | 28/12/18 13.30 | num. Ord.-PT-2 |
| 13 | 35 | 31/1/19 16.30 | 31/1/19 16.30 | 3 | 9 | 31/1/19 16.30 | 31/1/19 16.30 | 31/1/19 16.30 | 31/1/19 16.30 | 53 | 11 | num. Ord.-PT-53 | 53 | 28/12/18 15.00 | num. Ord.-PT-2 |
| 14 | 35 | 31/1/19 18.00 | 31/1/19 18.00 | 3 | 9 | 31/1/19 18.00 | 31/1/19 18.00 | 31/1/19 18.00 | 31/1/19 18.00 | 52 | 12 | num. Ord.-PT-52 | 52 | 28/12/18 16.30 | num. Ord.-PT-2 |
| 15 | 35 | 31/1/19 19.30 | 31/1/19 19.30 | 3 | 9 | 31/1/19 19.30 | 31/1/19 19.30 | 31/1/19 19.30 | 31/1/19 19.30 | 51 | 13 | num. Ord.-PT-51 | 51 | 28/12/18 18.00 | num. Ord.-PT-2 |
| 16 | 35 | 31/1/19 21.00 | 31/1/19 21.00 | 3 | 9 | 31/1/19 21.00 | 31/1/19 21.00 | 31/1/19 21.00 | 31/1/19 21.00 | 50 | 14 | num. Ord.-PT-50 | 50 | 28/12/18 19.30 | num. Ord.-PT-3 |
| 17 | 26 | 31/1/19 22.30 | 31/1/19 22.30 | 3 | 9 | 31/1/19 22.30 | 31/1/19 22.30 | 31/1/19 22.30 | 31/1/19 22.30 | 49 | 15 | num. Ord.-PT-49 | 49 | 28/12/18 21.00 | num. Ord.-PT-3 |
| 18 | 17 | 1/2/19 0.00 | 1/2/19 0.00 | 3 | 9 | 1/2/19 0.00 | 1/2/19 0.00 | 1/2/19 0.00 | 1/2/19 0.00 | 48 | 16 | num. Ord.-PT-48 | 48 | 28/12/18 22.30 | num. Ord.-PT-3 |
| 19 | 17 | 1/2/19 1.30 | 1/2/19 1.30 | 3 | 9 | 1/2/19 1.30 | 1/2/19 1.30 | 1/2/19 1.30 | 1/2/19 1.30 | 47 | 17 | num. Ord.-PT-47 | 47 | 31/12/18 0.00 | num. Ord.-PT-3 |
| 20 | 17 | 1/2/19 3.00 | 1/2/19 3.00 | 3 | 9 | 1/2/19 3.00 | 1/2/19 3.00 | 1/2/19 3.00 | 1/2/19 3.00 | 46 | 18 | num. Ord.-PT-46 | 46 | 31/12/18 1.30 | num. Ord.-PT-3 |
| 21 | 16 | 1/2/19 4.30 | 1/2/19 4.30 | 3 | 9 | 1/2/19 4.30 | 1/2/19 4.30 | 1/2/19 4.30 | 1/2/19 4.30 | 45 | 19 | num. Ord.-PT-45 | 45 | 31/12/18 3.00 | num. Ord.-PT-3 |
| 22 | 17 | 1/2/19 6.00 | 1/2/19 6.00 | 3 | 9 | 1/2/19 6.00 | 1/2/19 6.00 | 1/2/19 6.00 | 1/2/19 6.00 | 44 | 20 | num. Ord.-PT-44 | 44 | 31/12/18 4.30 | num. Ord.-PT-4 |
| 23 | 16 | 1/2/19 7.30 | 1/2/19 7.30 | 3 | 9 | 1/2/19 7.30 | 1/2/19 7.30 | 1/2/19 7.30 | 1/2/19 7.30 | 43 | 21 | num. Ord.-PT-43 | 43 | 31/12/18 6.00 | num. Ord.-PT-4 |
| 24 | 17 | 1/2/19 9.00 | 1/2/19 9.00 | 3 | 9 | 1/2/19 9.00 | 1/2/19 9.00 | 1/2/19 9.00 | 1/2/19 9.00 | 42 | 22 | num. Ord.-PT-42 | 42 | 31/12/18 7.30 | num. Ord.-PT-4 |
| 25 | 16 | 1/2/19 10.30 | 1/2/19 10.30 | 3 | 9 | 1/2/19 10.30 | 1/2/19 10.30 | 1/2/19 10.30 | 1/2/19 10.30 | 41 | 23 | num. Ord.-PT-41 | 41 | 31/12/18 9.00 | num. Ord.-PT-4 |
| 26 | 15 | 1/2/19 12.00 | 1/2/19 12.00 | 3 | 9 | 1/2/19 12.00 | 1/2/19 12.00 | 1/2/19 12.00 | 1/2/19 12.00 | 40 | 24 | num. Ord.-PT-40 | 40 | 31/12/18 10.30 | num. Ord.-PT-4 |
| 27 | 16 | 1/2/19 13.30 | 1/2/19 13.30 | 3 | 9 | 1/2/19 13.30 | 1/2/19 13.30 | 1/2/19 13.30 | 1/2/19 13.30 | 39 | 25 | num. Ord.-PT-39 | 39 | 31/12/18 12.00 | num. Ord.-PT-4 |
| 28 | 15 | 1/2/19 15.00 | 1/2/19 15.00 | 3 | 9 | 1/2/19 15.00 | 1/2/19 15.00 | 1/2/19 15.00 | 1/2/19 15.00 | 38 | 26 | num. Ord.-PT-38 | 38 | 31/12/18 13.30 | num. Ord.-PT-5 |
| 29 | 16 | 1/2/19 16.30 | 1/2/19 16.30 | 3 | 9 | 1/2/19 16.30 | 1/2/19 16.30 | 1/2/19 16.30 | 1/2/19 16.30 | 37 | 27 | num. Ord.-PT-37 | 37 | 31/12/18 15.00 | num. Ord.-PT-5 |
| 30 | 14 | 1/2/19 18.00 | 1/2/19 18.00 | 3 | 9 | 1/2/19 18.00 | 1/2/19 18.00 | 1/2/19 18.00 | 1/2/19 18.00 | 36 | 28 | num. Ord.-PT-36 | 36 | 31/12/18 16.30 | num. Ord.-PT-5 |
| 31 | 16 | 31/1/19 1.30 | 31/1/19 1.30 | 3 | 9 | 31/1/19 1.30 | 31/1/19 1.30 | 31/1/19 1.30 | 31/1/19 1.30 | 35 | 29 | num. Ord.-PT-35 | 35 | 31/12/18 18.00 | num. Ord.-PT-5 |
| 32 | 13 | 31/1/19 3.00 | 31/1/19 3.00 | 3 | 9 | 31/1/19 3.00 | 31/1/19 3.00 | 31/1/19 3.00 | 31/1/19 3.00 | 34 | 30 | num. Ord.-PT-34 | 34 | 31/12/18 19.30 | num. Ord.-PT-5 |
| 33 | 14 | 31/1/19 4.30 | 31/1/19 4.30 | 3 | 9 | 31/1/19 4.30 | 31/1/19 4.30 | 31/1/19 4.30 | 31/1/19 4.30 | 33 | 31 | num. Ord.-PT-33 | 33 | 31/12/18 21.00 | num. Ord.-PT-5 |
| 34 | 16 | 31/1/19 6.00 | 31/1/19 6.00 | 3 | 9 | 31/1/19 6.00 | 31/1/19 6.00 | 31/1/19 6.00 | 31/1/19 6.00 | 32 | 32 | num. Ord.-PT-32 | 32 | 31/12/18 22.30 | num. Ord.-PT-6 |
| 35 | 14 | 31/1/19 7.30 | 31/1/19 7.30 | 3 | 9 | 31/1/19 7.30 | 31/1/19 7.30 | 31/1/19 7.30 | 31/1/19 7.30 | 31 | 33 | num. Ord.-PT-31 | 31 | 1/1/19 0.00 | num. Ord.-PT-6 |
| 36 | 16 | 31/1/19 9.00 | 31/1/19 9.00 | 3 | 9 | 31/1/19 9.00 | 31/1/19 9.00 | 31/1/19 9.00 | 31/1/19 9.00 | 30 | 34 | num. Ord.-PT-30 | 30 | 1/1/19 1.30 | num. Ord.-PT-6 |
| 37 | 14 | 31/1/19 10.30 | 31/1/19 10.30 | 3 | 9 | 31/1/19 10.30 | 31/1/19 10.30 | 31/1/19 10.30 | 31/1/19 10.30 | 29 | 35 | num. Ord.-PT-29 | 29 | 1/1/19 3.00 | num. Ord.-PT-6 |
| 38 | 5 | 31/1/19 12.00 | 31/1/19 12.00 | 3 | 9 | 31/1/19 12.00 | 31/1/19 12.00 | 31/1/19 12.00 | 31/1/19 12.00 | 28 | 36 | num. Ord.-PT-28 | 28 | 1/1/19 4.30 | num. Ord.-PT-6 |
| 39 | 14 | 31/1/19 13.30 | 31/1/19 13.30 | 3 | 9 | 31/1/19 13.30 | 31/1/19 13.30 | 31/1/19 13.30 | 31/1/19 13.30 | 27 | 37 | num. Ord.-PT-27 | 27 | 1/1/19 6.00 | num. Ord.-PT-6 |
| 40 | 5 | 31/1/19 15.00 | 31/1/19 15.00 | 3 | 9 | 31/1/19 15.00 | 31/1/19 15.00 | 31/1/19 15.00 | 31/1/19 15.00 | 26 | 38 | num. Ord.-PT-26 | 26 | 1/1/19 7.30 | num. Ord.-PT-7 |
| 41 | 3 | 31/1/19 16.30 | 31/1/19 16.30 | 3 | 9 | 31/1/19 16.30 | 31/1/19 16.30 | 31/1/19 16.30 | 31/1/19 16.30 | 25 | 39 | num. Ord.-PT-25 | 25 | 1/1/19 9.00 | num. Ord.-PT-7 |
| 42 | 5 | 31/1/19 18.00 | 31/1/19 18.00 | 3 | 9 | 31/1/19 18.00 | 31/1/19 18.00 | 31/1/19 18.00 | 31/1/19 18.00 | 24 | 40 | num. Ord.-PT-24 | 24 | 1/1/19 10.30 | num. Ord.-PT-7 |
| 43 | 3 | 31/1/19 19.30 | 31/1/19 19.30 | 3 | 9 | 31/1/19 19.30 | 31/1/19 19.30 | 31/1/19 19.30 | 31/1/19 19.30 | 23 | 41 | num. Ord.-PT-23 | 23 | 1/1/19 12.00 | num. Ord.-PT-7 |
| 44 | 5 | 31/1/19 21.00 | 31/1/19 21.00 | 3 | 9 | 31/1/19 21.00 | 31/1/19 21.00 | 31/1/19 21.00 | 31/1/19 21.00 | 22 | 42 | num. Ord.-PT-22 | 22 | 1/1/19 13.30 | num. Ord.-PT-7 |
| 45 | 3 | 31/1/19 22.30 | 31/1/19 22.30 | 3 | 9 | 31/1/19 22.30 | 31/1/19 22.30 | 31/1/19 22.30 | 31/1/19 22.30 | 21 | 43 | num. Ord.-PT-21 | 21 | 1/1/19 15.00 | num. Ord.-PT-7 |
| 46 | 5 | 1/2/19 0.00 | 1/2/19 0.00 | 3 | 9 | 1/2/19 0.00 | 1/2/19 0.00 | 1/2/19 0.00 | 1/2/19 0.00 | 20 | 44 | num. Ord.-PT-20 | 20 | 1/1/19 16.30 | num. Ord.-PT-8 |
| 47 | 3 | 1/2/19 1.30 | 1/2/19 1.30 | 3 | 9 | 1/2/19 1.30 | 1/2/19 1.30 | 1/2/19 1.30 | 1/2/19 1.30 | 19 | 45 | num. Ord.-PT-19 | 19 | 1/1/19 18.00 | num. Ord.-PT-8 |
| 48 | 3 | 1/2/19 3.00 | 1/2/19 3.00 | 3 | 9 | 1/2/19 3.00 | 1/2/19 3.00 | 1/2/19 3.00 | 1/2/19 3.00 | 18 | 46 | num. Ord.-PT-18 | 18 | 1/1/19 19.30 | num. Ord.-PT-8 |
| 49 | 3 | 1/2/19 4.30 | 1/2/19 4.30 | 3 | 9 | 1/2/19 4.30 | 1/2/19 4.30 | 1/2/19 4.30 | 1/2/19 4.30 | 17 | 47 | num. Ord.-PT-17 | 17 | 1/1/19 21.00 | num. Ord.-PT-8 |

*Figure A- 21: Calculations scheduling assembly line 1 part 2*

| | W | X | Y | Z | AA | AB | AD | AE | AF | AG | AH | AI | AJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | |
| 2 | FINISHING DATE | MINIMUM | STARTING DATE | contatore | contatore | Ordine-Riga-Tipologia-Progressivo pezzo | | CONTATORE | CODICE GRAFICO (46-75) | CODICE GRAFICO (1-45) | CODICE PER TABELLA | | ORE AGGIUNTE |
| 3 | 31/1/19 1.30 | 31/1/19 1.30 | 31/1/19 1.30 | 63 | 1 | num. Ord.-PT-63 | 63 | 28/12/18 0.00 | | | | 0 | 0 |
| 4 | 31/1/19 3.00 | 31/1/19 3.00 | 31/1/19 3.00 | 62 | 2 | num. Ord.-PT-62 | 62 | 28/12/18 1.30 | num. Ord.-PT-1 | | num. Ord.-PT-1 | 0,0625 | 0,0625 |
| 5 | 31/1/19 4.30 | 31/1/19 4.30 | 31/1/19 4.30 | 61 | 3 | num. Ord.-PT-61 | 61 | 28/12/18 3.00 | num. Ord.-PT-1 | | num. Ord.-PT-1 | 0,125 | 0,125 |
| 6 | 31/1/19 6.00 | 31/1/19 6.00 | 31/1/19 6.00 | 60 | 4 | num. Ord.-PT-60 | 60 | 28/12/18 4.30 | num. Ord.-PT-1 | | num. Ord.-PT-1 | 0,1875 | 0,1875 |
| 7 | 31/1/19 7.30 | 31/1/19 7.30 | 31/1/19 7.30 | 59 | 5 | num. Ord.-PT-59 | 59 | 28/12/18 6.00 | num. Ord.-PT-1 | | num. Ord.-PT-1 | 0,25 | 0,25 |
| 8 | 31/1/19 9.00 | 31/1/19 9.00 | 31/1/19 9.00 | 58 | 6 | num. Ord.-PT-58 | 58 | 28/12/18 7.30 | num. Ord.-PT-1 | | num. Ord.-PT-1 | 0,3125 | 0,3125 |
| 9 | 31/1/19 10.30 | 31/1/19 10.30 | 31/1/19 10.30 | 57 | 7 | num. Ord.-PT-57 | 57 | 28/12/18 9.00 | num. Ord.-PT-1 | | num. Ord.-PT-1 | 0,375 | 0,375 |
| 10 | 31/1/19 12.00 | 31/1/19 12.00 | 31/1/19 12.00 | 56 | 8 | num. Ord.-PT-56 | 56 | 28/12/18 10.30 | num. Ord.-PT-2 | | num. Ord.-PT-2 | 0,4375 | 0,4375 |
| 11 | 31/1/19 13.30 | 31/1/19 13.30 | 31/1/19 13.30 | 55 | 9 | num. Ord.-PT-55 | 55 | 28/12/18 12.00 | num. Ord.-PT-2 | | num. Ord.-PT-2 | 0,5 | 0,5 |
| 12 | 31/1/19 15.00 | 31/1/19 15.00 | 31/1/19 15.00 | 54 | 10 | num. Ord.-PT-54 | 54 | 28/12/18 13.30 | num. Ord.-PT-2 | | num. Ord.-PT-2 | 0,5625 | 0,5625 |
| 13 | 31/1/19 16.30 | 31/1/19 16.30 | 31/1/19 16.30 | 53 | 11 | num. Ord.-PT-53 | 53 | 28/12/18 15.00 | num. Ord.-PT-2 | | num. Ord.-PT-2 | 0,625 | 0,625 |
| 14 | 31/1/19 18.00 | 31/1/19 18.00 | 31/1/19 18.00 | 52 | 12 | num. Ord.-PT-52 | 52 | 28/12/18 16.30 | num. Ord.-PT-2 | | num. Ord.-PT-2 | 0,6875 | 0,6875 |
| 15 | 31/1/19 19.30 | 31/1/19 19.30 | 31/1/19 19.30 | 51 | 13 | num. Ord.-PT-51 | 51 | 28/12/18 18.00 | num. Ord.-PT-2 | | num. Ord.-PT-2 | 0,75 | 0,75 |
| 16 | 31/1/19 21.00 | 31/1/19 21.00 | 31/1/19 21.00 | 50 | 14 | num. Ord.-PT-50 | 50 | 28/12/18 19.30 | num. Ord.-PT-3 | | num. Ord.-PT-3 | 0,8125 | 0,8125 |
| 17 | 31/1/19 22.30 | 31/1/19 22.30 | 31/1/19 22.30 | 49 | 15 | num. Ord.-PT-49 | 49 | 28/12/18 21.00 | num. Ord.-PT-3 | | num. Ord.-PT-3 | 0,875 | 0,875 |
| 18 | 1/2/19 0.00 | 1/2/19 0.00 | 1/2/19 0.00 | 48 | 16 | num. Ord.-PT-48 | 48 | 28/12/18 22.30 | num. Ord.-PT-3 | | num. Ord.-PT-3 | 0,9375 | 0,9375 |
| 19 | 1/2/19 1.30 | 1/2/19 1.30 | 1/2/19 1.30 | 47 | 17 | num. Ord.-PT-47 | 47 | 31/12/18 0.00 | num. Ord.-PT-3 | | num. Ord.-PT-3 | 1 | 0 |
| 20 | 1/2/19 3.00 | 1/2/19 3.00 | 1/2/19 3.00 | 46 | 18 | num. Ord.-PT-46 | 46 | 31/12/18 1.30 | num. Ord.-PT-3 | | num. Ord.-PT-3 | 1,0625 | 0,0625 |
| 21 | 1/2/19 4.30 | 1/2/19 4.30 | 1/2/19 4.30 | 45 | 19 | num. Ord.-PT-45 | 45 | 31/12/18 3.00 | num. Ord.-PT-3 | | num. Ord.-PT-3 | 1,125 | 0,125 |
| 22 | 1/2/19 6.00 | 1/2/19 6.00 | 1/2/19 6.00 | 44 | 20 | num. Ord.-PT-44 | 44 | 31/12/18 4.30 | num. Ord.-PT-4 | | num. Ord.-PT-4 | 1,1875 | 0,1875 |
| 23 | 1/2/19 7.30 | 1/2/19 7.30 | 1/2/19 7.30 | 43 | 21 | num. Ord.-PT-43 | 43 | 31/12/18 6.00 | num. Ord.-PT-4 | | num. Ord.-PT-4 | 1,25 | 0,25 |
| 24 | 1/2/19 9.00 | 1/2/19 9.00 | 1/2/19 9.00 | 42 | 22 | num. Ord.-PT-42 | 42 | 31/12/18 7.30 | num. Ord.-PT-4 | | num. Ord.-PT-4 | 1,3125 | 0,3125 |
| 25 | 1/2/19 10.30 | 1/2/19 10.30 | 1/2/19 10.30 | 41 | 23 | num. Ord.-PT-41 | 41 | 31/12/18 9.00 | num. Ord.-PT-4 | | num. Ord.-PT-4 | 1,375 | 0,375 |
| 26 | 1/2/19 12.00 | 1/2/19 12.00 | 1/2/19 12.00 | 40 | 24 | num. Ord.-PT-40 | 40 | 31/12/18 10.30 | num. Ord.-PT-4 | | num. Ord.-PT-4 | 1,4375 | 0,4375 |
| 27 | 1/2/19 13.30 | 1/2/19 13.30 | 1/2/19 13.30 | 39 | 25 | num. Ord.-PT-39 | 39 | 31/12/18 12.00 | num. Ord.-PT-4 | | num. Ord.-PT-4 | 1,5 | 0,5 |
| 28 | 1/2/19 15.00 | 1/2/19 15.00 | 1/2/19 15.00 | 38 | 26 | num. Ord.-PT-38 | 38 | 31/12/18 13.30 | num. Ord.-PT-5 | | num. Ord.-PT-5 | 1,5625 | 0,5625 |
| 29 | 1/2/19 16.30 | 1/2/19 16.30 | 1/2/19 16.30 | 37 | 27 | num. Ord.-PT-37 | 37 | 31/12/18 15.00 | num. Ord.-PT-5 | | num. Ord.-PT-5 | 1,625 | 0,625 |
| 30 | 1/2/19 18.00 | 1/2/19 18.00 | 1/2/19 18.00 | 36 | 28 | num. Ord.-PT-36 | 36 | 31/12/18 16.30 | num. Ord.-PT-5 | | num. Ord.-PT-5 | 1,6875 | 0,6875 |
| 31 | 31/1/19 1.30 | 31/1/19 1.30 | 31/1/19 1.30 | 35 | 29 | num. Ord.-PT-35 | 35 | 31/12/18 18.00 | num. Ord.-PT-5 | | num. Ord.-PT-5 | 1,75 | 0,75 |
| 32 | 31/1/19 3.00 | 31/1/19 3.00 | 31/1/19 3.00 | 34 | 30 | num. Ord.-PT-34 | 34 | 31/12/18 19.30 | num. Ord.-PT-5 | | num. Ord.-PT-5 | 1,8125 | 0,8125 |
| 33 | 31/1/19 4.30 | 31/1/19 4.30 | 31/1/19 4.30 | 33 | 31 | num. Ord.-PT-33 | 33 | 31/12/18 21.00 | num. Ord.-PT-5 | | num. Ord.-PT-5 | 1,875 | 0,875 |
| 34 | 31/1/19 6.00 | 31/1/19 6.00 | 31/1/19 6.00 | 32 | 32 | num. Ord.-PT-32 | 32 | 31/12/18 22.30 | num. Ord.-PT-6 | | num. Ord.-PT-6 | 1,9375 | 0,9375 |
| 35 | 31/1/19 7.30 | 31/1/19 7.30 | 31/1/19 7.30 | 31 | 33 | num. Ord.-PT-31 | 31 | 1/1/19 0.00 | num. Ord.-PT-6 | | num. Ord.-PT-6 | 2 | 0 |
| 36 | 31/1/19 9.00 | 31/1/19 9.00 | 31/1/19 9.00 | 30 | 34 | num. Ord.-PT-30 | 30 | 1/1/19 1.30 | num. Ord.-PT-6 | | num. Ord.-PT-6 | 2,0625 | 0,0625 |
| 37 | 31/1/19 10.30 | 31/1/19 10.30 | 31/1/19 10.30 | 29 | 35 | num. Ord.-PT-29 | 29 | 1/1/19 3.00 | num. Ord.-PT-6 | | num. Ord.-PT-6 | 2,125 | 0,125 |
| 38 | 31/1/19 12.00 | 31/1/19 12.00 | 31/1/19 12.00 | 28 | 36 | num. Ord.-PT-28 | 28 | 1/1/19 4.30 | num. Ord.-PT-6 | | num. Ord.-PT-6 | 2,1875 | 0,1875 |
| 39 | 31/1/19 13.30 | 31/1/19 13.30 | 31/1/19 13.30 | 27 | 37 | num. Ord.-PT-27 | 27 | 1/1/19 6.00 | num. Ord.-PT-6 | | num. Ord.-PT-6 | 2,25 | 0,25 |
| 40 | 31/1/19 15.00 | 31/1/19 15.00 | 31/1/19 15.00 | 26 | 38 | num. Ord.-PT-26 | 26 | 1/1/19 7.30 | num. Ord.-PT-7 | | num. Ord.-PT-7 | 2,3125 | 0,3125 |
| 41 | 31/1/19 16.30 | 31/1/19 16.30 | 31/1/19 16.30 | 25 | 39 | num. Ord.-PT-25 | 25 | 1/1/19 9.00 | num. Ord.-PT-7 | | num. Ord.-PT-7 | 2,375 | 0,375 |
| 42 | 31/1/19 18.00 | 31/1/19 18.00 | 31/1/19 18.00 | 24 | 40 | num. Ord.-PT-24 | 24 | 1/1/19 10.30 | num. Ord.-PT-7 | | num. Ord.-PT-7 | 2,4375 | 0,4375 |
| 43 | 31/1/19 19.30 | 31/1/19 19.30 | 31/1/19 19.30 | 23 | 41 | num. Ord.-PT-23 | 23 | 1/1/19 12.00 | num. Ord.-PT-7 | | num. Ord.-PT-7 | 2,5 | 0,5 |
| 44 | 31/1/19 21.00 | 31/1/19 21.00 | 31/1/19 21.00 | 22 | 42 | num. Ord.-PT-22 | 22 | 1/1/19 13.30 | num. Ord.-PT-7 | | num. Ord.-PT-7 | 2,5625 | 0,5625 |
| 45 | 31/1/19 22.30 | 31/1/19 22.30 | 31/1/19 22.30 | 21 | 43 | num. Ord.-PT-21 | 21 | 1/1/19 15.00 | num. Ord.-PT-7 | | num. Ord.-PT-7 | 2,625 | 0,625 |
| 46 | 1/2/19 0.00 | 1/2/19 0.00 | 1/2/19 0.00 | 20 | 44 | num. Ord.-PT-20 | 20 | 1/1/19 16.30 | num. Ord.-PT-8 | | num. Ord.-PT-8 | 2,6875 | 0,6875 |
| 47 | 1/2/19 1.30 | 1/2/19 1.30 | 1/2/19 1.30 | 19 | 45 | num. Ord.-PT-19 | 19 | 1/1/19 18.00 | num. Ord.-PT-8 | | num. Ord.-PT-8 | 2,75 | 0,75 |
| 48 | 1/2/19 3.00 | 1/2/19 3.00 | 1/2/19 3.00 | 18 | 46 | num. Ord.-PT-18 | 18 | 1/1/19 19.30 | num. Ord.-PT-8 | | num. Ord.-PT-8 | 2,8125 | 0,8125 |
| 49 | 1/2/19 4.30 | 1/2/19 4.30 | 1/2/19 4.30 | 17 | 47 | num. Ord.-PT-17 | 17 | 1/1/19 21.00 | num. Ord.-PT-8 | | num. Ord.-PT-8 | 2,875 | 0,875 |

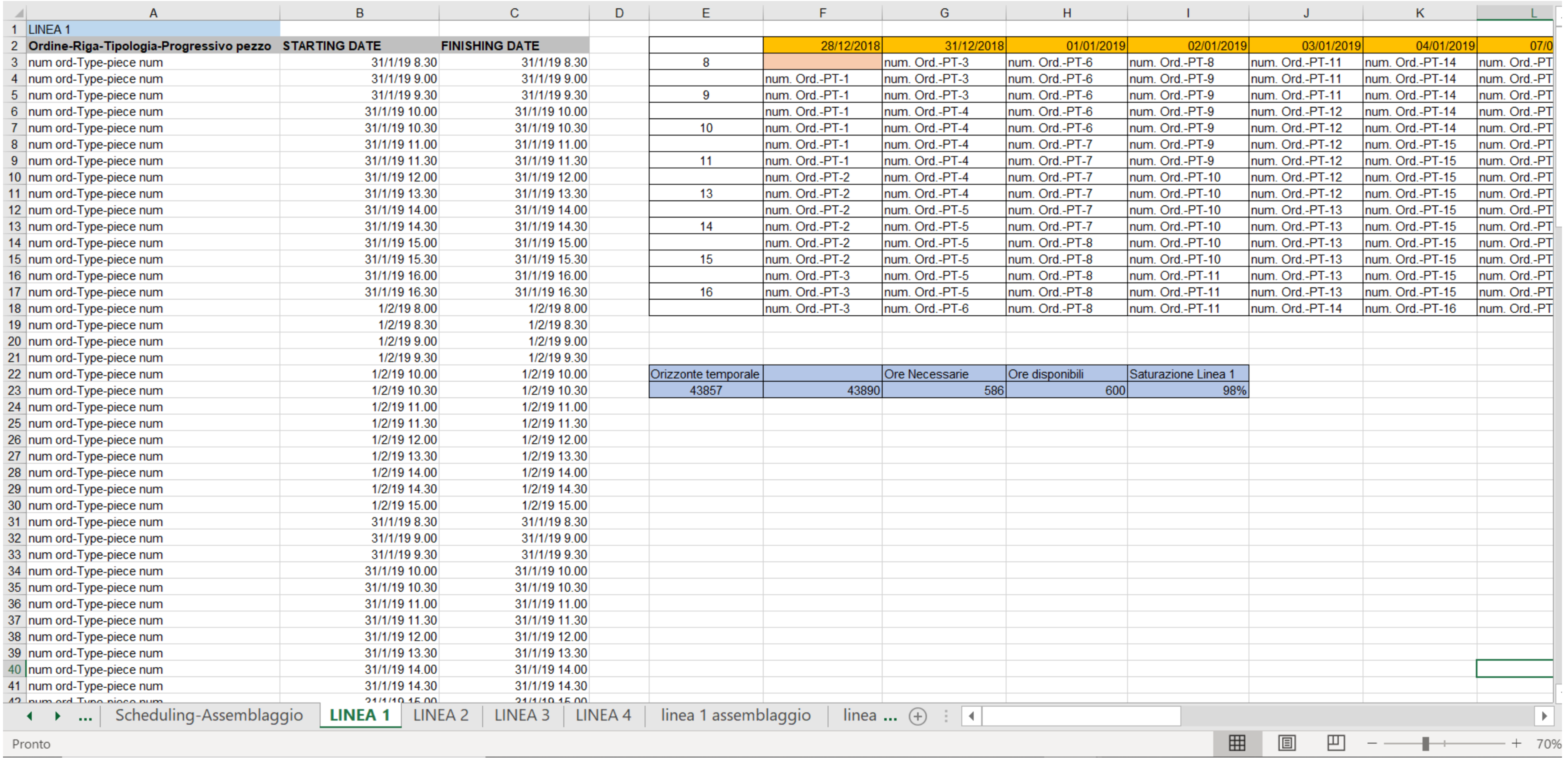
Scheduling-Assemblaggio | LINEA 1 | LINEA 2 | LINEA 3 | LINEA 4 | linea 1 assemblaggio | linea ...

Pronto — Conteggio: 581

*Figure A- 22: Calculations scheduling assembly line 1 part 3*

| | AY | AZ | BA | BB | BC | BD | BE | BF | BG | BH | BI | BJ | BK | BL | BM | BN | BO | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 10/02/2020 | 11/02/2020 | 12/02/2020 | 13/02/2020 | 14/02/2020 | 17/02/2020 | 18/02/2020 | 19/02/2020 | 20/02/2020 | 21/02/2020 | 24/02/2020 | 25/02/2020 | 26/02/2020 | 27/02/2020 | 28/02/2020 | 02/03/2020 | 03/03/2020 | |
| 6 | num. Ord.-PT-25 | num. Ord.-PT-28 | num. Ord.-PT-30 | num. Ord.-PT-33 | num. Ord.-PT-36 | num. Ord.-PT-38 | num. Ord.-PT-41 | num. Ord.-PT-44 | num. Ord.-PT-46 | num. Ord.-PT-49 | num. Ord.-PT-52 | num. Ord.-PT-54 | num. Ord.-PT-57 | num. Ord.-PT-60 | num. Ord.-PT-62 | FINITO | FINITO | FINITO |
| 7 | num. Ord.-PT-25 | num. Ord.-PT-28 | num. Ord.-PT-31 | num. Ord.-PT-33 | num. Ord.-PT-36 | num. Ord.-PT-39 | num. Ord.-PT-41 | num. Ord.-PT-44 | num. Ord.-PT-47 | num. Ord.-PT-49 | num. Ord.-PT-52 | num. Ord.-PT-55 | num. Ord.-PT-57 | num. Ord.-PT-60 | num. Ord.-PT-63 | FINITO | FINITO | FINITO |
| 8 | num. Ord.-PT-25 | num. Ord.-PT-28 | num. Ord.-PT-31 | num. Ord.-PT-33 | num. Ord.-PT-36 | num. Ord.-PT-39 | num. Ord.-PT-41 | num. Ord.-PT-44 | num. Ord.-PT-47 | num. Ord.-PT-49 | num. Ord.-PT-52 | num. Ord.-PT-55 | num. Ord.-PT-57 | num. Ord.-PT-60 | num. Ord.-PT-63 | FINITO | FINITO | FINITO |
| 9 | num. Ord.-PT-26 | num. Ord.-PT-28 | num. Ord.-PT-31 | num. Ord.-PT-34 | num. Ord.-PT-36 | num. Ord.-PT-39 | num. Ord.-PT-42 | num. Ord.-PT-44 | num. Ord.-PT-47 | num. Ord.-PT-50 | num. Ord.-PT-52 | num. Ord.-PT-55 | num. Ord.-PT-58 | num. Ord.-PT-60 | num. Ord.-PT-63 | FINITO | FINITO | FINITO |
| 10 | num. Ord.-PT-26 | num. Ord.-PT-28 | num. Ord.-PT-31 | num. Ord.-PT-34 | num. Ord.-PT-36 | num. Ord.-PT-39 | num. Ord.-PT-42 | num. Ord.-PT-44 | num. Ord.-PT-47 | num. Ord.-PT-50 | num. Ord.-PT-52 | num. Ord.-PT-55 | num. Ord.-PT-58 | num. Ord.-PT-60 | num. Ord.-PT-63 | FINITO | FINITO | FINITO |
| 11 | num. Ord.-PT-26 | num. Ord.-PT-29 | num. Ord.-PT-31 | num. Ord.-PT-34 | num. Ord.-PT-37 | num. Ord.-PT-39 | num. Ord.-PT-42 | num. Ord.-PT-45 | num. Ord.-PT-47 | num. Ord.-PT-50 | num. Ord.-PT-53 | num. Ord.-PT-55 | num. Ord.-PT-58 | num. Ord.-PT-61 | num. Ord.-PT-63 | FINITO | FINITO | FINITO |
| 12 | num. Ord.-PT-26 | num. Ord.-PT-29 | num. Ord.-PT-31 | num. Ord.-PT-34 | num. Ord.-PT-37 | num. Ord.-PT-39 | num. Ord.-PT-42 | num. Ord.-PT-45 | num. Ord.-PT-47 | num. Ord.-PT-50 | num. Ord.-PT-53 | num. Ord.-PT-55 | num. Ord.-PT-58 | num. Ord.-PT-61 | num. Ord.-PT-63 | FINITO | FINITO | FINITO |
| 13 | num. Ord.-PT-26 | num. Ord.-PT-29 | num. Ord.-PT-32 | num. Ord.-PT-34 | num. Ord.-PT-37 | num. Ord.-PT-40 | num. Ord.-PT-42 | num. Ord.-PT-45 | num. Ord.-PT-48 | num. Ord.-PT-50 | num. Ord.-PT-53 | num. Ord.-PT-56 | num. Ord.-PT-58 | num. Ord.-PT-61 | | FINITO | FINITO | FINITO |
| 14 | num. Ord.-PT-26 | num. Ord.-PT-29 | num. Ord.-PT-32 | num. Ord.-PT-34 | num. Ord.-PT-37 | num. Ord.-PT-40 | num. Ord.-PT-42 | num. Ord.-PT-45 | num. Ord.-PT-48 | num. Ord.-PT-50 | num. Ord.-PT-53 | num. Ord.-PT-56 | num. Ord.-PT-58 | num. Ord.-PT-61 | | FINITO | FINITO | FINITO |
| 15 | num. Ord.-PT-27 | num. Ord.-PT-29 | num. Ord.-PT-32 | num. Ord.-PT-35 | num. Ord.-PT-37 | num. Ord.-PT-40 | num. Ord.-PT-43 | num. Ord.-PT-45 | num. Ord.-PT-48 | num. Ord.-PT-51 | num. Ord.-PT-53 | num. Ord.-PT-56 | num. Ord.-PT-59 | num. Ord.-PT-61 | | FINITO | FINITO | FINITO |
| 16 | num. Ord.-PT-27 | num. Ord.-PT-29 | num. Ord.-PT-32 | num. Ord.-PT-35 | num. Ord.-PT-37 | num. Ord.-PT-40 | num. Ord.-PT-43 | num. Ord.-PT-45 | num. Ord.-PT-48 | num. Ord.-PT-51 | num. Ord.-PT-53 | num. Ord.-PT-56 | num. Ord.-PT-59 | num. Ord.-PT-61 | | FINITO | FINITO | FINITO |
| 17 | num. Ord.-PT-27 | num. Ord.-PT-30 | num. Ord.-PT-32 | num. Ord.-PT-35 | num. Ord.-PT-38 | num. Ord.-PT-40 | num. Ord.-PT-43 | num. Ord.-PT-46 | num. Ord.-PT-48 | num. Ord.-PT-51 | num. Ord.-PT-54 | num. Ord.-PT-56 | num. Ord.-PT-59 | num. Ord.-PT-62 | | FINITO | FINITO | FINITO |
| 18 | num. Ord.-PT-27 | num. Ord.-PT-30 | num. Ord.-PT-32 | num. Ord.-PT-35 | num. Ord.-PT-38 | num. Ord.-PT-40 | num. Ord.-PT-43 | num. Ord.-PT-46 | num. Ord.-PT-48 | num. Ord.-PT-51 | num. Ord.-PT-54 | num. Ord.-PT-56 | num. Ord.-PT-59 | num. Ord.-PT-62 | | FINITO | FINITO | FINITO |
| 19 | num. Ord.-PT-27 | num. Ord.-PT-30 | num. Ord.-PT-33 | num. Ord.-PT-35 | num. Ord.-PT-38 | num. Ord.-PT-41 | num. Ord.-PT-43 | num. Ord.-PT-46 | num. Ord.-PT-49 | num. Ord.-PT-51 | num. Ord.-PT-54 | num. Ord.-PT-57 | num. Ord.-PT-59 | num. Ord.-PT-62 | FINITO | FINITO | FINITO | FINITO |
| 20 | num. Ord.-PT-27 | num. Ord.-PT-30 | num. Ord.-PT-33 | num. Ord.-PT-35 | num. Ord.-PT-38 | num. Ord.-PT-41 | num. Ord.-PT-43 | num. Ord.-PT-46 | num. Ord.-PT-49 | num. Ord.-PT-51 | num. Ord.-PT-54 | num. Ord.-PT-57 | num. Ord.-PT-59 | num. Ord.-PT-62 | FINITO | FINITO | FINITO | FINITO |
| 21 | num. Ord.-PT-28 | num. Ord.-PT-30 | num. Ord.-PT-33 | num. Ord.-PT-36 | num. Ord.-PT-38 | num. Ord.-PT-41 | num. Ord.-PT-44 | num. Ord.-PT-46 | num. Ord.-PT-49 | num. Ord.-PT-52 | num. Ord.-PT-54 | num. Ord.-PT-57 | num. Ord.-PT-60 | num. Ord.-PT-62 | FINITO | FINITO | FINITO | FINITO |
| 22 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | |

*Figure A- 23: Visual scheduling line 1*



| | A | B | C |
|---|---|---|---|
| 1 | LINEA 1 | | |
| 2 | **Ordine-Riga-Tipologia-Progressivo pezzo** | **STARTING DATE** | **FINISHING DATE** |
| 3 | num ord-Type-piece num | 31/1/19 8.30 | 31/1/19 8.30 |
| 4 | num ord-Type-piece num | 31/1/19 9.00 | 31/1/19 9.00 |
| 5 | num ord-Type-piece num | 31/1/19 9.30 | 31/1/19 9.30 |
| 6 | num ord-Type-piece num | 31/1/19 10.00 | 31/1/19 10.00 |
| 7 | num ord-Type-piece num | 31/1/19 10.30 | 31/1/19 10.30 |
| 8 | num ord-Type-piece num | 31/1/19 11.00 | 31/1/19 11.00 |
| 9 | num ord-Type-piece num | 31/1/19 11.30 | 31/1/19 11.30 |
| 10 | num ord-Type-piece num | 31/1/19 12.00 | 31/1/19 12.00 |
| 11 | num ord-Type-piece num | 31/1/19 13.30 | 31/1/19 13.30 |
| 12 | num ord-Type-piece num | 31/1/19 14.00 | 31/1/19 14.00 |
| 13 | num ord-Type-piece num | 31/1/19 14.30 | 31/1/19 14.30 |
| 14 | num ord-Type-piece num | 31/1/19 15.00 | 31/1/19 15.00 |
| 15 | num ord-Type-piece num | 31/1/19 15.30 | 31/1/19 15.30 |
| 16 | num ord-Type-piece num | 31/1/19 16.00 | 31/1/19 16.00 |
| 17 | num ord-Type-piece num | 31/1/19 16.30 | 31/1/19 16.30 |
| 18 | num ord-Type-piece num | 1/2/19 8.00 | 1/2/19 8.00 |
| 19 | num ord-Type-piece num | 1/2/19 8.30 | 1/2/19 8.30 |
| 20 | num ord-Type-piece num | 1/2/19 9.00 | 1/2/19 9.00 |
| 21 | num ord-Type-piece num | 1/2/19 9.30 | 1/2/19 9.30 |
| 22 | num ord-Type-piece num | 1/2/19 10.00 | 1/2/19 10.00 |
| 23 | num ord-Type-piece num | 1/2/19 10.30 | 1/2/19 10.30 |
| 24 | num ord-Type-piece num | 1/2/19 11.00 | 1/2/19 11.00 |
| 25 | num ord-Type-piece num | 1/2/19 11.30 | 1/2/19 11.30 |
| 26 | num ord-Type-piece num | 1/2/19 12.00 | 1/2/19 12.00 |
| 27 | num ord-Type-piece num | 1/2/19 13.30 | 1/2/19 13.30 |
| 28 | num ord-Type-piece num | 1/2/19 14.00 | 1/2/19 14.00 |
| 29 | num ord-Type-piece num | 1/2/19 14.30 | 1/2/19 14.30 |
| 30 | num ord-Type-piece num | 1/2/19 15.00 | 1/2/19 15.00 |
| 31 | num ord-Type-piece num | 31/1/19 8.30 | 31/1/19 8.30 |
| 32 | num ord-Type-piece num | 31/1/19 9.00 | 31/1/19 9.00 |
| 33 | num ord-Type-piece num | 31/1/19 9.30 | 31/1/19 9.30 |
| 34 | num ord-Type-piece num | 31/1/19 10.00 | 31/1/19 10.00 |
| 35 | num ord-Type-piece num | 31/1/19 10.30 | 31/1/19 10.30 |
| 36 | num ord-Type-piece num | 31/1/19 11.00 | 31/1/19 11.00 |
| 37 | num ord-Type-piece num | 31/1/19 11.30 | 31/1/19 11.30 |
| 38 | num ord-Type-piece num | 31/1/19 12.00 | 31/1/19 12.00 |
| 39 | num ord-Type-piece num | 31/1/19 13.30 | 31/1/19 13.30 |
| 40 | num ord-Type-piece num | 31/1/19 14.00 | 31/1/19 14.00 |
| 41 | num ord-Type-piece num | 31/1/19 14.30 | 31/1/19 14.30 |

| E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|
| | 28/12/2018 | 31/12/2018 | 01/01/2019 | 02/01/2019 | 03/01/2019 | 04/01/2019 | 07/0 |
| 8 | | num. Ord.-PT-3 | num. Ord.-PT-6 | num. Ord.-PT-8 | num. Ord.-PT-11 | num. Ord.-PT-14 | num. Ord.-PT |
| | num. Ord.-PT-1 | num. Ord.-PT-3 | num. Ord.-PT-6 | num. Ord.-PT-9 | num. Ord.-PT-11 | num. Ord.-PT-14 | num. Ord.-PT |
| 9 | num. Ord.-PT-1 | num. Ord.-PT-3 | num. Ord.-PT-6 | num. Ord.-PT-9 | num. Ord.-PT-11 | num. Ord.-PT-14 | num. Ord.-PT |
| | num. Ord.-PT-1 | num. Ord.-PT-4 | num. Ord.-PT-6 | num. Ord.-PT-9 | num. Ord.-PT-12 | num. Ord.-PT-14 | num. Ord.-PT |
| 10 | num. Ord.-PT-1 | num. Ord.-PT-4 | num. Ord.-PT-6 | num. Ord.-PT-9 | num. Ord.-PT-12 | num. Ord.-PT-14 | num. Ord.-PT |
| | num. Ord.-PT-1 | num. Ord.-PT-4 | num. Ord.-PT-7 | num. Ord.-PT-9 | num. Ord.-PT-12 | num. Ord.-PT-15 | num. Ord.-PT |
| 11 | num. Ord.-PT-1 | num. Ord.-PT-4 | num. Ord.-PT-7 | num. Ord.-PT-9 | num. Ord.-PT-12 | num. Ord.-PT-15 | num. Ord.-PT |
| | num. Ord.-PT-2 | num. Ord.-PT-4 | num. Ord.-PT-7 | num. Ord.-PT-10 | num. Ord.-PT-12 | num. Ord.-PT-15 | num. Ord.-PT |
| 13 | num. Ord.-PT-2 | num. Ord.-PT-4 | num. Ord.-PT-7 | num. Ord.-PT-10 | num. Ord.-PT-12 | num. Ord.-PT-15 | num. Ord.-PT |
| | num. Ord.-PT-2 | num. Ord.-PT-5 | num. Ord.-PT-7 | num. Ord.-PT-10 | num. Ord.-PT-13 | num. Ord.-PT-15 | num. Ord.-PT |
| 14 | num. Ord.-PT-2 | num. Ord.-PT-5 | num. Ord.-PT-7 | num. Ord.-PT-10 | num. Ord.-PT-13 | num. Ord.-PT-15 | num. Ord.-PT |
| | num. Ord.-PT-2 | num. Ord.-PT-5 | num. Ord.-PT-8 | num. Ord.-PT-10 | num. Ord.-PT-13 | num. Ord.-PT-15 | num. Ord.-PT |
| 15 | num. Ord.-PT-2 | num. Ord.-PT-5 | num. Ord.-PT-8 | num. Ord.-PT-10 | num. Ord.-PT-13 | num. Ord.-PT-15 | num. Ord.-PT |
| | num. Ord.-PT-3 | num. Ord.-PT-5 | num. Ord.-PT-8 | num. Ord.-PT-11 | num. Ord.-PT-13 | num. Ord.-PT-15 | num. Ord.-PT |
| 16 | num. Ord.-PT-3 | num. Ord.-PT-5 | num. Ord.-PT-8 | num. Ord.-PT-11 | num. Ord.-PT-13 | num. Ord.-PT-15 | num. Ord.-PT |
| | num. Ord.-PT-3 | num. Ord.-PT-6 | num. Ord.-PT-8 | num. Ord.-PT-11 | num. Ord.-PT-14 | num. Ord.-PT-16 | num. Ord.-PT |

| Orizzonte temporale | | Ore Necessarie | Ore disponibili | Saturazione Linea 1 |
|---|---|---|---|---|
| 43857 | 43890 | 586 | 600 | 98% |



*Figure A- 24: Output scheduling line 1*

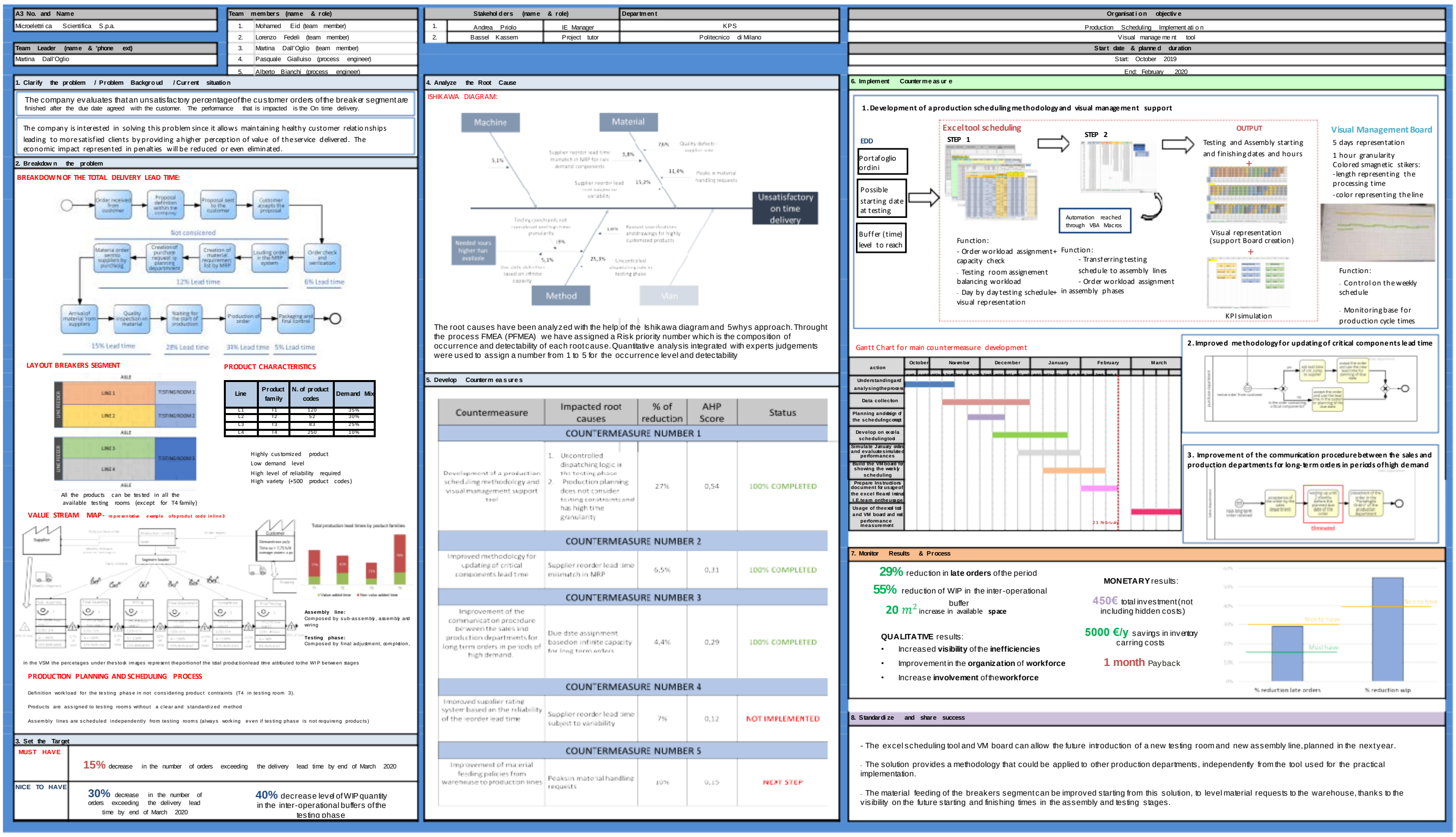


*Figure A- 25: A3 Microelettrica Scientifica*

| Root cause category | step 1 | step 2 | step 3 |
|---|---|---|---|
| **Material** | Components unavailability delays order's production start | Quality conformance issue detected in quality control phase | Suppliers' quality defects |
| | | Actual supplier reorder lead times higher than expected | Supplier reorder lead time mismatch in MRP for rare demand components |
| | | | Supplier reorder lead time subject to variability |
| | | High material picking times in warehouse during demand peaks | Peaks in material handling requests |
| **Manpower** | | | |
| **Machine** | Unreliable availability of components in MRP | Material software misalignment: MRP and WMS | |
| **Method** | Needed hours higher than available hours for testing rooms | Due date assignment based on infinite capacity for long-term orders | |
| | | Production planning does not consider testing constraints and has high time granularity | |
| | Uncontrolled dispatching rule in testing phase | | |
| | Waiting for the revised specifications and drawings for highly customized products | | |

*Figure A- 26: Root Causes*

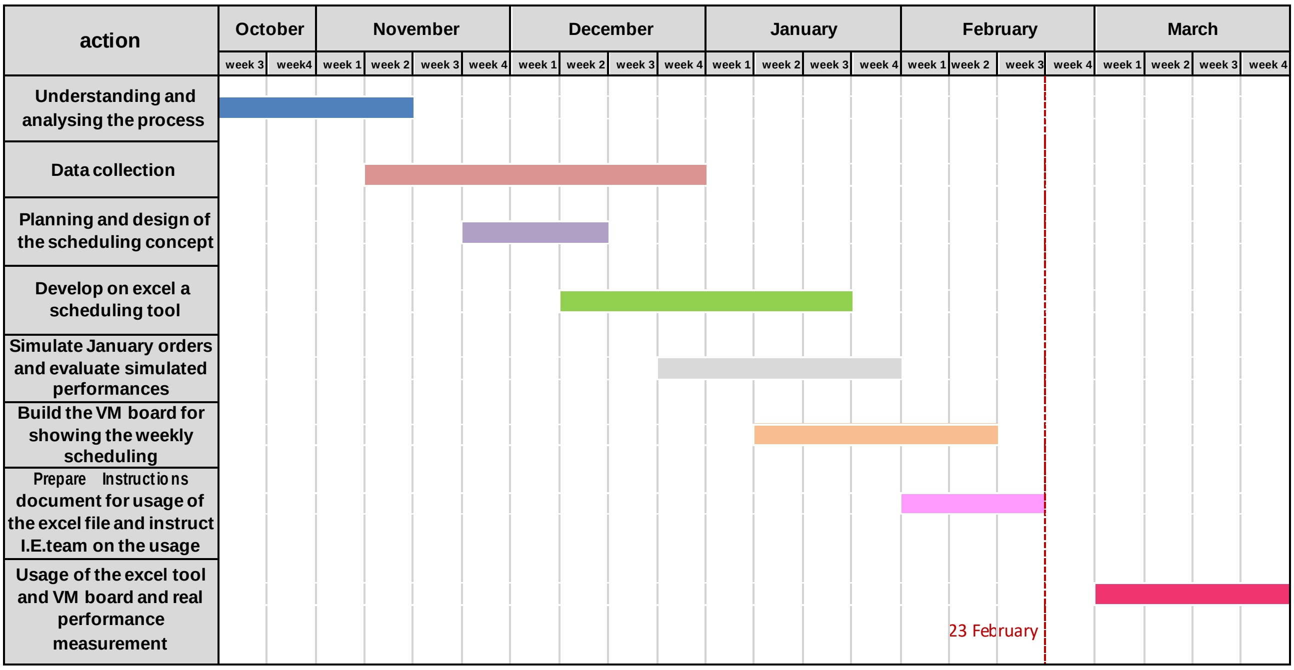



*Figure A- 27: GANT chart*

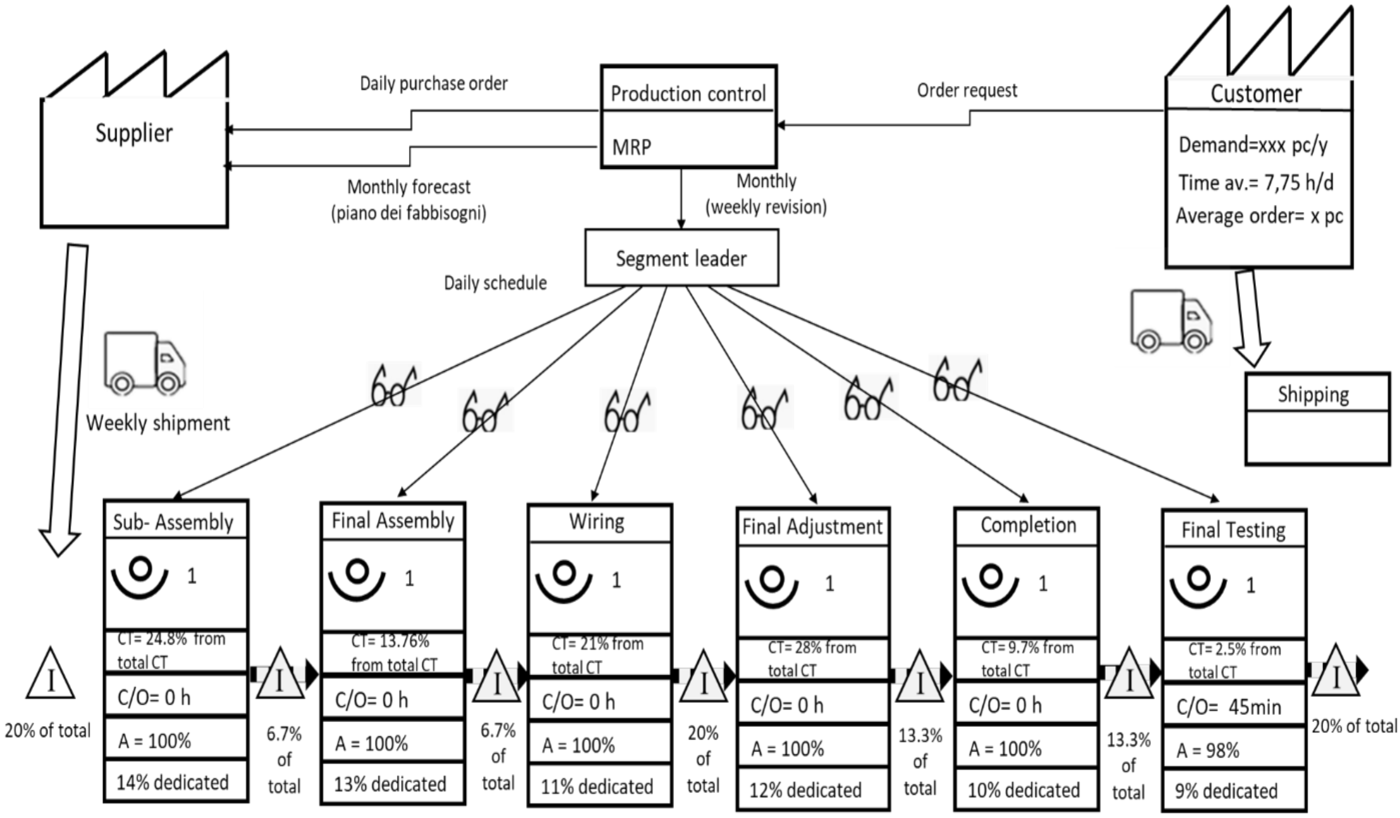



*Figure A- 28: Value Stream map*

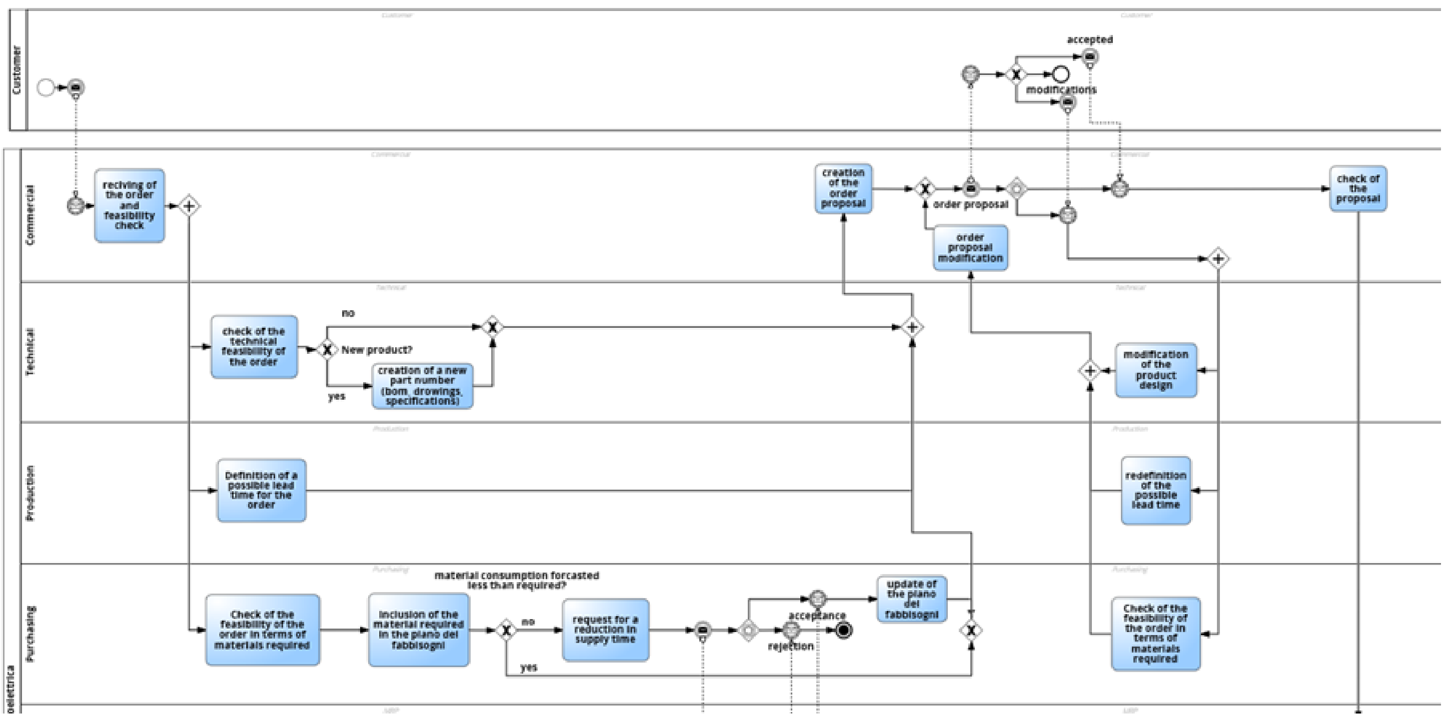



*Figure A- 29: Order processing part 1*

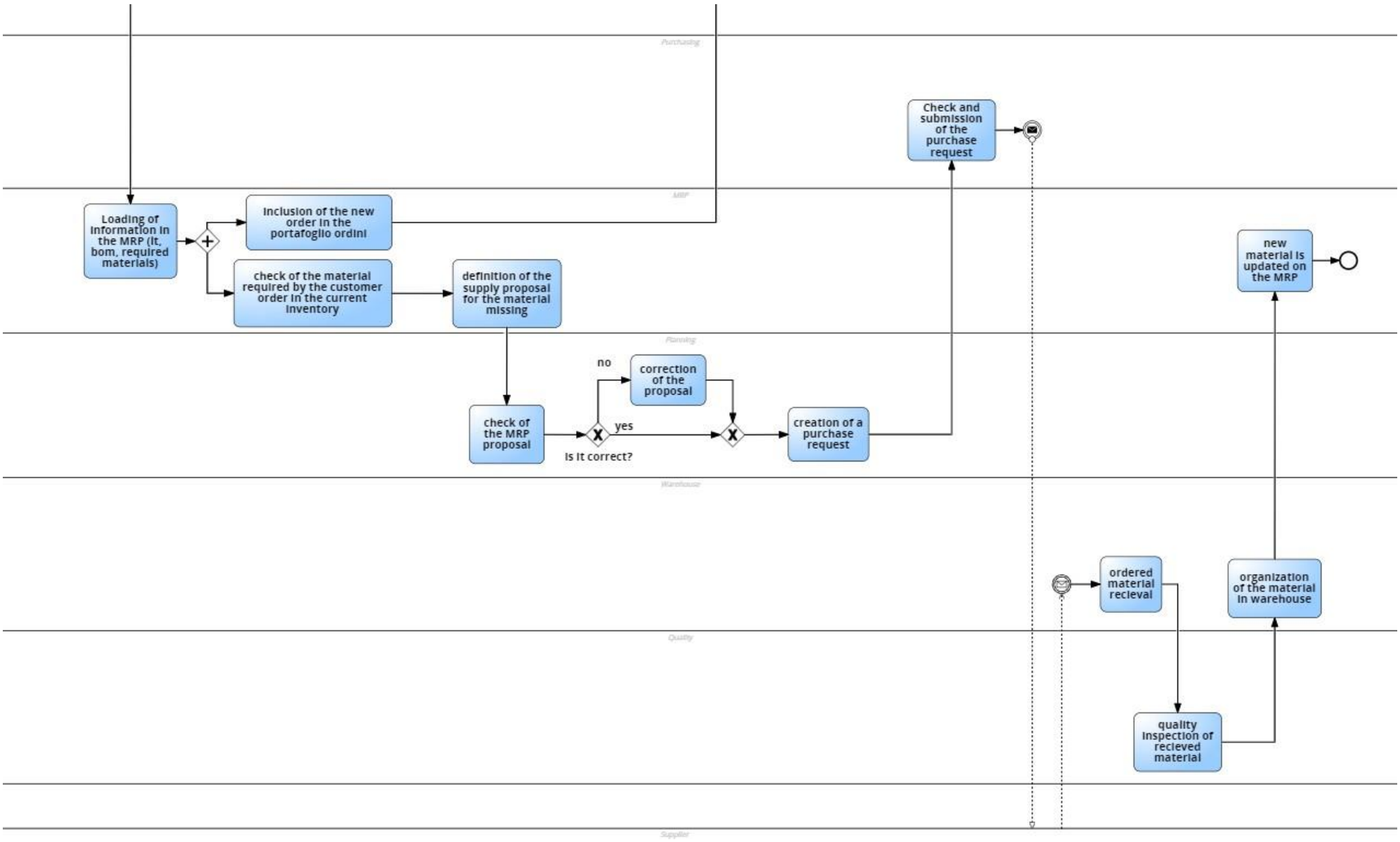



*Figure A- 30: Order processing part 2*

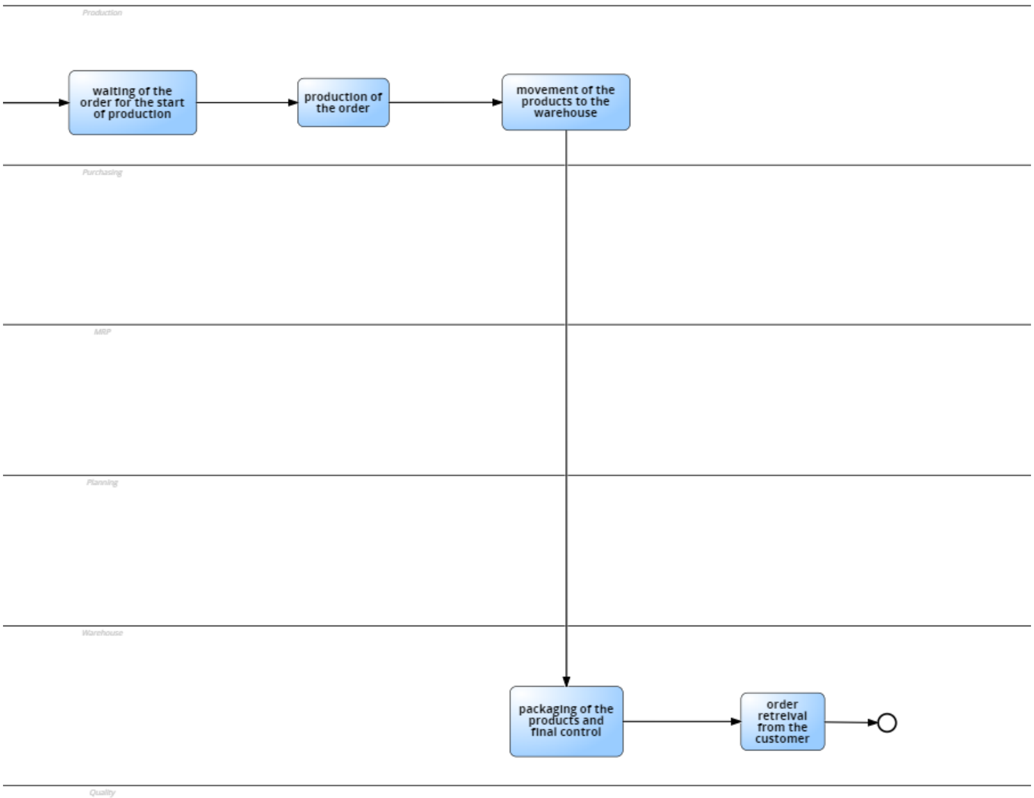
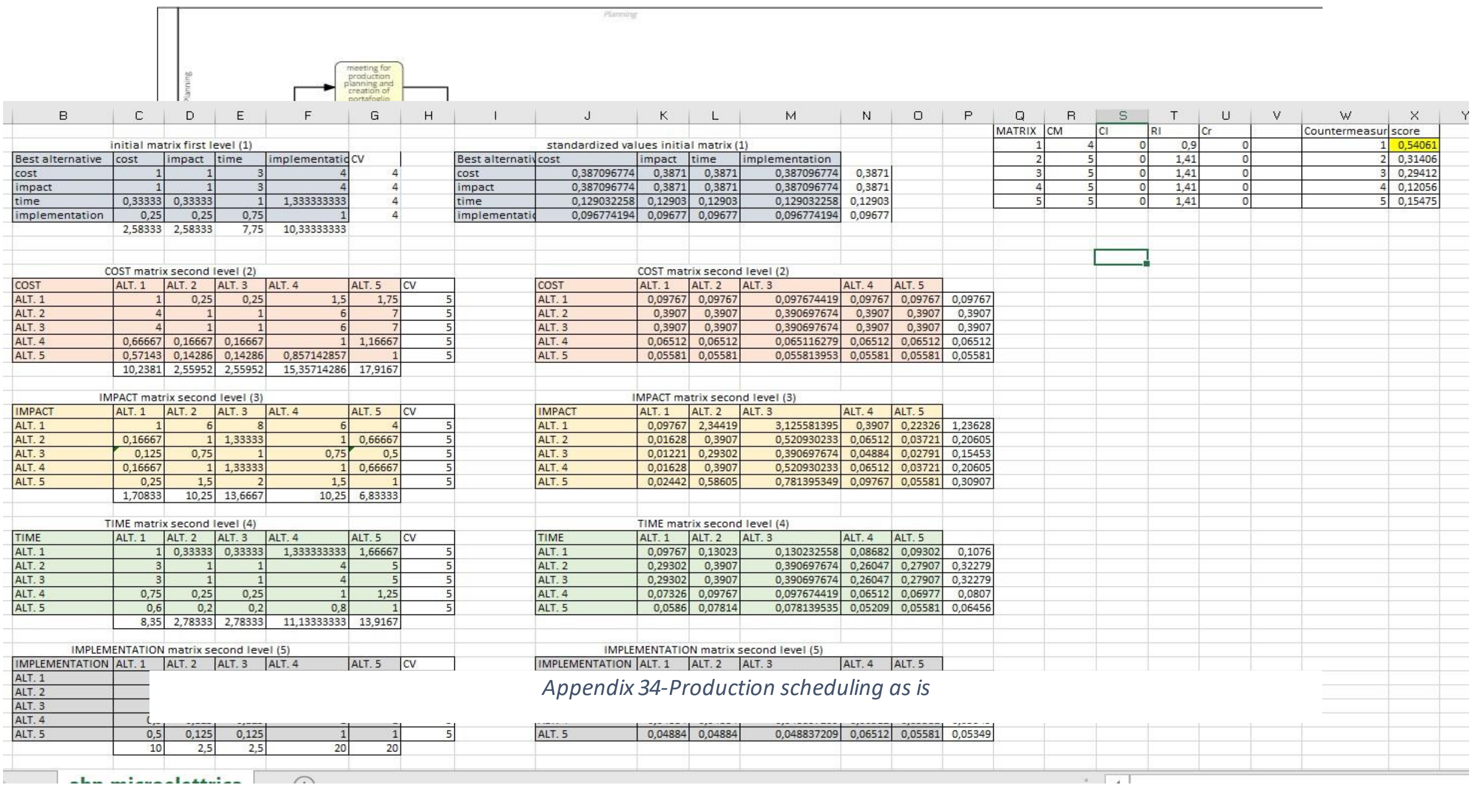



*Figure A- 31: Order processing part 3*




initial matrix first level (1)

| Best alternative | cost | impact | time | implementatio | CV |
|---|---|---|---|---|---|
| cost | 1 | 1 | 3 | 4 | 4 |
| impact | 1 | 1 | 3 | 4 | 4 |
| time | 0,33333 | 0,33333 | 1 | 1,333333333 | 4 |
| implementation | 0,25 | 0,25 | 0,75 | 1 | 4 |
| | 2,58333 | 2,58333 | 7,75 | 10,33333333 | |

standardized values initial matrix (1)

| Best alternativ | cost | impact | time | implementation | |
|---|---|---|---|---|---|
| cost | 0,387096774 | 0,3871 | 0,3871 | 0,387096774 | 0,3871 |
| impact | 0,387096774 | 0,3871 | 0,3871 | 0,387096774 | 0,3871 |
| time | 0,129032258 | 0,12903 | 0,12903 | 0,129032258 | 0,12903 |
| implementatio | 0,096774194 | 0,09677 | 0,09677 | 0,096774194 | 0,09677 |

| MATRIX | CM | CI | RI | Cr | | Countermeasur | score |
|---|---|---|---|---|---|---|---|
| 1 | 4 | 0 | 0,9 | 0 | | 1 | 0,54061 |
| 2 | 5 | 0 | 1,41 | 0 | | 2 | 0,31406 |
| 3 | 5 | 0 | 1,41 | 0 | | 3 | 0,29412 |
| 4 | 5 | 0 | 1,41 | 0 | | 4 | 0,12056 |
| 5 | 5 | 0 | 1,41 | 0 | | 5 | 0,15475 |

COST matrix second level (2)

| COST | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | CV |
|---|---|---|---|---|---|---|
| ALT. 1 | 1 | 0,25 | 0,25 | 1,5 | 1,75 | 5 |
| ALT. 2 | 4 | 1 | 1 | 6 | 7 | 5 |
| ALT. 3 | 4 | 1 | 1 | 6 | 7 | 5 |
| ALT. 4 | 0,66667 | 0,16667 | 0,16667 | 1 | 1,16667 | 5 |
| ALT. 5 | 0,57143 | 0,14286 | 0,14286 | 0,857142857 | 1 | 5 |
| | 10,2381 | 2,55952 | 2,55952 | 15,35714286 | 17,9167 | |

COST matrix second level (2)

| COST | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | |
|---|---|---|---|---|---|---|
| ALT. 1 | 0,09767 | 0,09767 | 0,097674419 | 0,09767 | 0,09767 | 0,09767 |
| ALT. 2 | 0,3907 | 0,3907 | 0,390697674 | 0,3907 | 0,3907 | 0,3907 |
| ALT. 3 | 0,3907 | 0,3907 | 0,390697674 | 0,3907 | 0,3907 | 0,3907 |
| ALT. 4 | 0,06512 | 0,06512 | 0,065116279 | 0,06512 | 0,06512 | 0,06512 |
| ALT. 5 | 0,05581 | 0,05581 | 0,055813953 | 0,05581 | 0,05581 | 0,05581 |

IMPACT matrix second level (3)

| IMPACT | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | CV |
|---|---|---|---|---|---|---|
| ALT. 1 | 1 | 6 | 8 | 6 | 4 | 5 |
| ALT. 2 | 0,16667 | 1 | 1,33333 | 1 | 0,66667 | 5 |
| ALT. 3 | 0,125 | 0,75 | 1 | 0,75 | 0,5 | 5 |
| ALT. 4 | 0,16667 | 1 | 1,33333 | 1 | 0,66667 | 5 |
| ALT. 5 | 0,25 | 1,5 | 2 | 1,5 | 1 | 5 |
| | 1,70833 | 10,25 | 13,6667 | 10,25 | 6,83333 | |

IMPACT matrix second level (3)

| IMPACT | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | |
|---|---|---|---|---|---|---|
| ALT. 1 | 0,09767 | 2,34419 | 3,125581395 | 0,3907 | 0,22326 | 1,23628 |
| ALT. 2 | 0,01628 | 0,3907 | 0,520930233 | 0,06512 | 0,03721 | 0,20605 |
| ALT. 3 | 0,01221 | 0,29302 | 0,390697674 | 0,04884 | 0,02791 | 0,15453 |
| ALT. 4 | 0,01628 | 0,3907 | 0,520930233 | 0,06512 | 0,03721 | 0,20605 |
| ALT. 5 | 0,02442 | 0,58605 | 0,781395349 | 0,09767 | 0,05581 | 0,30907 |

TIME matrix second level (4)

| TIME | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | CV |
|---|---|---|---|---|---|---|
| ALT. 1 | 1 | 0,33333 | 0,33333 | 1,333333333 | 1,66667 | 5 |
| ALT. 2 | 3 | 1 | 1 | 4 | 5 | 5 |
| ALT. 3 | 3 | 1 | 1 | 4 | 5 | 5 |
| ALT. 4 | 0,75 | 0,25 | 0,25 | 1 | 1,25 | 5 |
| ALT. 5 | 0,6 | 0,2 | 0,2 | 0,8 | 1 | 5 |
| | 8,35 | 2,78333 | 2,78333 | 11,13333333 | 13,9167 | |

TIME matrix second level (4)

| TIME | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | |
|---|---|---|---|---|---|---|
| ALT. 1 | 0,09767 | 0,13023 | 0,130232558 | 0,08682 | 0,09302 | 0,1076 |
| ALT. 2 | 0,29302 | 0,3907 | 0,390697674 | 0,26047 | 0,27907 | 0,32279 |
| ALT. 3 | 0,29302 | 0,3907 | 0,390697674 | 0,26047 | 0,27907 | 0,32279 |
| ALT. 4 | 0,07326 | 0,09767 | 0,097674419 | 0,06512 | 0,06977 | 0,0807 |
| ALT. 5 | 0,0586 | 0,07814 | 0,078139535 | 0,05209 | 0,05581 | 0,06456 |

IMPLEMENTATION matrix second level (5)

| IMPLEMENTATION | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | CV |
|---|---|---|---|---|---|---|
| ALT. 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| ALT. 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| ALT. 3 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| ALT. 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| ALT. 5 | 0,5 | 0,125 | 0,125 | 1 | 1 | 5 |
| | 10 | 2,5 | 2,5 | 20 | 20 | |

IMPLEMENTATION matrix second level (5)

| IMPLEMENTATION | ALT. 1 | ALT. 2 | ALT. 3 | ALT. 4 | ALT. 5 | |
|---|---|---|---|---|---|---|
| ALT. 5 | 0,04884 | 0,04884 | 0,048837209 | 0,06512 | 0,05581 | 0,05349 |

*Appendix 34-Production scheduling as is*

*Figure A- 32: AHP*

| Probability to detect the problem before it impacts on OTD | Detectability |
|---|---|
| For sure | 1 |
| High probability | 2 |
| Medium probability | 3 |
| Low probability | 4 |
| The problem will not be detected | 5 |

*Figure A- 33: Detectability qualitative scale*

| % of delayed orders caused by the failure mode | | Occurrence rank |
|---|---|---|
| 0 | 5 | 1 |
| 5 | 10 | 2 |
| 10 | 15 | 3 |
| 15 | 20 | 4 |
| 20 | 100 | 5 |

*Figure A- 34: Occurrence quantitative scale*