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MASTER THESIS

Application of Lean Methodology in a Digitalization Process

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INTRODUCTION

Manufacturing companies are trying to find a better way through industrial digitalization and adopting new digital tools anticipating improvement of their production efficiency, and consequently of their competitiveness, in an evolving global economy.

The newly emerging fourth industrial revolution was introduced for the first time at the Hannover industrial fair in Germany in 2011, and indicated with the term “Industrie 4.0” (we will refer to it as Industry 4.0: I4.0). Along with Germany, several advanced countries are actively pursuing studies in the area of manufacturing, which are leading to consistent investments in fixed assets (mainly advanced machinery and software).

The primary goal of I4.0 is to build advanced smart factories by combining various ICT tools with typical and established manufacturing methods. This combination allows the collection of huge amount of in-plant data through the synchronization of the factory components and information systems, and it also improve both productivity and production quality through smart and flexible responses to abnormal events that occur in a plant. In addition to this, the huge computational power of the ICT tools available nowadays allows the exploitation of this data: real-time, or almost real-time, data can be used to analyze current and past production performances, and improve future ones.

The basic characteristics of smart factories include smart networking based on IoT technologies (such as wireless or smart sensor/smart actuators), uncertainty of various factory situations based on big data, and the flexibility of consumer needs.

One of the business areas that can strongly benefit from support of the application of digital technology within the era of I4.0 is production planning and control (PPC).

PPC aims to deliver products on-time, in the correct amount, and in the right place to a suitable cost, avoiding high inventory, long waiting times, obsolescence products, and delays in deliveries. PPC can be complex and stochastic when affected by disturbances, which can be better monitored and managed thanks to automated and digital tools for PPC such as advanced planning and scheduling (APS) software. They are designed to handle scheduling and rescheduling in dynamic shop floor environments in order to cope with breakdowns and material shortage deriving from delays along the supply chain.

Despite the long-time existence of digital PPC systems (the thesis will regard APS systems) and recent developments in I4.0, e.g., Internet of Things (IoT) and big data analysis, manually updated spreadsheets are still very widespread.

The APS systems represent the natural replacement and evolution of the manually updated spreadsheets, but this innovation trend is slowed down.

Nevertheless, the literature has barely touched this phenomenon. A research conducted by de Man and Strandhagen (2018) highlights two lines of reasoning observed against the implementation of APS systems to support the PPC. The first reason is in the form of not wanting to lose control over the planning process. Self-designed spreadsheets are often well understood by its users and their replacement generates confusion and uncertainty in the PPC function of the company. This happens due to the fact the planner does not want his planning system to be a black-box. The second reason is that the benefits of adding extra modules into or next to the ERP system are experienced as risky, while the financial benefit is not clear at the beginning of the implementation process. The company (especially if the focal company is a SME) does not want to involve ERP consultants to build in extra planning functionality. Starting with such a project can lead to high costs, while functionality is not guaranteed in the end.

Therefore, practitioners still struggle on a daily basis with the planning, scheduling and dispatching tasks they perform in spreadsheets, but their managers are at the same time very hesitant in adapting new software for planning. Even though the case data that is used in the de Man and Strandhagen' paper is from 2015 to 2017, the situation is not much changed from then as it is possible to understand from the future estimation for the market. Indeed, the APS software market was valued at US$ 1,491.22 million in 2020 and is projected to reach US$ 2,941.27 million by 2028 according to Research and Markets; it is growing at a CAGR (Compound Annual Growth Rate) of 8.86% and it is expected to maintain or increase this pace. The fact that the market is expected to almost double within 2028 describes a situation of still low penetration of the software category.

The predominance of spreadsheets on APS systems is also confirmed by the case study that will be presented further in the thesis, where the as-is situation was characterized exactly by the usage of Excel as main tool to support the company's production planning and scheduling.

An additional issue generally associated with the adoption of ICT tools finalized to the either start or consolidate the digitalization process of the company is represented by the hardships featuring the implementation process itself and more specifically the identification of the actual company's requirements and the solution that can correctly and completely satisfy them. It is also important to underline that the path to get to the solution is not always smooth since the contextual and environmental factors that affect the readiness of a firm towards the successful adoption of Industry 4.0 innovation may not be totally developed.

The main enablers that a company must have to implement more easily an I4.0 project are HR expertise to drive the cultural change required, IT skills (even though firms can get access to them through the involvement of third-parties), the presence of an evolved IT function that plays the role of a business support function, able to guide the choices on the technologies that are at the basis of the information generation, processing, storing and sharing.

However, there are others enablers that are sometimes put aside and undervalued such as organizational maturity and culture, which instead are fundamental enabling factors. In fact, on one hand, the firm needs to be able to map, analyze and manage internal process to find gaps and plan improvement countermeasures, and on the other hand, corporate culture has to be inclined to continuous improvement as well as internal and external collaboration.

These last two elements are strongly enhanced by Lean thinking and culture, which provide very powerful tools and methodologies that can support the company while choosing and carrying out improvement projects, consequently also I4.0 projects.

The objective of this thesis is the one of investigating the relationship between I4.0 technologies implementation (broadly speaking digitalization) and Lean methodologies and tools. More specifically the analysis of this relationship will be focused on the potential benefits brought by the application of Lean methods to the digital evolution processes that a huge number of companies are undergoing.

The work will be integrated with a practical case study, which is represented by a 4-months project that I carried out in a manufacturing company operating in the eyewear sector. The project was focused on the identification and implementation of an ad-hoc software solution that could replace the use of spreadsheets for the support of production planning and scheduling processes.

LITERATURE REVIEW

Industry 4.0

The concept of I4.0 is very complex and comprehensive, and literature does not provide a univocal definition. Among the many, Pan et al. (2015) focused on the fact that I4.0 represents the ability of industrial components and actors to communicate. I4.0 can be described as "a vision of the future of Industry and Manufacturing in which Information Technologies are going to boost competitiveness and efficiency by interconnecting every resource in the Value Chain" (Politecnico di Milano, 2017). Another very widespread definition is based on its combining nature and considers I4.0 as an umbrella term to describe a set of connected technological advances for increasing the digitization of a business. This last aspect was underlined by the key work in the I4.0 formalization developed by Rüßmann et al. (2015), who identified nine technological 'pillars' of I4.0: Autonomous Robots, Simulation, Horizontal and Vertical

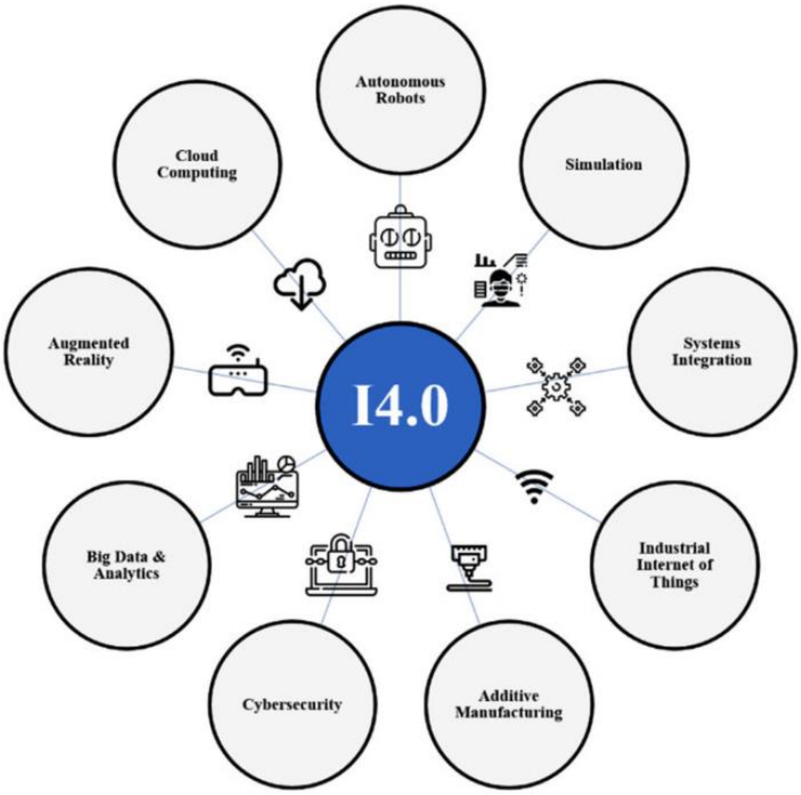


Figure 1. Industry 4.0 components formalization by Rüßmann

Integration, Industrial Internet of Things (IIoT), Cybersecurity, Cloud, Additive Manufacturing, Augmented Reality, and Big Data and Analytics.

These elements will be intended and described in their application in the operations field.

Autonomous Robots include: Collaborative Robots, that perform repetitive and, generally, non-ergonomic tasks in direct collaboration with the operator; Automated Guided Vehicles (AGV), that allow the decentralized coordination of supplies; and Smart Machines that communicate with robots and products to make consequent decisions.

Simulation can leverage real-time data to mirror the physical world in a virtual model. Horizontal and Vertical System Integration guarantees the truly automated value chain.

Horizontal Integration, across the whole value chain, and Vertical Integration, within the company, are possible due to MES/ERP/APS software, sensors and IIoT for data sharing. IIoT allows the interconnection at the basis of the integration, enriching some devices with embedded computing. Some of the most common examples of IIoT are RFID, sensors, tags, global positioning systems, real-time scanning through smartphones.

With interconnection, companies need protection from cyber-attacks that is provided by Cybersecurity systems. The most commonly listed in literature are encryption, cryptography, virus scanners, signature scanner, ICT Anomaly Detection/IDS.

Data sharing and data analytics can be helped by the adoption of Cloud-based software. In fact, cloud computing enables ubiquitous and on-demand network access to a shared collection of resources, without mentioning the great savings in terms of investments in fixed assets allowed by the adoption of this technology, and a consequent shift from fixed to variable costs that allows the company to be financially more resilient.

Additive Manufacturing, namely a layer-by-layer build-up of parts, such as 3D Printings, allows a quickly customized single-item or small batches production that gives a strong help to firms to satisfy all customer requirements with a single category of machine (this is a huge help for companies since they have to deal with the wide spread concept of mass customization).

Augmented Reality (AR), as an overlap of computer generated sensory input in a physical real-world, and Virtual Reality (VR), as a completely artificial environment created by software, might be exploited for different purposes: warehouse management, layout testing, operators' training, and remote maintenance. Besides the simplification of asset management, these technologies can replace pilot tests, pilot projects and prototypes to reduce costs of innovation and ease project management.

Big Data collected in the smart factory allows a much more solid optimization process. Data Analytics divides into Descriptive, Predictive and Prescriptive. Descriptive Analytics describes the current situation and helps in the identification of the issues; Predictive Analytics predicts future events; while Prescriptive Analytics concerns and improves decision making mechanisms (Nguyen et al. 2018). Artificial Intelligence can exploit the collected data to make the system self-aware, self-adaptive, proactive and prescriptive (Kibria et al. 2018).

Digitalization process support

However, if not implemented right, digital transformation can become a source of waste and result in a huge failure. A report from BCG shows that around 70% of the digital transformation processes fail, because of the lack of project strategy and medium-long term thinking. It is also important to mention that due to the high costs averagely involved in digitalization projects, their failure can represent a true financial disaster for a firm, especially for a small-medium sized one.

In order to improve the possibility of success Lean is taking the lead by helping to add value to the new digital transformation. Authors in identify that Lean is seen as an important agent in the implementation of Industry 4.0 and highlights Lean concepts such as standardization of work, organization and transparency as bridges to allow a more effective digital consolidation in such critical projects.

Integrating Lean principles into digital technologies implementation projects helps achieve radical simplification of the process, allowing companies to identify the most effective levers for the digital journey. These levers are not always clear to companies, especially to SMEs, due to the inability to get access to highly skilled professionals. This simplification - along with the contribution of the continuous improvement culture fostered by Lean thinking that can be seen as a sustainable and perpetual way of developing employees - can be very helpful to avoid another common pitfall: the lack of employee engagement. The metabolization process of this huge changes is sometimes taken for granted, but it can truly slow down or jeopardize these transformations.

Lean thinking emerged as a Lean response to combating the waste of training people and employees, focusing on solving problems, implementing technologies and facilitating the flow of information in organizations.

It is also interesting to see that some articles from the literature suggest that will be necessary to introduce Lean thinking from a digital perspective (also indicated with the term Digital Lean Thinking, DLT) to start the transformation to Lean 4.0. All this because if Lean thinking is not implemented in advance to support Lean 4.0 thinking, organizations will be digitizing waste in the future. Lean application has to be performed both before the beginning of the digitization processes and especially during them.

What's more, this philosophy serves as the basis for Industry 4.0 implementations since it is from there that Lean thinking and the fight against traditional and digital waste are introduced, simultaneously.

Instead of starting a process of digitization in the organization by acquiring and implementing technologies, it is more efficient to first raise awareness and train employees from the DLT in order to promote and cultivate innovation initiatives, accelerate the Industry 4.0 implementation and reduce waste of time and resources digitally.

More generally speaking this correlation between the Lean world and Industry 4.0 has become an hot topic over the last 3 to 5 years, since its importance has incredibly grown thanks to the boost that the Covid-19 pandemic has given to the digitization process of companies of every industry. This can be clearly seen from *Figure 2* that contains a graph of the trend of the number of documents per year – associated to combination of the key words "Lean" and "Industry 4.0" - published on Scopus. Scopus is the largest abstract and citation launched by Elsevier's in 2004, indexing many serial and non-serial publications and millions of conference papers, including the majority of the most important journals in the field of operations management research.

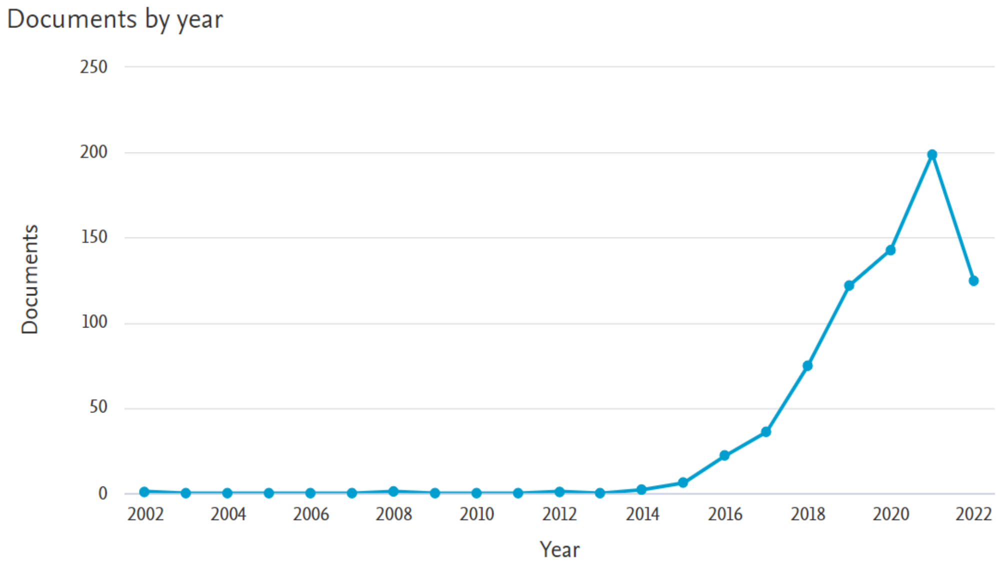


Figure 2. Number of publications related to "Lean" and "Industry 4.0" keywords

Since research on this relationship accelerated in 2016, studies have switched from being very conceptual to be more empirical-based (Buer, Strandhagen, and Chan 2018). They claim that most Lean manufacturing tools will benefit from the introduction of Industry 4.0 technologies, while some Lean manufacturing tools can also be facilitators or even prerequisites for a move towards Industry 4.0. They especially consider total productive maintenance (TPM), Kanban, production smoothing, autonomation (intelligent automation supporting humans while carrying out their operations, to easily and quickly identify issues), and waste elimination as aspects of Lean manufacturing that will benefit from introducing digital technologies. Similar results were found out also by other researchers, such as Kolberg and Zühlke (2015). They highlighted the role of Lean in the implementation process of Industry 4.0: concepts such as work standardization, organization and transparency are highlighted as support for implementation of solutions linked to I4.0.

In addition to that, for instance, Rüttimann and Stöckli argued that Industry 4.0 initiatives are likely to fail unless they are inserted into a proper scenario that takes into account essential manufacturing laws given by the Lean approach.

A strong support to this hypothesis is given by a more empirical work carried out by Rossini, which highlights the fact that EU manufacturers that aim to adopt higher levels of Industry 4.0 must concurrently implement Lean production as a way to support process improvements. According to his findings, companies that aim at achieving higher levels of Industry 4.0 must have previously implemented a certain level of LP practices. This fact allows companies to fully benefit from the incorporation of technologies into well designed and robust processes.

Starting from this accepted-by-literature concept, the robustness conferred upon processes by Lean, this thesis aims at providing a quite practical example of how the same robustness can be applied to digital implementation projects and their management. The perspective adopted will allow to focus more on how what happens before the “go live” can be carried out with less efforts in terms of costs and time, and with a higher quality thanks to the application of commonly shared Lean tools.

Lean approach

Lean manufacturing is a production method aimed primarily at reducing times within the production system as well as response times from suppliers and to customers. Nowadays, it is still representing the best established driver for a company to reach a high-level efficiency. Lean philosophy is based on the reduction of waste in production processes, simultaneously increasing productivity and reducing production costs (Womack et al., 1990). It is closely related to another concept called Just-in-time manufacturing (JIT manufacturing in short). JIT manufacturing tries to match production to demand by only supplying goods which have been ordered and focuses on efficiency, productivity (with a commitment to continuous improvement) and reduction of "wastes" for the producer and supplier of goods. Lean manufacturing adopts the just-in-time approach and additionally focuses on eliminating activities which do not add any value for the customer.

The history of this concept is quite long and starts in US with Henry Ford: the first person that was able to truly integrate an entire production process. In 1913, he put together consistently interchangeable parts with standard work, implementing the production flow. He was able to turn the inventories of the company every few days; however, the issue with this new production system was the inability to provide variety to its customers.

Other carmakers thought that a successful way to solve this problem was investing in larger machines that ran faster. This solution resulted in a reduction of costs per process step, but on the other side throughput times and inventories kept increasing, except in rare cases where all of the process steps could be linked and automated. Kiichiro Toyoda, Taiichi Ohno and others Japanese engineers looked at this situation, especially after the World War II when Japan had the necessity to re-build and make more efficient its manufacturing industry. They tried to introduce a series of simple quick-win improvements to have both continuity in the process flow and a wide variety in product offerings. They revisited Ford's original thinking and invented the Toyota Production System (TPS).

Lean manufacturing is particularly related to this operational model, mainly developed by the Japanese automobile company Toyota during the 1950s and 1960s, and – for this reason - also called "The Toyota Way". It grounded on the two pillars: just-in-time management (JIT) and automated quality control (Jidoka).

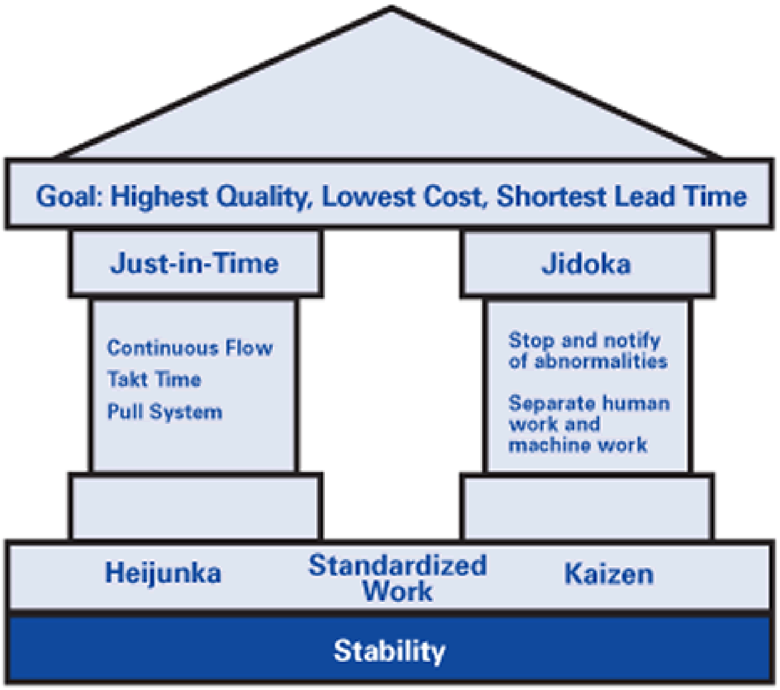


Figure 3. Toyota Production System "house", the main pillars

The seven "wastes" ("muda" in Japanese), first formulated by Toyota engineer Shigeo Shingo, are the superfluous inventory and finished goods, overproduction (producing more than what is needed at each moment), over-processing (processing parts beyond the standard expected by customer), transportation (unnecessary movement of people and goods inside the system), motion (automating before improving the method), waiting (inactive working periods due to job queues, namely Work In Progress), and making defective products (reworking to fix avoidable defects). The reduction and, ultimately, elimination of these wastes is the true core of Lean approach.

However, it is important to notice that the term "Lean" was coined only in 1988 by the American businessman John Krafcik, within his article "Triumph of the Lean Production System”.

According to Lean methodology, the systematic elimination of the sources of inefficiencies is only possible through five actions, defined as principles by Womack and Jones, which are the reference points for process reorganization. The first step is the definition of value as perceived by the customer. The second action aims at identifying the value stream for each product. The third principle states that it is necessary to implement a continuous product flow through the remaining value added steps. The fourth action aspires to a flow which is pulled by the customer, where continuous flow is possible. The last principle aims at striving for perfection . These actions must be performed ad infinitum, every day, like a cycle in order to obtain the so-called continuous improvement.

Lean problem solving approach

Lean has inherited the structured approach developed by Toyota for problem solving named A3 process or method. The aim considered while developing this method was finding a simple procedure with immediate effect: for this reason, all the key information had to be clearly and logically reported in a limited space that could be analyzed in a little time by any reader (any person involved in the project to resolve the issue identified). The space chosen was a A3-size sheet. This allows to focus on necessary information to solve the problem, without getting lost in useless details.

Another advantage is related to the engagement of people, by fostering communication and participation: each actor is allowed to write on the A3 sheet each time new information or problems emerge. Obviously the method was developed when pen and paper were the main means to execute the process; nowadays thanks to the possibility of exploiting digital tools to create shared spaces both its effectiveness and its efficiency are enhanced.

The A3 model consists of seven areas, which recall the steps of the PDCA cycle: Background (or Problem Statement), Current Situation (or Problem Breakdown), Targets definition, Root Cause Analysis (Plan), Countermeasures (Do), Confirmation of the results (Check) and Follow-up plan (Act).

As it can be seen from the example reported in *Figure 4*, the A3 method is an effective tool because it contains not only text, but also – actually especially - pictures, diagrams, and charts, all of which enrich and clarify the data. The visualization of data is key, since it allows anyone involved to easily capture information to be used to work towards the right direction.

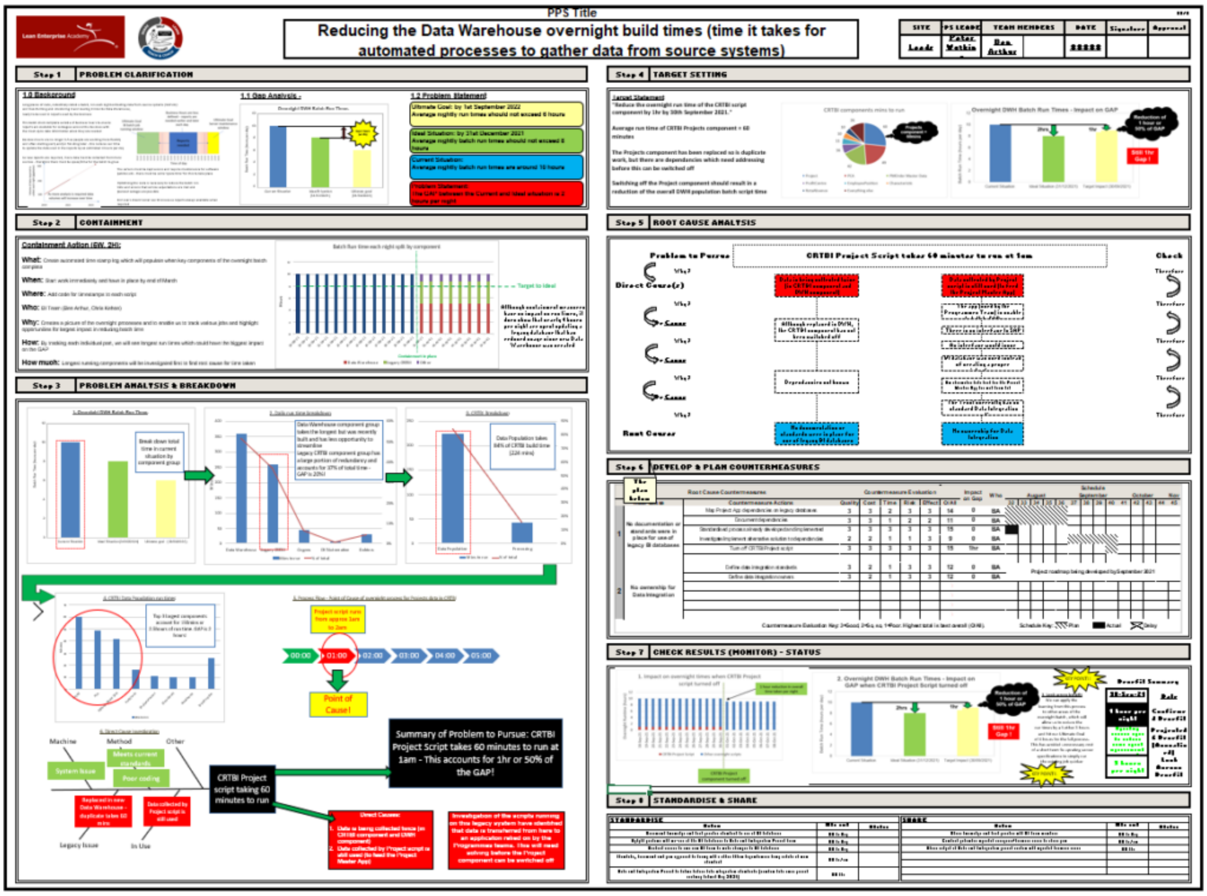


Figure 4. Example of A3 Report

Moreover, this structured and precise approach is supported by other problem solving techniques: Value Stream Mapping, Fishbone Diagram and Five Whys. These techniques are generally exploited to support the approach and make it more solid. To be more precise, these are some of the tools that have been exploited during the case study; however the available tools provided by the Lean approach are more numerous and include – for instance - the Gemba Walk (observation session on the shop floor), SMED (Single Minute Exchange of Die), 5S (five step methodology for creating a more organized and productive workspace) and so on.

Value Stream Mapping (VSM) is used to map the current situation, in order to identify where the value for the customer is created and later focus on areas to be improved, by the elimination of non-value adding activities (Rother et al., 2003).

There are two kinds of value stream maps, current state and future state. The current state value stream map is used to determine what the process currently looks like, the future state value stream map focuses on what the process will ideally look like after process improvements have occurred to the value stream. The distinction between value adding and non-value adding activities is always done considering the final customer point of view.

The *Fishbone Diagram* (also known as Ishikawa Diagram) is one of the most interesting tools used in problem solving, because it allows the identification of all the trigger factors until the root cause of the problem. It is very useful for the identification of the cause-effect relationship. It is also used to help with the classification of the trigger factors within main categories in order to know on which resources (humans, machines, procedures, software and so on) to focus when tackling a potential cause of the problem to find a countermeasure.

The Ishikawa Diagram, beyond assuring a complete mapping of the trigger causes, guarantees the following advantages:

- all causes are identified following a specific framework, shared by all participants to the project;
- it allows knowledge sharing/proliferation among all the components of the (usually cross functional) team during brainstorming sessions, enhancing the possibility of exploiting the experience of any actor;
- high focus on the problem causes to tackle, limiting the irrelevant discussions;
- immediate visualization of the results obtained during the root causes analysis phase.

In order to go deeper into the analysis of the justifications for each factor, the *Five-Whys technique* is used to find the issues and continue proposing solutions. This technique consists of investigating each factor by inviting all actors involved in the project to ask themselves, in an iterative way for five consequent times, the reason why that factor persists. Generally speaking within the five cycle the root cause, so the cause for which no explanation can be found, is identified.

As a matter of fact, Kaizen (the inclination to continuous improvement) requires that, before the implementation of a certain improvement plan, the rationale and the benefits of all the measures are examined with attention. This is why Five-Whys technique is so important: each planned improvement has to be criticized and questioned before its implementation, moving towards five level of whys in order to be sure of the final result (Ishikawa, 1976).

The implementation of digital transformation within a manufacturing process requires costly investments and will be ineffective if the manufacturing process produces a lot of waste and is not well managed (Bittencourt et al., 2019). This reasoning does not only regard the physical wastes observable on the shop floor, but also the digital ones, which usually derive from poor management of data flows. In addition to this, the implementation of I4.0 technologies within a manufacturing environment without being lean puts the use of such technologies at risk of being inefficient (Bittencourt et al., 2021).

Indeed, the consequence of automating an ineffective process would be to continue producing some sort of waste, as automating an ineffective process does not necessarily result in an effective process (Bittencourt et al., 2019). For this reason – as previously mentioned – Lean Production principles, with the focus around organization, transparency and standardization, are regarded as a foundation for the adaptation of I4.0 technologies. Lean supports the adaptation of I4.0 through eliminating waste, simplifying processes and increasing transparency (Bittencourt et al., 2019).

In addition to this, since Lean-based manufacturing systems should produce minimal waste and be streamlined, they make it easier to introduce digitalization and automation within the production process. In fact, Rossini et al. (2019) highlighted that the adaptation of I4.0 technologies within Lean companies will be more efficient since the production environment is already properly designed and stable.

This finding represents a true call for companies, also the ones that are not very Lean: the rush for digitalization should be accompanied by a parallel work of “leaning” the organization and the processes. This process does not have to be exclusively executed before the digital transformation: laggers can adopt and push on Lean approach during this journey.

Therefore, the Lean Production system and its principles act as an enabler for the implementation of I4.0 technologies (Davies et al., 2017).

Lean project management and the concept of Lean Project Delivery

Therefore - as seen - despite the increasing number of research contributions on the I4.0 topic, companies are struggling with understanding how digital transformation should actually take place.

The risk companies are facing is to start an inefficient digital transformation and not be able to get rid of this inefficiencies along the way. Sometimes, what prevents managers from starting this type of journey is the experience of similar companies (or, anyway, the experience of ex-colleagues working for other companies different from the one they are guiding) where the mentioned inefficiencies lead to almost never-ending projects. The high complexity of this type of projects can lead to extra cost and time due to the poor approaches adopted to manage this complexity.

Up to now, researchers' attention has been paid in explaining Lean as a philosophy of Operations management, with its principles and objectives. However, it seems like literature has not given enough credit to the contribution it can give to reform – in the light of the higher and higher complexity coming with projects such as the digital transformation ones - project management and its practices. Nonetheless, the increasing interest of companies towards new project management methods that allow them to reduce duration, increase performance and avoid confrontational relations during project execution is well known.

So far, few authors have explained Lean project management practices theoretical foundations as well as its convenience for different types of projects according to their complexity. Researchers, along with practitioners, have focused on decreasing uncertainty instead of trying to deal with situations of uncertainty and complexity. Thus, a more in-depth analysis about lean project management its practices could be helpful in order to support managers in handling different levels of project complexity.

In this way, when a new challenge brought by each project is established, it will be possible to choose the best approach to handle it: traditional or lean.

In the Lean Project Management perspective projects are considered as small and temporary production systems, thus they have to be organized in order to be as much as possible error-proof: in this way value maximization and waste minimization can be achieved.

Although Lean Project Management has not been widely applied, there are some examples that show how this approach can be successfully implemented. In a study carried out in BBC Worldwide, Middleton and Joyce (2012) explained how lean principles can be applied to software project management in order to improve the performance of the software and consequently, project results. This technique uses tools as visual management, value mapping, team-based problem solving, smaller batch sizes, and statistical process control to foster software development.

According to Ballard and Tommelein (2012), Lauri Koskela, a research scientist, was the first one that connected Lean to Project Management. The connection, which took place in 1992, was specifically meant and applied to the field of construction, after Koskela noticed the existing problems of project management in this field. There was an existing need to adapt and redefine this area with the new practices that were developing in the manufacturing industry, precisely in the company Toyota.

So far, Lean Project Management has been developed both theoretically and practically. During approximately a period of ten years, Koskela and some researchers have been studying the theoretical basis of project management and they have opposed their transformation-flow-value theory of project versus the transformation theory, in which projects are seen only as the transformation of inputs into outputs. With this integrative vision of the production and flow of information and materials, they tried to accomplish the following objectives: reducing costs, saving time, and increasing customer value (Howell and Koskela, 2000). Koskela and Howell (2002) proposed to give more emphasis to the flow view instead of the over attention on the transformation view.

These new approaches of project management have had great acceptance among researchers and practitioners and have also shown its effectiveness. Koskela and Howell (2002), as cited in Bertelsen (2004), compared construction projects with scientific experiments. By comparing them, they accepted the random nature of these types of projects, which constitutes a general feature of complex projects. Thus, the change in the theoretical basis of project management was justified because in a simple project, reducing variability can enhance order. In addition, chaos can be controlled with the appropriate use of countermeasures aimed at the elimination of causes of mistakes. However, uncertain projects need to be managed with values of collaboration, discussions and education.

The complexity and the variability featuring this type of project can be find also in software development and implementation projects, such as the ones this thesis is referring to. This correlation leads, transitively, to the possibility of applying Lean Project Management to this type of project.

One truly important aspect of Lean Project Management is focusing on creating value by challenging the conventional way of managing a project work. This conventional way consists of witnessing the project manager telling people what to do and receiving the reports of the work done. Subordinates comply with what is requested from them and then report to the project manager. In this scenario the project manager takes responsibility of what should be done, even though - in most cases - the subordinate has the best knowledge of what should be done. This is especially true when talking about software, which are organized in modules or functions/masks that are very tailored and usually come with peculiarities that make the difference between a final successful implementation and an incomplete one. These peculiarities, or missing peculiarities that can be inserted in the scope of the project for an implementation able to cover existing capability gaps, can only be known by subordinates (the so called key users) due to their hands-on experience.

Conventional management creates waste by separating responsibility from action, knowledge, and feedback. Waste is also created, and consequently value diminished, by making people work for bureaucratic priorities instead of working the customer.

Efficiency and effectiveness are also critical aspects deeply related to communication. Studies show that in some conventional companies significant amount of time is spent dealing with e-mails, voice mail, and looking for information. Also a large part of the work day is spent in meetings. A consistent portion of this hours spent between meetings and e-mail to communicate updates or new problems encountered are most likely waste.

This widespread issue can be solved with the Lean approach. More specifically by resorting to the previously mentioned A3 method, especially in its new "updated" version supported by the shared virtual spaces created by the Microsoft package, for instance, which also allow to have full traceability of modifications and updates; as well as the possibility of leaving comments. Not only: using visual information and visual management tools is essential when implementing Lean in Project Management and efficient communications since visual information is something that the brain can process better than any other type of information.

Currently the literature does not provide much empirical and practical material regarding the effects of the application of Lean techniques during a project of software implementation. This thesis aims at enriching the amount of this type of material available, especially for practitioners, by showing the actual impact of Lean methodologies on some of the main KPIs used to evaluate a project: more specifically on time and on quality (this last KPI will be measured as the number of needs identified, and satisfied by the solution, and on the satisfaction of the actors involved in the project).

CASE STUDY

The case study presented refers to the practical experience that I lived in a company operating in the eyewear sector.

The experience lasted from March to June 2022 and consisted of the development of a pilot project aimed at the identification of a proper software solution able to improve the performances of the production planning and scheduling processes.

In the different parts of this section, after an initial description of the company necessary to contextualize the case, I will subsequentially describe all the steps that I have undergone in order to get to a solution accepted by the company's management: starting with the understanding of the initial situation (as-is scenario) and its problems, moving on with the identification of both the company needs and the software solution that could satisfy them, the consequent software selection process, and concluding with the value assessment of the impacts of the potential future implementation.

Except for the value assessment, the different phases of the project will be analyzed with a strong focus on the Lean methodologies adopted to carry them out and the benefits brought by their application.

An important part of the section is represented by the description of the Advanced Planning and Scheduling system ultimately identified as ideal solution for the company and, furthermore, a description of the theoretical concepts exploited to develop the algorithms behind the software category to which this solution belongs to.

Company description

The company that welcomed me and gave me this great opportunity, with its approximately 3300 employees, represents one of the main global competitors in the industry worldwide. It operates in more than 80 countries through 18 owned commercial branches, 4 retails divisions and more than 100 independent distributors. It counts approximately 1,000 stores around the world stocking its retail chains and over 50000 retail stores that have chosen it as supplier. The company portfolio is very wide: it counts 24 brands for which the firm designs, manufactures and distributes eyewear products all over the world. The overall company's production is carried out thanks to 4 global production sites located in Italy, China, Japan and United States. The plant where I stayed during my experience was the one located in Italy.

The production strategies adopted in the plant varies depending on the products.

The main products are managed according to either Make-To-Stock or Assembly-To-Order strategies in order to satisfy the requests of short Lead Times required by the market. The first strategy mentioned is usually dedicated to those products belonging to this category and featured by a lower value density (and a simpler production process), which allows to manufacture and store in the plant the finished products without incurring in huge increase of Operating Working Capital. The second strategy is, instead, dedicated to the products with higher value density and a more complex production process, that require the exploitation of semi-finished/intermediate products to any way assure a short Lead Time: the request of the market is 4 weeks LT. This is especially true when referring to those products that are manufactured on behalf of huge international brands. These two strategies are adopted for the majority of the company portfolio: around 75-80% of products.

In the case of less requested products, namely niche products, and the so-called "evergreen" products that represent the history of the company (so the iconic ones that cannot be dismissed to preserve the company image and identity, even though are characterized by mediocre-small volumes and, in some cases, marginality) the

Make-To-Order strategy is adopted. In this way, naturally, production Lead Times are stretched, going from 4 weeks to 7-8 weeks LT. This case regards 20-25% of the product range.

The shop floor is organized in manufacturing cells; more specifically in two ones: one dedicated to the production of metal-based eyewear and one dedicated to the production of plastic-based eyewear. As a regular cell configuration, each cell presents all the machines and stations necessary to perform the different step of the production process the related product family. The intercell movements are very rare.

The differentiation between machines and stations has to be highlighted since it is important to mention that the manufacturing process is not very automatized due to the manual nature of several of its steps. This necessity of manual skill is required by the high-end nature of most of the finished products distributed by the company; this skill cannot be replicated by machines. Therefore, products – along the manufacturing process – are worked both by machines (mostly semi-automated) and by people (namely artisans) working on stations. Even the movement of goods within the shop floor is not automatized and the registration of movements depends on the registration executed by employees.

The approach to the project

The whole project has been carried out following the steps of the A3 method. Beyond the academic need, the decision of relying on this method came from the need of following a solid framework that could lead to a solid solution. In addition to this, the adoption of this method was triggered by the necessity of dealing with several people within the planning, the commercial and the purchasing departments. The employees that supported me during the project were also required to follow their regular working activities, so they did not have plenty of time to dedicate to the project and the possibility of quickly understanding and visualizing the advancements of the project was very helpful.

Problem Statement

The first phase of the project was aimed at the identification of the problem faced by the company.

Within the first three weeks, thanks to the availability of the planning department employees and of the planning manager, it was possible to understand the issue: the production planning and the production scheduling processes were both ineffective and inefficient, with the low quality of the first process that was contributing to the invalidation of the output of the second one.

The first side of the problem, so the mediocre output of these processes, was highlighted by the presence of a very consistent amount of missing parts ("mancanti di produzione"), which lead both to high inventory costs - due to the presence of several semi-finished products waiting for at least one component in the plant warehouse –

and to the low ability of the company to respect the delivery due dates promised to the customers.

These were the ultimate tangible manifestations of this problem, but it could be observed also by monitoring the usual daily activity of the production planners. The result of their daily scheduling activity, the production schedule with the orders to be sent into the production system, had to be revised and modified several times (up to 3-4 times) within the same day, and - in many cases - also the day after due to the presence of deviations of the production system behavior from the one expected by the planners.

At this point it is also necessary to provide a more precise theoretical definition of the two processes involved in the project: production planning and production scheduling.

Production planning is carried out to organize the production department and plan future production. It is a tactical-strategical process characterized by a consistent complexity deriving from the huge amount of constraints and variables to consider, and the high uncertainty associated to these variables. This last aspect is the natural consequence of the time horizon this process covers: it is focused on the medium term (semester or year). Due to these features, production planning is handled with a hierarchical approach that consists of splitting the problem into sub-problems of simpler resolution, due to the lower number of variables associated to each of them. Production planning can be structured in three main phases:

- <u>Phase one: aggregate production planning</u>
  It is carried out referring to the medium term (time horizon: one year), therefore the accuracy of the available data is mediocre and, to compensate this, they are aggregated into product families. It aims at identifying the most

efficient way to match the expected demand with the production capacity available.

- Phase two: master production schedule (MPS)
  It is generally executed referring to a time horizon of a semester, so the accuracy of the data exploited is medium-high. This phase is characterized by a time fence equal to a month (in some rare cases equal to a week) and aims at defining a detailed production plan starting from the output of phase one. The information has a higher level of detail in this case, they are referred to the single products or SKUs
- Phase Three: operative planning
  It is executed on the short term (time horizon: quarter) and the data accuracy is very high. The time fence adopted in this case can also be equal to a day. The level of detail is still the single product or SKU.

Production scheduling is an executive-type scheduling of activities. This process is characterized by a focus on the very short term, as well as a more practical and operational nature. Indeed, it aims at assigning a sequence of activities (basically representing the work orders) to the manufacturing resources, depending on their availability and effective production capacity, with the ultimate objective of minimizing manufacturing costs and time in the respect of the plan defined during the operative planning phase. Other objectives can be concurrently chased: inventory levels minimization, set-up times minimization, maximization of the work balance between resources and so on.

To obtain this result, the production scheduling requires - as inputs – other key information in addition to the operative plan:

- warehouse status, with inventory levels;
- confirmed customer orders;
- bills of materials (BOMs);
- nominal features of production resources, or work centers;

- material and human resources availability (so also number of daily work shifts and their duration);
- lists of the production process steps undergone by each product;
- scheduling constraints

It has to be highlighted that the way the two processes are intended, structured and performed by the company planning department is very adherent to the theoretical concepts just explicated.

As a summary of this phase, the two main problems identified were:

- the presence of inefficiencies in the scheduling workflow, which were stretching the times to carry out the process and increasing the efforts of the planners;
- the discrete inaccuracy associated to the output of the scheduling process.

Problem Breakdown

The firm's ICT structure was constituted by the SAP ERP and a SQL server, which was used as a support to transfer the interested data from SAP to the Excel files and Access Databases used by the planners to carry out the planning and scheduling activities.

SAP ERP was constituted by the SAP ECC (Central Component), which included the PP (Production Planning), MM (Material Management), QM (Quality Management) and WM (Warehouse Management) modules, integrated with SAP EWM (Extended Warehouse Management) to have full control of the warehouse movements.

During the definition of the as-is procedure, or workflow, it was interesting to notice that SAP was not the main pillar, actually it was only used as simple data source. The PP module was not used to perform any planning or scheduling activity.

The well-known solidity of SAP was used to have a reliable and constantly updated database from which retrieve data of interest for the planning and, especially, for the scheduling processes: BOMs (Bill of Materials), inventory levels, production LTs, raw material and components delivery dates.

The daily scheduling process consists of the following phases:

- All data of interest are transferred to the company's SQL server every morning thanks to customized and automatic transactions. Having the data here represented a key aspect to the whole scheduling process since the SQL server can be more easily interrogated in comparison with SAP database. More specifically, in this case, it is queried trough a complex system of VBA macros that the company has in-house developed over more than 16 years (the first lines of the programs were written in 2006).

Some of these macros are used to execute computations used to support the planners in the draft of the definitive schedule, for instance to validate it considering all constraints.

The importance of this system of macros, which basically represents the actual production scheduler, is extremely high for the company and for this reason I only had the possibility the have access to it during the guided explanation of the planners.

- These macros are launched from the same Excel files used by the planners to compile (in a manual way, as mentioned before) the production schedule.

  Each one of the different planners present in the department (three planners, two for the metal-based products since their scheduling is subdivided into semi-finished and finished products, and one for the plastic-based products since they do not present semi-finished products whose production has to be scheduled) uses specific macros since they have different informational needs. This specificity is also necessary to avoid that the consistent amount of data retrieved and used during the elaboration performed by Excel can make these elaboration too slow or, worse, block them due to the limited computational power of Excel. In fact, this spreadsheets only contain simple tables; the absence of any graphic element to better visualize the overall schedule is necessary to make these files as light as possible.

  To summarize, in this phase, the “artisanal” system created via VBA (Visual Basic for Applications) allows the planners to use the same Excel spreadsheets to launch ad-hoc interrogation to the SQL server, use the retrieved data (presented in the form of Excel tables) to obtain as output the ultimate detailed production schedule and verify the feasibility of this schedule.

- The last step of the process consists of uploading the approved production schedule on SAP (in order to have an alignment between SAP and the “Excel environment”) and use the PP module to print out the physical work orders, which are then physically taken to the production area managers to start the actual production.

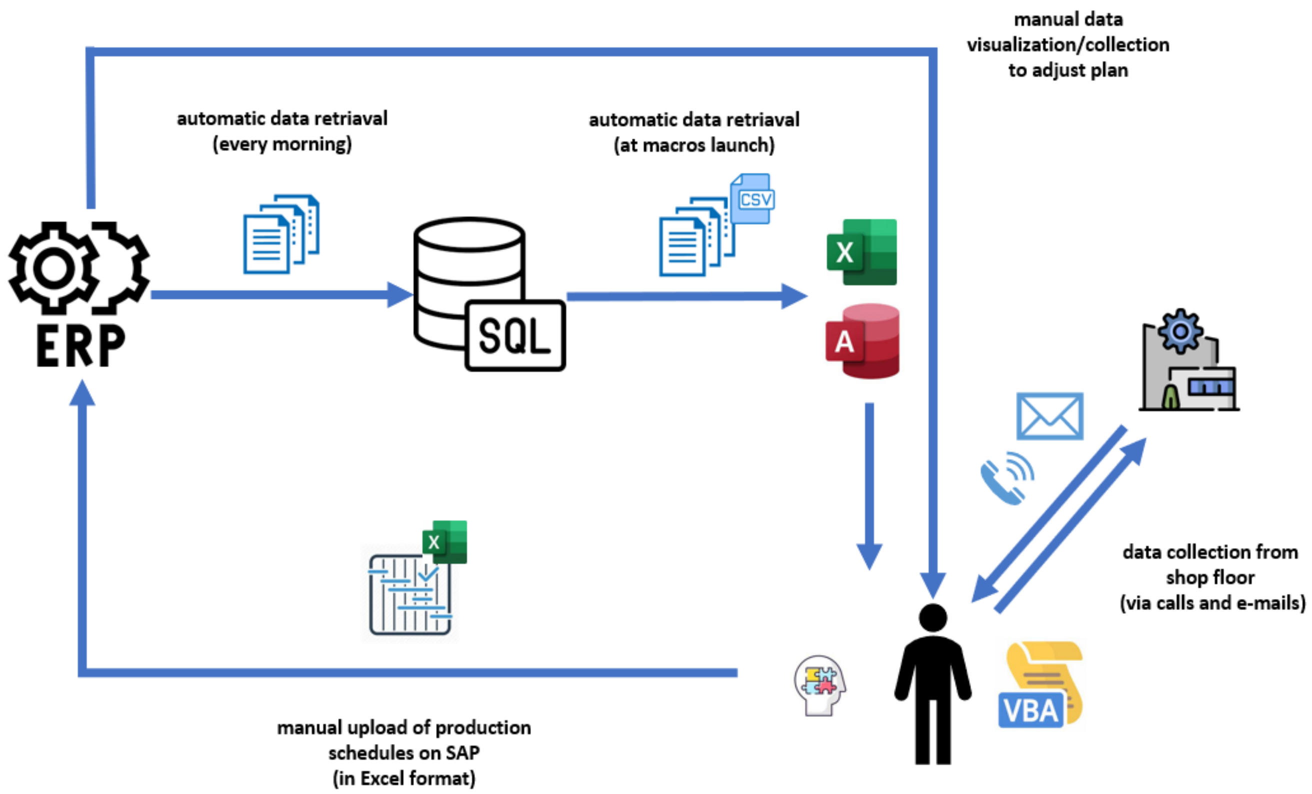


Figure 5. Production scheduling workflow and dataflow

During the daily scheduling the three planners, along with their supervisor, were required to exchange calls and e-mails with the different production area managers and with the purchasing department to respectively gather information regarding the actual production potentiality (more specifically to be updated on the shop floor situation: delays, breakdowns, ongoing ordinary maintenance interventions and so on) and the availability of materials to understand if the production schedule they were developing had to be revised or if it could be confirmed. In addition to this, they have to manually visualize (or retrieve through extractions, depending on the volume of data required) data from SAP since those data are updated real time and are characterized by high reliability.

The reason why this handcrafted integrative system to SAP was implemented and used by the company is represented by the fact that the configuration of German ERP owned by the company, due to the absence of the SAP APO (Advanced Planning and Optimization) integration, only provides the potentiality of the pure MRP and MRP II functions. The optimization function, also indicated with the term MRPDS (MRP Detailed Scheduling), associated with this integration was not present.

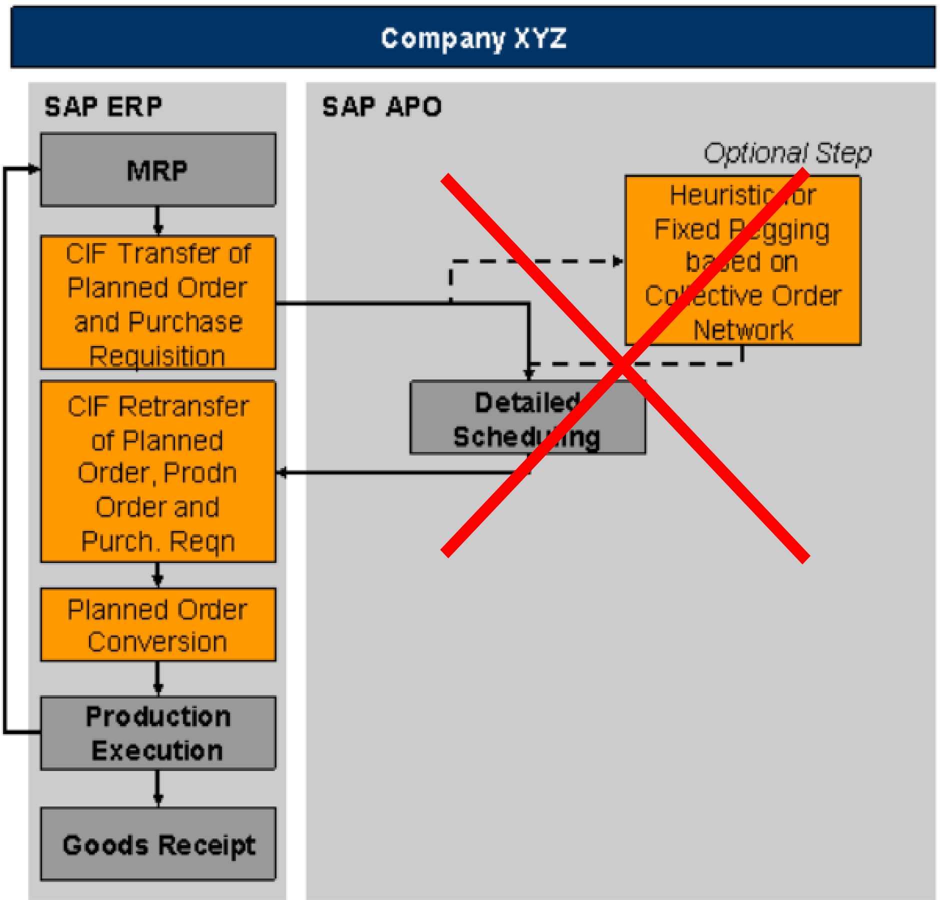


Figure 6. SAP MRP-based Detailed Scheduling schema

The MRP (Material Requirements Planning) is a technique designed to plan manufacturing production. It aims at calculating the net material requirements (finished goods, semi-finished goods, components and raw materials), and plan both production and purchase orders taking into consideration market demand, bill of materials, production and purchase LTs, inventory levels and inventory management policies. More specifically, it determines when materials will be required in order to meet the production schedule and manages delivery timing, with the objective of meeting the market demand.

However, the MRP gives as output schedules based exclusively on these two aspects:

- the explosion of the bill of materials present in its database, which is used to generate the requirements for sub-assemblies, components and raw material starting from the demand of the finished product "received" from the MPS;
- the offset of the lead times: the production LT of the finished product is computed stating from the production LTs of its components. This translates in to a backwards time compensation that indicates when the components should be available in order to respect the agreed date, namely the one indicated in the MPS.

The biggest and most well-known criticalities of MRP systems derive from the rigidity with which these two features are applied within the MRP logic, and they lead to the release of potentially unfeasible production plans that have to be manually revised.

The first category of errors made by these systems is associated to the assumption related to the LTs. The fact that – in reality - they are not fixed and the fact that, beside this aspect, they are used as parameters for key constraints that drive the identification of the solution can lead the MRP to alert the planner about the undesired consequences of this wrong assumptions: the planner may be required to reschedule orders already released.

The second category of errors is associated to the constraint of the availability of materials: when a work order involving an item with sub-components generates a negative value of material stocks for at least one of the sub-components, due to a requirement higher than the available stocks, a replenishment order for all the sub-components of that item is issued. So the explosion of the BOM could lead to the proliferation of inventories and related costs.

There are also weaknesses of the MRP systems that are less known, but not less impactful: such as the synchronization with the materials supply flow. For example, when a product that has to be assembled in a cascading way cannot be produced on time due to a missing component, MRP will not order the other components necessary for the realization of the product with a timing that will allow to have them all available together for assembly. It will order them immediately when the need arises and they will be put on hold (generating inventory related costs) until the actual moment when they will be consumed. Basically, not only the amount of replenished material could be wrong, but also the timing of the replenishments.

These weaknesses have not been eliminated with the introduction – during the 80s and 90s - of the MRP II system (Manufacturing Resource Planning). It represents the updated version of the MRP and is currently constituting the engine of the production planning in the ERPs, including SAP ECC. The improvements introduced with MRP II were the Rough-Cut Capacity Planning (RCCP), a summary check of the production resources capacity based on what indicated in the MPS, and the Capacity Resource Planning (CRP), a sort of reporting/alert system that highlights potential capacity problems to the human planner (without elaborating concrete solutions to them).

The reason behind this inability of the ERP to properly support the production planning and scheduling processes stands on the fact that it is the result of a professional evolution process: its structure has been realized through a huge number of attempts perpetrated with the empirical approach of the “trial and error”, which has led to marginal increments, but never to a change of the pillars at the basis of the MRP logic: no disruption has been introduced since the introduction of this technique in the 60s.

The company has found the same hardships with the production plans performed by its SAP system and, as many other companies, has decided to rely on Excel to offset this gap.

The use of this parallel system for the production scheduling generates the necessity of doing extra activities to share information with the sales department, in order to provide the proper visibility. This visibility is obtained through the exchange of e-mails, along with calls and informal chats that are favored by the open space environment where the three department are located.

Target setting

This phase of the project consisted of the identification of quantitative targets that could guide the project and, at its end, be used to define the success or the failure of the work performed along it.

After having understood the current situation, it was clear that the path to be followed was the one of working on the improvement of two main aspects:

- reducing not value-adding activities in order to smooth the production scheduling procedure, with a specific focus on the reduction of the manual portion of the process that is predominant.
  The quantitative target adopted in this case was the (expected) amount of time dedicated to those activities identified as not-value adding that could be saved thanks to the countermeasure introduced;

- reducing the risk associated to the production scheduling by making the production planning more reliable (in order to feed the production scheduling with more accurate data) and by reducing the amount of manual data exchanges, which carries high risks of mistakes. This will have a direct positive impact on the number of revisions averagely performed on the production schedule daily, and on the number of missing parts.
  In this case the number of daily times the production schedule was revised before obtaining the definitive one was considered as an intangible indicator, or - anyway - very hardly measurable.
  For this reason, the target adopted was the (expected) reduction in the number of missing parts. This parameter could be used to compute the Value At Risk (VAR) associated to the mentioned risk.

A side target identified was also the increase of interaction and communication between the planning department and the departments mostly influenced by its activity: the sales department and the purchasing department.

The quantitative measure that was chosen to define a quantitative target was the number of e-mail and calls exchanged by the planners, and the time required for their processing, or execution. Naturally, it was not a very technical target, but it was very practical and operative. This was considered a side target since this savings in time can be associated to the reduction of non-value adding activities.

Root causes analysis

The constant involvement of both the management and the employees of the three departments mentioned (mainly the planning one) allowed the identification of the problems to be tackled and the targets to be achieved; at this point the project proceeded with the next logical step: the root causes analysis.

This phase is one of the most delicate and fundamental ones of the A3 method, indeed its execution is supported by several Lean tools and solid procedures.

In this phase the observation of the scheduling workflow was done with a different perspective: with the objective of identifying the origin of the problems roughly observed in the first phase.

The initial effort was done in order to draft the Ishikawa Diagrams, one for each problem and related target, with the aim of defining the causes of the problems, which were classified in three groups: man, software and method.

The first category included all the causes associated to the human capabilities sphere. The second category included all the causes related to the inadequacies or lacks characterizing the software tools used to carry out the scheduling process.

The third category collected all the causes related to the procedures followed to perform the scheduling process.

The first problem to be presented is the one associated to the high percentage of non-value adding time.

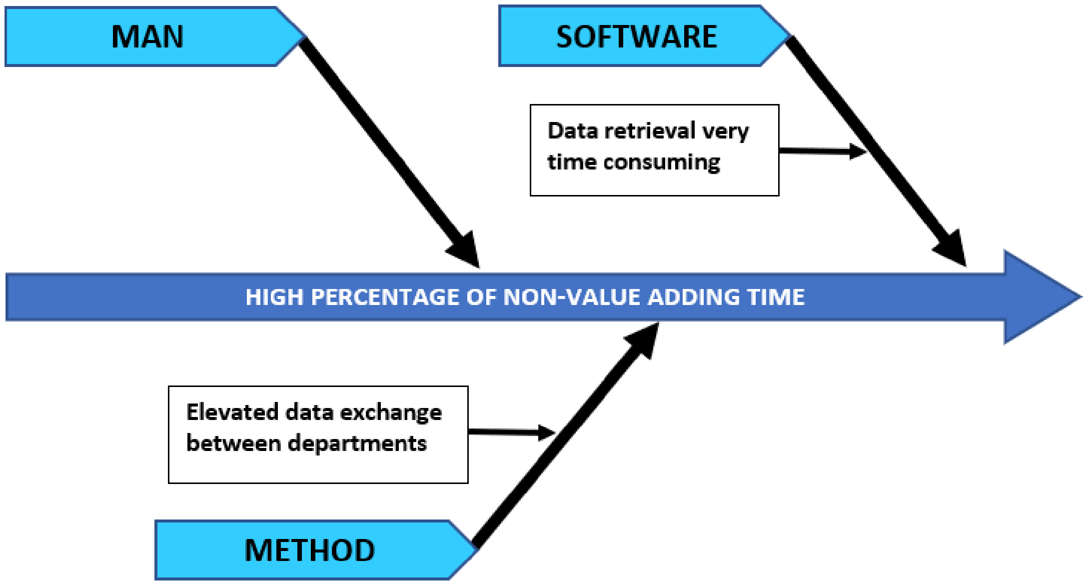


Figure 7. Ishikawa Diagram for High Percentage of Non-Value Adding Time problem

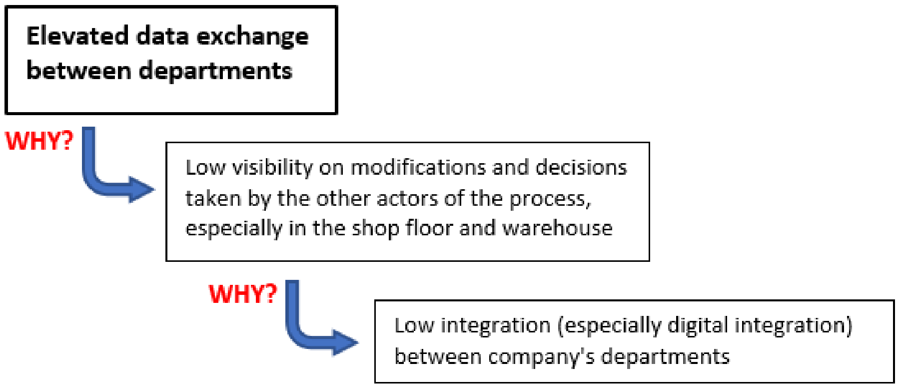
In this case the *"man"* category remained unpopulated due to the absence of any cause of this nature. However, this could not be know at priori and considering the fact that the human component was very present in the process – in order to perform a complete analysis – this aspect had to be investigated too. The observations showed that all planners demonstrated noticeable skills in handling the available scheduling tools: this was probably the result of the use of specific, almost customized, software supports.

Meanwhile, the observation on the field highlighted some criticalities regarding the *method*. Indeed, it was clear that the data exchange required to perform an accurate production scheduling was very consistent: the planners had to exchange several e-mails with the production area managers and with the warehouse to gather information and to communicate their scheduling decisions. The communication of the scheduling decisions had to be done also towards the sales department. Actually the communications had to be done also between the planners, especially the two ones dedicated to the metal-based products scheduling, since their activities were highly interconnected.

With the cooperation of the three planners, it was possible to monitor the average number of e-mail they had to exchange daily: the monitoring phase lasted for two weeks (which was considered to be a reliable time span, considering the discrete repetitiveness of the process, as well as its stability in terms of workload) and returned an average number of 40 e-mails per day (39,6 for the precision). Considering an average time of 2 minutes per e-mail, we discovered an amount of 80 minutes/day per planner of non-value adding time.

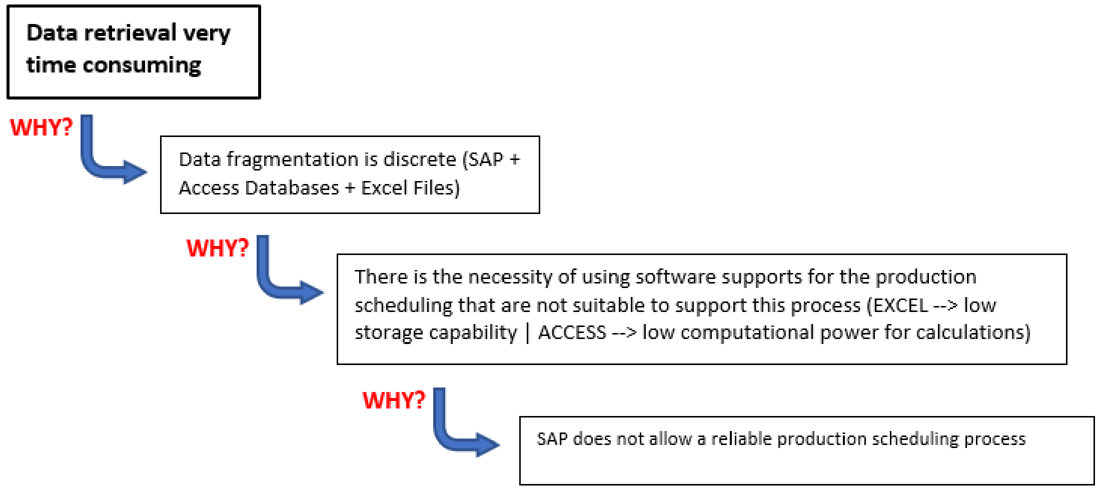
This analysis could not be deepened by including the time spent with calls and small informal chats, due to the high effort to monitor them. For this reason it was decided to consider a +10-15% factor to include them in the considerations. Therefore, the overall time was 90 minutes/day per planner.

The Five Whys analysis was applied to deepen this investigation:



The root cause identified was the low (digital) integration between departments, especially with the shop floor ones since the communication with them cannot be replaced with informal chats. More precisely, with this root cause “statement” the objective was to highlight the unfitting of e-mails as main digital tool used to convey this type of communication and - more in general - the necessity of having it that should be strongly reduced (at least by 75-80% = 65 minutes per planner per day saved), if not erased.

Eventually, one cause was also attributed to the *software*. The following is the output of the Five Whys analysis conducted:



In this case the true issue was represented by the lack of functionalities offered by the SAP ERP, which could not be covered by the functionalities offered by the system created by the company with Excel and Access. The analysis conducted highlighted the fact that this limitation, and this “delta” of capabilities, was not a problem of the architecture of the artisanal system (its accuracy and precision were very high, and the functionalities implemented corresponded to the basic ones required for the realization of a regular production scheduling: MRP, MRP II, availability of materials, new requirements of materials, available-to-promise, capacity-requirement-planning for the departments more easily monitorable, rough-cut-capacity-planning). The actual problem was represented by the natural lack of computational power offered by available software tools. They could be used for the production scheduling in cases of process industry and/or in cases with a limited number of finished products and components to be monitored, roughly speaking less than 100. This number – in the case of the company - was much bigger than this: only counting the finished products this limit was overcome.

The second problem, with related target, where analyzed adopting the same - profitable - approach.

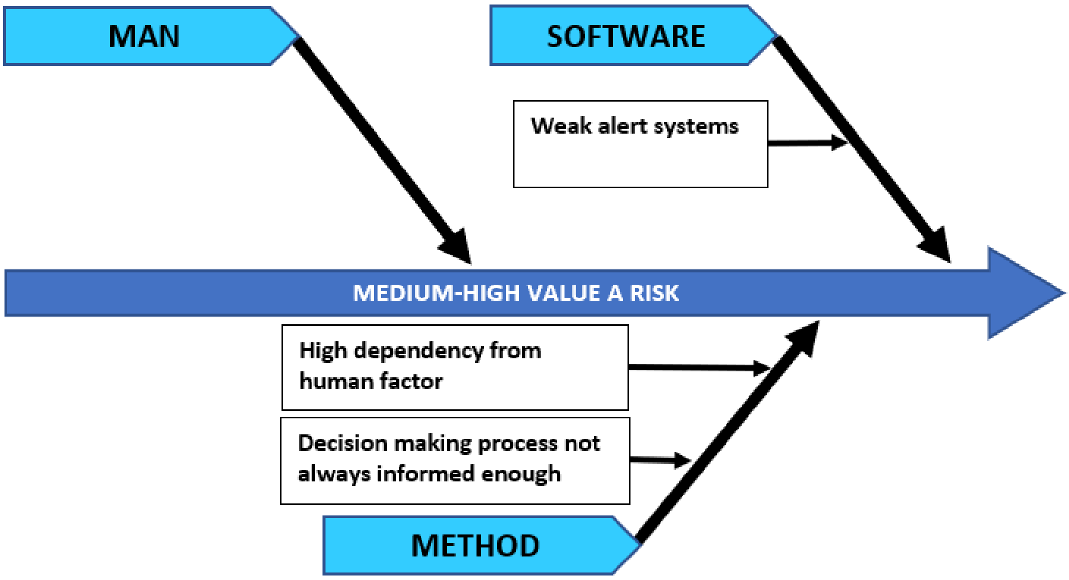
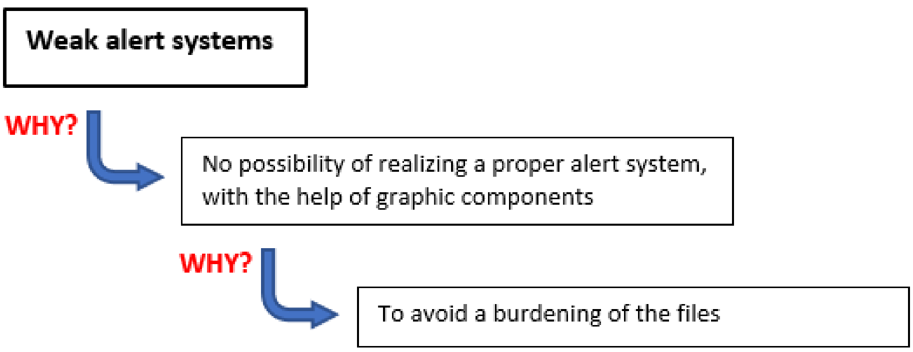


Figure 8. Ishikawa Diagram for Medium-High Value At Risk

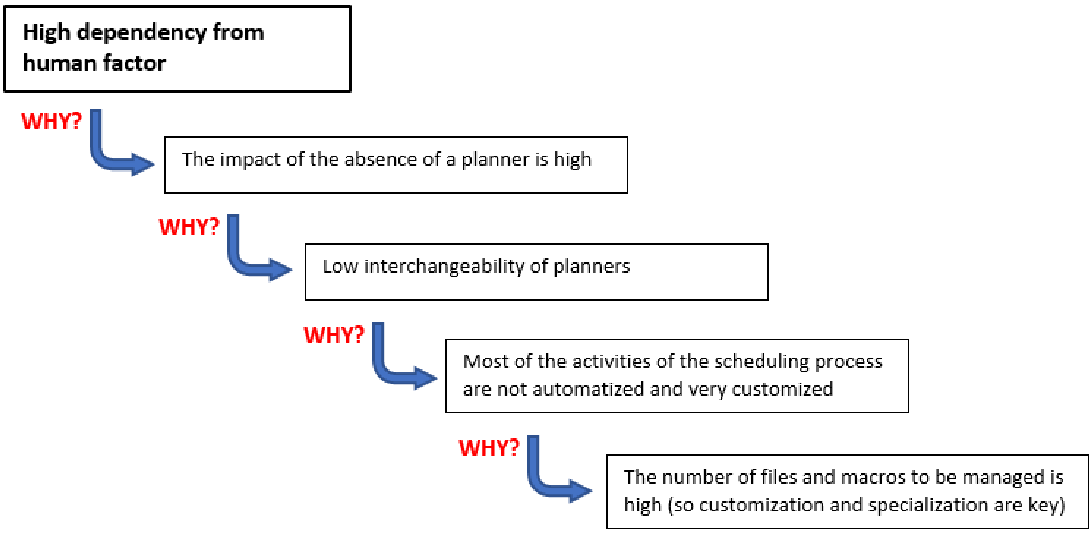
The *man* cluster was unpopulated even for this problem. Indeed, the human mistakes could be inserted, but - considering that the production scheduling is an activity carried out by human with the support of software and will hardly be completely replaced by machines – this cause will always be present.

The software side was further investigated:



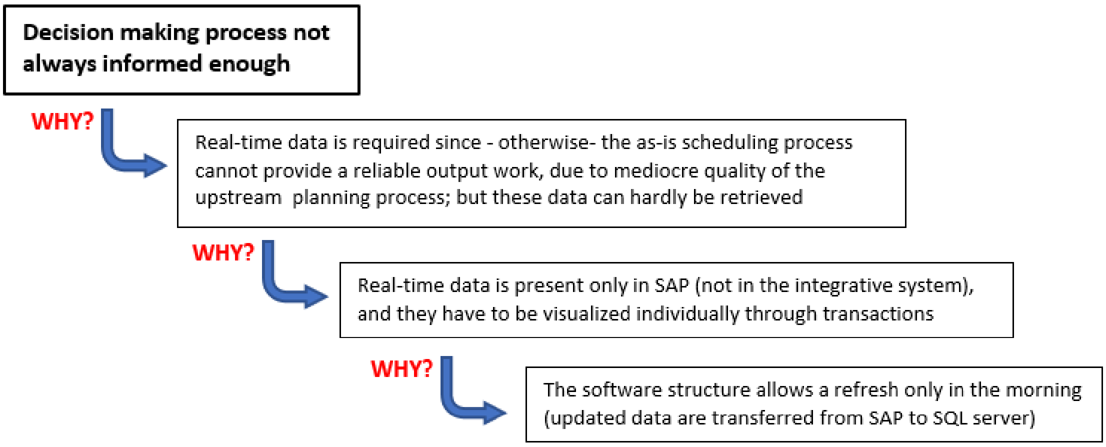
the weakness of the alert system in the artisanal system created by the company did not prevent the planner to commit mistake. The system was not error proof, though. The ultimate reason behind this weakness was the necessity of not burdening the files used by the planners with the risk of incrementing consistently the number of breakdown during the computations.

The method in this case presented two causes to study.



The high dependency from human factor ended up to be originated by the high amount of files and macros to be used to perform a reliable scheduling process. Not only, they must be launched according to a precise order to avoid that some computations lack of inputs. In a scenario like this one, specialization becomes key and – unfortunately – leads to a strengthening of the dependency from humans.

The critical observation of the processes highlighted an additional aspect that reinforced the weight of this cause/criticality: only one of the planners was able to manipulate the parallel system. It was able to intervene in case of malfunctioning or if any modification to the scheduling rules had to be implemented. It represented a true potential single-point-of-failure, especially considering that the training for such high level programming topics could take several months.



The second cause is triggered by a combination of two factors, which are highlighted along the Five Whys escalation: on one side we have the planners' necessity of accessing real time data during the production scheduling due to the mediocre quality of the "indications" received from the upstream process of the production planning. On the other side we have the software limitations, which make the access to real time data very time consuming and exposed to human mistakes: indeed, what planners do to retrieve these data is to go on SAP and use transactions to get to the specific desired data for the different products/components that they are about to schedule, and either remember them when reasoning or copy and paste them in the parallel system's file/s they are using.

In some cases the data required are not present in SAP (such as the precise advancement of a batch in the production system, with consideration of the WIP and other manufacturing variables) and calling or e-mailing colleagues is the alternative way to get to the data: however, it is possible that some colleagues may not answer or answer late generating delays in the process or forcing the planner to use the approximate data found on SAP.

Summarizing, the five causes identified during this phase were the following ones:

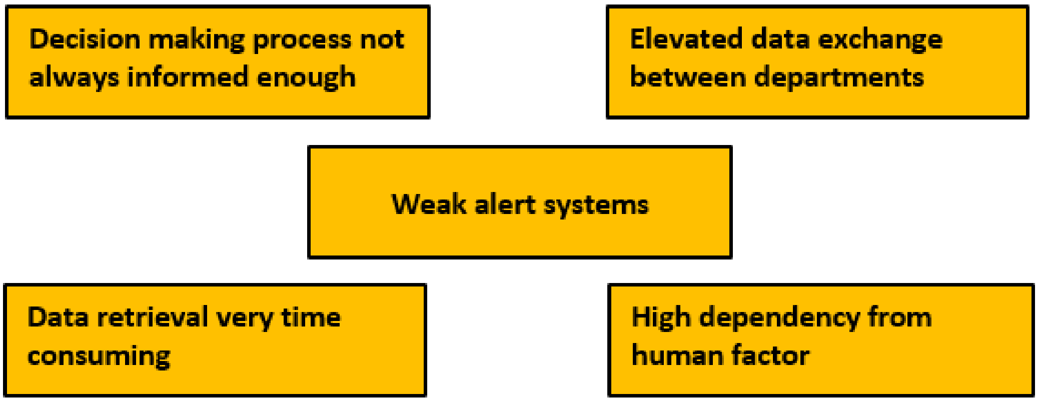


Figure 9. Problem causes identified

At this point of the project, reached after around two months from the beginning of the experience, it was necessary to move on and make the previous phases fruitful by identifying the countermeasure/s (namely the solutions) to tackle as many of these causes as possible.

Countermeasures development

This phase of the method, as its name suggests, aims at the identification of the countermeasures that allow to reduce – and possibly eliminate – the causes of the problem by tackling their root-causes.

This phase was initially supported by the execution of some brainstorming sessions, which involved the different actors potentially influenced by the solution/s (mainly the planners, their supervisor and the planning manager). These sessions were fundamental to guide the research for the solution/s. The common idea that resulted from these encounters was the one of trying to avoid quick-win solutions that could have been useful just in the short term.

The objective shared with, and accepted by, the management was the one of aiming at a small "software revolution" within the department: more specifically the guiding desire was the one of changing the software support exploitable by the planners. In addition to this, the hope was to find a solution that could also modify the way the interaction between departments was taking place.

The long term vision adopted had as main objective the one of setting aside the usage of Excel spreadsheets for the production planning and scheduling processes. They should have become a supportive tool, especially used for reporting purposes, leaving the core of the process in the hands of an ad-hoc software that could satisfy the needs of the company, without interfering negatively with the SAP. The company's ERP represented a true pillar for the company and a reference point for the definition of the to-be scenario.

At this point, thanks to the output of the Root Causes Analysis, it was possible to obtain a satisfying level of custom-tailoring.

Having in mind the needs previously identified, the researches for a proper solution were very fast. In less than two weeks a valid potential solution was identified: the implementation of an Advanced Planning and Scheduling (APS) system.

APS system description

An APS system is considered as a software extension of the ERP system, indeed it must work symbiotically with it and exploit it as database. As previously indicated, the integration between the two pieces of software was a critical (and discriminating) aspect considered during the project and this solution was perfectly fitting this strong constraint. It is possible to see the ERP as the platform of the operation and the data, and the APS as the optimization center. Indeed, while the ERP has

- the focus on integrating and managing the enterprise data through elaborations of batch type
- models the production capacity as infinite or manages indirectly through LTs
- resorts to simple, automatized and repetitive computational logics

the APS is focused on

- analysis and simulation of the activities in the production departments (also real time)
- scheduling process based on finite capacity
- detailed modelling of production resources
- computational logics based on algorithms (heuristics or optimization ones) modifiable by the programmers.

It is clear from this comparison that the scheduling and production control needs of a company are averagely satisfied in a more accurate way by the APS, thanks to their inclination to the simulation and detailed replication of the problem. Therefore, to satisfy both the enterprise needs of control centralization and the production-logistic ones is suggestable to integrate the two software, integrated.

Thanks to APS systems, it is possible to simultaneously plan, and schedule operations based on available materials, labor and plant capacity. APS is especially well-suited to environments addressing complex trade-offs between competing priorities and where production scheduling is intrinsically very difficult due to the number of items to be manufacture.

These systems are also defined as “interactive schedulers” and, from a logical point of view, they represent a very simple solution since the scheduling process is not actually done by the software.

It is the planner that actually performs the production scheduling activity.

Indeed, the philosophy behind this type of software is basically the one of leaving to the user the (rich) decisional task and delegate to the system all the feasibility/consistency checks. The true symbol of this philosophy is the fact that the APSs allow the user to perform some forcings, so to take decisions that lead the schedule to break some constraints.

A peculiarity of this typology of software is the relatively low presence of automation, usually limited to the development of an initial rough schedule (which respects the general rules indicated by the user during the implementation) that the user can modify and force if necessary.

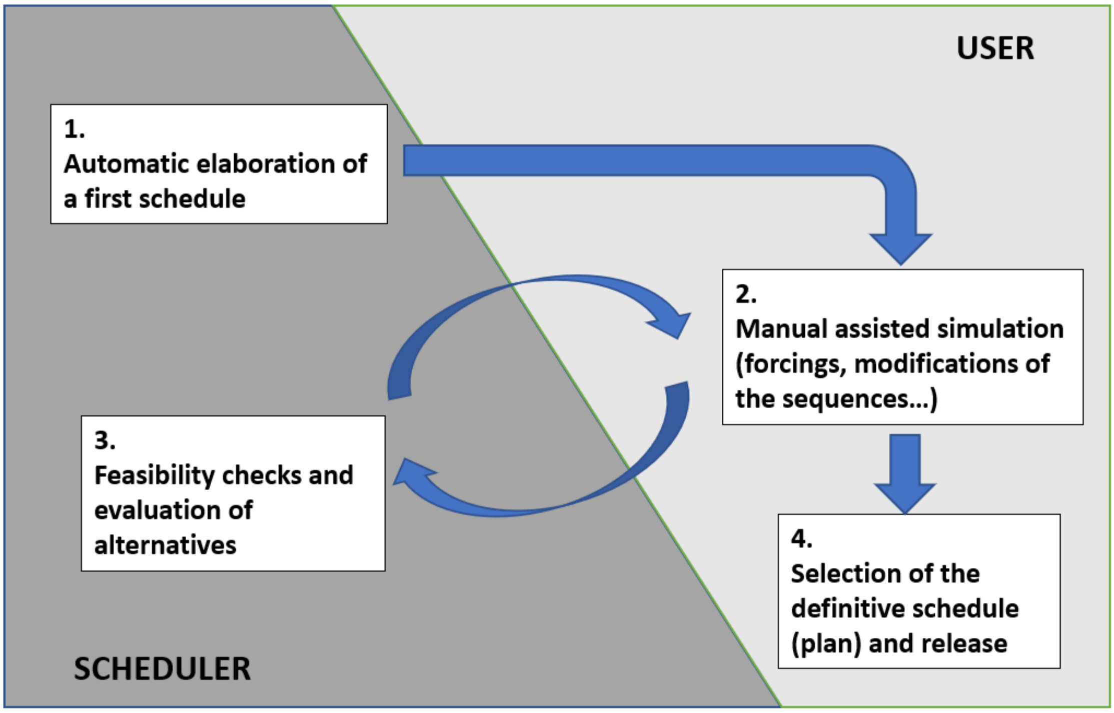


Figure 10. Functioning of an APS (interactive scheduler)

These systems firstly appeared in the 80s and 90s, however their popularity has grown during the last years following the great technological improvements registered: they have strongly benefitted from the huge development of the functionalities offered by computers in terms of computational power, graphical representation, multi-window management and object-based architecture. This last aspect plays a very important role; indeed one of the most common (and winning) features to the majority of the APSs present on the market is represented by the high flexibility and adaptability to the different companies' configuration and needs.

This feature has been enabled - as said - by the object-based architecture, but it is originated from the fact that this type of software was born with the necessity, and objective, of adapting to the specific reality of application, without imposing its standard: this standard had already been set by the "first comer" ERP. This type of software is able to perform the detailed scheduling process also for those companies presenting a production system (or portions of it) with specific peculiarities that cannot be handled, or better "virtually replicated", by the ERP due to its higher rigidity.

The presence of a high number of products and components (maybe with multi-level BOMs), whose production/purchase has to be scheduled, does not represent a problem to these systems.

Indeed, a great technological innovation introduced by the APS system is the usage of the so called "in-memory database". In this database only the portion of data necessary to develop the production schedules is uploaded. This architecture allows to perform elaborations in RAM that are characterized by very competitive time performances (the order of magnitude is seconds), making the production scheduling process more efficient.

In addition to this, the in-memory database allows to rapidly build simulative scenarios, giving the planner the opportunity to operate on the elements of the schedule (production and/or purchase orders, work shifts, production resources schedule, batch sequencing, desired inventory levels) and to understand the effects of his/her actions on reality, before these actions are actually implemented. The simulative scenarios can also be saved until the optimal one (according to the planner) is found; at this point the definitive schedule is transmitted to the company's ERP.

The exploitation of the in-memory database technology allows the application of the Concurrent Planning Logic. This logic overcomes the traditional sequential logic adopted by the closed loop MRP and allows the users to have higher freedom within the planning and scheduling processes.

The idea behind this logic is very simple and consists of integrating, into an interactive graphical environment, a set of modules that operate in a synergistic and simultaneous way (this is where the adjective "concurrent" comes from).

The mentioned modules are:

- modules for the analysis and elaboration of the demand (MPS);
- MRP modules (both MRP and MRPII with CRP), Available To Promise/Capable To Promise (ATP/CTP) components and Finite Capacity Scheduling (FCS) that are able to match requirements and availability, generating – in case of misalignments - new production or purchase proposals;
- tool of pure dating that is able, thanks to the sophisticated algorithms installed, to allocate in the time line the work orders, as well as the production and purchase proposals.

The Concurrent Planning does not provide a predefined schema in the logic flow of the scheduling process: within the simulation environment the users can adopt top-down, bottom-up or circular approaches until the definitive schedule is identified.

Software selection (Vendor Rating)

This typology of software represents a niche within the huge variety of tools that support the Supply Chain Management process. However, during the last fifteen years this niche has grown a lot and several APS providers has emerged; each of those uses their own techniques, algorithms and logic to plan and schedule operations.

A software selection was necessary at this point of the project.

The decision taken was the one of identifying the criteria to be used during the process in accordance with the Production Planning Manager (the planners and the components of the other departments were not involved thanks to the execution of the previous steps of the A3 Method, which had given to all actors the possibility to express their needs) and, after that, proceeding with the research of a potential future partner.

The criteria identified were:

A) APS integration with SAP

   A system classified (or better certified) as SAP add-on would represent the optimal condition.

B) Number of companies operating in the eyewear sector belonging to the customer base

   The highest this number is, the highest the reliability of the provider to the focal since the probability of success of the project would be very high thanks to the familiarity of the vendor with the firms operating in this sector.

C) Size of client companies

   The focal company of this case study is a large company, so the best case would be represented by a software house dealing exclusively with this category of companies.

D) Advanced planning algorithms adopted

   The solidity of the algorithms is fundamental to the success of the project, they should be able the results of years of research and – most importantly – they should be easily modifiable in case of necessity; therefore, also their flexibility plays a huge role in the decision.

E) <u>Provider specifications, characteristics and experience</u>

The evaluation of the vendor itself is decoupled from the quality of its product: in this instance the aspects considered are represented by the reviews (number and quality) of the customer relationship management found on the most known comparison sites (Capterra and Gartner), the presence on the Italian territory (especially in the province of Veneto). During this portion of the vendor rating process also the care given by the provider to its website (latest updates, content richness, successful case studies presented) has been taken into account: it has been considered as a sign of strong reliability.

It was not possible to include the cost in the evaluation due to a time constraint: this typology of software is very tailor-made and the cost defined by the vendor cannot be identified before it visits the company and understands the perimeter of the implementation. The cost of this type of solution is directly related to the number of users enabled to operate (concurrently) on the virtual environment and, especially, to the complexity of the reality to replicate and control. Usually the time span between the first encounter with the provider and the stipulation of an economic offer lasts around 2-3 months. This is the average time required to the consultants to collect all the necessary information regarding the company: production system, number of items to handle, BOMs, amount of data to be transferred from ERP database to the APS's in-memory database, production strategy and so on.

After the identification of the criteria, several providers (with their products) were analyzed.

The qualitative analysis conducted was translated into quantitative terms by firstly assigning to each criterion a specific weight and secondly evaluating each supplier on the different aspects with a score from 0 to 5.

The weights assigned were:

A) 35%
B) 25%
C) 15%
D) 10% (this weight was influenced by the poor capability of evaluating this parameter)
E) 15%

Every score was, later, multiplied by the correspondent weight and the intermediate values were summed up in order to have a unique score for each provider. The comparison was done considering these output.

The Vendor Rating lasted for almost three weeks and the main supportive tool used has been the Web: starting from the analysis of the most general results returned by a basic query/request such as "advanced planning and scheduling system providers" to the analysis of the private websites of the different providers identified. Also the social media accounts (almost exclusively the LinkedIn account) have been checked and used as source of information.

The results of this investigation were constantly reported on a shared excel file, so that everyone could check the advancements of the research and contribute to its evolution.

The ultimate results of the Vendor rating process are presented here below:

Vendor	Product	Crit. A	Crit. B	Crit. C	Crit. D	Crit. E	Total score
Cybertec (Zucchetti Group)	CyberPlan	5/5	5/5	3,5/5	4/5	4,5/5	**4,6**
Tecnest	J-flex APS	3/5	0/5	2/5	2,5/5	4/5	**2,2**
SedApta	sedApta suite	3/5	0/5	3/5	N/A (= 0/5)	2,5/5	**1,9**
Delmia (Dessault System)	Delmia Ortems APS	3/5	0/5	4/5	N/A (= 0/5)	3,5/5	**2,2**

Figure 11. Results of the Vendor Rating

The vendor rating indicated Cybertec as potential best partner for the company, with its APS: CyberPlan.

Cybertec is a software house (with a sales volume of 9 Mio €, of which almost 35% generated outside Italy) belonging to the Zucchetti Group. The entrance in the Group took place in 2020, however the company has a longer history. It was founded by Helmut Kirchner in 1991: the decision of investing and developing a competitive APS system originated from the desire of finding a point of contact between simulation, artificial intelligence and ease of use, with the objective of concretely solving the managing challenges the manufacturing industry has to face. The trigger point for Kirchner was represented by the discovery of this typology of software (the so called finite capacity scheduler) at the MIT in Boston and the total absence of this product in the Italian market: it could represent a true disruption.

The origin of the algorithms logic was, for this reason, considered as reliable. Not only, the peculiarity of Cybertec is represented by the fact that during its more than 30-years history it has focused all resources on the development of its APS, which represent the flagship product of the company. During the Vendor Rating, the quality of this software was considered as almost certain considering that it convinced a huge IT player such as Zucchetti Group, which is characterized by a turnover of almost 1,4 Bn €, to invest in it to enrich its portfolio: the resources of the group could have allowed the development of an in-house solution.

The result of CyberPlan robust evolution is also represented by a long list of successful case studies presented on the company's website and by the notorious companies appearing within the list of the main clients: Pietro Fiorentini, General Electric, Lamborghini, ABB, Baker Hughes, Vertiv, Caleffi, Artsana Group, Carraro, HP Composite. However, the most important aspects obtained from the analysis of the clients of this vendor were the fact that it deals mainly with medium and large companies, and the fact that it serves the majority of the competitors of the focal company in the eyewear sector: Luxottica, Marcolin Eyewear and Thelios. The other vendors did not present any company operating in the eyewear industry among their clients.

Most importantly, CyberPlan is equipped with an interface module that complies with the official guidelines provided by SAP and has an official certification. In fact, CyberPlan is part of the list of solutions certified by SAP, a company with which Cybertec has a partnership.

The mentioned module provides data selection, filtering and extraction functionality along with feedback integration and data updating via BAPIs (Business Application Programming Interfaces). The integration interface between CyberPlan and SAP that has been certified is composed of a package that contains all the objects necessary for the interface (programs, tables, structures, etc.) thus eliminating the need to modify standard SAP objects (tables, programs, etc.). In particular, the CyberPlan module dedicated to SAP identifies relevant information for planning and scheduling processes and transforms them into a simplified format for SAP management. Thanks to this module, companies obtain great usability and remarkable performance.

None of the other providers mentioned any certification that could confirm the ability of their product to integrate with SAP; they just mentioned the ability of their APS to work side-by-side with the client's ERP. However, this information was not considered reliable enough, especially considering that – by definition – this type of solution needs to be supported by an ERP. In addition to that, CyberPlan has been the first Italian software certified by the Demand Driven Institute - and seventh worldwide – for two of its six modules (DDMRP and DDS&OP).

The cited aspects were the ones that convinced the company to identify Cybertec as the vendor to start the negotiation with.

In addition to all this, the people involved in the project were also convinced by the very encouraging reviews about CyberPlan found on Capterra, a free online marketplace vendor serving as an intermediary between buyers and technology vendors within the software industry. The other APSs analyzed were either not present or without any review.

Finally, another decisive aspect that favored Cybertec over the other providers considered initially was the closeness of its headquarter (Trieste) and its offices (Padova and Milano) to Longarone. The geographical closeness, in addition to the fact of having other important clients nearby (Thelios and Marcolin located in Longarone and Luxottica located in Agordo), would have almost certainly assured a high service level in case of professional relationship.

CyberPlan: the FCS

One of the biggest innovation introduced by CyberPlan (and generally by the APSs) is the Finite Capacity Scheduling.

It assigns the workloads (corresponding to the different work orders expected, which are always translated by the software in terms of time) to the company's resources not only referring to the MRP and CRP planning, but also verifying the real production capabilities of the production system. It considers the availability of resources, the links between different working phases, the calendars, the priorities indicated by the planners and – most of all – the workload already assigned to the single resources.

The FCS starts from the date of execution of the scheduling activity and queues up the subsequent working steps that have to be performed on the timeline, based on real production capacities. In this way (thanks to the consideration of all the primary constraints of the firm), it is possible to forecast with a much higher accuracy the actual delivery dates of the finished products to the clients and the real availability of semi-finished products in the production system.

As a matter of fact the efficiency of FCS strongly depends on the detailed representation of the production resources of interest, the ones constituting the skeleton of the enterprise structure, such as machines, tools, instruments, teams.

In order to make these resources considered by the CyberPlan scheduling algorithm as not infinitely available for production, it is necessary to indicate that the WorkCentre to which they belong is characterized by finite capacity: this can be done by activating the *"Finite Capacity" flag* of the WorkCentre and the same must be done also for the single resource. In this way the suite will know that the capacity of that resource will depend on the calendar associated to it.

In order to provide a complete consideration of the actual production capacity, the software allows to replicate situations in which several resources perform the same working phase and the overall available capacity is actually given by the sum of the capacities of the single resources by activating the *"Automatic Capacity" flag*.

CyberPlan: the synthetic indicators (KPIs)

Within CyberPlan the planner has the possibility of exploiting synthetic indicators made available by the suite. They quickly show the quality of the simulated plan resulted from the What-if analysis performed. Their presence allow to easily compare the different scenarios hypothesized.

These indicators can be found in the *Measure* section of the CyberPlan suite. Several of them are available such as:

- WIP
- Service Level (intended as capability of the plan to satisfy the delivery dates promised to the customer)

Figure 12. Example of KPI in CyberPlan

The number and typology of KPIs adopted can vary according to the necessity of the planner: he/she could decide to add also the Utilization Rate of the resources or the OEE.

The communication of this key information represent a huge plus for the planner.

Cyberplan and the Theory Of Constraints: the Drum Buffer Rope model

The theoretical dissertation at the basis of the Drum Buffer Rope model has been developed for the first time by Eliyahu M. Goldratt in the book "The Goal: a process of going improvement", released in 1984. The key concept on which the theory is based is that any firm, which sells either products or services, is constituted by a series of processes connected to each other. Every process is featured by a specific capacity of realizing its output and the one with the lowest capacity will limit the throughput of the entire firm's production system. Therefore, for any company, it is useless and damaging not to consider this aspect when scheduling and proceed with the introduction of new workload in the system.

In this case, the one of a manufacturing company, this approach (unintentionally adopted by the firm, due to the lack of performing tools) translates into the insertion of noticeable quantities of inventories in the system. These big quantities of inventories end up worsening the production flow:

- they generate hardships in the process monitoring and in the identification of priorities;
- they determine the stretching of the production LTs, due to the addition of units waiting to be worked by the resources with the lowest production capacity;
- they complicate the forecasting of the orders overall LT, which leads to the poor dating and the communication of already unsatisfiable delivery date to the clients.

All these problems lead to generation of a huge amount of wastes and a reduction of the company's profit.

All these problems are originated by the fact that the materials are literally pushed in the system with the objective of utilizing at maximum the resources available. This is driven by the basic assumption that is the utilization of resources (all resources) is not high, the productivity will not be high. However, even though, this idea may seem correct, it is not: indeed, the optimal of the system is not given by the sum of the optimal of the single resources belonging to the system.

If resources are optimized, without a global vision/approach, the result will be constituted by optimal local performance, but the system performances will not improve.

Therefore, the concept highlighted by Goldratt is that companies used to concentrate mainly on cost cutting, but this approach only lead to a reduction of the throughput and, consequently, to a departure from the company's objectives. This problem seems to be still present today and, for this reason, the solution indicated by Goldratt is still valid: the improvement of the throughput capacity of the most problematic resources and the reduction of inventory levels must be the drivers for the production system performance improvement.

The Theory Of Constraints allows to pursue this objective: it also triggers and fuels the continuous improvement.

The main step of the theory are the following five ones:

1) Identification of the bottleneck
2) Exploitation of the bottleneck
3) Subordination of all resources to the bottleneck (intended as acknowledgment of the limit imposed to the system by the bottleneck and reorganize production to avoid wastes proliferation)
4) Elevation of the bottleneck (investment of resources to eliminate the bottleneck)
5) Identification of the new bottleneck

The Drum Buffer Rope establishes itself as scheduling model to be exploited to correctly implement the Theory Of Constraints.

Goldratt defined the following three elements:

- Drum
  It represents the resource with the lowest throughput capacity. The so called "pace maker". Its ideal cycle time is defined by the market and it is also indicated as "Takt Time": this parameter is equal to the ratio between the yearly demand from the market and the yearly available time. The delivery dates to the clients are determined by the Drum.

- Buffer
  They are safety times strategically introduced within the value chain in order to shield the system from variability. They basically represent the anticipation with which the materials/components/semi-finished products have to get to the Work Centers before being worked. The concept of buffer is expressed in terms of time, but it is actually constituted by inventories (a safety reserve).

- Rope
  It is the element that connects the material/workload release within the system and the scheduling of the Drum. The Rope basically pulls the materials towards the Drum, without overloading it (accepting also the fact that this upstream resources are not saturated). The downstream resources are simply required to indulge the Drum.

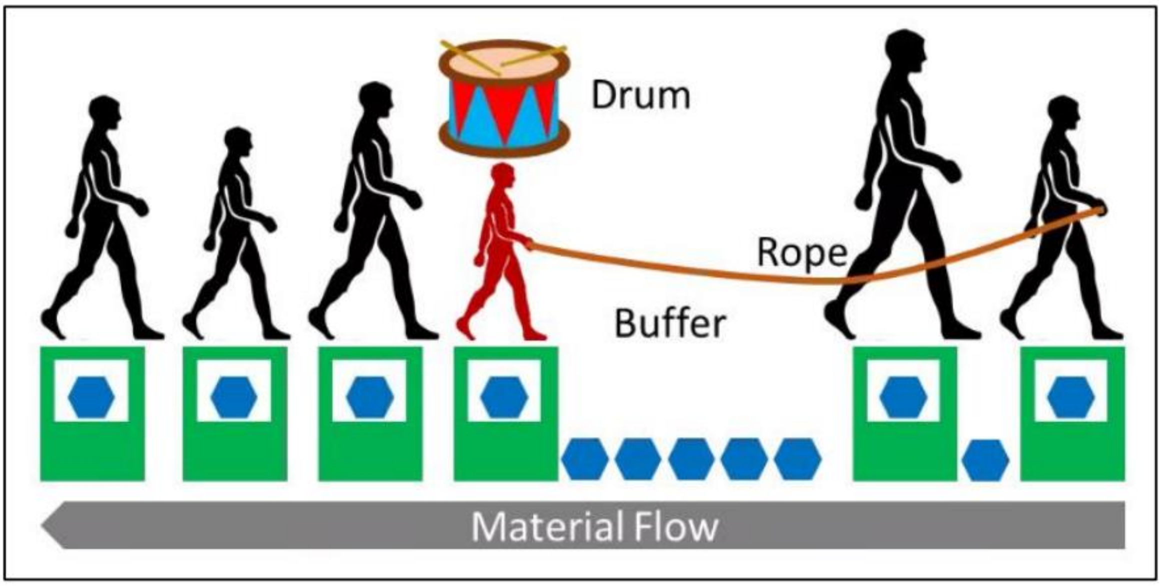


Figure 13. Drum Buffer Rope model explicative representation

It is possible to apply the Drum Buffer Rope thanks to CyberPlan and its functionalities.

It is possible, as already said, to perform several simulations (also identifiable as What If analysis) in order to find the best compromise and observe the consequences by looking at the change of the KPIs selected.

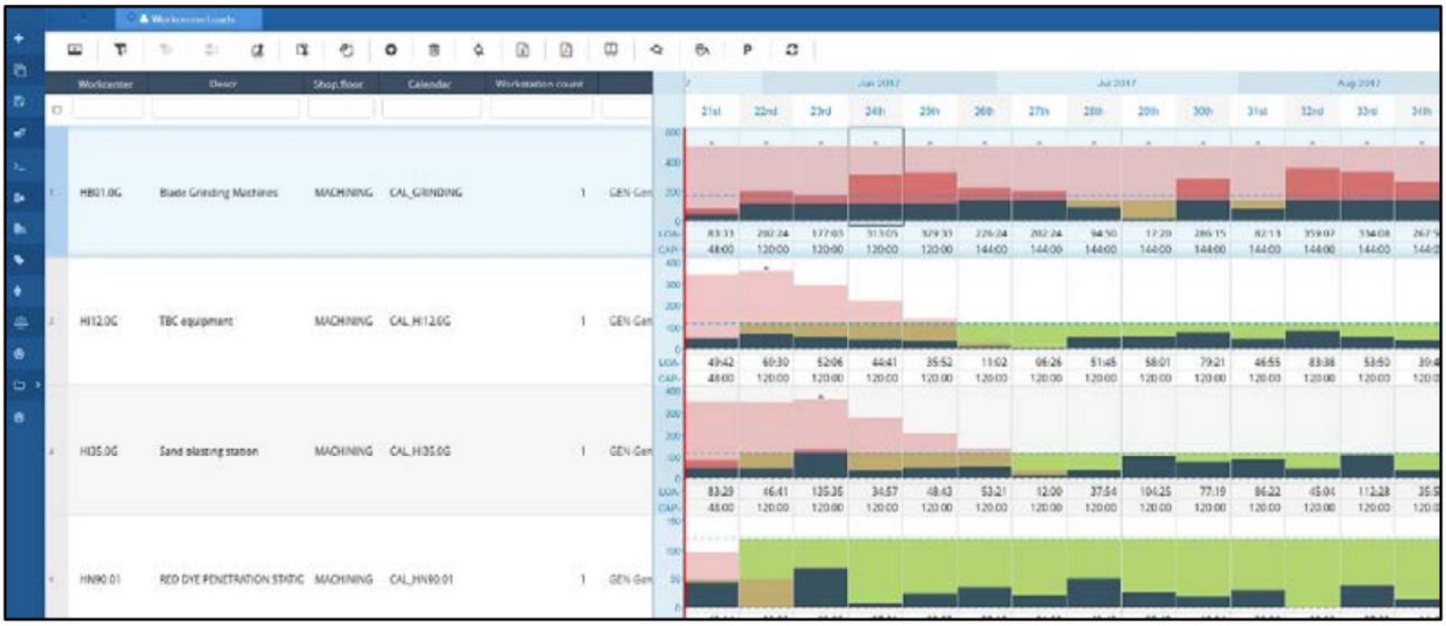


Figure 14. Saturation level of the different work centers showed by CyberPLan after simulation run

Everything starts with the identification of the bottleneck from the workloads section of the suite: this very explicative visual representation is returned by CyberPlan after the simulation is completed and it will be modified according to the changes applied by the planner during any simulation. The legibility of this mask is high thanks to the application of colors:

- The dark blue colored column represent the actual workload of the resource.
- The light green color assigned to the column indicates that the workload expected for the resource - according to the simulation just terminated - is bearable by the resource capacity, which means the conservative threshold indicated (by the planner) as maximum limit is not overcome.
- The light red color assigned to the column indicates that the workload expected for the resource - according to the simulation just terminate - is not bearable by the resource capacity, which means the conservative threshold indicated (by the planner) as maximum limit is overcome. The same color is assigned to the column when the workload overcome the capacity of the resource: in this case the portion of expected workload that exceeds the capacity is represented in dark red.

After the identification of the bottleneck is finished (in figure 13 it is easily understandable that the first resource is the bottleneck by the prevalence of the red color on several days), the planner can adjust the schedule to its necessity and the software will show the evolution of the "bottleneck situation" and will also provide the KPIs related to each new scenario. Obviously, the optimization of the order sequencing and, therefore, of the set-ups is performed is performed by the software for each resource. At this point, the only task of the planner will be doing is to find the best compromise between the protection of the bottleneck (Drum) and the service level: the objective remain the one of exploiting the bottleneck (the second step of the theory).

Cyberplan allows also to perform the third step of the theory, thanks to its functionalities. Indeed, this APS gives the possibility of subordinating all the resources to the bottleneck (or at least the ones located upstream) in a very simple way.

The software gives the possibility of setting a time buffer upstream the bottleneck resource; in this way the all production will follow and respect the rhythm imposed by that resource, providing what necessary to keep it saturated. The value indicated as buffer will practically correspond to the maximum time an item can wait in the queue before being worked by the resource: so the upstream resources will be forced to produce the right amount of pieces, otherwise the exceeding quantity will be waiting for too long in the queue.

It is possible, once defined the first value of this buffer, to iteratively it until the optimal value is found: naturally, even in this process the planner will be supported by the CyberPlan suite, which will allow to perform, save and compare several simulations.

This method will allow to reduce the overall WIP and the production LT, without affecting the system throughput capacity.

In addition to all this, CyberPlan provides very useful indicators that signal the availability of material in relation to the feasibility of the production orders. The scheduler automatically performs an analysis of the missing items related to the weekly production schedule. It also performs a daily analysis of the items to be solicited (expediting).

It is also possible to create in the suite some control masks dedicated to the single product or to the single family of products, in order to be able to execute a daily revision of the Purchase Requests keeping under control the expected consumption, the historical consumption, the inventory levels and the future availability.

Implement Countermeasure

The time spent in the company was not enough to assist and take part to the implementation of the software.

Indeed, even though the application of Lean Approach to the project had strongly reduced the timing expected by the management, it was only possible to arrange the first meetings with the Cybertec consultants. These first meetings strengthened the belief that Cybertec could be the right partner for the company, the competence of the consultants encountered was very high, as well as their ability to comprehend the needs of the company.

Before my leaving, the perimeter of the project was identified and the economical offer was being defined by the vendor. Its draft was expected by the end of July 2022 and, after that moment, it would have approximately taken 2-3 months (probably 4 considering the 2-weeks summer closure of the company) to the top management to analyze the offer and decide upon its approval.

Normally, the implementation of an APS can require between 6 and 9 months, and this indications were given by the Cybertec consultants as well. However, considering that the focal company's IT function was already under pressure and saturated due to the support it had to provide to the US branch for the update of the SAP version, the expected time needed for implementation will be around 12 months.

The company will most likely start working with CyberPlan during the last quarter of 2023.

Monitor results

Even though the actual implementation could not be finalized due to the lack of time, in this brief part of the thesis some estimations of the impacts of the project, or better of the future potential implementation of the APS, are presented. They are informed assumptions based on data provided by the company itself and on the results obtained with similar implementations.

The biggest impacts generated by CyberPlan will be on:

- Service level: with an improvement of the customers satisfaction due to high reliability of delivery dates communicated and promised.

- Workflow smoothing: the functionalities provided by the suite will almost eliminate all low, or non, value adding activities, such as data collection and feasibility analysis since it will perform them automatically in the background, without "bothering" the planners.

  Not only, the presence of a unique virtual place where all the information regarding the production system saturation and performance information are present and accessible by members of different departments will allow a strong reduction of the time spent exchanging key information.

- Inventory costs reduction and missing parts reduction: the approach imposed by the algorithms of the software will allow to change the company culture and obtain a strong reduction in inventory related costs that are now generated by the useless oversaturation of the system with materials and components that cannot be processed by the resources, due to the limit imposed by the bottleneck (still not clearly identified). In addition to that, the higher reliability of the production planning output used to perform the production scheduling will allow to have a more reliable interaction between the different phases of the production system and between the production system and the network of suppliers and third party manufacturers. The Purchase Orders will be more accurately dated (by identifying the right Purchase Request date and knowing the supplier/third party manufacturer LT) and the synchronization with the internal production process will increase.

More precisely, thanks to this implementation, the planning department will allow to free up several man hours every year.

Indeed, for what concern the time dedicated to non-value adding activities such as retrieval of specific information related to the single products (inventory levels of related components/raw material, incoming supply of components and so on) and the time required for the exchange between departments in order to be aligned to provide a high service level to the client, it will be possible – according to case studies analyzed and to the experience of consultants – to obtain a reduction of 65-70%. As indicated in the Root Causes Analysis section, the expectation was a reduction close to 75-80% of the almost 90 minutes/day per planner of non-value adding time (which means 15% of the daily working time). Nonetheless, this result should be considered quite satisfying and, most importantly, very credible. It would represent a reduction of 60 minutes/day per planner: this means 3 hours/day , consequently, (considering an amount of 250 working days per year) 750 hours/year. The company kindly provided an indicative hourly salary for this position in the company, since it can slightly vary according to the seniority, which is equal to 14 €/hour. This means a saving of 10500 €/year.

However, the important aspect is that the real benefit in this sense is the possibility of having every planner dedicated 1 additional (to the as is scenario) hour to the production scheduling or to the strengthen the integration with the other departments (especially the sales department) through alignment meetings or co-working sessions, situations that are not present at the moment and that could boost the overall company’s service level.

The second great aspect to consider is related to the second problem identified: the Value At Risk.

The Value At Risk considered in this project is the monetary value of the semi-finished products that are blocked at the last production stage due to missing parts, which means they are very close to be considered finished products. They can considered as lost revenues due to the missing parts issue generated by the poor quality of the production planning and, especially, scheduling processes. The true Value At Risk could not be computed due to the fact that the estimations of the mark-up applied by the company, which would have allowed to know the average unit selling price and the revenues, would have been most likely incorrect.

Due to internal policies, the company decided not to share the selling price of the finished products so the lost revenues could not be computed. However, they agreed to share the value of this semi-finished products as well as the number of days they spent waiting at the last production stage.

This allowed to monitor the average actual Value At Risk during the first semester of 2022, which actually represents the amount of financial resources frozen.

Month	Average weighted days of waiting	Sum of Q x days of waiting	Average unit value (weighted)	VAR (Value Blocked at last stage)
Jan-22	17,01	154078	31,54 €	**4.860.273,11 €**
Feb-22	19,33	173715	32,92 €	**5.718.953,66 €**
Mar-22	15,76	159947	36,90 €	**5.901.957,16 €**
Apr-22	18,60	187712	34,79 €	**6.530.793,21 €**
May-22	19,06	137197	30,52 €	**4.187.485,82 €**
Jun-22	15,10	135290	31,42 €	**4.251.260,83 €**

The first column indicated the average weighted number of days spent by the semi-finished products. The second column represents the sum of the products (one for each semi-finished item) between the number of unit waiting and the days spent by those unit waiting beyond the expected completion date. The third column represents the average weighted value of the units blocked, which namely is given by cost sustained by the company until that last production stage plus the cost of material and/or components constituting that semi-finished item. The forth column represents the overall amount of financial resources blocked, it is given by the multiplication of the value present in the second and the third column.

It must be noticed that, a portion of these items are waiting to go through the last production stage on purpose due to the MTO production strategy, and they should not be considered in this estimation. This percentage has been estimated as equal to 20-25%.

The average total value registered during the first semester of 2022 is 5.241.787,30 €/month.

The introduction of CyberPlan can lead to a reduction of 30-35% of the number of missing parts (the promise of the vendor is actually 50-55%, however it seemed to be a too optimistic percentage: it probably represents one of the best case scenarios) and therefore an equal reduction of the number of units of semi-finished products waiting.

This means a potential reduction of 1.179.402,14 €/month. In comparison to the almost 425 Mio € of revenues and the almost 180 Mio € of COGS generated by the company in 2021 this figure does not represent a huge amount and it has also to be compared to the annual cost of the CyberPlan licenses and maintenance, but it represents for sure an interesting improvement for the company.

Conclusions

The research proposal of this thesis was practically "How can Lean Methodology impact positively on a digitalization project? How can it, broadly speaking, improve project management?" and the answer can be given by a simple parameter that is always monitored during projects: time.

Indeed, the time required to get to the definition of the technical project perimeter with the vendor's consultants has been almost 4 months, more precisely 15 weeks. The portion of this time dedicated to the software selection has been almost 9 weeks. The time dedicated to a software selection, according to Software Path, is averagely 20 weeks, and this time can increase of 5-8 weeks in case of large companies. So, considering the 20 weeks duration as benchmark, the almost 11 weeks difference between the average time required and the one actually registered in this project represents a reduction of around 50% in time.

This find a validation in reality of things on the workplace, which is characterized by a noticeable number of useless meetings (almost a third according to a recent article published by BnnBloomberg) that could be avoided with the exposure or the sharing of self-explaining report such as the A3 Report. Easy information visualization can represent a key asset for companies to save time and the A3 Report represents the best method to leverage on this potential.

Not only, the solidity of the A3 Method leads to the identification of all the fundamental needs to be satisfied by the solution and this aspect allow the probability to identify the right solution at the first attempt and in a short time. So, beyond time aspects, the A3 Method gives a bigger probability of obtaining a high quality result since it allows to involve all the interested actors in a deeper way and push them to share their point of view in a clear and synthetic way.

The high satisfaction of the company represents the best KPI to monitor the project's quality: the company has - indeed – explicitly required to keep collaborating with the Politecnico of Milano through these typology of projects, which have been introduced in the academic path of the Industrial Management Stream (Management Engineering) by Professor Portioli Staudacher Alberto, a huge expert and divulgator of Lean Thinking.

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Figure1. https://www.researchgate.net/publication/344842357_How_the_combination_of_Circular_Economy_and_Industry_40_can_contribute_towards_achieving_the_Sustainable_Development_Goals

Figure2. https://www.scopus.com/search/form.uri?zone=TopNavBar&origin=&display=basic#basic

Figure3. https://www.lean.org/lexicon-terms/toyota-production-system/

Figure4. https://www.leanuk.org/not-every-problem-requires-an-a3/

Figure5. NOT NECESSARY → Figure manually created with figures not covered by copyright.

Figure6.

https://help.sap.com/saphelp_SCM700_ehp02/helpdata/en/4c/3accbeb73b5793e10000000a15822b/frameset.htm

Figure7. NOT NECESSARY → Figure manually created with figures not covered by copyright.

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Figure10. NOT NECESSARY → Figure manually created with figures not covered by copyright.

Figure11. NOT NECESSARY → Figure manually created with figures not covered by copyright.

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Figure13.

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1. Clarify the problem / Problem Backgroud / Current situation

Is:

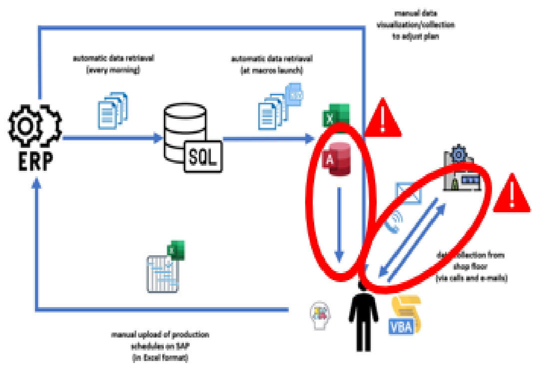
Is not:

Problem statement:

INEFFICIENCIES IN THE PRODUCTION SCHEDULING PROCESS	INACCURACY OF THE PRODUCTION SCHEDULING PROCESS

2. Breakdown the problem

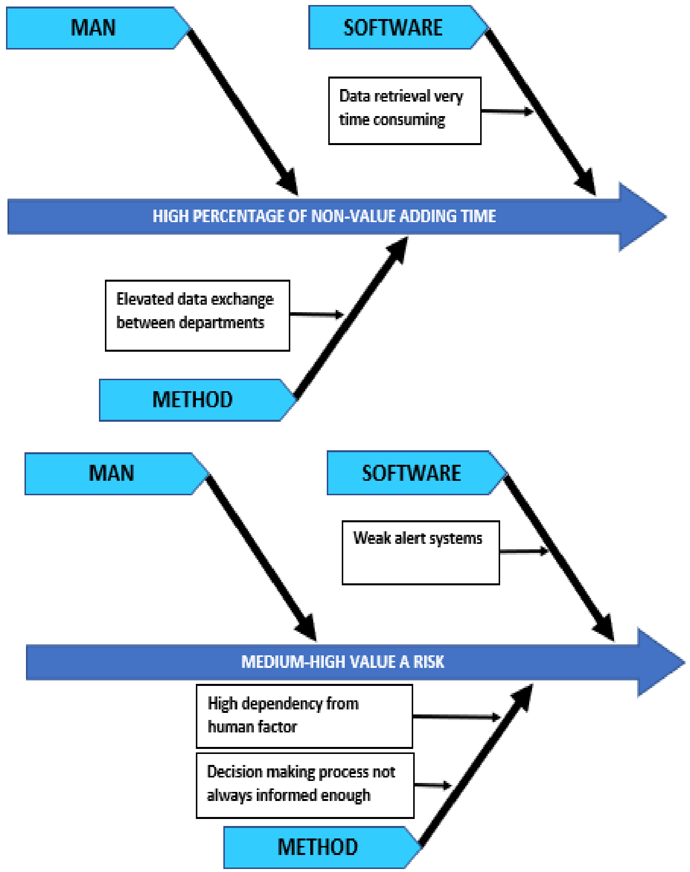
The use of the MRP SAP, which operates at infinite capacity, does not allow to proper consider production constraints: they are therefore monitored with Excel and Access.



3. Set the Target

1	REDUCTION OF PERCENTAGE ON NON-VALUE ADDING TIME BY **80%**
2	REDUCTION OF VALUE AT RISK BY **35-40%**

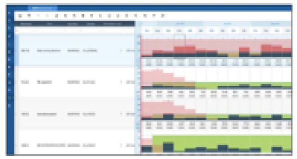
4. Analyse the Root Cause

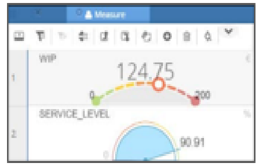


5. Develop Countermeasures

	Countermeasure	**Impact on target**
1	APS IMPLEMENTATION	REDUCTION OF LOW VALUE ADDING TIME INCREASE OF SCHEDULING RELIABILITY

6. Implement Countermeasure





7. Monitor Results & Process

Month	Average weighted days of waiting	Sum of Q x days of waiting	Average unit value (weighted)	VAR (Value Blocked at last stage)
Jan-22	[illegible]	[illegible]	[illegible]	[illegible]
Feb-22	[illegible]	[illegible]	[illegible]	[illegible]
Mar-22	[illegible]	[illegible]	[illegible]	[illegible]
Apr-22	[illegible]	[illegible]	[illegible]	[illegible]
May-22	[illegible]	[illegible]	[illegible]	[illegible]
Jun-22	[illegible]	[illegible]	[illegible]	[illegible]

POTENTIAL SAVINGS:
1.179.402,14 €/month

8. Standardise & Share Success