POLITECNICO DI TORINO

Master Degree in Automotive Engineering

Master Thesis

APPLICATION OF WORLD CLASS MANUFACTURING METHODOLOGY AT FPT INDUSTRIAL SPA

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Index

Introduction

The World Class Manufacturing (WCM) system integrates the methodologies of Total Productive Maintenance (TPM), Total Quality Management (TQM) and the philosophy of Lean Manufacturing. This standard was introduced in the industrial plants of Fiat group in 2005 by the then CEO Sergio Marchionne, who had the task of raising the fortunes of the group from a period of deep crisis. The WCM methodology has made it possible to establish an effective system able to reduce losses, eliminate waste, increase product quality and monitor economic and production trends, based on the logic of continuous improvement.

The present thesis illustrates the case of application of the WCM method in the FPT Industrial S.p.A. production plant in Turin developed at the Gearboxes and Thermal Treatment operating unit, in particular the activity described was carried out during the first half of 2021 and includes applications in the two macro areas of the WCM structure of Autonomous Maintenance and the industrialization of new products, with practical examples and evident results.

The first chapter of the thesis deals with an overview of the WCM method, with its origins, its objectives and a general description of the technical pillars that compose the WCM temple. Then, a focus on the organization of the company and on the structure of the plant, where the thesis project was developed, is reported in the second chapter. The third and the fourth chapters are the core of the work, the former discusses the main activities carried out in the first part of the thesis project and it contains the seven steps proper of the Autonomous Maintenance pillar methodology, with example of applications and main outcomes. The latter represents the second important contribution, and it deals with the Workplace Integration activity. It is a fundamental tool that the WCM methodology proposes to adopt and follow in the industrialization of new products.

Finally, a brief summary of main results, limits and future applications is presented in the last chapter of the thesis.

It is interesting to observe how carrying out activities according to a well-established and well-interpreted method leads first of all to effectively predict the costs and potential benefits, but also to complete projects according to deadlines and customer requests.

The company has been part of the world class for about 13 years, and this means that within it there are workers with a very high know-how and extensive experience, fundamental requirements for the proper performance of activities. However, the periods of economic crisis

and pandemic have limited the potential of the company and of the method. This caused, within the plant, a strong division between areas in which WCM's activities have been able to continue equally and areas instead more neglected that struggle to align with the new performance standards. For that reason, the company needs to daily work on the imbalance generated, especially in the last period that sees a new increment on volumes and workloads.
Most valuable results achieved by this thesis regard firstly a project in the field of Autonomous Maintenance. Its implementation ensured to maintain the full utilization of the line that operates the turning and the toothing of the secondary shafts of the gearboxes before the heat treatment. Its implementation kept the efficiency close to 93%, and ensured to be competitive in the market generating a cost saving of about 10,400 €/year. Another important result concerns the workstation analysis carried out during the Workplace Integration (WPI) activity. It led to reduce the not value-added actions from the 27% to the 8% of the whole operation sequence, hence it meant improvements in terms of takt time, ergonomics, and safety, consequently meeting the customer requirements.
Both the cited activities were very appreciated during the WCM audit days in the spring of 2021 giving a consistent contribution to the global WCM mark, that represents a company target.

1. The World Class Manufacturing philosophy and pillars

The World Class Manufacturing (WCM) program has been introduced in all plants of the FCA group since 2005 and, as the responsible of the manufacturing, Stefan Ketter, at Fiat Group Automobiles SpA declared, the WCM gives a clear visibility of losses and sources of waste but also a strong orientation towards their reduction. The Cost Deployment is distinctive of the WCM approach, it enables the identification of the most effective ways to success (FIAT Group Automobilies, 2007).

To do that the WCM integrates the quality control, the preventive maintenance and effective management into a platform composed by ten technical pillars and several management criteria, each of them deploys in 7 steps, it represents a simple scheme that allows the diffusion. This chapter will deal with an overview of the origins the method and the structure of the World Class Manufacturing system.

1.1. WCM origins

The WCM method was developed in the United States in the 90s. In Italy it was introduced by the FIAT group around 2005 and is considered the basis of the recent positive turn.

The WCM method is a coherent set of methodologies that have been implemented since the second half of the 1900s.

A methodology that will certainly need to be mentioned is the lean production or Toyota Production System which, through its principles, constituted a sort of revolution compared to Henry Ford's *mass production.* What lean production brings to WCM definitely is the customer orientation, producing only what the customer asks for (pull logic), creating a continuous flow that allows the product to leave the factory as soon as possible. The constraint to the customer, allows to generate output only when the customer requests the product, thus avoiding creating excesses in the warehouse. The other lean principle that WCM has mastered is the search for perfection**:** WCM wants to improve the performance of the production process by eliminating waste and improving quality (Shonberger, 2008).

But it must not only be quality that improves safety, people's working conditions and respect for the environment are also part of the improvement program.

In addition to lean production, another methodology absorbed by WCM is the "Six Sigma".

It is a statistical term and indicates a quality management based on the control of the mean quadratic deviation (usually indicated by the Greek letter Sigma). The goal is to reduce the variability on production processes that can cause waste and defects, thus trying to reach a quality level as high as possible.

Another important methodology for WCM, also inherited from Toyota, is TPM, Total Productive Maintenance. This method aims to prevent machine failures, rather than correcting them at the time of failure. In this way, machine downtime is drastically reduced and consequently production blocks as well.

1.2. WCM method

The WCM, as well as the Lean Production, is based on the concept of "Continuous Improvement", it is intended to maximize value added activities (VAA) by eliminating each source of loss or waste. This by means the involvement of all people that operates at each level of the company. The three main terms to focus on are: "Value added" activities, that are what the customer recognizes as a value of the product, the "Loss" especially the allocation of a resource that does not create added value and the "Waste", it exists when more resources then necessary are adopted to (Fabio De Felice, 2013).

A fundamental task of the WCM is the involvement of the whole organization, from the shop floor to the quality department, through the logistic, work analysis until the management department.

In order to achieve WCM objectives it is important to implement a specific and standardized methodology, to apply specifical tools and to work on the people mentality.

One of the most relevant innovation introduced by the engineer H. Yamashina is the *Total Industrial Engineering,* it is a system based on the reduction of unnatural operations (Muri), irregular operations (Mura) and non-value added operations (Muda).

The WCM methodology is composed by ten technical pillars and ten managerial, each of them is focused on specific themes, these will be investigated in the section 1.3.

The path that the WCM usually follows is a bidimensional one, the former is the "Depth", each technical pillar has to develop seven steps that drives the process towards the continuous improvement, and they can be collected into three different levels. These are the "Reactive", so when issues are individuated, and corrective activities are consequently adopted to recover negative effects of that problem. The second level is the "Preventive" one and it passes through the study of processes where problems occur, the identification and the elimination of root causes to empower the process. Finally, the "Proactive" is a hard task that involves the study of the process before its definition (Fabio De Felice, 2013).

The second dimension is the “Extension”, the WCM activities always start from a model area then they are extended to the similar ones according to the cost deployment while the model area develops more complex projects.
The validation and the achievement of the several levels of the performance is due to an “Audit” system, they can be both intern and extern and thy evaluate the level of implementation of WCM toward those standards of the World Class. Intern audits are adopted as auto-evaluation and pillar leaders are in charge to carry out them. The extern audits, instead, are holden by World Class Manufacturing association delegates.

1.3. WCM pillars

A brief overview of each technical pillar that sustains the WCM temple (Figure 1) is presented in this section, so main fields of occupation and tasks are summarized for each of them.

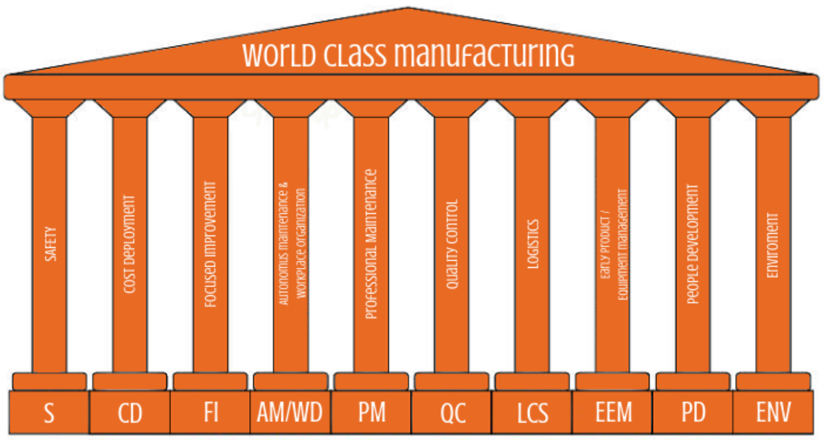


Figure 1: WCM Temple [4]

- Safety (SAF):
  The safety pillar has the aim to develop a not dangerous and healthy way of working, by following ergonomic rules on workstations. The final scope of the pillar is to reach the zero accidents and to continuously improve the working environment.
  Main principles of the safety pillar are:
  - Do not pollute
  - Instantaneous optimization of resources
  - To adopt products eco friendly

As it is common in the WCM approach, the activity of the pillar is deployed according to 7 steps, they lead to a full implementation of the safety management system.

The team starts its activity by analyzing all the injuries and their root causes in order to develop the proper risk evaluation, this is achieved by means several tools that the WCM method offers, they are checklists, KPI and KAI of safety, risk assessment tools, etc. Following steps are intended to establish countermeasures against those possible injury causes and to extend them toward all similar areas. This approach has the objective to set initial standards that will lead to the zero accidents objective but also ensure an efficient monitoring of unsafety conditions in the plant. Final steps are dedicated to the automatization of all the activities thanks to the introduction of autonomous safety standards and finally with a complete safety management system.

- Cost Deployment (CD):

  It is a method intended to the improvement of plants' administration and control because it introduces a connection between areas to be improved and performance improvements, those obtained by applying all technical WCM pillars. CD allows to define those projects that have an impact on loss reduction, waste, or non-value-added actions.

  Its activity is based on the study of costs factors, observation of losing processes, verification of proper know how for loss reduction, prioritization of projects according to their impact and their importance in accordance with benefit/costs analysis and the continuous monitoring of progresses and results of improving projects.

  The higher task for CD pillar is to transform all measurable losses into costs and it is possible thanks to the relationship between losses and their root causes. Wastes and losses are always linked to the machine either than the human or the materials and the objective of cost deployment is to go back to the principal cause.

- Focused Improvement (FI):

  This pillar represents the logic link that ensures that all the improving actions are coherent with each other. The aim of the pillar is to reduce the higher losses that influence the production system of the plant, moreover it is intended to develop competences and know-how about problem solving. The pillar team works to eliminate main losses highlighted by the Cost Deployment pillar focusing its activities on priority issues that an elimination belongs to the highest benefit for the company. In particular,

the scope is to eliminate all those non added value activities and to drastically reduce process inefficiencies in order to improve the competitiveness of the product.
Expected results from the FI pillar are the improvement of the Overall Equipment Efficiency (OEE), the reduction of set-up times and wastes, the professional growing and the development of a spread attitude toward the continuous improvement.

- Autonomous Maintenance (AM):

  The Autonomous Maintenance is one of the three pillars grouped under autonomous activities, together with Workplace organization and the Professional Maintenance. The former has the aim to prevent breakdowns and minorstoppages of machines that are caused by the lack of base conditions.

  The AM is not a specialistic activity as the professional maintenance, but it something that has to be learnt and applied by all the people that daily interface plants and machines. It is based on operators’ knowledges, and it exploits very simple tools as plastic covers to protect some parts of the machine.

  Typical actions of AM are the cleaning, the lubrication, screw regulation, temperature checks, noise and vibration control, small repairs and little improvements.

  The final scope is to let operators to restore, autonomously, basic conditions of machines, to make inspections and to eliminate dirt causes. The scope can be achieved by applying standards and their continuous improvement. Despite the activities of AM and PM, till the third step, are both prevention and periodic maintenance activities it is advisable to separate working teams and standards between the two pillars.

- Workplace Organization (WO):

  The Workplace Organization pillar is constituted by a group of several technical criteria, methods and tools useful to build the workplace as ideal with the intent to improve the quality, the maximum safety and the highest value of the product. This means that ergonomics, quality and safety have to be ensured by actions based on continuous improvement and robust work processes. Main specifics of this pillar are the correct training of operators, the perfect position of tools, materials and consumables in order to guarantee the principle of minimum material movement.

  Since this pillar must consider several aspects and processes the team is composed by the operative unit responsible, which usually is the pillar leader, but also by the production responsible, a member of manufacturing engineering department, the logistic referent and the ergonomic one, and finally members from safety of the operative unit and the quality responsible.

- Professional Maintenance (PM):

  This technical pillar includes activities act to the implementation of a maintenance system able to achieve the objective of zero breakdowns and zero minorstoppages of facilities so creating savings making machines more durable. Activities are based on predictive and corrective maintenance methods.

  The professional maintenance enters in the endless cycle of the continuous improvement of the plant together with pillars of FI, AM and EEM (early equipment management). This continuous improvement process is developed starting from the Cost Deployment activity that individuates main losses and it allocates them in the process, then the elementary unit where the loss is generated becomes the model area for improvement activities. For example, if the major loss is due to a manipulator robot that frequently stops for breakdown, the 5 Whys method has to be adopted to discover the cause that can be a problem in the control system. Once the problem is solved it is necessary to control all the other manipulator robots in the plant and eventually the problem exists as well, the previously adopted solution must be implemented. The continuous improvement hance proceeds with the formalization of the new lesson learnt.

  This kind of approach leads to high benefits in a relative short time while AM and PM activities ensure the maintenance through the time so optimizing efficacy and efficiency.

- Quality Control (QC):

  The quality pillar covers a group of activities that define the process conditions in order to completely avoid “Not Conformities”, it means when a feature of a component or a product is far from the specified characteristics. Moreover, the pillar has to maintain all of those conditions in the time to ensure a perfectly compliant production.

  Production conditions are kept under control with a fixed time interval in order to verify that all the values respect preset standards of Conformity.

The trend of all measured values is regularly checked directly on the process in order to anticipate a possible defects generation and suddenly act creating and applying proper countermeasures.
The quality control is needed in a company specially to satisfy customer needs and because each scrap generated represents a cost.
Thanks to the quality control, the company can ensure to ship products compliant with the customer requirement at the lowest price. Furthermore, it is useful to define the conditions of production systems that avoids nonconformities. Finally, who works on the solution related with quality problems improves his competences and obtain a professional grows.
All the features that the market senses related with “Quality” need to be strictly linked with material specifics, production methods, workers knowledges and machine characteristics. This kind of connections lead to a group of conditions relative to the process intended to avoid nonconformities.

- Logistics & Customer Services (LCS):
  Logistic regards the organization of physical fluxes and materials flows that enables the customer satisfaction. This pillar involves three different sections of the company, hey are the commercial and sales process, the manufacturing and the one in charge of buy and distribution of components.
  Therefore, main scopes for LCS are the improvement of customer satisfaction both in terms of quality and time to delivery, then to reduce movements costs and to break down capital investments on semifinished products and work in progress.
  One of more relevant aspects of the logistic pillar is to be able to produce exactly required products by the customer, at the right time and in the right quantity. To reach those objectives it is necessary to reduce at minimum semifinished products in order to reduce as much as possible the delivery time. A further task from Logistic is to minimize the inventory because it enables a continuous production flow that maximize the efficiency of the invested capital. The third principle is the “Minimum Material Handling” principle, it deals with the objective to avoid any not useful movement that does not create value-added, lowering costs as well.

- Early Equipment Management (EEM):

  Industrial plant management is a hard task that is influenced by production issues, maintenance problems, quality defects generation, technical specialists needed, high levels of performance difficult to reach, special safety requirements hard to manage. Those listed problems negatively impact on the cost trend, both on initial costs and working costs, labor costs, maintenance and losses due to non-conformities and breakdowns. The EEM methodology makes equipment competitive, specially from the continuous improvement by means the ability to anticipate equipment problems occurrence. It is enabled by including on new equipment project all the past experiences learnt on equipment launches, both in the former steps and at regime.

  For that reason, it has a fundamental role a correct collection of the knowledges acquired because it constitutes the base for new equipment projects. Main task is to anticipate problems occurrence and to solve them before the production start, this allows shorter industrialization time that verticalize the production curve.

- People Development (PD):

  This is the pillar dedicated to the people growing from a professional point of view, it represents a competitive key fundamental to reach the excellence. This pillar is in charge to establish a permanent competences development system, based on a continuous evaluation of gaps in terms of skills and competencies and on the management of training programs. Principal objectives to get zero human errors, therefore, to realize a perfect collaboration between people and technical systems, ensuring the correct execution of operations. The pillar has to motivate and involve workers assigning responsibilities in the continuous improvement cycle.

  From a focused point of view, people training may represent a source of loss because it requires time to spend on improvements. However, enlarging the prospective, people development belongs to a global loss reduction due to higher skilled workers, therefore it is important that all the activities need to have quantitative and qualified results related with the impact they have on losses and quality issues.

- Environment (ENV):

  "Environment technical pillar concerns the entire production system through the knowledge and management of environmental aspects and impacts related to the activities carried out. The pillar Environment is therefore the management tool which allows to know, reduce and control the environmental impact generated by the production realities, based on the awareness that every activity generates effects on the environment. The ENV pillar therefore provides for a series of actions aimed at reducing the environmental impact of production both to ensure compliance with current regulations, both to decrease autonomously the waste of energy and natural resources, responding to the ethical principle of civil liability.

The basic principle on which the Environment pillar is based is that of continuous improvement of the environmental performance of production sites. Companies are certified according to the voluntary UNI EN ISO 140011291 standard, which applies the P-D-C-A (Plan-Do-Check-Act) methodology. The figure 2 shows the schematization of the P-D-C-A approach, with reference to the points of the ISO 14001 standard (FIAT Group Automobilies, 2007).

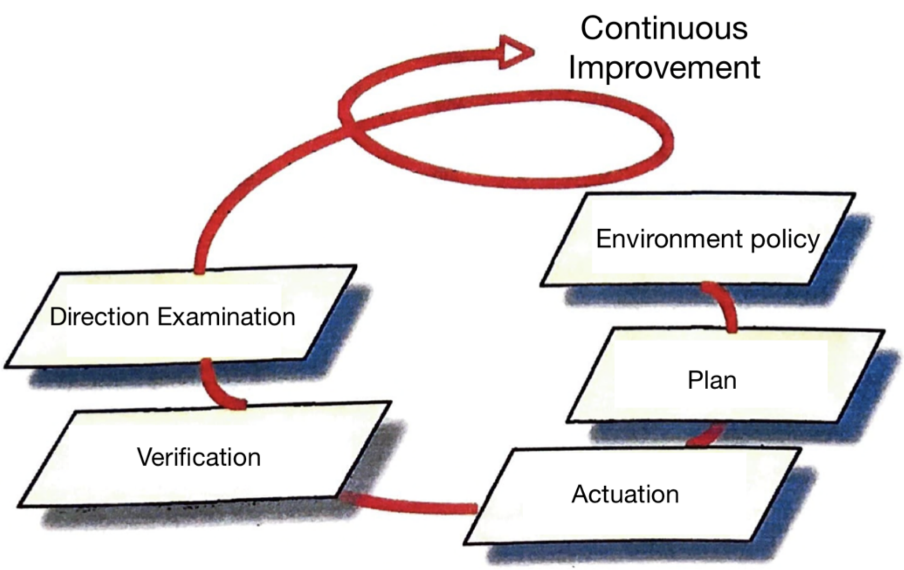


Figure 2: Continuous improvement cycle (Adapted from FPT Industrial S.p.A., 2020)

2. FPT Industrial presentation

FPT Industrial was born in 2011 from the union of the engine, transmission and axle activities of IVECO, CASE IH and NEW HOLLAND.

FPT Industrial has developed the revolutionary Common Rail injection system and the EGR-free HI-eSCR after-treatment solutions, imposing itself as a leader in the sector.

Today, FPT Industrial is CNH Industrial's brand dedicated to the development, production, sale and service of powertrains for on-road, off-road, marine and power generation applications.

It is a company innovation-oriented, able to guarantee customer benefits through continuous research and improvement processes and by our ability to create value based on these advantages. Currently, FPT Industrial is one of the leading companies in the field of engines, axles and transmissions for the industrial sector and is one of the top four manufacturers in the world in the segment of diesel engines from 2 to 20 liters [2].

2.1. Scope of the company

FPT Industrial is a reference point in the design, development, production and sale of engines, transmissions, bridges, and axles. With over a hundred years of experience in the sector, FPT Industrial has always been committed to introducing innovative technological solutions that aim to achieve the highest performance, reduce consumption, and minimize emissions levels. The FPT Industrial product range is extremely wide, offering engines from 2.3 to 20 liters of displacement, powers from 42 to 1,006 hp and longitudinal gearboxes with 5 and 6 gears with maximum torque from 300 to 470 Nm. The range is completed with versions that use alternative fuels, including methane solutions and engines compatible with biodiesel up to 20%. In the FPT Industrial research centers, solutions have been tested that have allowed engines to reduce emissions and anticipate Euro VI and Tier 4B emission regulations. In addition, the study of combustion, thermal and mechanical loads have made it possible to create engines more efficient. FPT Industrial is also experimenting with solutions for using second-generation biodiesel and high-quality synthetic fuels that can be made from certain types of plants and biomass.

FPT Industrial's mission is to become a technology leader in all areas related to industrial propulsion systems through innovation, product excellence and continuous improvement.

Customer satisfaction is a driving force.

To achieve this mission, it is necessary to implement a process of sustainable growth, based on respect for the environment and commitment to the social well-being of employees and the communities [3].

2.2. Company organization

Today, FPT Industrial engines are used across CNH Industrial products ranging from tractors and combine harvesters to trucks and construction equipment. Its engines are also sold to third-party customers in those industry sectors and others. The company has 10 factories and 7research and development centers around the world, and commercial and service networks in almost 100 countries. It employs around 8,000 people and has annual production outputs of approximately half a million engines and a quarter of a million transmissions and axles [1].
The Organization chart is reported in the figure 3, it highlights the intricate hierarchical structure proper of such a wide company. Commercial functions are centralized, and they control the whole company administration, while lower levels of the organization as the industrial functions are both at global and at plant level, close to the shop floor.

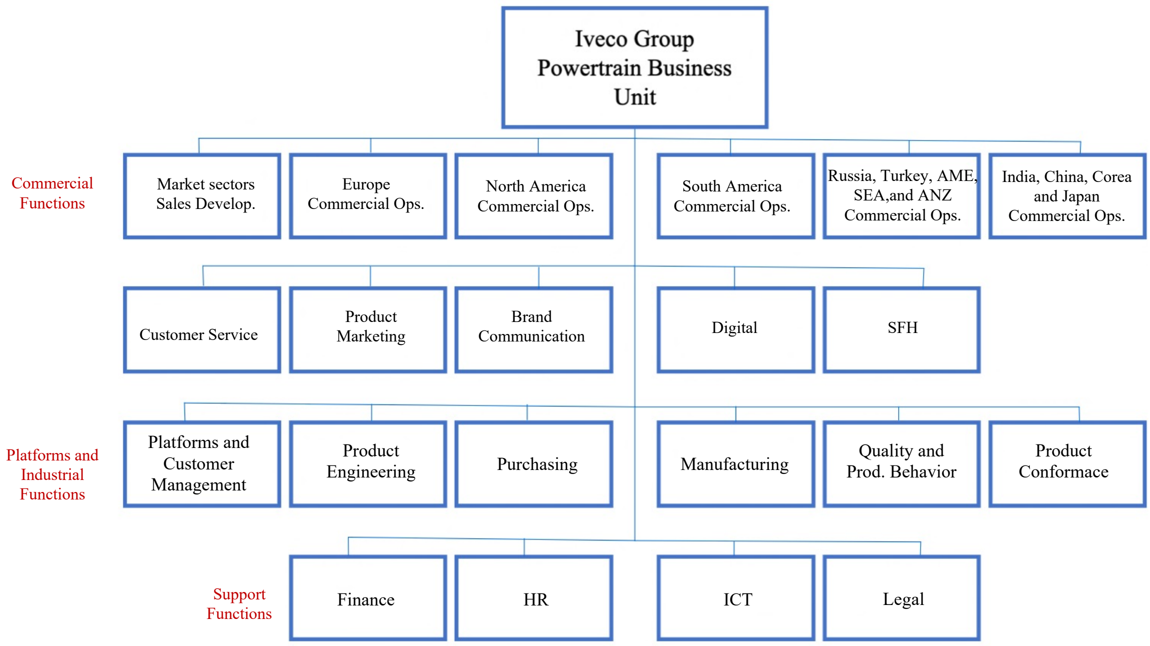


Figure 3: Company Organization Chart [1]

Each plant has a central core that is all that manufacturing concerns, it represents the engine of the company that must continuously run, this involves several collateral departments that supports the production perimeter. They mainly are the "Manufacturing Engineering" department that moves the industry forward using the most advanced technologies, engineers are principally involved in the early stages of new concept creation and product industrialization, and the "Quality" department, it goes across all departments and business segments, and it impacts every stage of the product's life. The quality team adopts the best-in-class system that dives the continuous improvement approach on processes, products, and services.

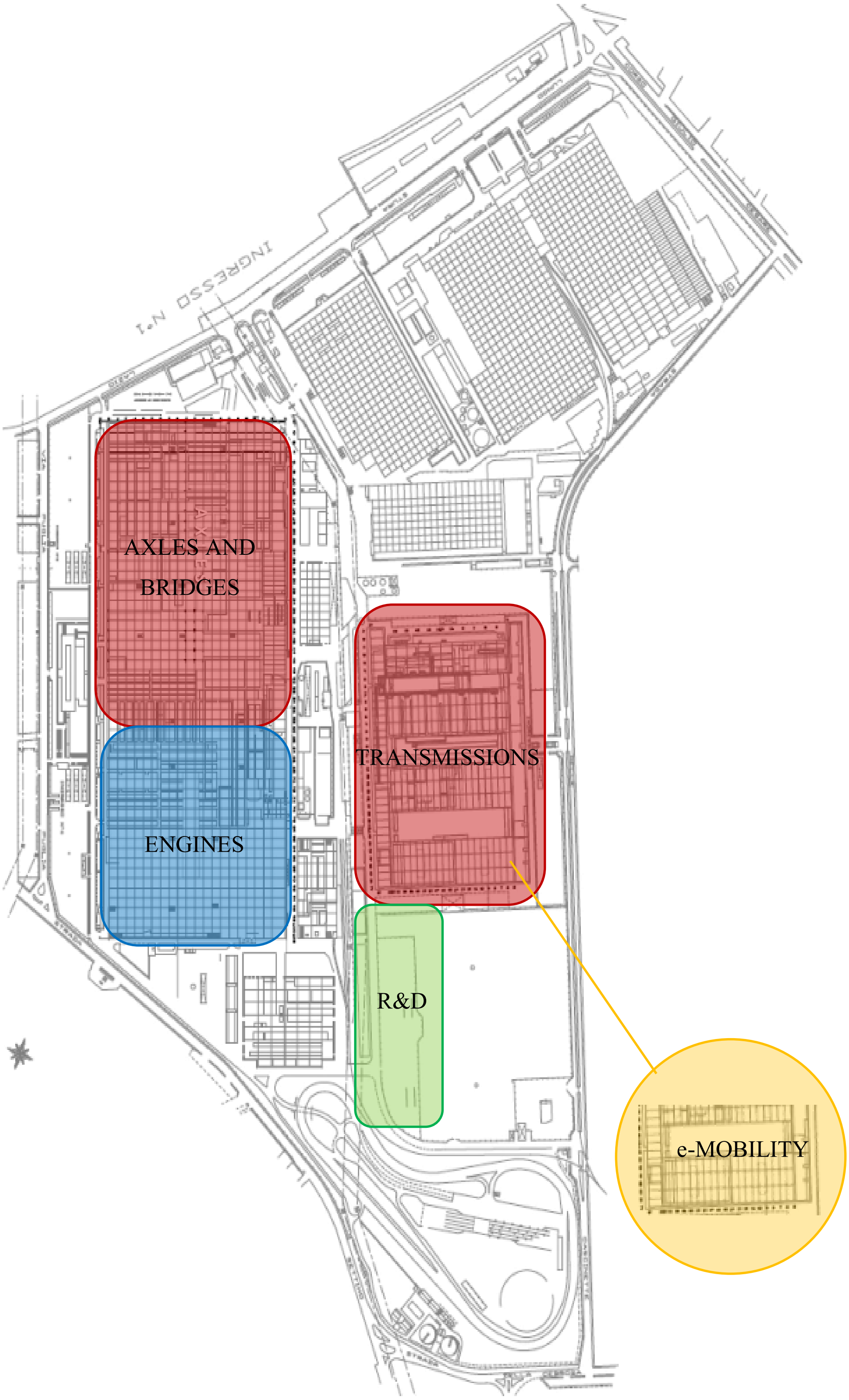
Other complementary departments are the "Purchasing" and the "Supply Chain" one, the former is to select best-in-class suppliers and develop a solid partnership with them, while the latter manages the flow of goods, from sourcing to manufacturing and finally to distribution.

To complete the structure there are the financial service team and human resources, they work closely with the business, providing solutions with expertise and knowledge.

Finally, professional people with a relevant importance are the internal auditors, they help the organization accomplish its objectives with a disciplined approach to evaluate and improve the effectiveness of risk management, control and governance processes [1].

2.3. Turin Plant description

The experience presented in this thesis work was totally conducted in the FPT Industrial plant located in the industrial area of the city of Turin, Italy. This area hosts the three main facilities of the company, two of them are the "Driveline" and the "Engines" and they are productive plants, the third is an R&D one. The former is the biggest one, it comprehends either the main building where offices of central bodies are located and the two productive areas where transmission and front-rear axles for light, medium and heavy vehicles are produced. The near Engine plant is dedicated to the production of Light, Medium and Heavy Engines for on-road and off-road applications.



AXLES AND
BRIDGES
ENGINES
TRANSMISSIONS
R&D
e-MOBILITY

Figure 4: Overall Plant Layout (Adapted from FPT Industrial S.p.A., 2020)

The norther plant, that in the figure 4 is indicated as the transmissions plant, it is currently expanding, because the company has recently reached agreements with important automotive customers to the production of components for electrified vehicles, those are for example high-voltage batteries, electric transmissions, and electrified axles for heavy-duty transports. To this scope the company has decided to create an area completely dedicated to the production of those e-mobility oriented components. The figure 5 represents this just described area and a draft layout the company is currently building up and improving. This e-mobility area will be further investigated in chapter 4.

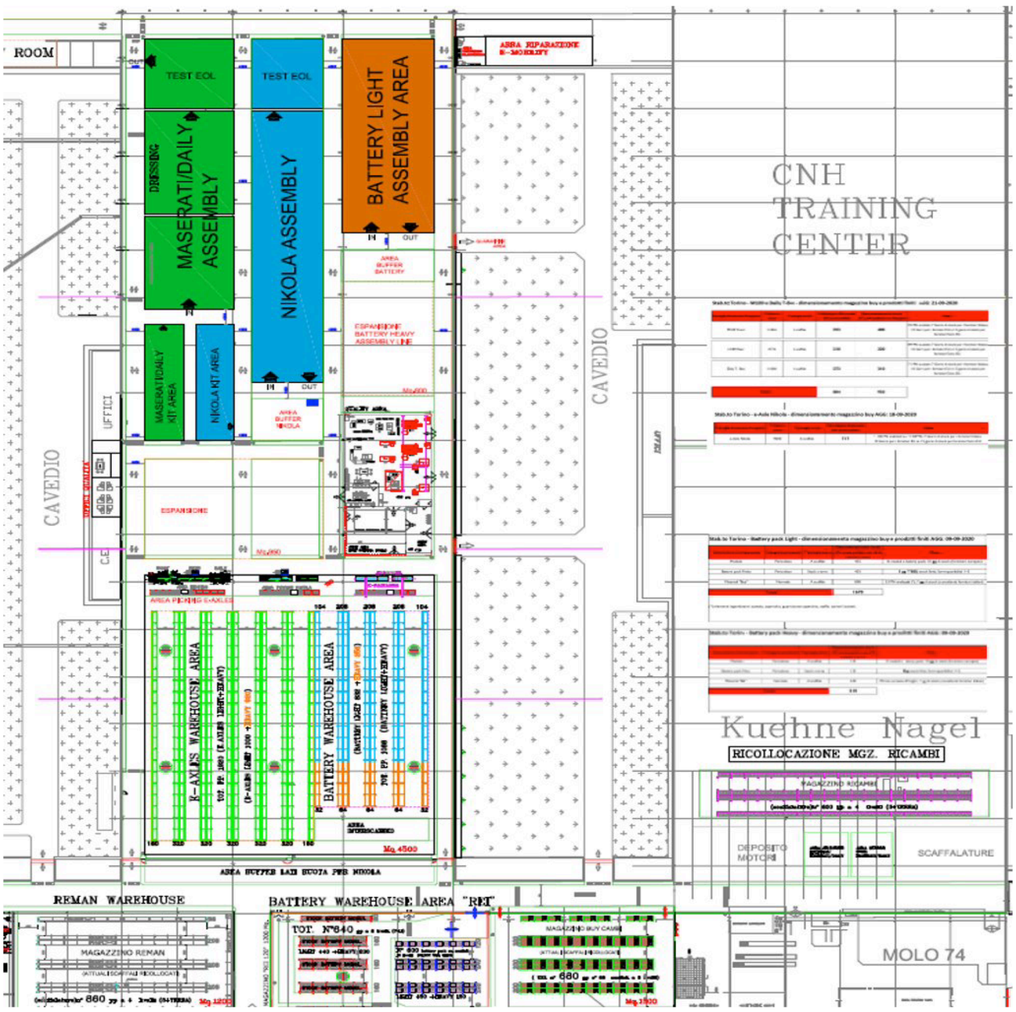


Figure 5: e-Mobility plant layout (Adapted from Fpt Industrial S.p.A., 2020)

It is worth to notice that all the plants are located very close to the Stura of Lanzo river, it plays a very important role in the environmental mission of the company, specially, for what the waters' management and waste's treatment regards.

3. Autonomous Maintenance pillar practical application

The aim of this chapter is to describe the practical application of the WCM method in the field of machinery efficiency. The activity was fully developed at the plant of FPT Industrial where all the components of the produced transmissions are machined and assembled. Activities described have been carried out in the years 2020-2021 and they have been presented to an external WCM auditor during the audit that took place in June 2021.

3.1. The gearboxes plant: setting the analysis

The Figure 6 represents the plant at issue is divided in 4 Elementary Technical Units (ETUs), the area Kapp is a separated part of ETU 4 and contains 5 grinding machines produced by the German company " Kapp ".

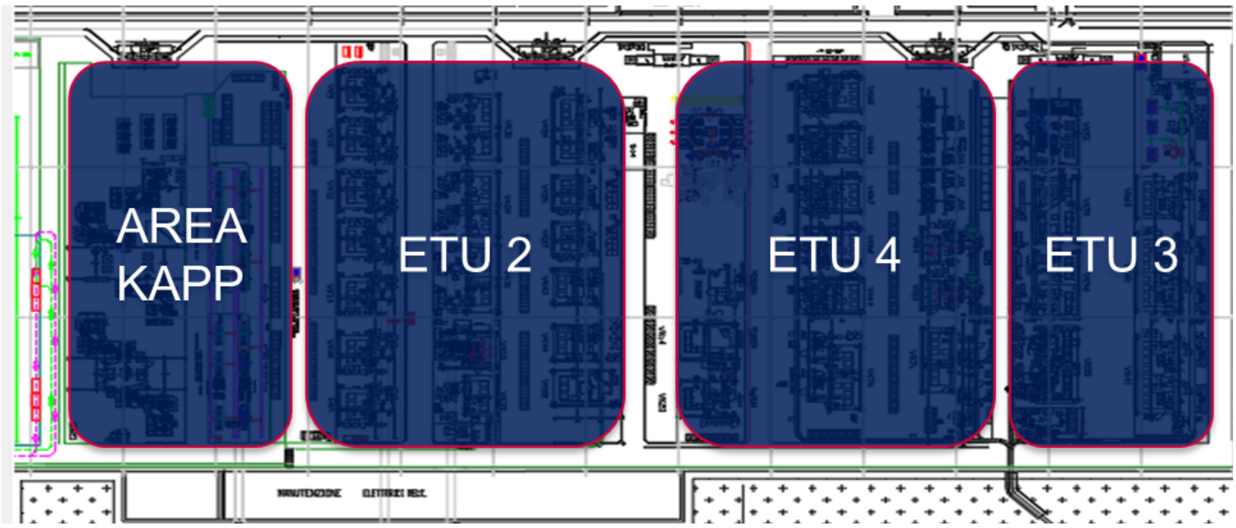


Figure 6: ETUs Plant Division (Adapted from FPT Industrial, 2018)

At ETU 2 row gears are firstly turned, then parts are divided into two groups, to be welded and to be caulked, so they go through two kind of toothing operations and finally each tooth of the gears is blunt before leaving the ETU 2 to be transferred towards the thermal treatment. At ETU 3 instead, entrance shaft and secondary shaft of the gearbox are machined, in particular, row components are delivered from the warehouse, then they are turned, toothed and blunt in order to be delivered to the thermal treatment as well as single gears.

The last step is carried out at ETU 4 that receives both gears and shafts from thermal treatment and operates rectifications of internal holes and teeth. All components exit from ETU 4 will be collected in an inter-operational buffer or directly transferred towards the assembly.

Since not all the machines of the plant can be attacked with Autonomous Maintenance (AM) pillar, it is needed to prioritize the activities according to machine classification.

From the Book of knowledge of AM created by the WCM central team of the company, there are three different approaches of machines classification: the **reactive** approach where countermeasures are taken after an event has taken place, the **preventive** one by learning from the past, countermeasures are taken to avoid a repeat (including similar problems under similar conditions) and the **proactive** strategy that is based on theoretical risk analysis and proper countermeasures are taken to avoid a serious event to occur.

In the reactive phase, losses are high and evident so it is enough to follow the cost deployment of the several machines to prioritize them from the most expensive in terms of economic loss towards the one that causes less losses.

As shown in the figure 7, machines are classified by following the Pareto principle according to the following classes:

- AA – 50% of the total breakdown losses due to lack of basic conditions
- A – Up to 70%
- B – Up to 90%
- C – Up to 100%

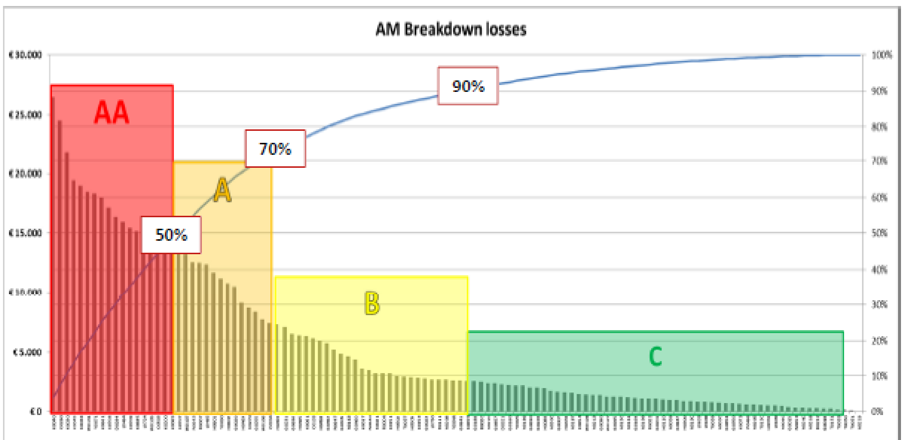


Figure 7: AM breakdown losses machine classification

The objective of AM pillar is to attack firstly the AA machines and then the followings to reduce losses and to get the highest advantages.

The reactive phase ends when the losses for breakdowns due to lack of basic conditions have been drastically reduced (ZERO breakdowns due to lack of basic conditions in model machines), extending the AM activities following the priorities given by the Cost Deployment. Next step is to work in a preventive way, to prevent losses according to the experience. The Cost Deployment is no more able to give a direction to assign priorities, because losses due to lack of basic conditions are small. Therefore, from now on machines are classified with a Production, Quality, Costs, Delivery**,** Safety, Morale **(PQCDSM**) analysis, based on:

- Statistical parameters (average repair time and breakdown probability) though the historical of breakdowns
- Criticalities of the machines (in terms of consequences on quality, environment, costs of a breakdown)

PQCDS&M is a method to classify the machines based on 6 main criteria:

P – is the impact on the production in case of a breakdown

Q – is the impact on quality in case of a breakdown

C – is the impact on costs in case of a breakdown

D – is the impact on the service level in case of a breakdown

S – is the impact on safety & environment in case of a breakdown

M – is the age of the machine

Each criterion is made of subgroups called "Items" as reported in Figure 8

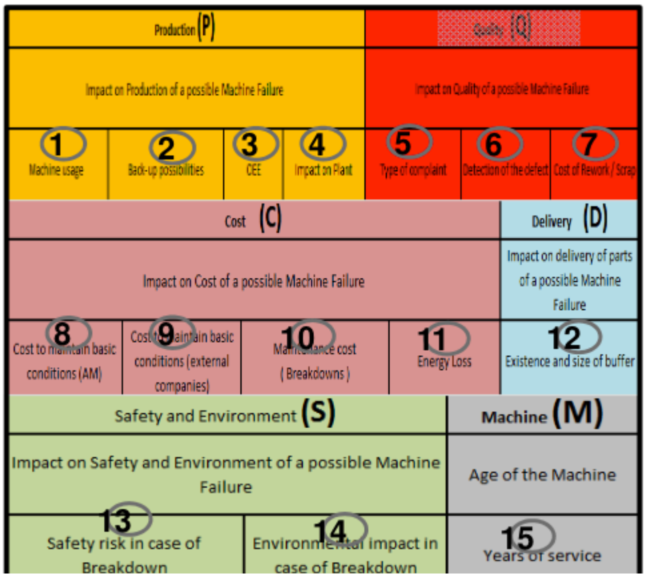


Figure 8: Machine classification criteria

Then the steps are to attribute a score for each of the items with a definition of a maximum and a minimum value, then to produce a sum up of the results of all the items.
Hance, following the classification rule showed in the figure 9 machines are classified.

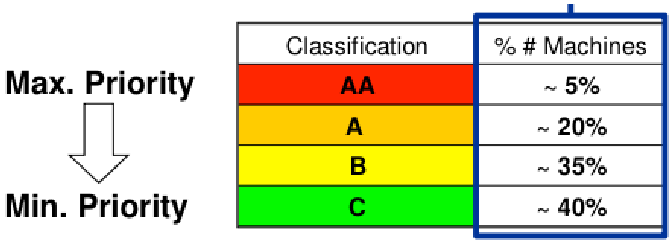


Figure 9: Machine classification rule

The figure 10 reports a result of the PQCDSM classification for several machines of the plant with the cumulative curve that represents the percentage of breakdown losses.

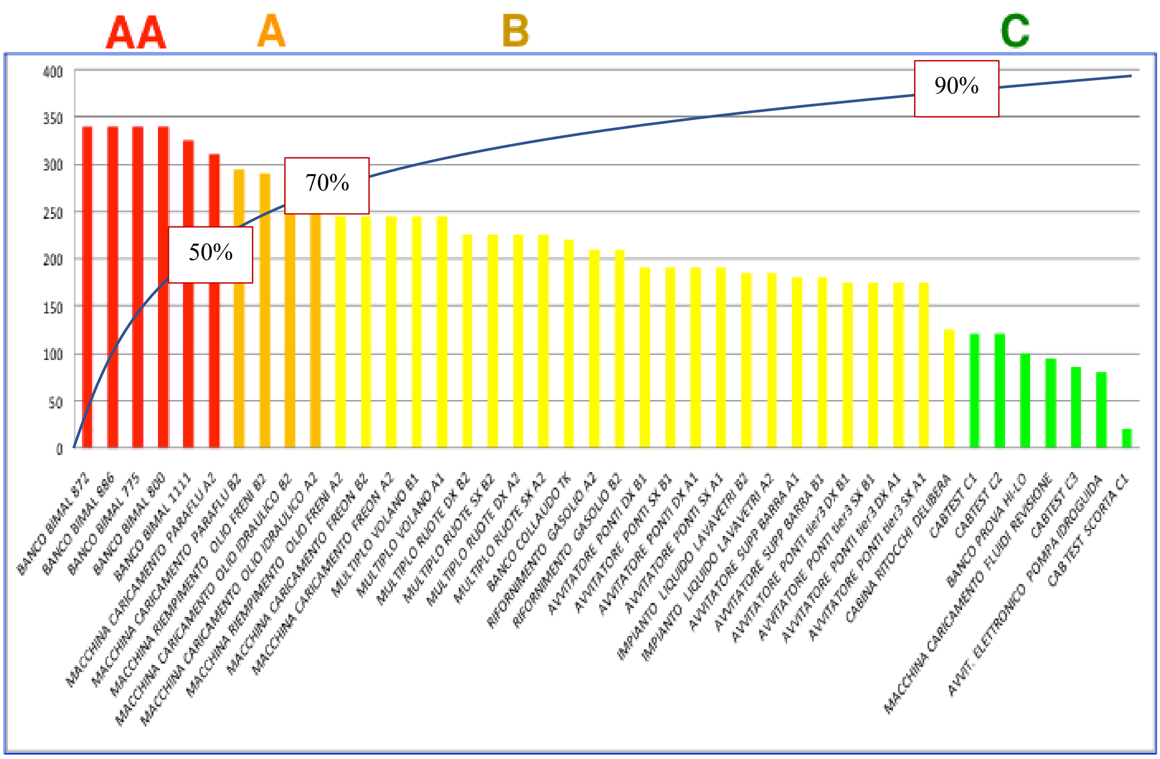


Figure 10: Pareto diagram for machine classification

3.2. Analysis of critical machines

The focus of the activity was based on the Elementary Technical Unit 1, where, the most critical machineries are placed. The considered area is of paramount importance for the plant because all of row gears arrive therefore a stop of those machines can cause a low or a stop as well of the entire plant, causing a late toward customers. In order to frequently monitor the behavior of this area, the pillar leader has composed a dedicated team intended to analyze data coming from the production and to program, week by week, the activities needed to face all of the major losses coming from the lack of basic condition.

Machines that have been observed are 6 lathes, 6 toothing machines and 2 bevelers, they carry out the operations that transforms gears from row material to its final shape before the thermal treatment.

To this scope, it was necessary to collect production data, to meet directly operators by using the (GEMBA tool), to have comparison with the chief of them and to directly observe working machines on field, in order to propose activities that according with the WCM logic would bring back the highest benefit with the lowest cost.

The team was used to meet every week, in a dedicated area called AM_PM Lab, in which, in collaboration with PM pillar the progressive behavior of activities in time and the planning of new ones is discussed.

The output of each meeting was a filled table called master plan, in which all the proposals figured out are collected, prioritized and scheduled according to the availability of both personnel and machines. An example of it is reported in the Figure 11.

ACTIVITIES TO REDUCE BREAKDOWNS AND MINORSTOPPAGES															
Activity	Machine	PRIORITY	RESPONSABLE	RDA/ORDER	P/C	MARCH					APRIL				
						W9	W10	W11	W12	W13	W13	W14	W15	W16	W17
Restoring Marposs WEISSER 021	TURNING MACHINE WEISSER 021		maintence (PLAN)	RDA	P										
					C										
				ORDER	P										
					C										
Sostituzione scheda asse x e asse c del caricatore	TURNING MACHINES WEISSER 059 e 027		Maintenance (CHECK)	RDA	P										
					C										
				ORDER	P										
					C										
Allineament o porte	TURNING MACHINE WEISSER 049		maintenance (PLAN)	RDA	P										
					C										
				ORDER	P										

Figure 11: Activity Master Plan

3.3. 7 Steps of AM application

In this chapter an activity for each step of autonomous maintenance will be described in order to show how the method can lead to consistent results.

Before starting of a project, it is necessary for the AM team to prepare everything for the implementation of activities, so firstly it is needed to produce plans, drawings, manuals of the chosen machines, then the teaching materials for the initial training of operators, AM tags, forms, sheets for recording information boards for visual management (Activity Board). Moreover, all the procedures, rules and responsibilities for managing and updating of project documentation are established and the list of materials necessary for the initial cleaning of the area is compiled (figure 12).
Finally, materials and equipment needed to work on the machines (keys, screwdrivers, hammers) and the analysis of activities under the safety point of view, identifying the possible causes of an accident and taking the necessary countermeasures.

Figure 12: Documentation collection

To evaluate results and performance of equipment, in order to better understand the effectiveness of the actions put in place, it has been monitored by KAI (Key Activities Indicator) and KPI (Key Performance Indicator) indicators. As far as the AM pillar principal KAI are the number of emitted TAGs opened/solved, number of dirt sources founded/solved, the amount of Quick kaizen/person produced. The last indicator has to be set in accordance with pillars of PD and FI. About KPIS, mains are the number of breakdowns due to lack of basic conditions, they should be 0 so the objective of the pillar is to reduce this kind of loss as much as possible even though each action needs to be always evaluated in terms of benefits and costs, so it may happen that despite the cause of breakdown is known it is not eliminated

because of the cost of the activity. Another indicator is the C-I-L-R Time, It is the time dedicated to cleaning, inspection, lubrication and refastening activities and the aim is to reduce to the 10% after the Step 3 of AM.
Then there is the B/C that usually after Step2 it is higher than 1, the OEE behavior and in particular the impact of the reduction of breakdowns due to lack of basic conditions. The last is the economic losses measured in euros again produced by the lack of basic conditions.

Once all preparatory documents, KPIs and KAIs are set activities can be developed in order to improve machine conditions and to get through step by step in the AM classification.
Autonomous Maintenance activities introduces major changes in the management of plant processes; therefore attentive, constant monitoring by the management of results achieved on each machine and of application of the method and of team behavior is essential. All the actions need to be certified, certification is valid if obtained on the basis of measurable and repeatable facts. The concept of measurement applied to a multiplicity of variables and states is implemented using checklists.
Therefore, specific checklists have been developed, one for each AM step. These must be attentively assessed by the management for suitable personalization and retuning according to the technological and organizational context of each area. The aim of certification is also to draw the management's attention to in-field problems in order to adopt suitable corrective actions, to develop a culture of coaching and to demonstrate the importance of the project. The check-lists are also a useful instrument for the team for verifying the progress of Step Activities Certification must be carried out directly on machine by the AM pillar leader, together with the Team leader in the presence of all members of the Team Certification is preceded by auto-certification by the Team and is planned according to the Unit plan. The assessments will be shared between the Certifiers and the Team, and it will be used to identify strong points and to eliminate weaknesses of the Team and/or of the rest of the unit.
It is possible to move to the next Step only after positive certification.

3.3.1. Step 1 – Initial Cleaning and Inspection

To clean means “to inspect” because defects are easy to recognize in a cleaned workstation and it is easier to take suddenly countermeasures.

Following the WCM proceeding method, it is useful to start from a deployment of the several Breakdown losses due to AM, so a Pareto diagram is developed (figure 13), a histogram ordered in a decreasing way according to the value of loss that was obtained considering the costs of each working center so mainly the workers’ salaries, the cost of utilities consumed in the period of the stop.

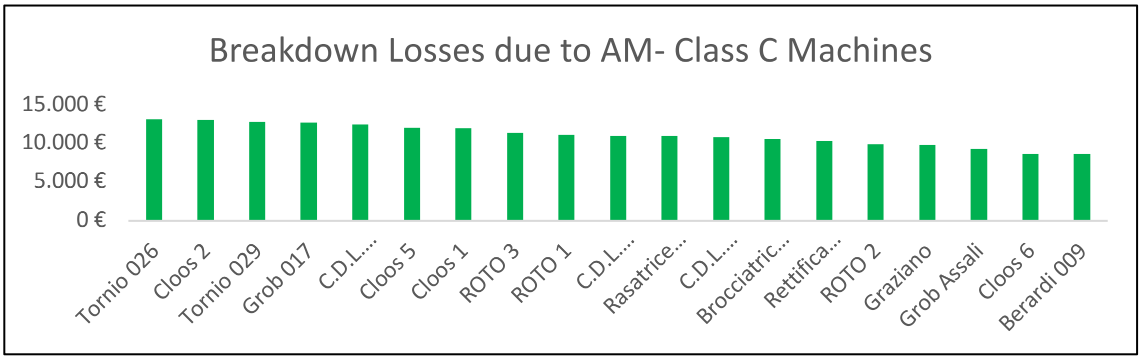


Figure 13: Pareto Cost Deplyment

The first machine in the diagram is the one that belongs to the highest costs and hance it is the one to be attacked. Before to organize the activity called “AM site” it is necessary to develop the risk map and all of the safety equipment to ware during workers’ activities, this is reported in figure 14.

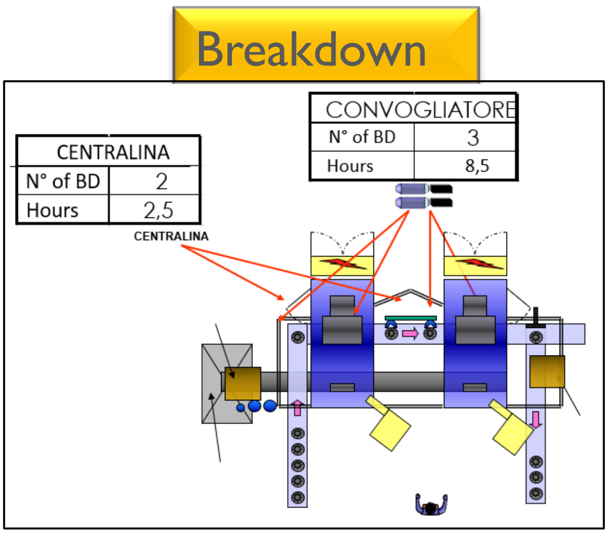
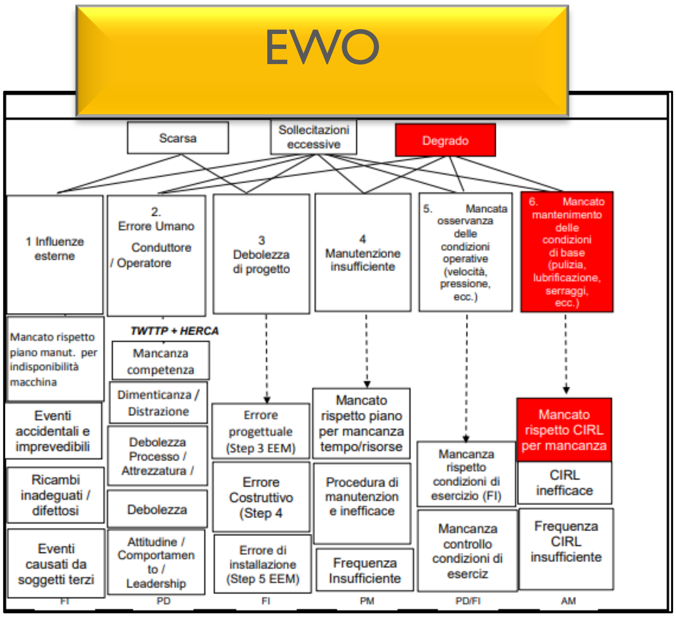


Figure 14: Machine risk map

As first, an analysis of breakdowns is conducted and in particular, through the Emergency Work Order (EWO) tool, the team individuated those caused by lack of base conditions. In the reported example (Figure 15), three repetitive events have been discovered due to the presence of chip in the tipper compartment.



1° Perché	2° Perché	3° Perché	4° Perché	5° Perché
Positivo e negativo danno continuità tra loro	Cavo px in corto	Truciolio infilzato tra i fili positivo e negativo	Acumulo dei trucioli	Manca ciclo di pulizia

Figure 15: EWO analysis

Therefore, the first activity is called “AM site”, thanks to the cleaning of the machine several pointing tag are emitted, one for each recognized issue (figure 16).

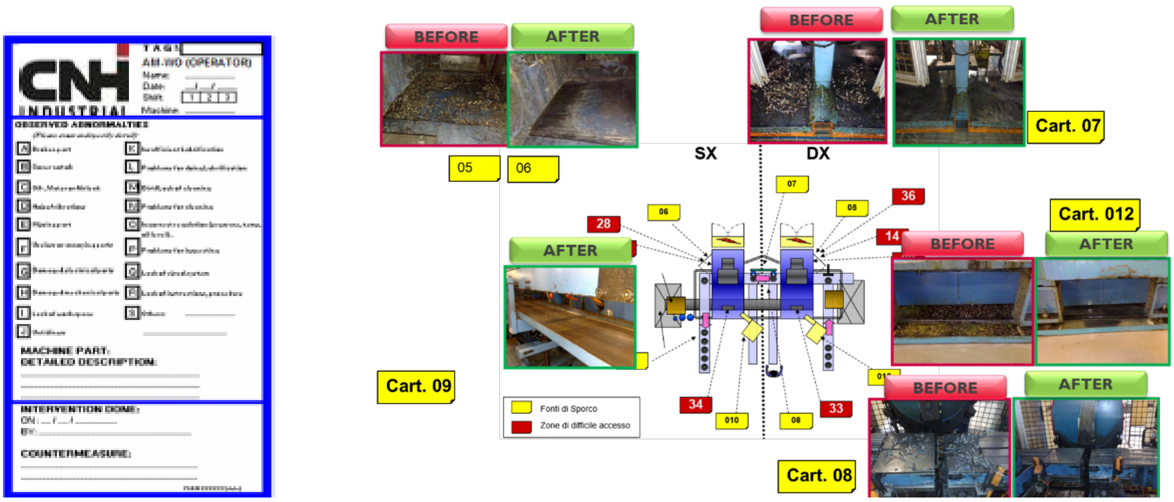


Figure 16: Pointing Tags from the AM site

This kind of activity allows to define temporal standards.

The results of the step 1 have then collected and measured making comparisons with respective KPIs and KAIs, as figure 17 reports.

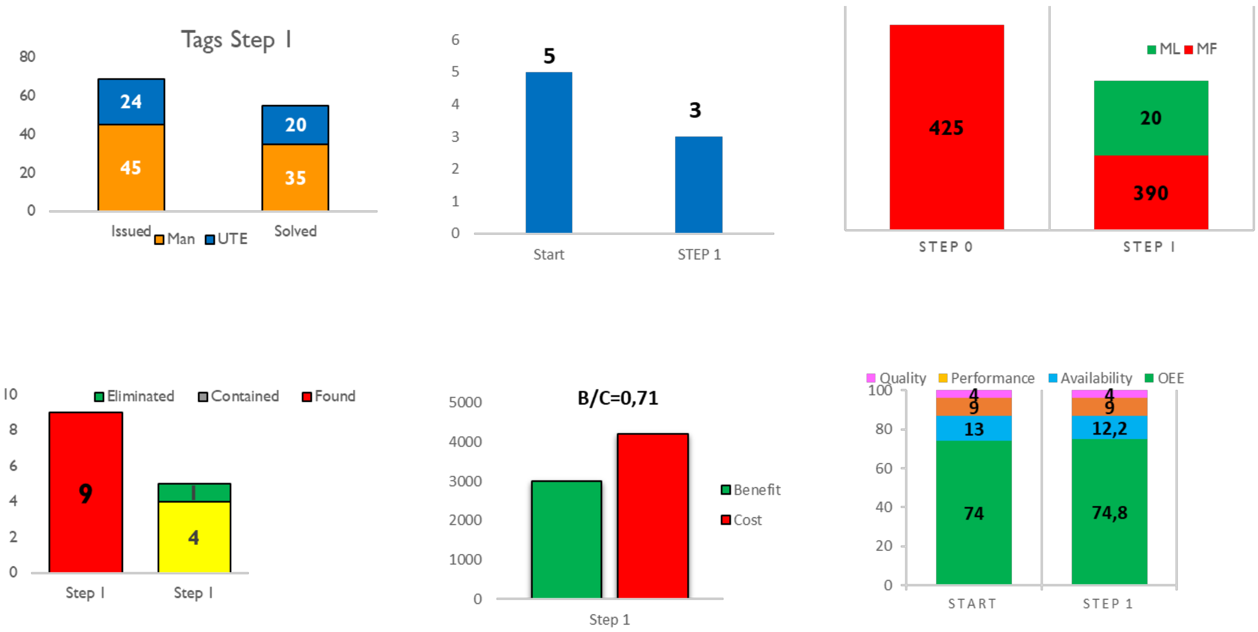


Figure 17: KPIs and KAIs for results monitoring

3.3.2. Step 2 – Countermeasures against dirt sources and difficult access areas

The scope of this second step is to reduce housekeeping time by eliminating sources of dust and dirt, preventing scatter, and improving parts that are hard to clean, check, lubricate, tighten, or manipulate.

- Identification of dirt sources & difficult access areas
- Setting of improvement targets
- Countermeasures against dirt sources and difficult access areas
- Step certification

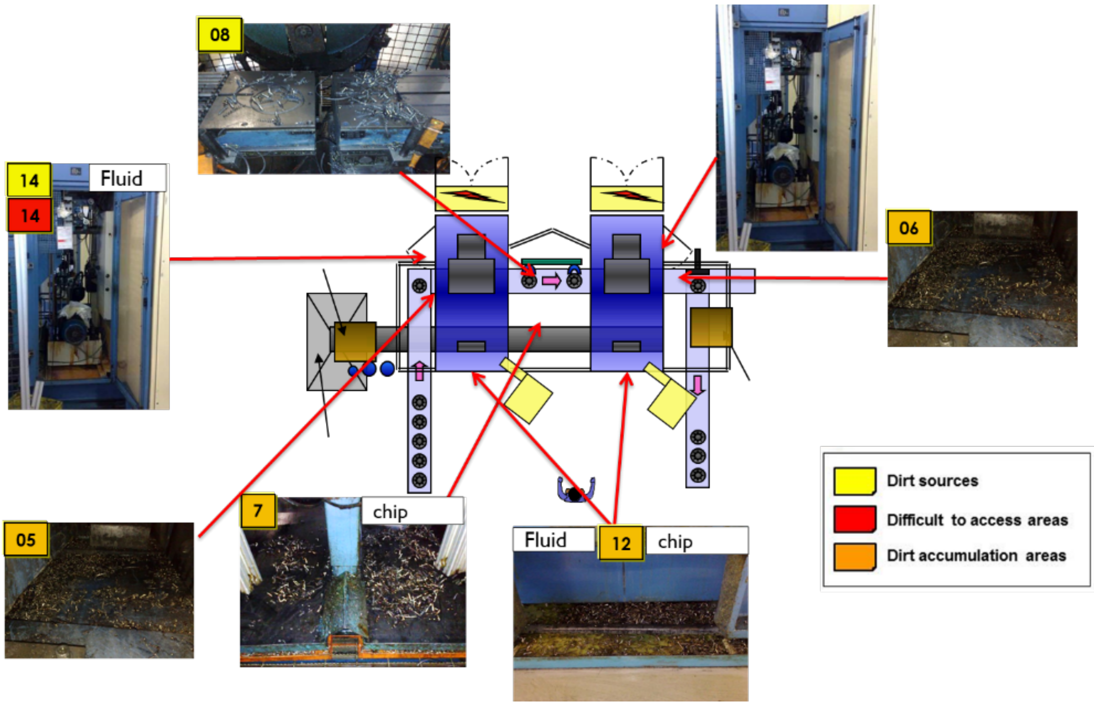


Figure 18: Dirt sources, difficult access areas and dirt accumulation areas

Dirt sources can be easily clustered in two main categories

- **Equipment anomalies**

  Oil leakages

  Broken pipes

  Untightened connections

- **Process dirt sources**

  Chip scattering

  Lubricant/coolant sputtering

  Powders

  Vapors

A first example regards a chip accumulation problem near to the conveyor area. This condition comes from the step 1 observation, and it belonged to two cleaning cycles for a total duration of 225 min per week. As a step 2 solution, two vessels with air flux and coolant fluid have been inserted, (figure 19) they help the chip evacuation and reduces the total amount of time cleaning till 30 min per week.

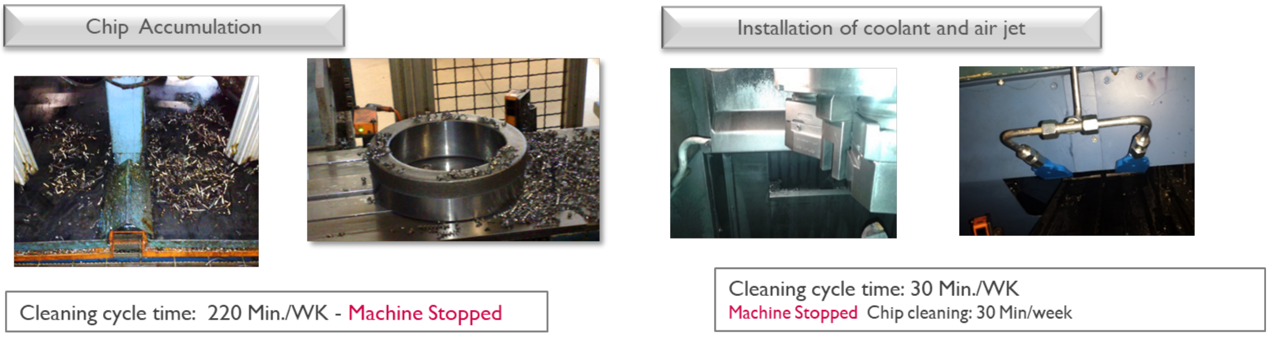


Figure 19: Step 2 Solutions

The project was approved since it reported a final B/C higher than one, equals to 7.5 and then a benefit was registered.

As far as difficult access areas, they can be easily clustered in three main categories, Difficult cleaning areas in which dirt is hidden in inaccessible areas and cleaning is uncomfortable (i.e. too high to clean), then there are Difficult inspection area where inspection points are not visible from outside and their position is uncomfortable. Finally, there are those areas Difficult to lubricate for example because there are too many lubrication points or because its position is difficult to reach.

During AM step 2, we keep using the indicators shown in step 0, but cleaning time and inspection time are the most important KPI's for measuring the real effectiveness of AM step 2. A target of those two indicators must be set at the beginning of step 2, at the level of every single dirt source/difficult access area. Thanks to all the improvements done, the cleaning and inspection time will be strongly reduced.

The objective is to reduce it by 90% by the end of step 3.

A practical example of difficult access area elimination can be the activity carried out on a machine where the hydroulic unit was very difficult to reach and the cleaning cycle time consted of 25 Min/Week and due to the position, it was absolutly necesssary to stop the machine in order to operate in saefety conditions. Following always the PDCA approach, it was proposed to replace the hydroulic unit ouside from the perimeter of the machine, this operation allowed to reduce the cleaning time to just 2 min/week and moreover, all the operations can be taken while the machine is still working, avoiding so losses of production (figure 20).

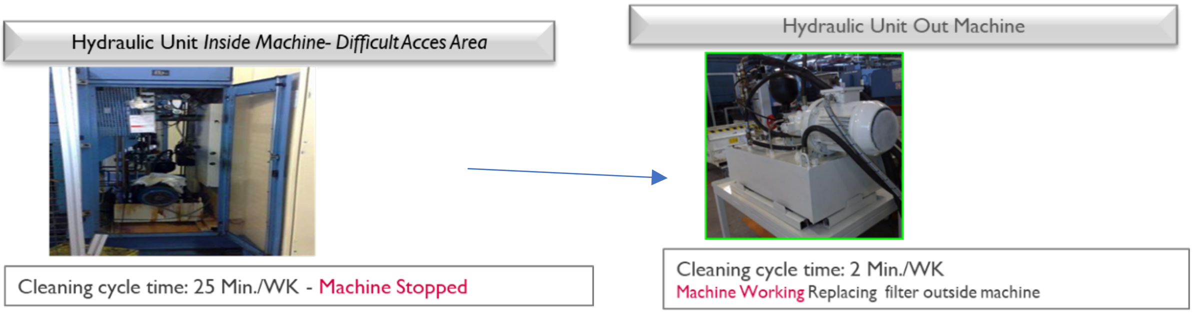


Figure 20: Difficult access area removal (Adapted from FPT Industrial S.p.A., 2021)

The final step of eache activity, once a positive benefit has been registred, is always to standardize the cleaning cycle through the MP info generation and by modifying the CILR (cleaning, inspection, lubrication and refastening) calendar (figure 21).

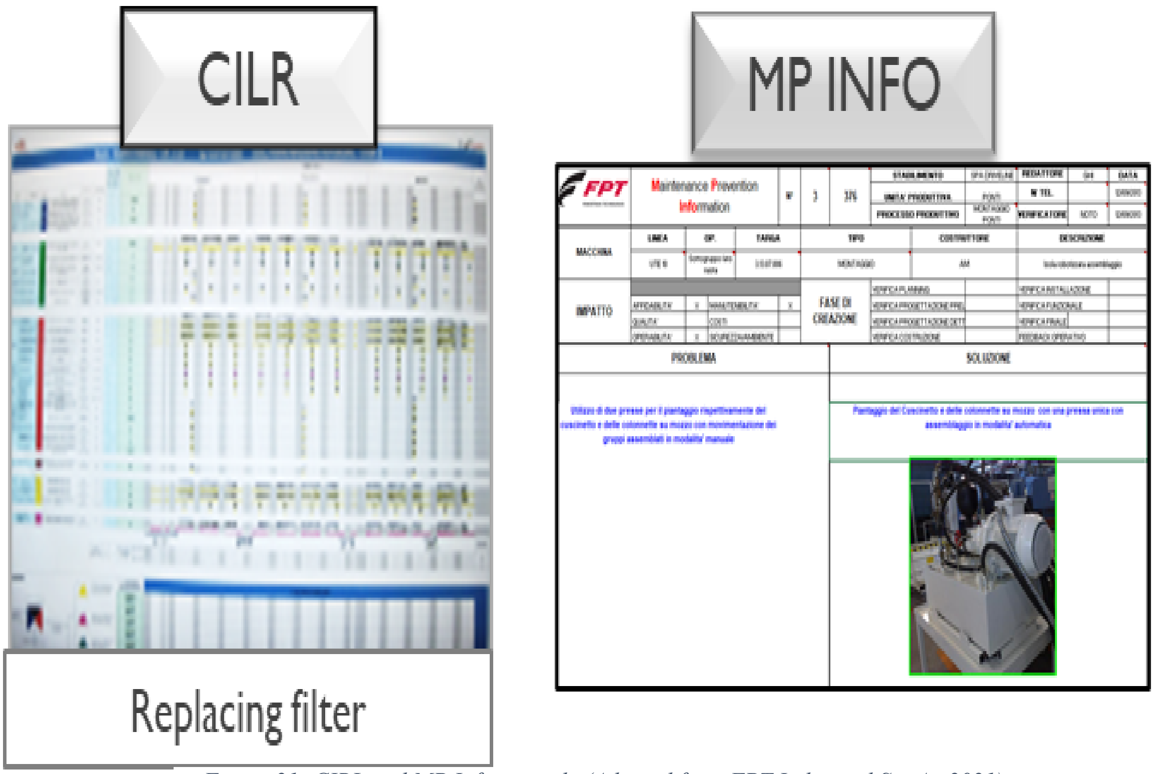


Figure 21: CIRL and MP Info example (Adapted from FPT Industrial S.p.A., 2021)

The problem solving is driven by **Kaizen** tool (figure 22).

In order to eliminate sources of contamination and difficult to access areas, a Kaizen project is applied to define improvements on the machines according to PDCA logic.

The most common applications consist in Quick Kaizen/ Standard Kaizen, as they are supposed to come directly from shop floor people. Instead, major Kaizens are rare.

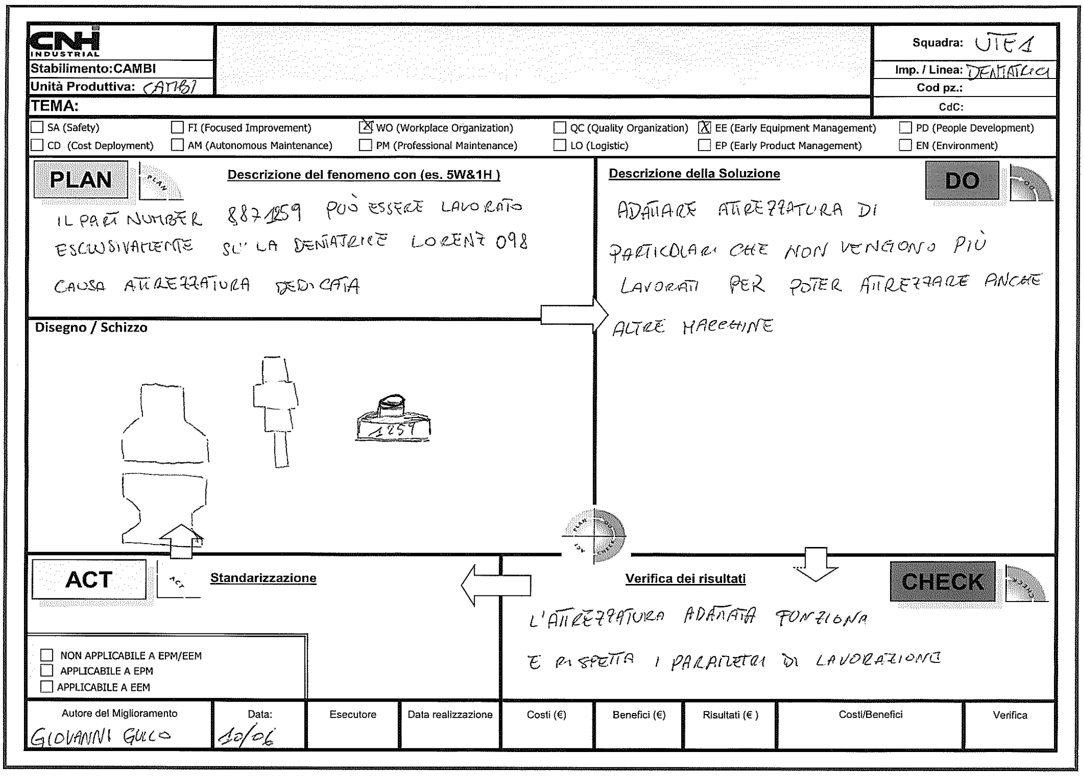


Figure 22: Quick Kaizen exaple

3.3.3. Step 3 – Initial Standards

This activity consists of the formulation and the optimization of work standards that help to maintain cleaning, lubricating and tightening levels within minimal time and effort. Moreover, it improves the efficiency of checking work with an extensive use of visual management.

The AM calendar in step 3 is scheduled according to four steps, as first it is fundamental to define the content (**Content definition)** so to list up all points where regular tightening, cleaning, lubricating and inspection has to be done. Then we find the **Standardization** phase according to the list of points mentioned above, make a standard having Location / Component / Item, What to do, Why to do, Who will do, frequency, required condition, and Action if required condition is not achieved.

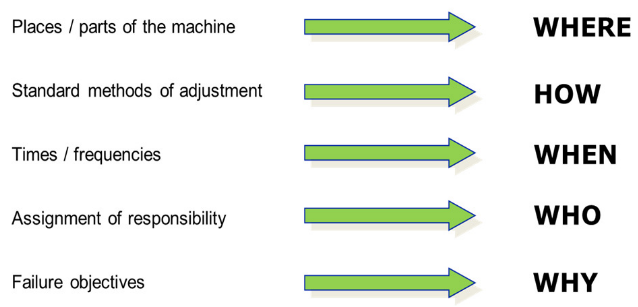


Figure 23: 4W and 1H model approach

The following phase is the **Planning,** once the frequency of CILR activities have been defined, activities are planned by putting a yellow triangle in the shift/day/week when the activity should be done. The unit of the calendar comes from the activity with maximum frequency. Normally for AM is the shift.

The **Workload** distributes the activities evenly over all shifts.

One of the most important points of this third step is the visual management adoption helps in executing the cleaning, inspection, lubrication and refastening cycles in a more comfortable way. With a good visual management, activities will be easier and quicker. After the cycles have been defined, it is useful to paint the paths for doing the CILR activities around the machines, put stickers on the machines next to where the activity has to be done, to use visual devices for a rapid execution of the activities and to mark each item of equipment with its name and number to make everyone aware of important units.

Moreover, to put marks on nuts and bolts to simplify checking for slackness and to indicate good ranges on instruments, such as pressure gauges, vacuum gauges, thermometers, and ammeters to facilitate correct operations is necessary.

It is important also to indicate lubricant levels, types, and quantities to improve maintenance activities, to label the covers of devices such as V-belts, chains, and couplings with their rotation direction and specifications to improve maintenance activities and simplify checking. To label pipes with their flow direction and contents and finally to provide on/off indications on valves and switched to improve maintenance activities, operability, and safety.

One of the tools that is largely adopted to set initial standards and to carry out step 3 activities is the SOP tool. **AM Standard Operative Procedure (SOP)** is a detailed description of an AM activity. It must be read quickly by operators so photos/sketches must be used extensively with few words as in the example reported in figure 24.

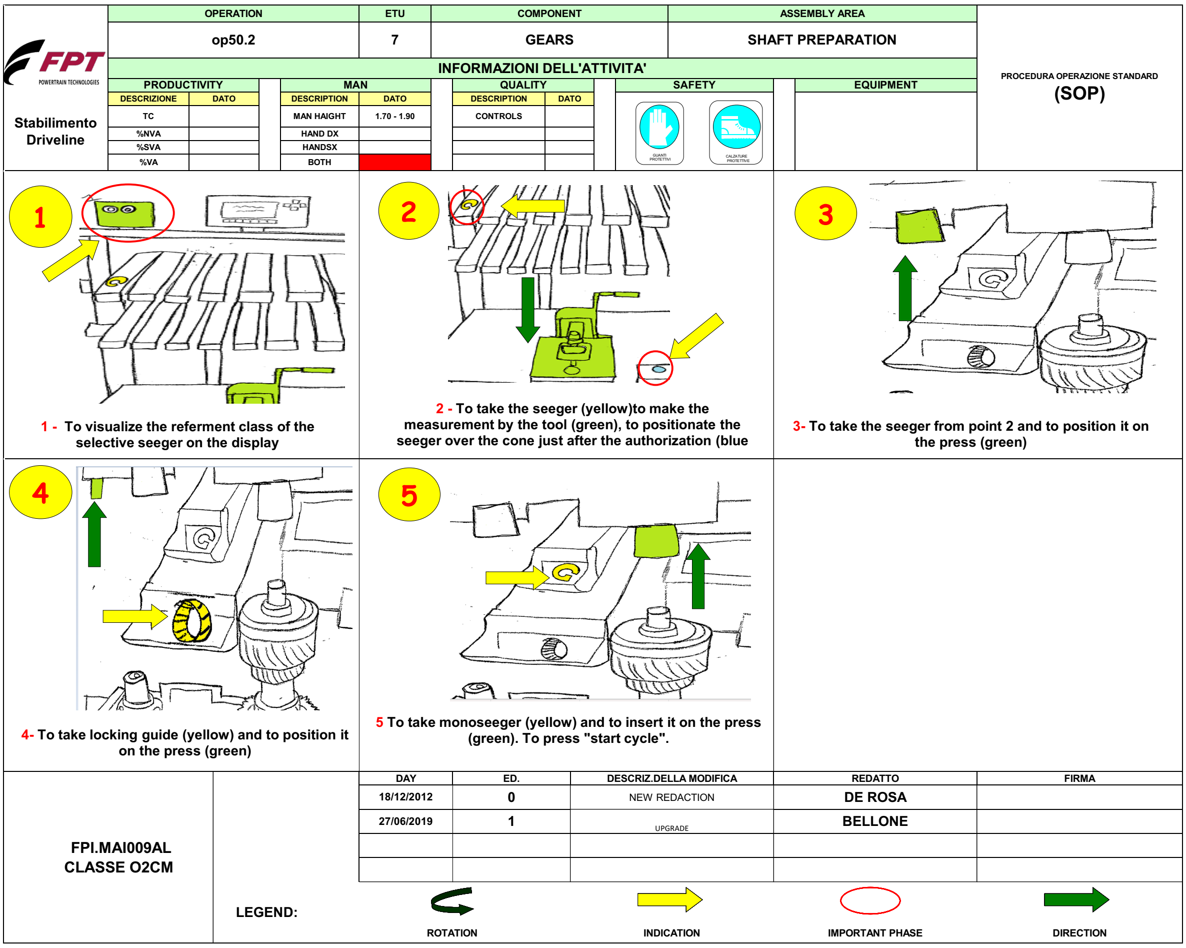


Figure 24: AM SOP example

In the following figures 25,26 some examples of visual management application are reported.

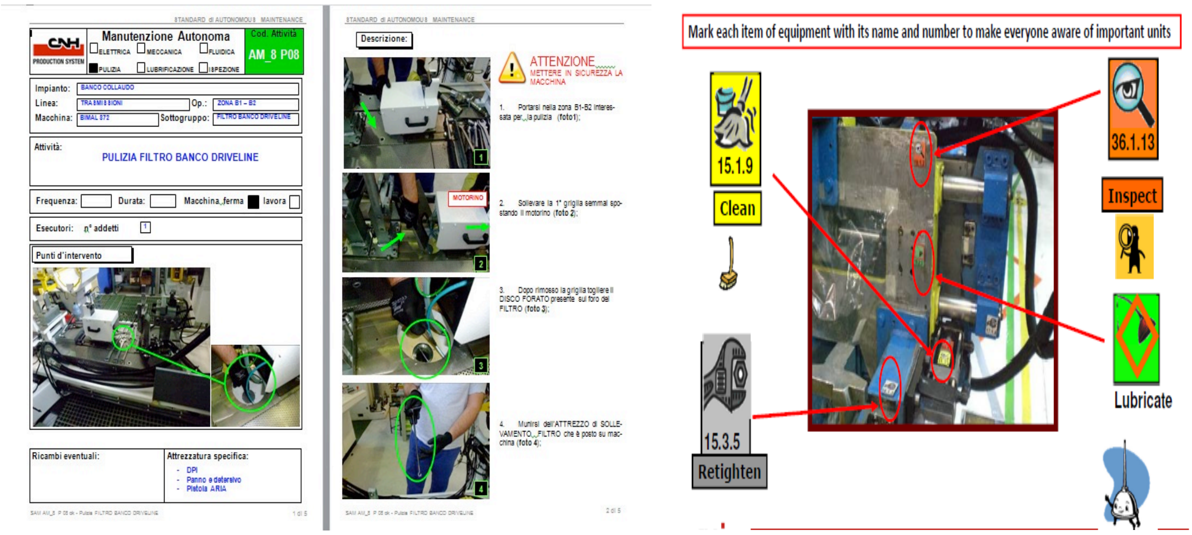


Figure 25: Visual Management application for conductor

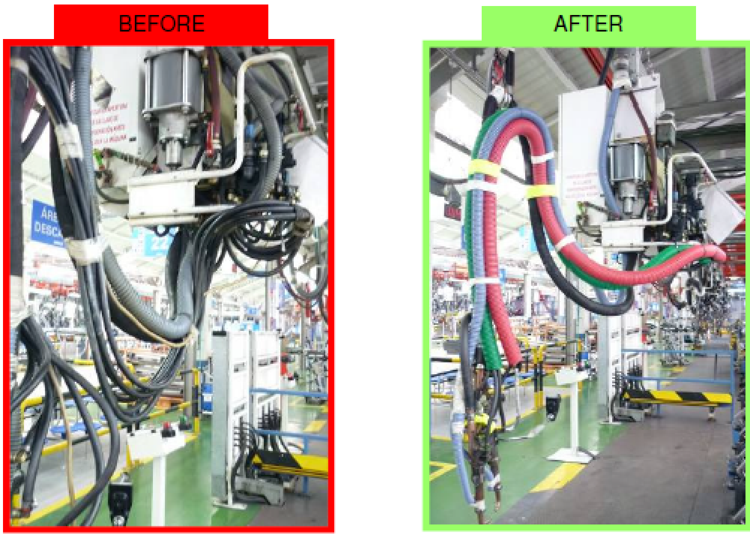


Figure 26: Visual management application pipe distinguishing

The other fundamental activity in the step 3 is the optimization of cleaning cycles by using the **E.C.R.S. METHOD** that is a method to reduce the time for Cleaning, Inspection, Lubrication and Refastening cycles. It is composed of 4 steps; it starts with the **elimination** of double or obsolete controls then to **Combine** different controls on the same component. **Reduce** the frequency using as a basis the MTBF. **Simplify** Control methods, improving and developing tools for visual control (figure 27).

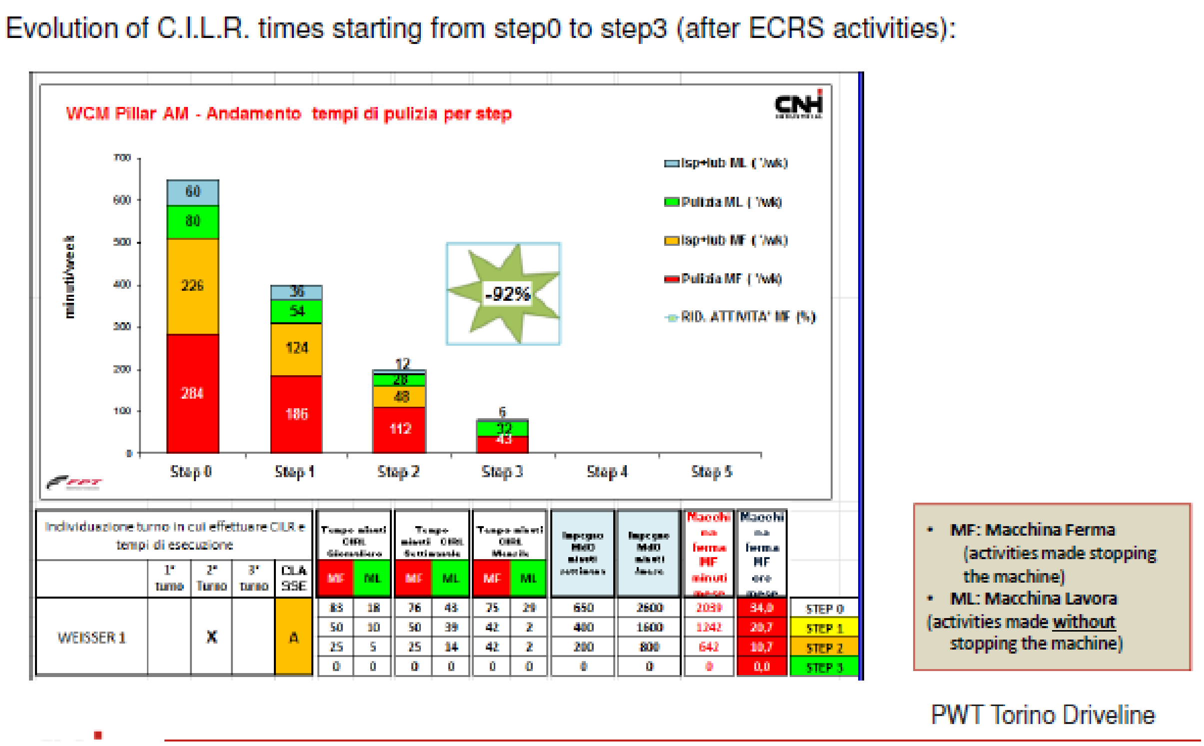


Figure 27: Evolution of CIRL times after ECRS activities

3.3.4. Step 4 – General Inspection

The fourth step is intended to improve **reliability** by performing general inspection and reversing deterioration of each equipment and to enable anyone to inspect reliability by introducing visual controls, such as gauge ranges, valve on-off indicators, etc.

The **Mission** of the step is to learn equipment structure, functions, assessment criteria and checking skills with hands-on, checking training, to learn to deal with equipment abnormalities with on-the-spot practice, to use relay teaching, to enable leaders to learn leadership and members to develop team spirit and let people understand the usefulness of data by collecting general inspection data.

The O**bjectives** that the team sets when it is approaching a step four activity are referred to the increment of the efficiency by attacking equipment residual losses, after elimination of breakdowns in the first three steps of AM, to provide inspection skill training, to modify equipment to facilitate training, to Get individual equipment items to peak conditions thanks to general inspection

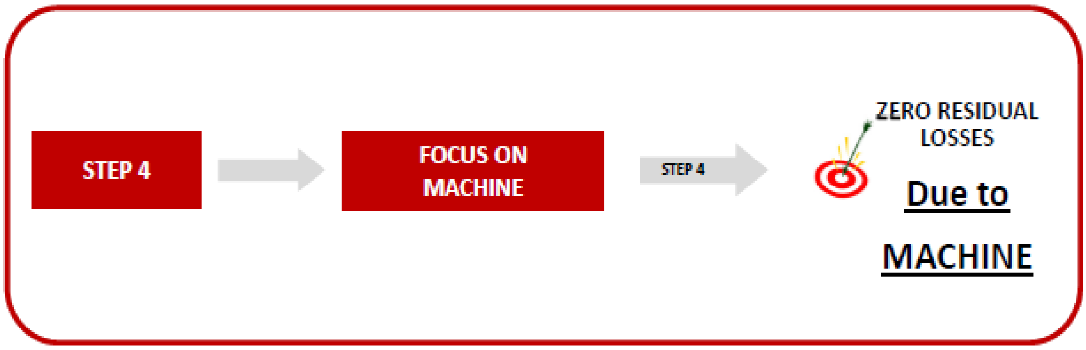


Figure 28: Step 4 Overview

Each activity proposed at this point must economically be justified so as evaluation criteria, Focused Improvement and Quality Control activities must help to make AM step 4 approach applicable in terms of B/C ratio.

It is worth to notice that when AM acts, the objective is to increase line productivity and so line output. If we implemented step 4 to increase efficiency of Model Machine, machines M2 would become the line bottleneck.

In order to carry out the AM step 4, several actions have to be implemented, therefore once all the breakdown losses have been removed, the pillar can keep working on the Model Machine by attacking the other losses with step 4-5.

Once evaluated line scenario and usefulness of AM step 4 application, OEE (overall equipment efficiency) becomes the driver of all the activities for the identification of residual losses (i.e. scraps, rework, minor stoppages, etc.), the identification of loss priorities in terms of OEE impact (%) and the 4M analysis: which M (Machine, Man, Method, Material) is involved in each loss.

It is necessary to stratify each loss by type of issue (figure 29):

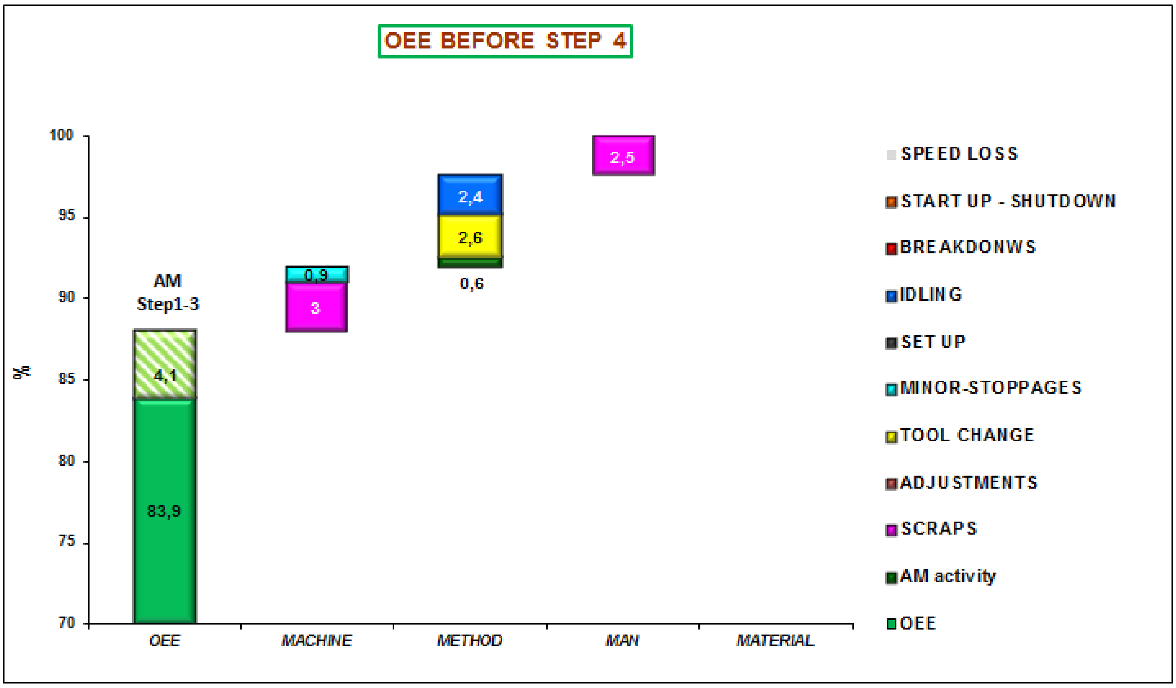


Figure 29: Losses stratification by issues

When a problem occurs (i.e. scrap due to wrong diameter, etc.), a quick 4M analysis is done in order to relate each part of loss to its correct M.

Before starting Step 4 activities, it is necessary to estimate B/C to know whether Step 4 is economically justified. The benefit estimation is based on the recovery of loss amount, that comes from CD pillar, while the cost estimation consists in the identification and the estimation of all the costs (i.e. training, project cost, new AM activities, machine modification). Once B/C is estimated positively (B/C>1), we can move forward with step 4.

When the problem is correctly identified and prioritized, the team can proceed to problem solving phase.

Here must be used tools provided by Focused Improvement and Quality Control, those are for example quick, standard and major kaizens, for what the FI it concerns, and the quality maintenance as far as the QC pillar.

The differences among the three different kaizens (figure 30) depend on the working conditions because a quick kaizen is needed when the loss is obvious or it was already identified and the limits of the problem have been already set, all relative data are available, and the plant needs suddenly results. While, a standard kaizen is a more complex and structured tool, it needs a preparing phase in which the root cause has to be identified and the target was not already defined. The Major kaizen is more complex than the standard one, it requires a stratification of the plan phase, and it requires the presence of technical expertise and working teams composed by more than five people.

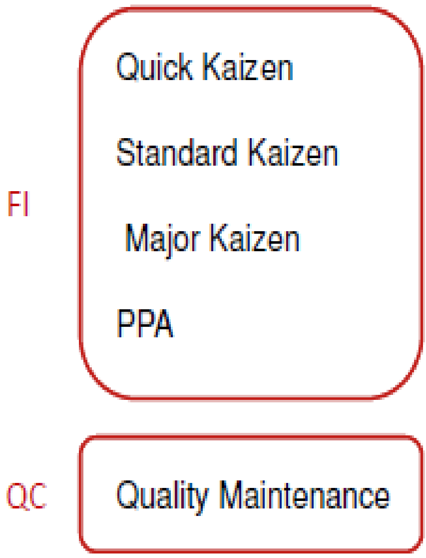


Figure 30: FI and QC tools for step 4

An on-field example was the frequently occurrence of a broken component on a toothing machine.

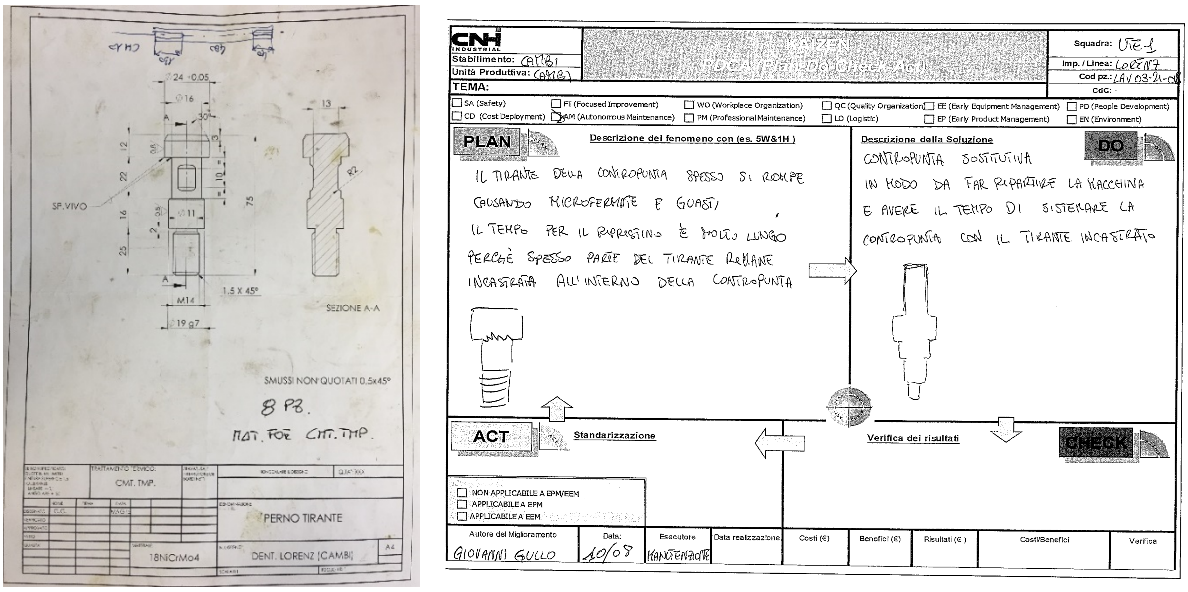


Figure 31: Traction shaft characteristics

The figure 31 represents the drawing of the component with all information about material characteristics and specific dimensions. The scope of the component is to ensure that the gear, during toothing, is well locked and centered. This kind of component enters in the category of consumables so it is foreseen that is has its own life and hance it may happen that with a certain frequency it needs to be substituted. However, directly from the shop floor has been reported an uncommon breaking frequency of this component. In this case, I was in charge to work on a solution to avoid the repetitiveness of this condition.

By following the method, firstly a data collection was necessary in order to have a clear view of the problem.

From the daily comparison with workers, a collection of the broken component allowed to a first hypothesis of the root cause because, as the figure 32 shows, the phenomenon belongs to the same broken surface.

Figure 32: picture of daily broken components

However, the correct way to proceed in order to take in consideration all the possible causes is to pass through the 4M's tool.

It allows to exclude the possible causes of the breakdown and it leads to the root cause of the problem. By exploiting this kind of tool, it is analyzed the impact on the phenomenon of Man, Machine, Material and Method.

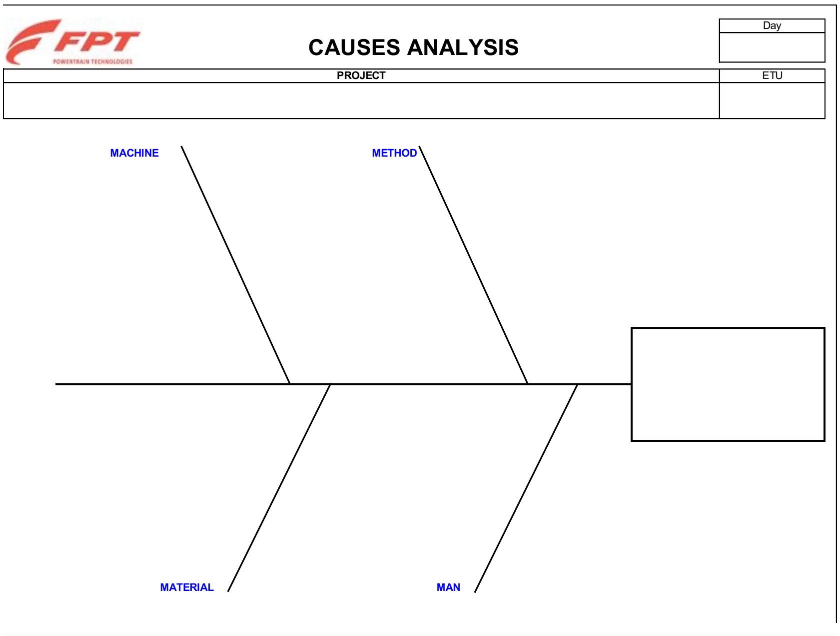


Figure 33: 4M themeplate

Thanks to this analysis it figured out that the possible root cause was related to the material because it was noticed that a failure occurred during the thermal treatment process so the mechanical performance of the component ware not more guaranteed, therefore it was planned that a new way of treatment was necessary, this meant that an economic evaluation was needed to establish whether the B/C coefficient was higher than one. To do that, the impact on the overall efficiency and the cost of the new treatment ware evaluated. Once the planning phase was terminated, the “DO” phase started, it allowed to obtain a more resistant component suitable for the workload required. After an observation period of two weeks the new procedure has been checked and its performances ware certified. Finally, the activity has been standardized, so the “ACT” phase started and the activity became a best practice for the plant.

As practical example of step 4 carried out it can be shown on the Fritz machining center, as the method requires the first step is the identification of the residual losses, therefore an analysis of the performance of the machines is necessary.

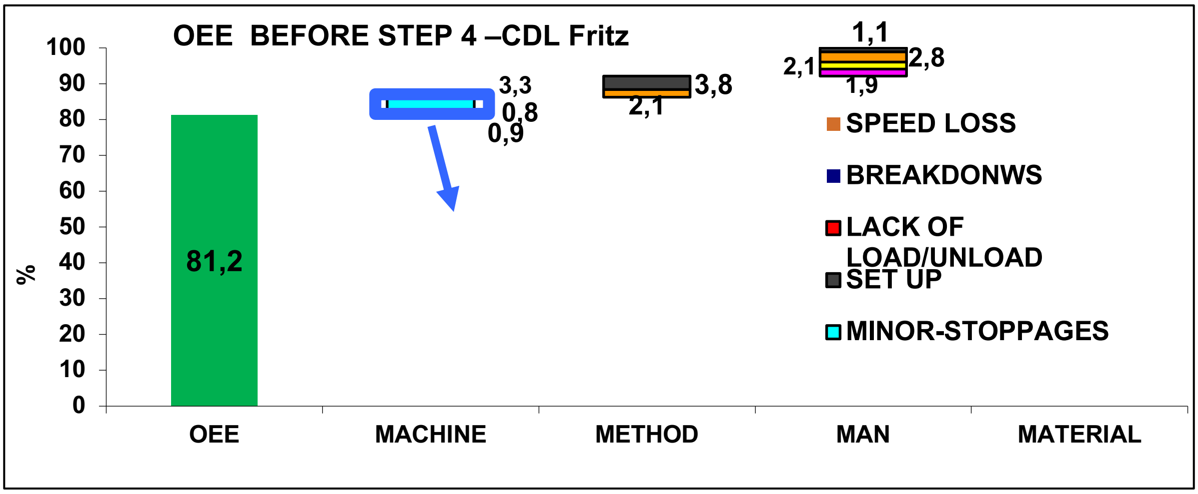


Figure 34: OEE deployment of Fritz Machine

In the figure 34. The highlighted losses have been classified by means the 4M tool and a 3,3% of minor-stoppages resulted. At this phase it is necessary to estimate a preventive B/C ratio about the impact that an activity on this kind of loss may belong to. The computation was conducted and by considering the cost of the improvement, the cost for training and documentation and the cost for the time spent for the analysis, a final B/C of 2,9 resulted hance the improving activity can start.

The first step is the problem description, it was done by means the 4W+1H tool answering to the typical questions, what, when, where, who, which and how.

The problem under study was a minor-stoppage due to an acceleration machine alarm. The frequency of the signal occurred two times per shift with a mean duration of 14.85 min the stop happened randomly throughout the shift therefore any correlation between the issue and a specific moment of the shift can be established. As reported in the figure 35 the problem grew in the work zone during the machine cycle-piece champing spindle and from the relative data collection it figured out any correlation with a specific worker because it occurred independently. Particularly, the minor-stoppage was related with the T1 tool, that was dedicated to the milling operation and finally it is worth to notice the machine was generally in a good state.

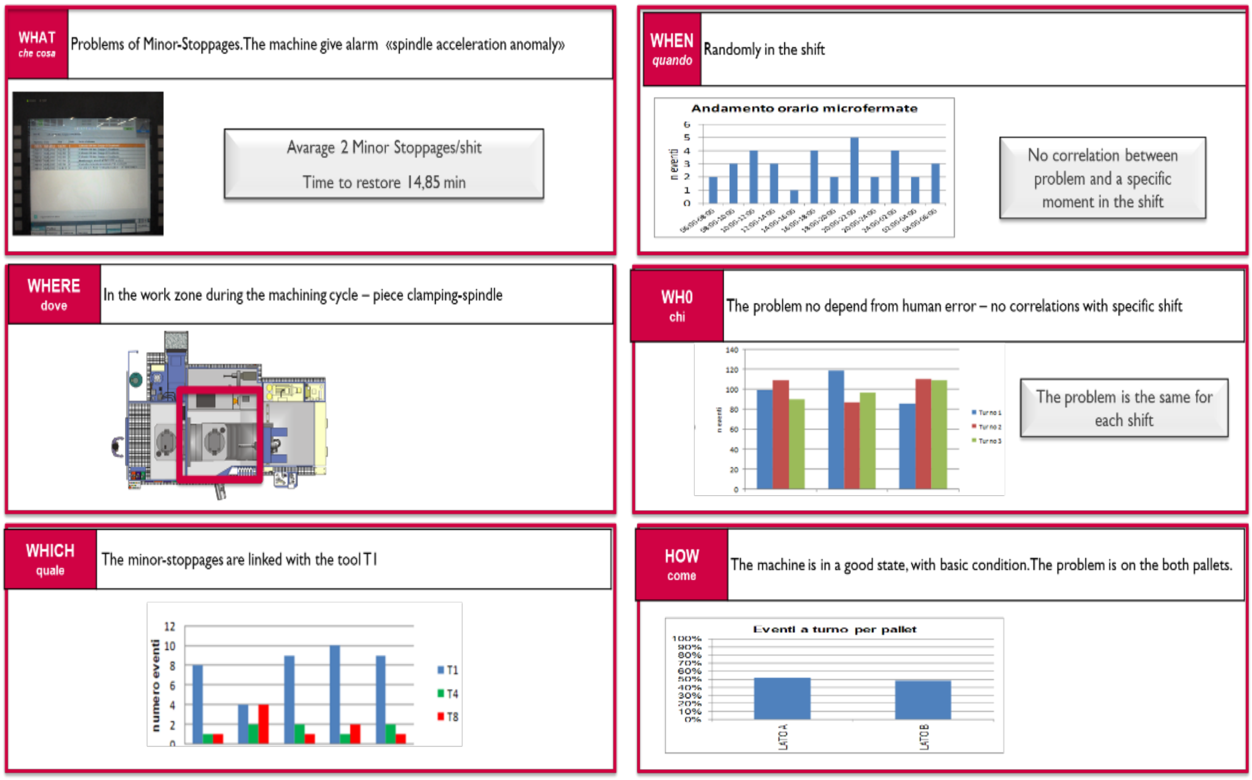


Figure 35: 4W + 1H For problem description

Then a description of the working process is necessary to have a clear picture of the work center, the machine can be divided in two zones, one for the charging and one for the unloading, the worker loads two row components in the A zone, and he sets the pressurization of the Hydraulic circuit, meanwhile the previous loaded components are machined (figure 36). Once the operation is ended, the phase of pallet exchange starts.

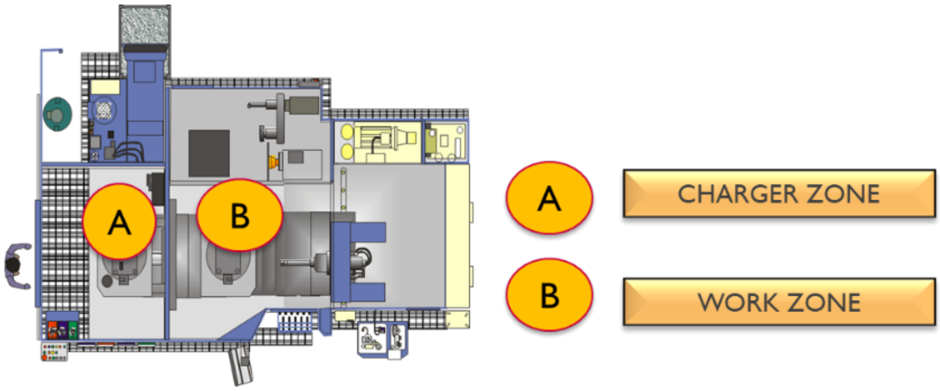


Figure 36: Charger zone and work zone

The pallet switching consists into un up phase, then the rotation of the platform and the down phase. During this process "Staubli" covers a fundamental role, they determine the pallet locking over the platform by means a hydraulic system. In order to observe the process while the machine was working the team decided to adopt a high-speed camera. By means this inspection process it has been discovered that during the milling phase the component was not totally blocked and this caused frequently minorstoppages.

In order to reach the root cause of the problem it has been adopted the 5-why tool as described in the figure 37

Analisi 5 Whys

Nr°	Team Leader:	Macchina:	Data:	UTE:

Spindle acceleration alarm

Fase N°	1° PERCHE'		2° PERCHE'		3° PERCHE'		4° PERCHE'		5° PERCHE'		AZIONE
	mechanical anomalies on the spindle	OK									
	Component not correctly locked	KO	Locking equipment anomalies	OK							
			Locking system not compliant	OK							
			Locking system not compliant	OK							
			Pressure parametes compliant	KO	Pressure settings	OK					
					Pressure keping tool	KO	Broken Pipes	OK			
							Staubli tension	KO	Component wear	OK	
									Tolerance Project error	KO	

Figure 37: 5WHYs deployment

The analysis belonged to a final root cause. The minorstoppage was due to a drop of pressure caused by the oil draining from the “Staubli” and it is caused by a weakness in the design of the tolerance parameter about the alignment between the pallet and the platform.

To have a further description of the root cause the team was focused on the study of the locking system. In particular, during the disengagement phase a drop of pressure has been observed by means of a manometer properly positioned, this sudden lowering of the pressure loosens the locks and as a consequence a shift of the part during the machine phase occurred.

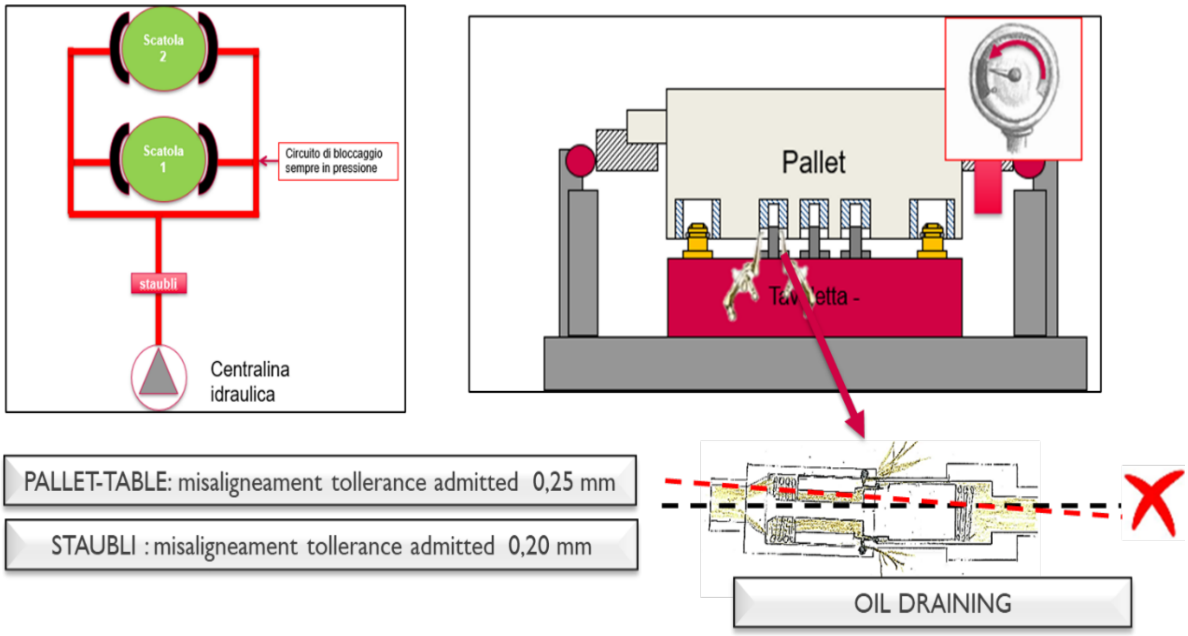


Figure 38: Locking system desription

As descripted in the figure 38, the current misalignment tolerance admitted by “Staubli” was 0,20 mm but the engagement between pallet and platform had a tolerance of 0,25 mm, this meant that a high level of misalignment could cause the oil draining and hance the pressure drop.

Entering in the solution phase of this 4th step activity, the introduction of a new type of “Floating Staubli” with 0,5mm as tolerance parameter was proposed and, moreover, the team decided to insert a NR Valve and a wireless sensor to ensure a continuous monitoring of the pressure in that area.

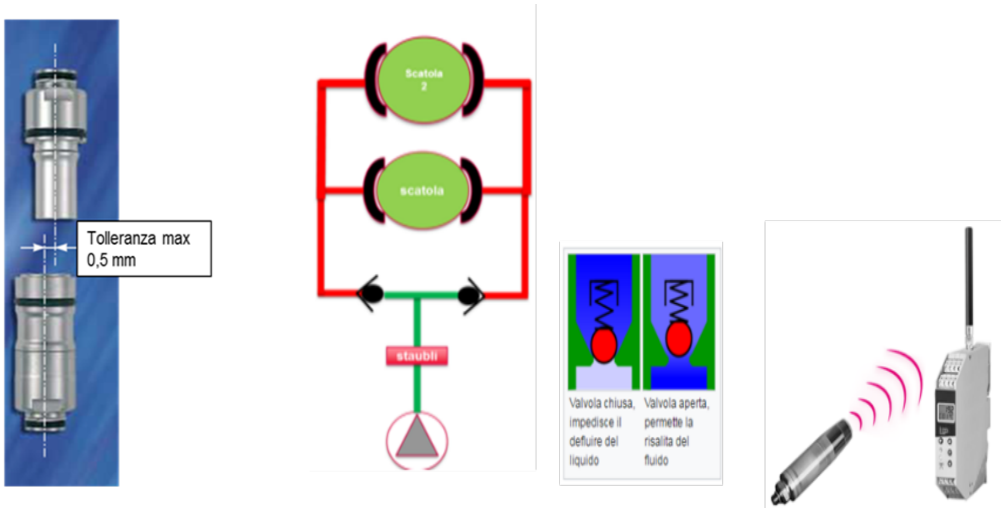


Figure 39: NR valve and pressure seensor

The carried-out activity led to a complete elimination of the minor-stoppages of the working center with a total benefit of 9,200 €, sustained costs were the cost of improvement, the training and the documentation to be produced and the time for the analysis. The final B/C ratio was equal to 2.21 therefore the activity had a positive result.

As foreseen by the method, the final step to definitely conclude the step is the standardization phase, so that the generation of the relative "MP Info" , all the technical documentation always needed when a modification of a product occurs, the modification of the CIRL document because of the presence of the new sensor to monitor the pressure and finally the extension toward all the similar area of the plant that works in a similar way.

3.3.5. Step 5 – Autonomous inspection

The vision of the fifth step regards the improvement of the overall stability and safety of process through correct operation and the introduction of sharpen process inspection precision by extending and improving visual controls. For example, the indicators for pipe contents and flow direction

It includes also the modification of the equipment to make it easier to operate.

Therefore, the step is intended to enable operators to operate processes and deal with abnormalities correctly, to enable operators to understand the relationship between equipment and the properties of the materials to be processed and to master the correct adjustment and setting techniques. Moreover, it is important to make operators aware of their roles in planned maintenance and foster self-management through periodic inspection and replacement.

The AM pillar has to provide instruction in process performance, operation and adjustment and in methods of handling abnormalities in order to improve operational reliability with process competent operators and to incorporate provisional cleaning/inspection standards of single equipment items into periodic inspection/replacement standards of entire processes or areas.

Figure 40: Step 5 Oveerview

The OEE is the driver of AM step 5 activities for the identification of loss priorities in terms of OEE impact (%). The main adopted tool in this phase is the 4M analysis, (Man, Method, Material) because it allows to further decompose residual losses and to identify the actual responsible of the problem.

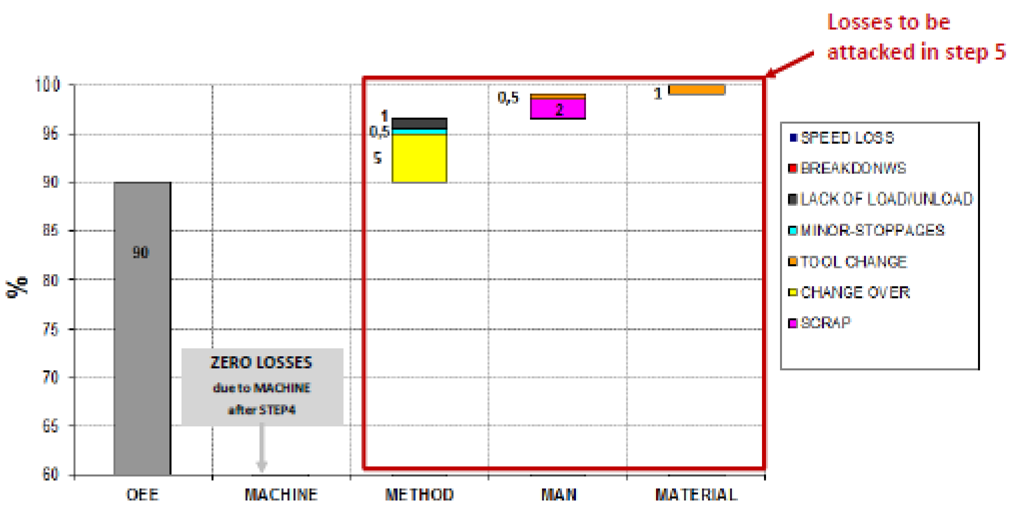


Figure 41: OEE deployment for step 5

It is necessary to stratify each loss by type of issue and its category (figure 42):

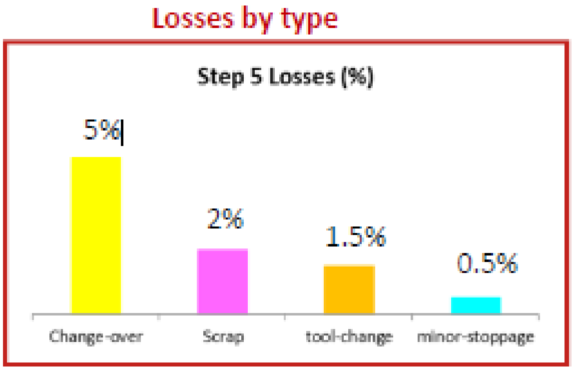


Figure 42: Losses stratification

At step 5, for each project against scraps, minor stoppages, etc, we have to calculate Benefits and Costs before starting up with activities, therefore a practical example is following developed to describe the approach of the method on field.

The proposed activity has been carried out on a cost center called "Pfauter", the analysis was intended to identify the remaining losses.

However, the first step is to analyze the performances of the machine and then to look at the OEE indicator, as proposed in the figure 43.

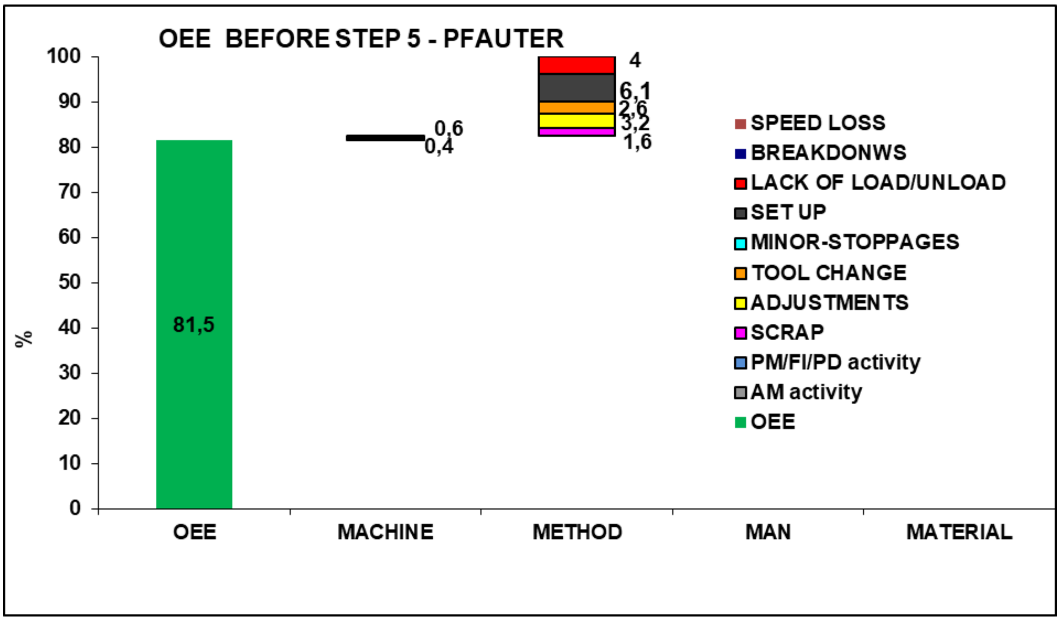


Figure 43: Losses classification

The losses stratification was obtained by means of the 4M tool and the activity was carried out to attack the residual losses of scraps because from the analysis of benefits and costs this was the only action that belonged to a final benefit.

As for the step 4, initially it is needed to describe the problem according to the five Ws and one H questions. The problem occurs an all the Pfauter machines and it is evident that those scraps are directly linked to the set-up activity as it is shown in the figure 44.

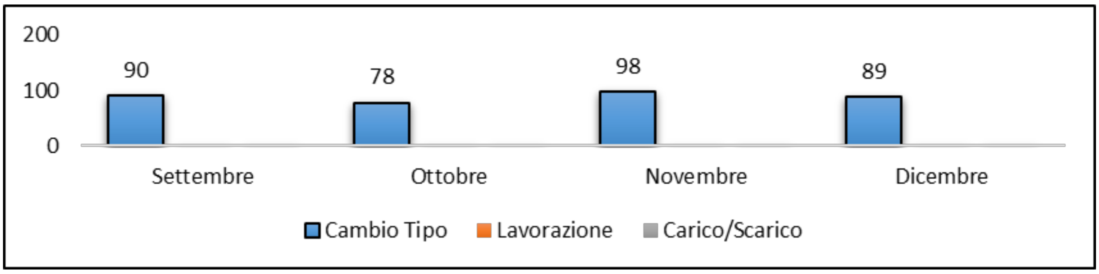


Figure 44: activities that causes losses

During the observation period it has been defined that the issue is not linked with the operator because it occurs independently on different shifts. Moreover, it was noted that the frequency of the scrap production increases as the number of set up does (figure 45).

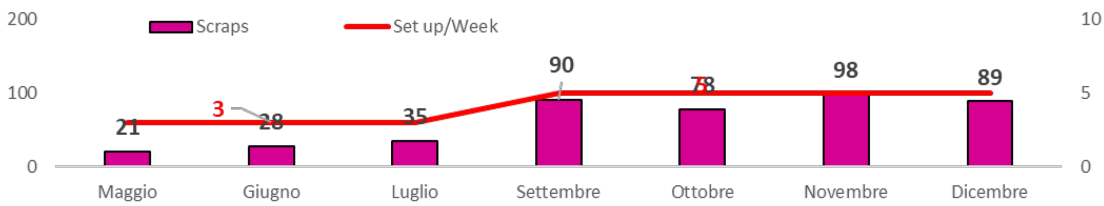


Figure 45: scraps trend due to set-up increasing

The observation of the cycle highlighted that at the end of the working cycle, the component just machined would be controlled and measured on a proper bench outside from the machine, then the worker applies corrections to the working parameters according to the measures observed. This way of working led to scraps generation because every time that a set up was performed, at least the first machined gear became a scrap.

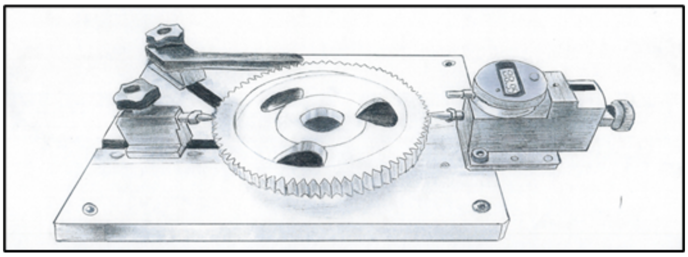


Figure 46: Autonomous mesurement system

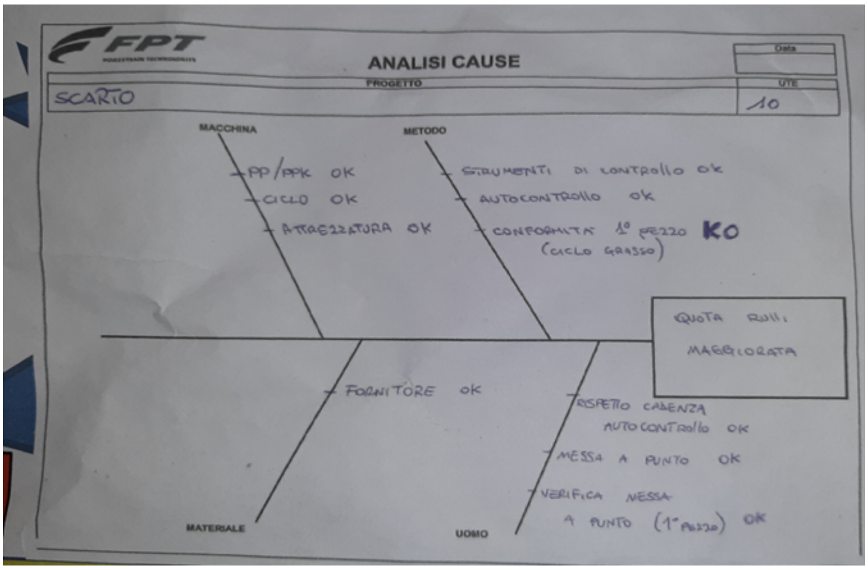


Figure 47: 4M problem Identification

The solution implemented by the AM pillar was to set a first working cycle, after the set up, so called fat cycle, therefore the machined gear has always more material then necessary. Then by introducing a new measurement instrument, a plate micrometer, the gear can be measured directly on the spindle of the machine, hance, once all corrections are applied, the gear can be reworked to get its final shape.

This solution belonged to a complete elimination of the scraps and accordingly to an improvement of 2% in terms of OEE.

The final B/C ratio was of 4,45 so highly over 1 (figure 48).

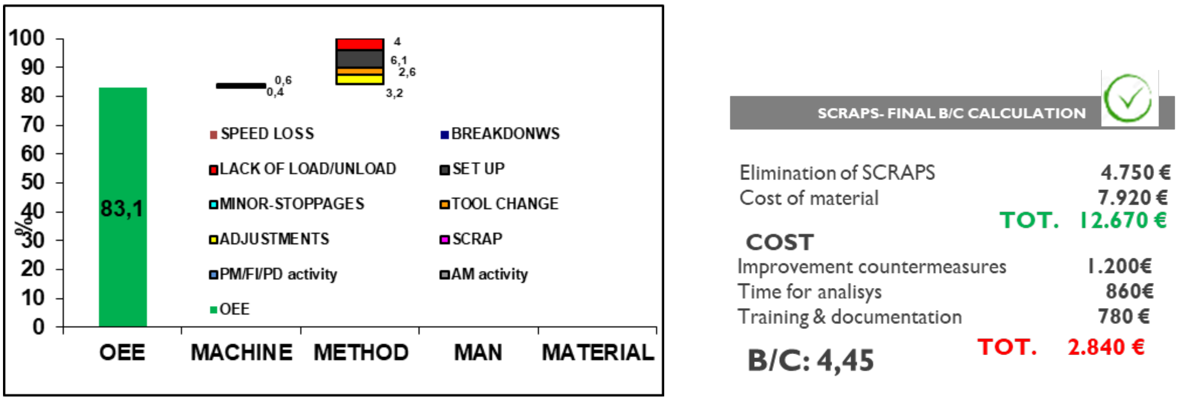


Figure 48: Final OEE and B/C

As always, the last activity to perform is the standardization of the results, this generates SOPs, training plans and the extension toward all the other similar machines.

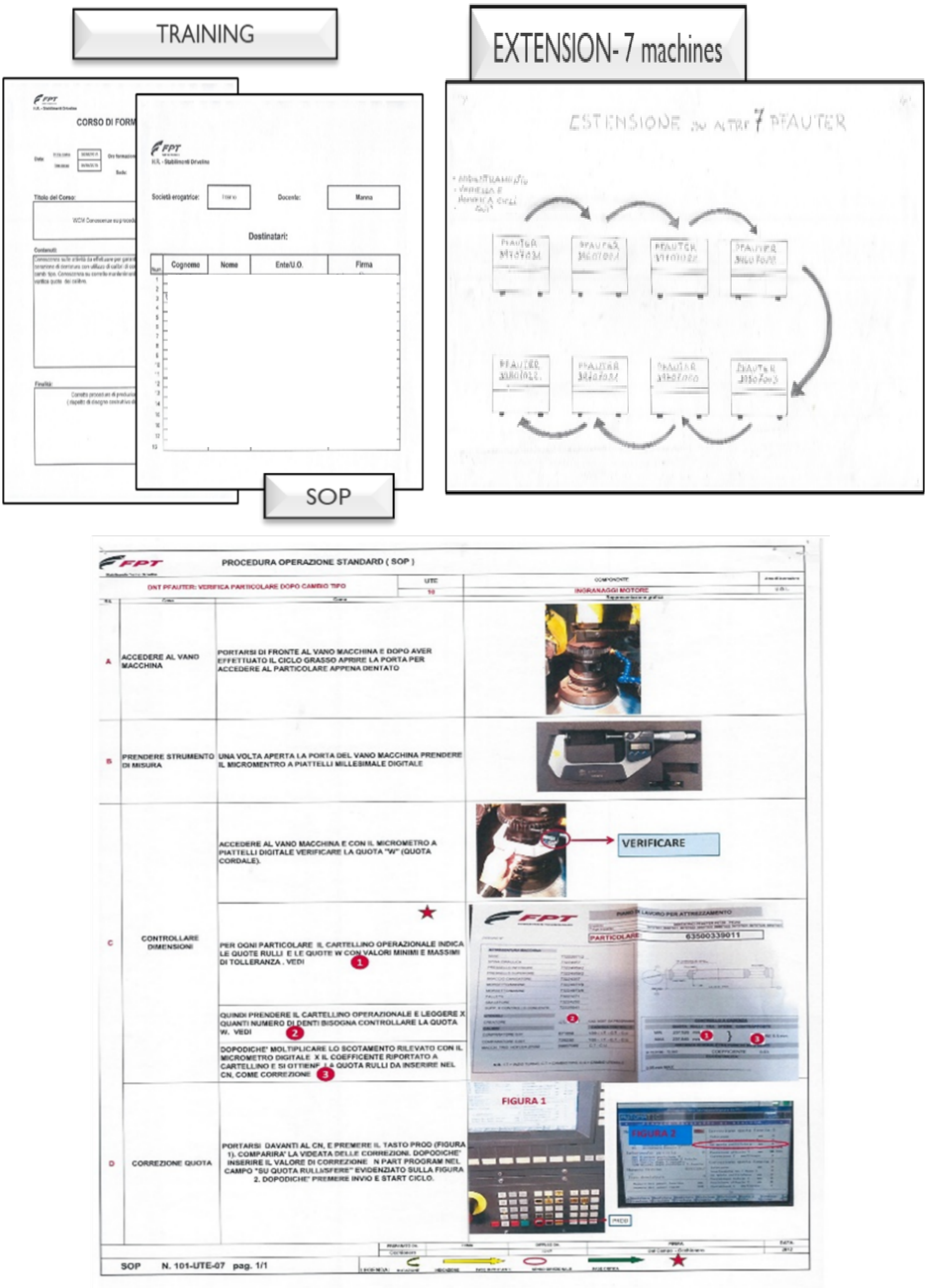


Figure 49: Standardization tools

3.3.6. Step 6 – Improvement of standards (workplace organization & housekeeping)

When major losses on single machines are reduced and the OEE reaches high standards about 85/90% the AM pillar can start to move forward by starting the step 6 activities, they are intended to improve Line Balancing and Efficiency applying Workplace Organization approach, to set operator selfmanaging activities and to create integration among other pillars such as SAF, QC, PD.

The scopes of the step 6 are to remove residual Managerial Losses of single Machine, then to move from Single Machine point of view to Line/System point view and to make operators aware of relation of machine parameters with other Pillars such as SAF and QC, it is important that operators feal to be part of a team and they are able able to self-manage abnormalities.

The set objectives when a step 6 is conducted requires obtaining zero managerial residual losses, an OLE and Line Productivity increment by attacking residual losses, Machine MUDA and Man MUDA and finally to have Level 4 Operators.

Figure 50: Step 6 Overview

After recovering of the losses thanks to the reactive (step1-3) and preventive (step4-5) approach, the task of the step 6 is to recover all the other residual losses because the machine is not working in accordance with the design cycle time (speed losses), in the optimum cycle time (NVAA) or because the interaction with other machines and operators is not balanced, so making deeper analysis with OEE, and starting to consider also the impact of the machine on the performance of overall line (OLE)

First aim of step 6 is to attack managerial residual losses applying the similar contents of WO step 2, eliminating all difficult and unnatural operations (MURI), unevenness and irregularity (MURA) and uselessness and waste (MUDA) in Man and in Machine and performing

standardization of maintenance and control of transport, spare parts, cleaning equipment and so on introducing new visual controls in the workplace.
After elimination of residual losses on the bottleneck machine, next mission is to investigate the complete line, extending all the improvements to similar machines.
Second aim is the Balancing of the line working with WO Step2 concept eliminating MURI MURA MUDA considering entire line.
Saturation of all operators of the line should be investigated and standardizing operator activities with much more integration with SAF and QC and PM Pillars.
The tools that are utilized for these activities are: Man-Machine charts, Machine & Process data Analysis, Cycle Time Analysis, Muri-Mura-Muda Analysis, Bottleneck Analysis, VSM.
Before starting Step 6 activities, it is needed to estimate B/C to know if Step 6 is economically justified and so we need a benefit estimation that it is based on the recovery of loss amount, that is provided by CD pillar and a cost estimation (i.e. training, project cost, machine modification).

Once B/C is estimated positively (B/C>1), it is possible to move forward with step 6.
It is important at this point to provide a clear definition of the Overall Line Effectiveness (OLE) indicator, it is a key performance indicator that can be implemented to analyze and improve a production process by measuring inefficiencies and groups them in different categories. In other words, OLE is total utilization of time, material and facilities in a manufacturing process line in a situation where a manufacturing line consists of unbalanced/decoupled machines Overall Equipment Efficiency (OEE) of single machine is not sufficient.
OEE is measured for an isolated individual equipment and controlling a single tool does not seem to be effective.
The Overall Line Efficiency shows how well a manufacturing line is running compared to how well it could be run.
OLE in a complex and verticalized plant is not applicable at all level.

Line	OLE Applicable	Formula	Kaizen Level
Balanced One Piece Flow	Yes	OLE formula = OEE formula $OLE = A\% \times P\% \times Q\% = \frac{OT}{PPT} \times \frac{NOT}{OT} \times \frac{FPT}{NOT} = \frac{FPT}{PPT}$	Single Machine OEE
Unbalanced With known Bottleneck	Yes	$OLE = OEE_{Bottleneck}$	$OEE_{Bottleneck}$
Unbalanced With intermidiate buffer	Yes	OLE Easy Formula $OLE = \frac{\text{Time taken to produce the Good Parts}}{\text{Total Planned Production Time}} \times 100$	Single Machine OEE
One input Several output	Not	No Formula	Change Line definition

Figure 51: OEE and OLE computation

When OLE is not applicable it is required to recheck the Line level definition separating the previous considered Line into smaller ones and adopting OLE formula for each of individual smaller line (figure 52)

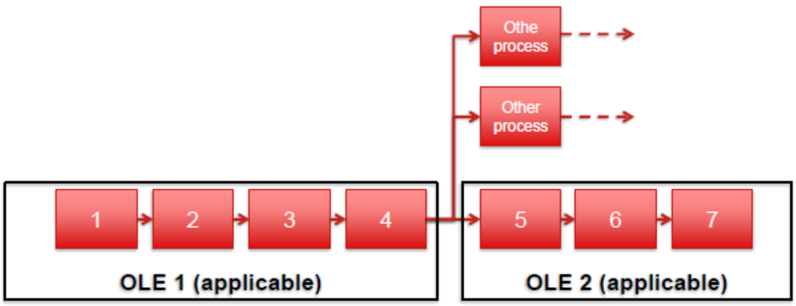


Figure 52: Line Level Definition

Machine MUDA losses: In order to understand the root cause of the residual losses in equipment and attack them immediately, the operator needs to be able to monitor and analyze the real-time data of operations.

In ordinary production facilities, these data are kept manually or by excel based software. For that reason, OEE losses may not be recorded at all rather than recorded but periodically or recorded in different ways depending on the operator (Unstandardized).

When managed by an Online Data Collection system, residual losses are recorded immediately and be ready for the analysis on a daily base.
To report a practical case study that properly represents a step 6 activity development, an action of line efficiency improvement is described. The activity deals with a sequence of operations intended to machine secondary shafts of produced gearboxes, in particular in this area of the plant there are two operators that are in charge to drive machines, to make autonomous maintenance operations and to keep always under control the production according to the imposed quality standards.
The line is composed by six machines and based on the skills of the two operators, two machines are conducted by one of them and the other four by the second operator, according to their own skills and preparation. Since all carried out WCM activities until the 2021 belonged to have each machine of the line at least at step 5 with parameters of OEE higher than 85%, the autonomous maintenance pillar decided to perform a further improvement activity in order to get higher benefits with low costs.
The starting performance condition of the line was the one described in the figure 53.
In particular, the highest rate of residual losses stays in the group of “Method Muda” and it results that loading and unloading activities and tool changes impact on the overall line of a total 4,6% of the OLE indicator.

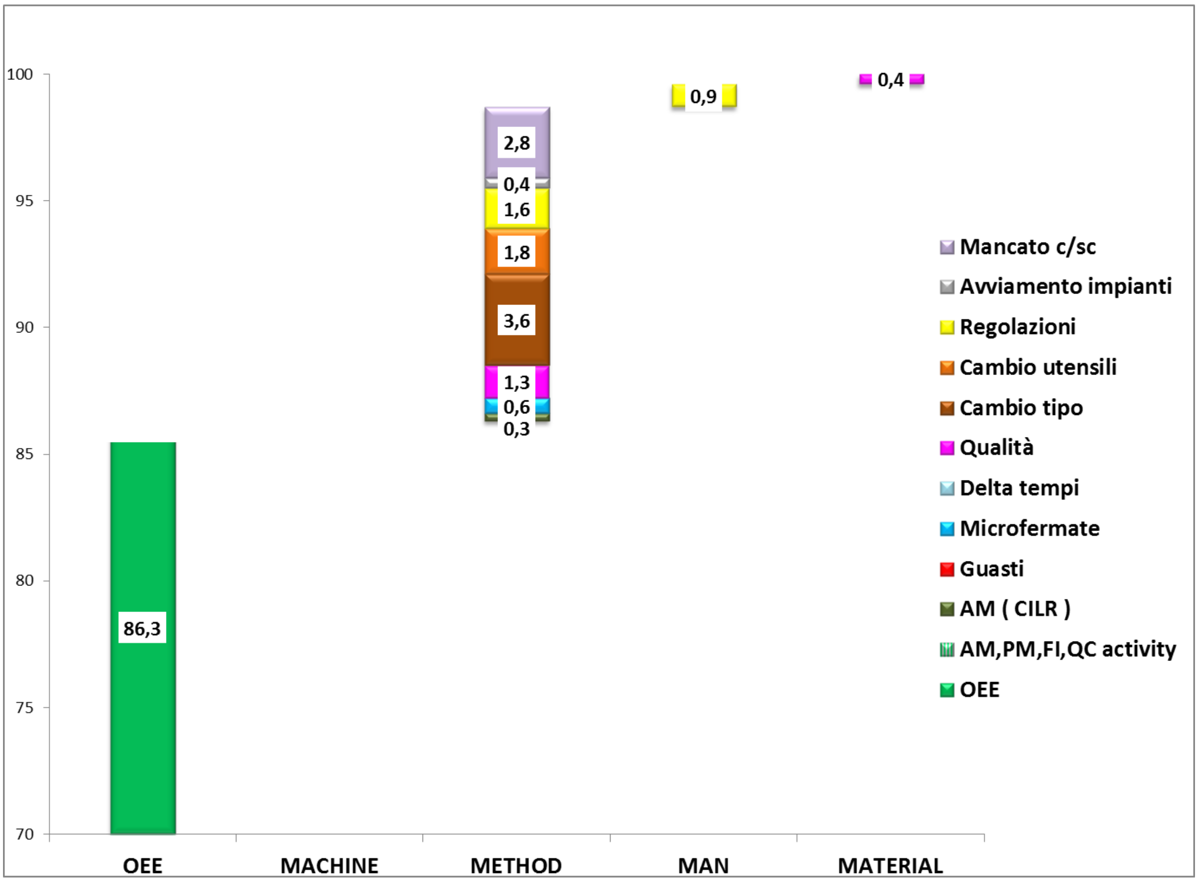


Figure 53: Starting OEE deployment

According to the analysis of the line efficiency, the team started to evaluate how to lower those percentages of losses with major impact and weather these activities had a B/C ratio higher than 1.

To follow a correct methodology, it is important to properly describe the phenomenon.

Thanks to the cycle time analysis and the man-machine charts (figure 54), the description of the tool change distribution throughout a period of observation of 4 weeks is simplified.

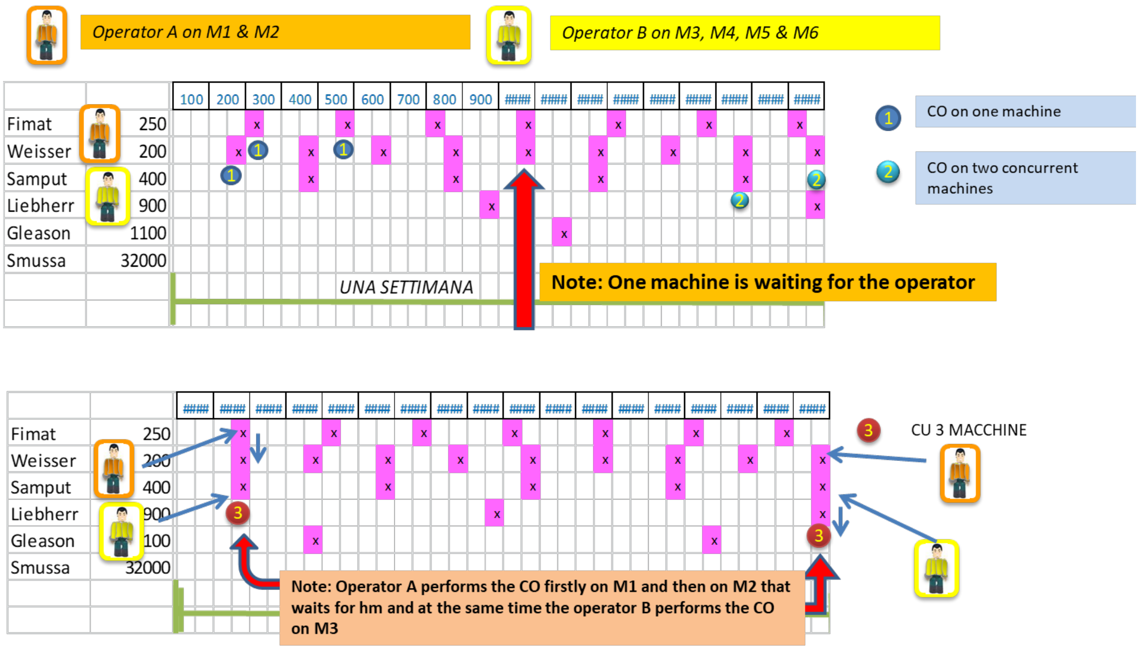


Figure 54: Men-Machine Chartes

As reported on figure 54 some possible scenarios highlight how the workload is not perfectly distributed and it may happen that more than one machine needs to be stopped and it has to wait the operator ends the tool change on another machine.

The conducted analysis led to all frequencies of concurrent tool changes, they cause not only the trivial stop to perform the activity but, since the operator need to follow simultaneously other working machines, the production runs not steady for a longer period than the needed for a simple tool change.

Cases	Macchine	Monthly
Case 1 (M singola)	Fimat	16
Case 1 (M singola)	Weisser	10
Case 1 (M singola)	Liebherr	3
Case 1 (M singola)	Gleason	2
Case 2 (2M contemp.)	We Fi	4
Case 2 (2M contemp.)	Weis Su	11
Case 2 (2M contemp.)	Wei Liebherr	2
Case 2 (2M contemp.)	Wei Glea	2
Case 2 (2M contemp.)	Fim Lieb	1
Case 2 (2 M contemp.)	Fim Gle	1
Case 3 (3 M contemp.)	Fim Wei Su	2
Case 3 (3 M contemp.)	Wei Su Lieb	3
Case 3 (3 M contemp.)	Wei Su Gle	1
Case 4 (4 M contemp.)	Fim Wei Su Lieb	1

Figure 55: Possible scenarios and Occurrence frequency

In order to further investigate the phenomenon, the team developed an operation cycle analysis (figure 56) that highlighted the behavior not continuous of the line just after the tool change.

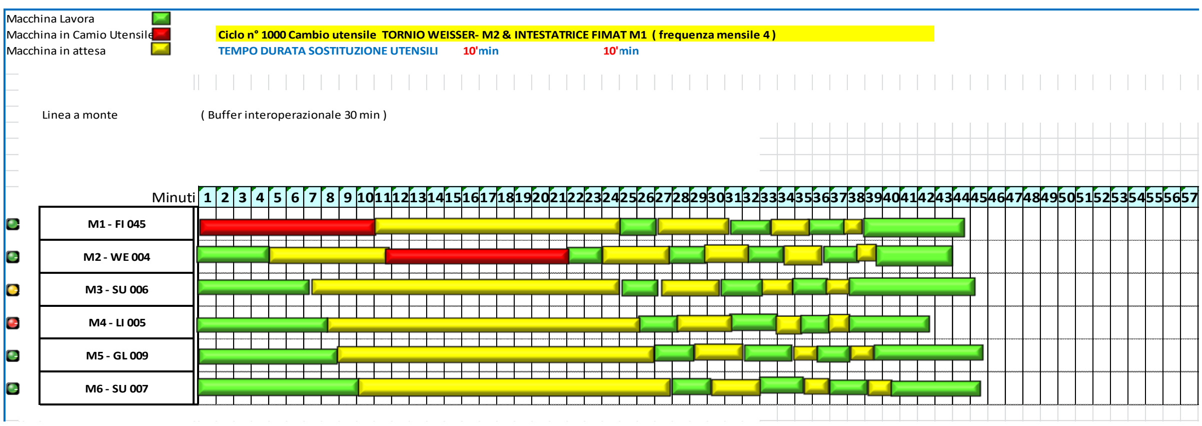


Figure 56: Operation Cycle analysis

The figure 56 shows an example of observed scenario where the red segments represent the full stop of the machine caused by the tool change frequency and yellow segments indicate the line is working but lower than target cycle time.

Consequently, the objective to reduce the impact of the tool change phase became of major importance to lower the total time spent on this not value-added activity (NVAA).
Therefore, the team adopted a simple strategy but anyway effective in order to improve the simultaneous action. Firstly, one more operator has been trained in order to have another person able to operate a tool change and so to avoid a machine waiting while the other is stopped. Moreover, the other proposal was to review the tool change frequencies of each machine, to understand weather a more efficient combination among several machine could optimize the time spending for the tool change activity further reducing the impact on the overall production flow of the line.
The computation considers the combination of the simultaneous machines' stops, here the comparison between the previous scenario and the new one is reported.

Figure 57: Operation Cycle comparison

The figure 57 reports the case of two machines that requires the tool change simultaneously and a consistent reduction in terms of time is evident, it is worth to notice that also for three and four simultaneous machine the result is still a reduction of spent time. Moreover, the computation led to an improved combination among several machine in terms of tool change frequency, that impacts on that part of speed loss that occurs when the operator is busy on the tool change operation on a single machine.

The figure 58 properly shows how tool changes have been grouped among several machines.

Type of combinations	Machine combination	Frequncy in 4 weeks
Case 1	Fimat – Weisser	15
Case 2	Fimat – Weisser – SU	7
Case 2	Fimat – Weisser – Gle	4
Case 3	Fim – Wei – SU – Lie	8
Case 3	Fim – Wei – SU – Gle	2
Case 4	All	1

Figure 58: table of tool change groups

Finally, it is possible to distinguish the two results in terms of the pure time spent on the tool change activity and the loss linked to the unsteady behavior influenced by the tool change as reported in figure 59.

Pure tool change loss

BEFORE

Yearly volume 67000 units
Yearly hours 2792 production hours

machines	frequency T.C.	minutes per T.C.	Num. T.C. per year	T.C. yearly hours	% di OLE
Fimat	250	10	268	45	1,6%
Weisser	200	10	335	56	2,0%
Samput 6	400	15	168	42	1,5%
Liebherr	900	20	74	25	0,9%
Gleason	1100	15	61	15	0,5%
Samput 7	14000	35	5	3	0,1%
		105	911	185	1,1%

AFTER

Yearly volume 67000 units
Yearly hours 2702 production hours

machines	frequency T.C.	minutes per T.C.	Num. T.C. per year	T.C. yearly hours	% di OLE
Fimat	500	10	134	22	0,8%
Weisser	500	10	134	22	0,8%
Samput 6	1000	15	67	17	0,6%
Liebherr	1000	20	67	22	0,8%
Gleason	1000	15	67	17	0,6%
Samput 7	14000	35	5	3	0,1%
		105	474	103	0,6%

Speed losses caused by the T.C. activity

BEFORE

Yearly volume 67000 units
Yearly hours 2792 prouction hours

	Min. per week . No Prod	hours/year	% di OLE
Case 1 - Single change ➲ (Fim/Wei/Lie/Gl	106	65	2,34%
Case 2 - Double change ➲ (6 various types	126	78	2,78%
Case 3 - Triple change ➲ (Various)	73	53	1,90%
Case 4 - Four changes ➲ (Fim/Wei/Su/Lie)	10	6	0,21%
		Totale perdita Linea	4,90%

AFTER

Yearly volume 67000 units
Yearly hours 2702 prouction hours

	Min. per week . No Prod	hours/year	% di OLE
Case 1 - 2 simultanei ➲ (Fim/Wei)	46	28	1,01%
Case 2 - Double change ➲ (6 various types	33	41	1,46%
Case 3 - 4 machines ➲ (Various)	83	51	1,82%
Case 4 - All machiness ➲	8	5	0,18%
		Totale perdita Linea	4,47%

Figure 59: Benefits of the activity

3.3.7. Step 7 – Full-scale application of the autonomous maintenance system

The step 7 of AM is an expansion of the method therefore in this paragraph will be presented a project that was successfully evaluated by an external auditor during the WCM audit activities, carried out on March 2021.

The activity has been performed on an high performant line, where secondary shafts of the transmissions are machined.

Figure 60 shows the layout of the line and all of the performed operations are listed as consequence.

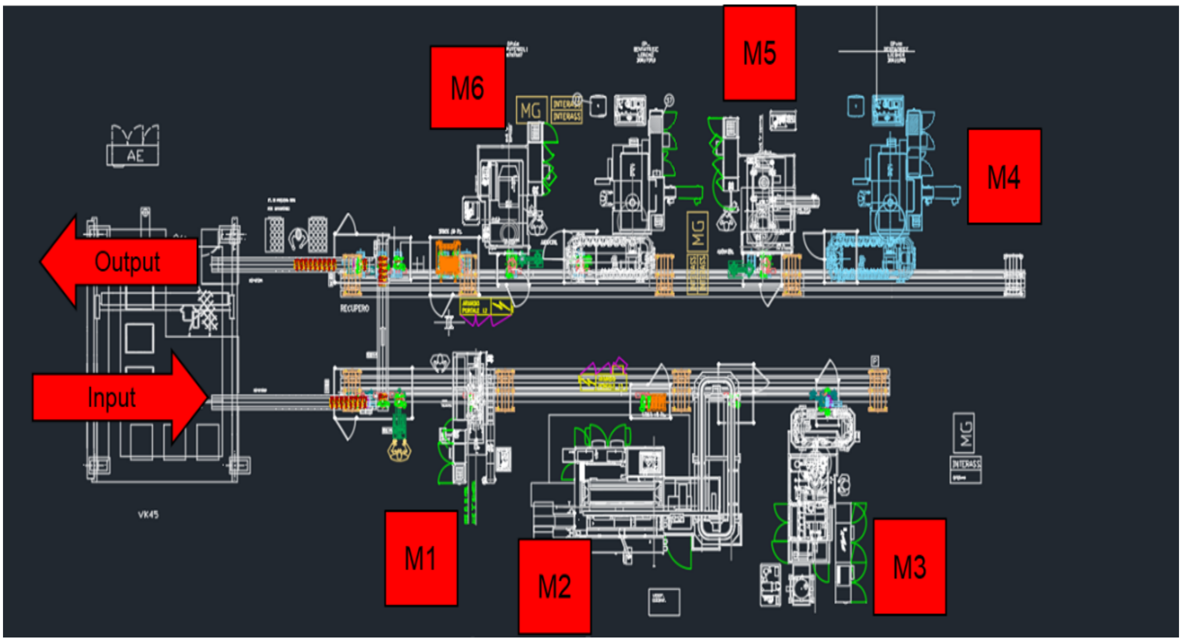


Figure 60: Line Layout (Adapted from FPT Industrial, 2021)

- M1 FIMAT 045 header (MM)
- M2 WEISSER 004 turning machine (A)
- M3 SAMPUTENSILI 006 toothing machine (AA)
- M4 LIEBHERR 005 toothing machine (A)
- M5 GLEASON 025 toothing machine (B)
- M6 SAMPUTENSILI 007 smoothing machine (B)

The OLE of the line is 95% so no more activities on losses can be performed.

However, since the demand scenario is changing and the production mix accordingly, the company asked whether a new type of shaft (figure 61) could be industrialized passing through the operations of this line.

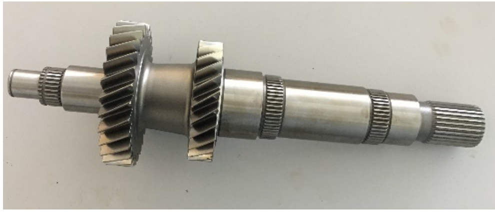


Figure 61: New Primary Shaft

In other to satisfy this request, a team was built including several members coming also from other WCM pillars and high specialized operators that everyday work on those machines.

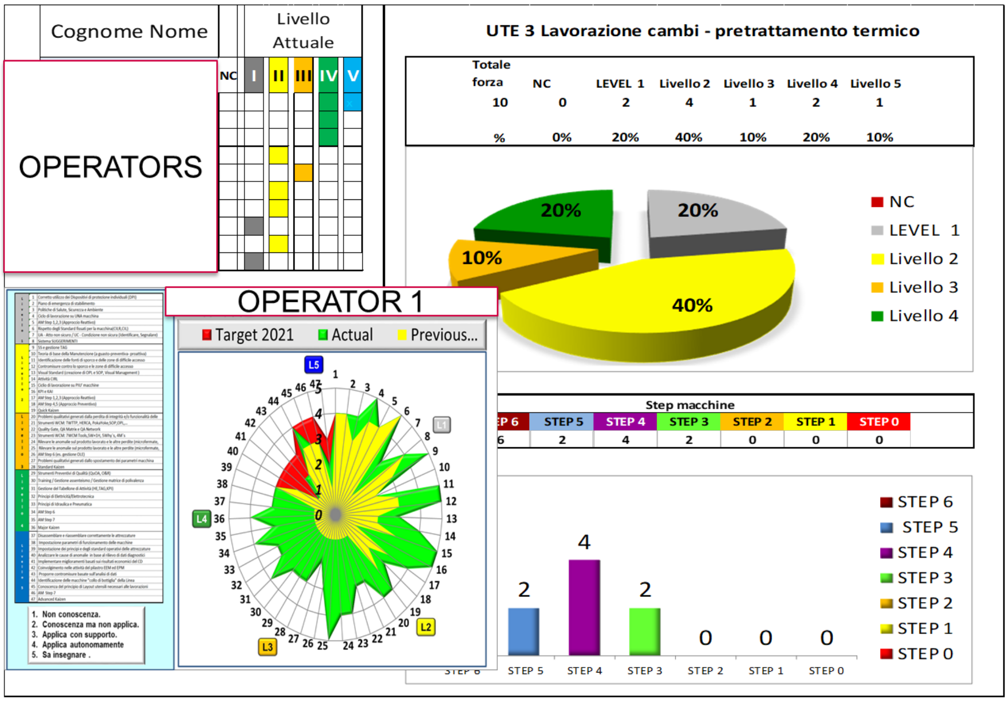


Figure 62: Operator skills classification

Once the team is constituted, the program planning of the activity is performed in order to be aware of the progresses of the project.

Firstly, operators solved those technological constrains that did not allow to machine the new component on the line as it is composed. Those limits regarded the encumbrance of the teeth of the largest gear, and the support platforms adopted to transport the shaft along the line.

The former issue has been solved with a simple modification on the structure of the machine, while the latter has been adapted to transport the new shaft just modifying the side shape.

Once ensured that the shaft could be worked on the line, the next step was to understand the competitiveness of the process with respect to market competitors. To this scope, a benchmarking analysis have been performed in order to establish the position of the company in the market. From the study it figured out that a competitor could perform the same transformation of the product with a lower price.
For this reason, the company asked the team if some modification to the production process could be implemented in order to lower the production cost.

The team conduced an analysis on the expenses of each machine in order to understand where the AM pillar could intervene to lower the losses. Machines of the line are sufficiently new therefore they are equipped with proper performance measurement systems, these enable the data collection of about all machine stops and installed sensors are able to indicate the cause of the stop. Hance, knowing the cost of each operation, of row material, of labours and consumables, the pillar can compute losses and consequently machine expenses.

NAME OF MACHINES OF THE LINE

	Fimat Int	*Weisser*	*Samputensili 006*	*Liebherr*	*Gleason*	*Samputensili 007*
Labour (k€)	*4*	*4*	*4*	*4*	*4*	*4*
Other expanses (k€)	*4*	*4*	*4*	*4*	*4*	*4*
Utilities (k€)	*1,9*	*2,6*	*2,2*	*4,4*	*2,2*	*1,6*
Indirect labours (k€)	*1,8*	*1,8*	*1,8*	*1,8*	*1,8*	*1,8*
Salary (k€)	*1,5*	*1,5*	*1,5*	*1,5*	*1,5*	*1,5*
Consumable (k€)	*0,2*	*0,5*	*2,2*	*4,1*	*2*	*1*
Maintenance (k€)	*0,5*	*0,7*	*1,05*	*2,31*	*1,33*	*1,05*

Figure 63: Expanses by machine

The three voices of Table XX that the AM pillar can attack are the utilities, consumables, and the maintenance costs, so a cost deployment of them among the machines of the line have been conducted in order to put in evidence some possible criticalities.

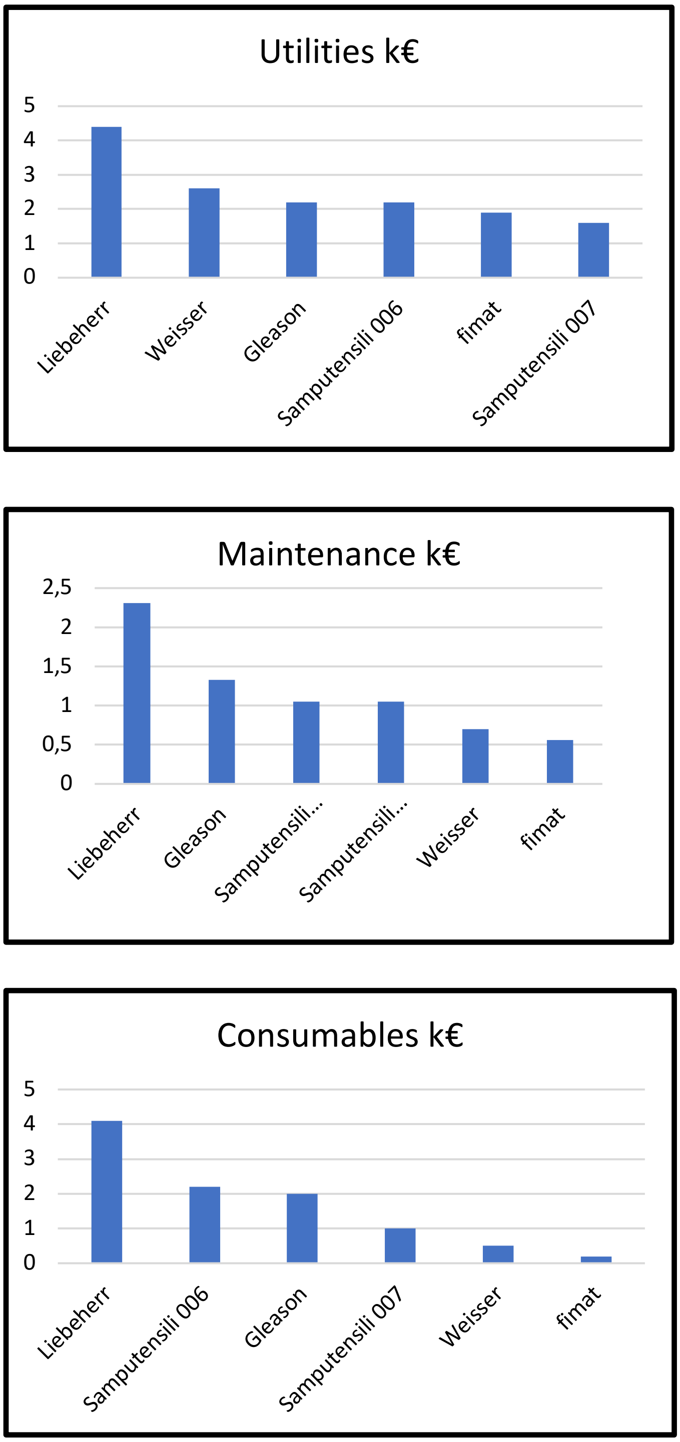


Figure 64: Expenses deployment by machines

The three proposed diagrams (figure 64) it is evident that the gear hobbing machine “Liebeherr” were the most expensive, this is mainly due to the age of the machine that is the

oldest in the line and also it is a machine that needs cutting oil to perform the toothing operation, obviously the oil represents a consumable that cannot be recovered and therefore it is a loss.
The final solution proposed by the team and, in particular, by operators was to eliminate the machine from the workflow thanks to the modification of the cutting tool (figure 65)

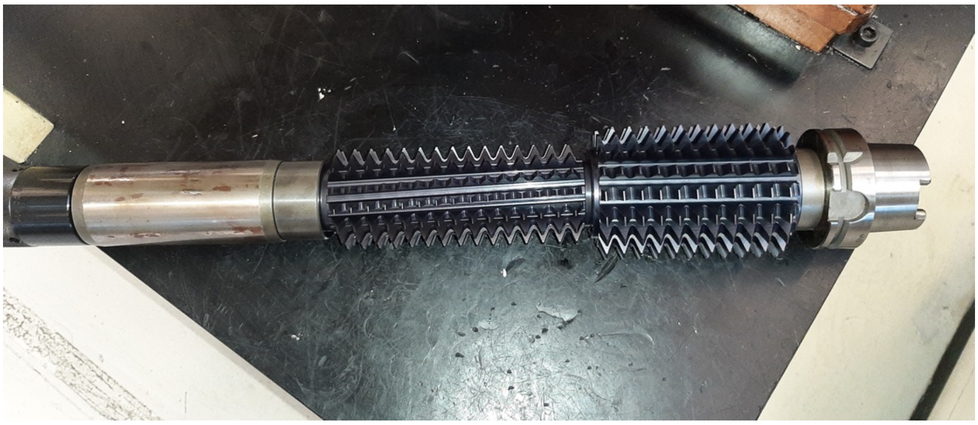


Figure 65: New cutting tool

Its doble hobbing allows to perform, both of the gear shaping, on the hobbing machine “Samputensili” with a single operation cycle. Since the machine is more performant than the “Liebeherr”, this proposal ensures that the line can machine the component with a lower takt time, with a lower cost of transformation as well.
The solution belongs the company to be competitive enough and to industrialize the new component.

3.4. Benefits and results of the AM activity

All the activities described so far through the 7 steps enters in a wider group of activities carried out by the AM team. A way to quantify the overall contribution of the AM team to the performances of the plant is to make comparisons among several KPIs and KAIs according to the machine classification.

In particular, in the last year 23 machines classified as AA reached the step 5 thanks to the AM activities and figure 66 clearly show the improvements of these machines by means three significant KPIs, the number of breakdowns due to lack of basic conditions, the OEE and the cleaning time of the workstation divided in actions taken while the machine is working (ML) and activities in which the machine is necessary stopped (MF).

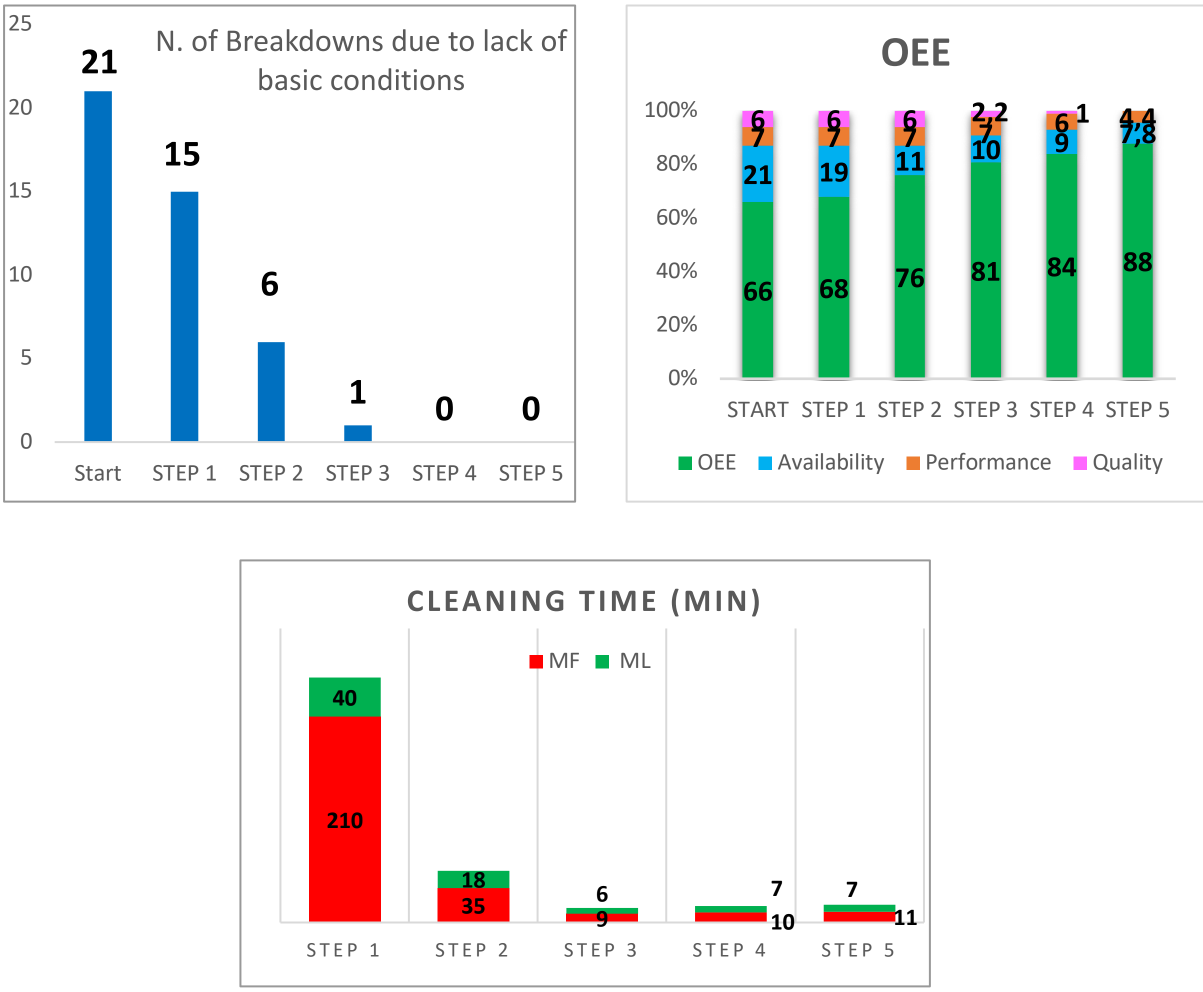


Figure 66: AM KPIs to AA Machines

Moreover, KAIs are significant as well and they give back the idea of the impact of the AM pillar, therefore the two most relevant are the number of dirt sources and the number of areas of difficult access, it is worth to notice how many of them have been contained or better eliminated as figure 67 reports.

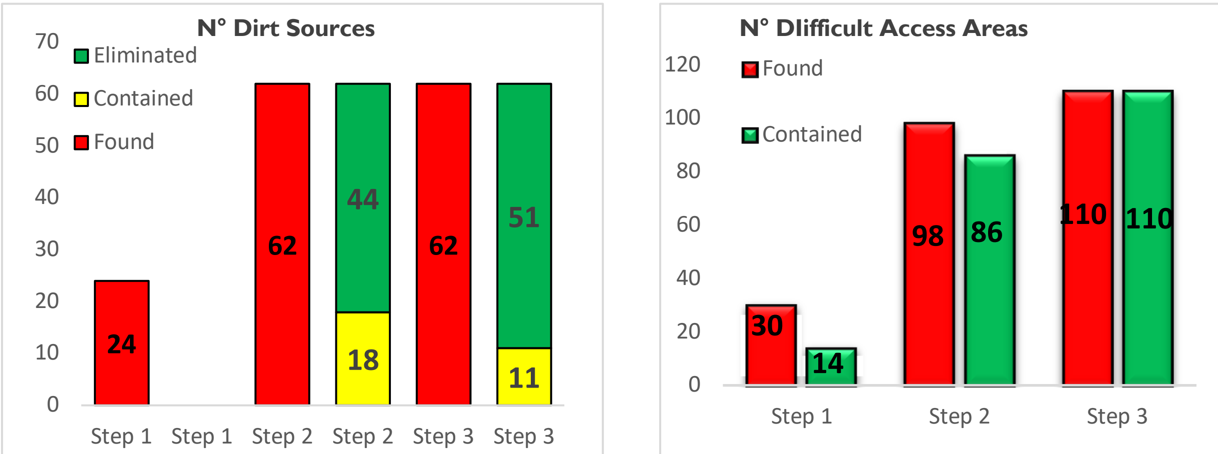
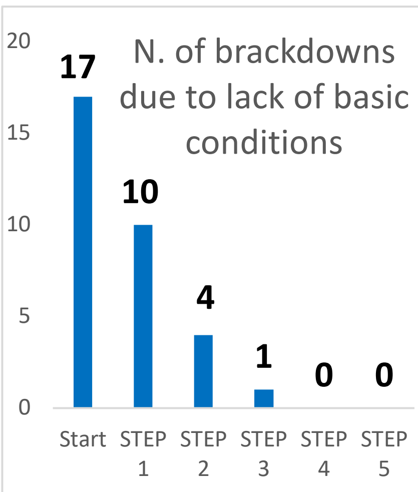


Figure 67: AM KAIs to AA machines

Same kind of results' analysis has been conducted for 26 machines in class A, 60 machines classified as B and 276 machines of C class. Relative diagrams are reported.

- A machines KPIs and KAIs



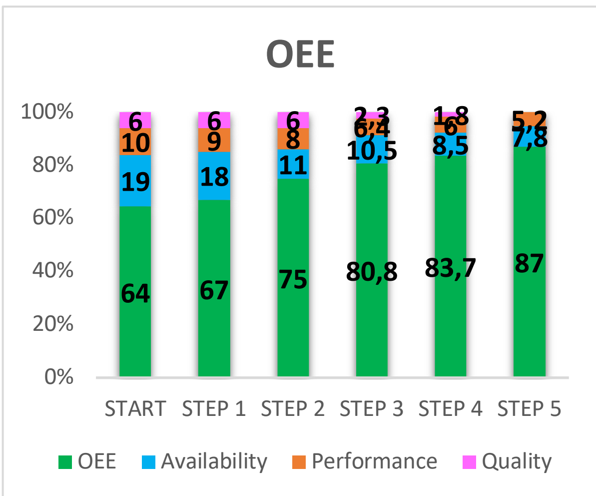
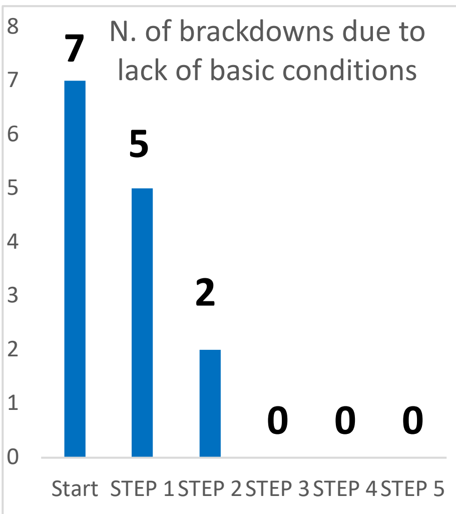
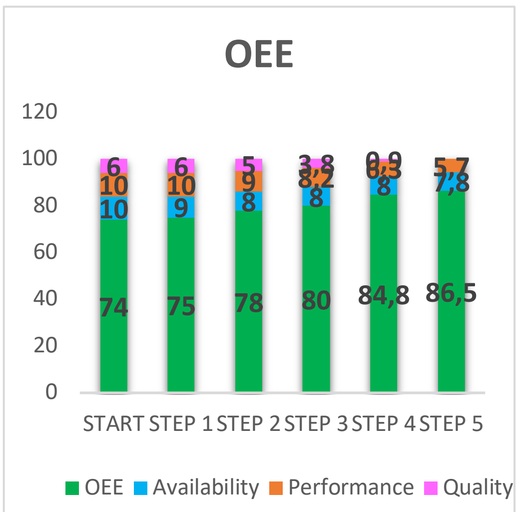


Figure 68: KPIs and KAIs to A Machines

- B Machines KPIs and KAIs





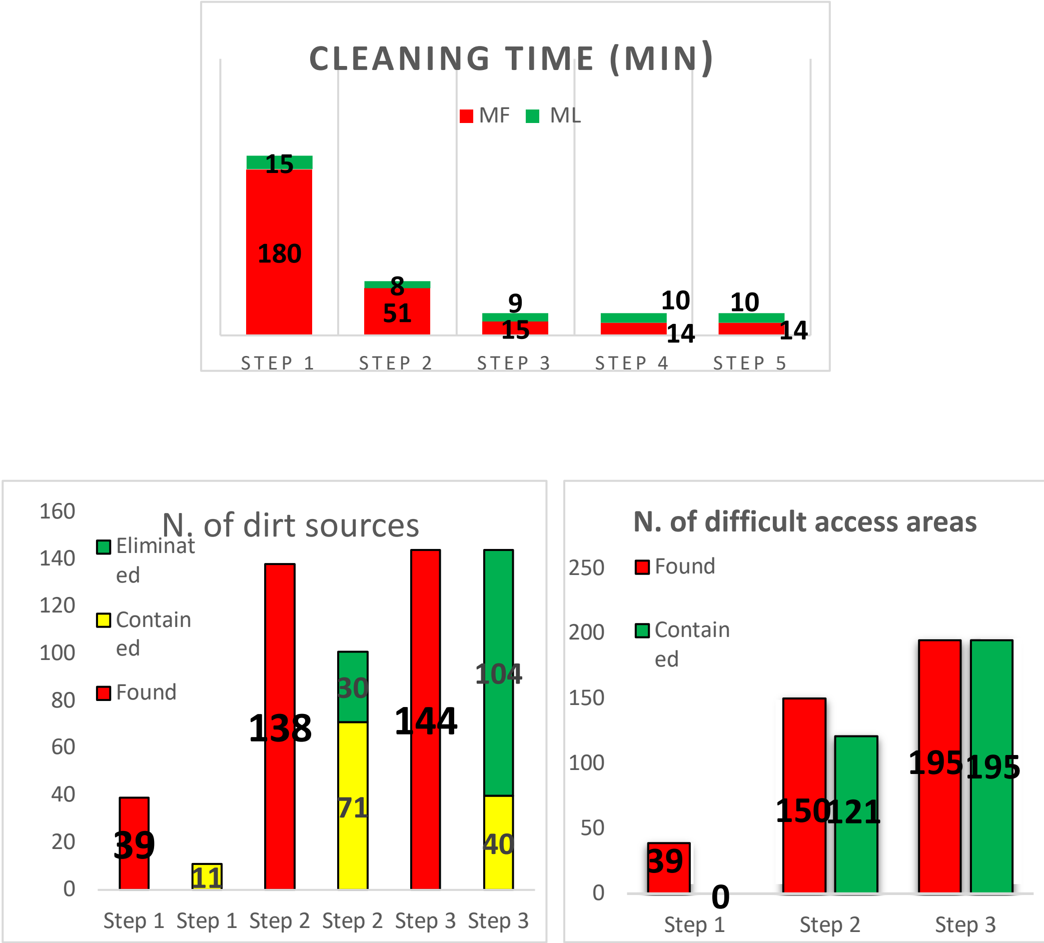
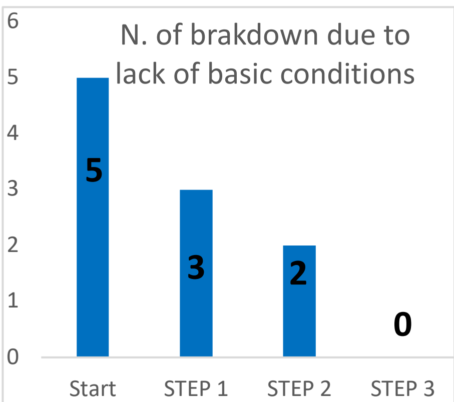
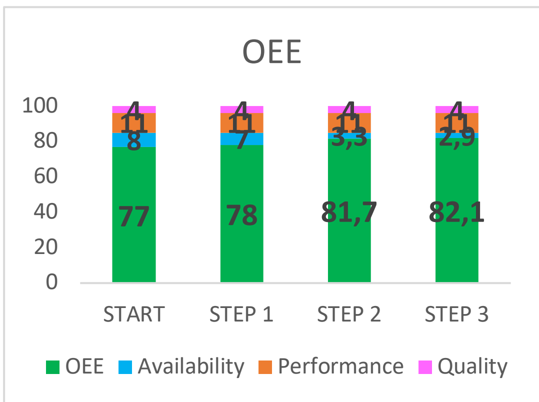


Figure 69: KPIs and KAIs to B Machines

- C machines KPIs and KAIs





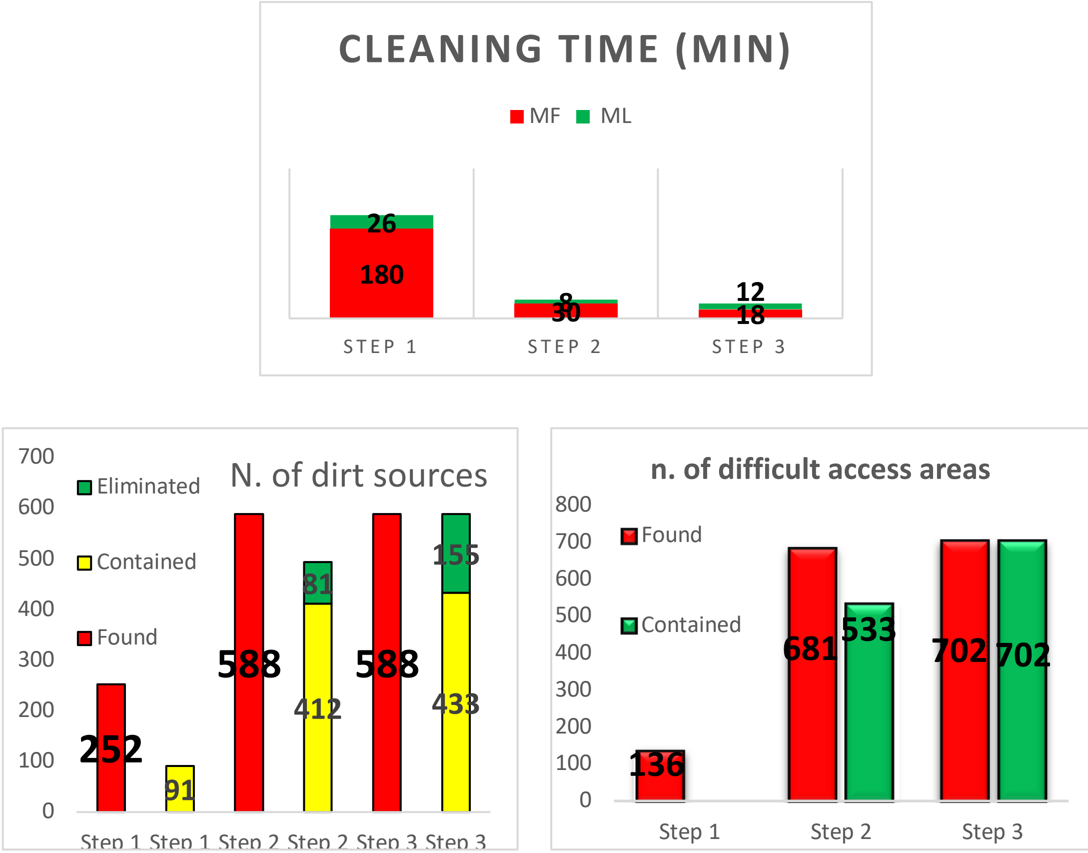


Figure 70: KPIs and KAIs to B Machines

To conclude, it is relevant to report the increasing trend of pillar's KAIs of emitted SOP (standard of operation), quick kaizen from operators and best practices produced throughout years (figure 71), they well indicate how the WCM philosophy is spreading with a positive impact through all levels of workers in the plant.

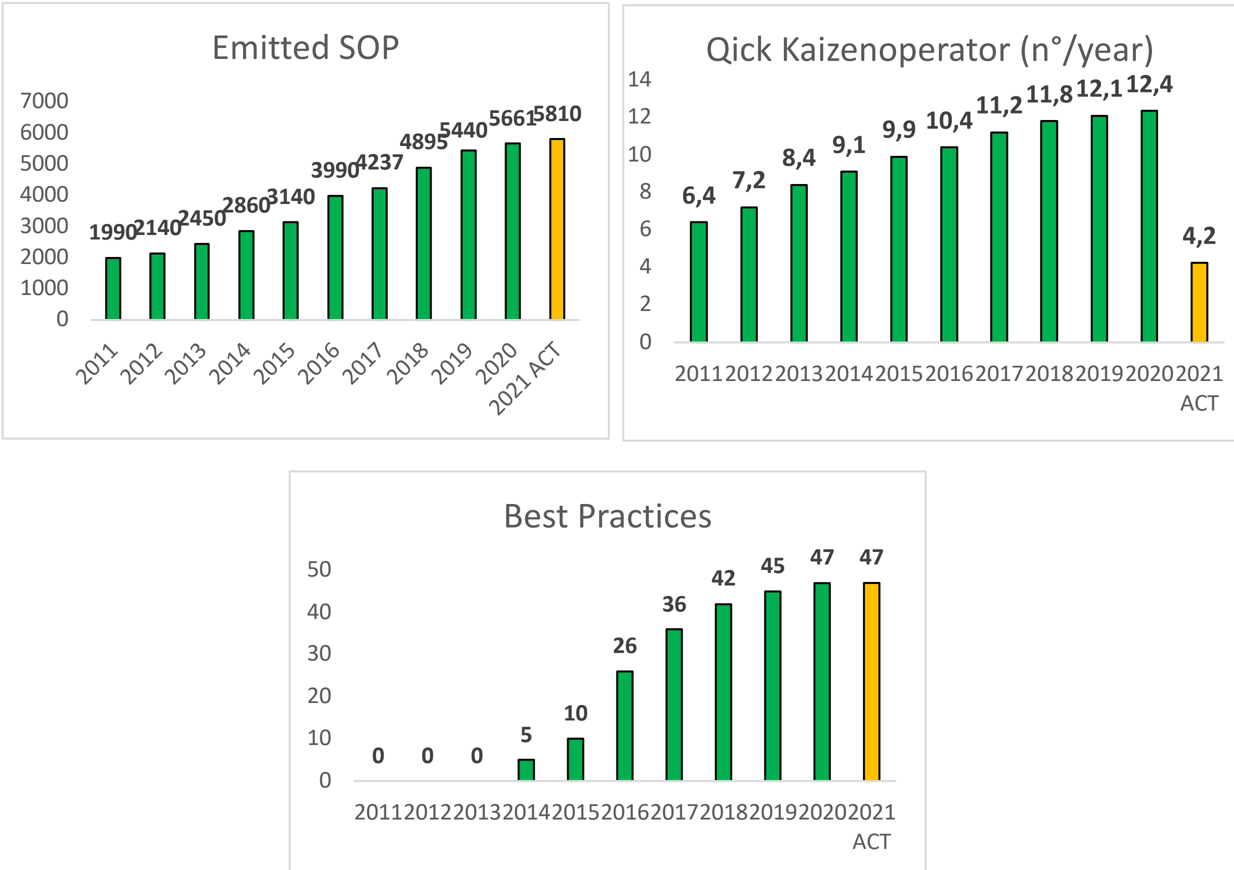


Figure 71: AM KAIs along years

4. Early Product Management pillar application

The second part of the experience was focused on the launch of a new product. When a new product must be industrialized the WCM provides specific tools and guidelines in order to proceed with the highest benefit over costs (B/C) rate.

The chapter has the aim to describe all the necessary steps that are behind the industrialization of a new product, in particular the attention is set on the launch of the production of the front and rear electric transmission for a next car from Maserati company. This project enters in a wider scenario towards the implementation of an entire plant dedicated to the production of electrified components, aligned with market and environment requirements.

The industrialization of a new product grows from the cooperation of the Early Product Management pillar (EPM) and pillars of Workplace Organization (WO), Quality (QA) and Logistics (LCS).

4.1. The Maserati Project

The product in consideration is the electric transmission of the new Maserati model, main characteristics and configurations are expressed in figure 72.

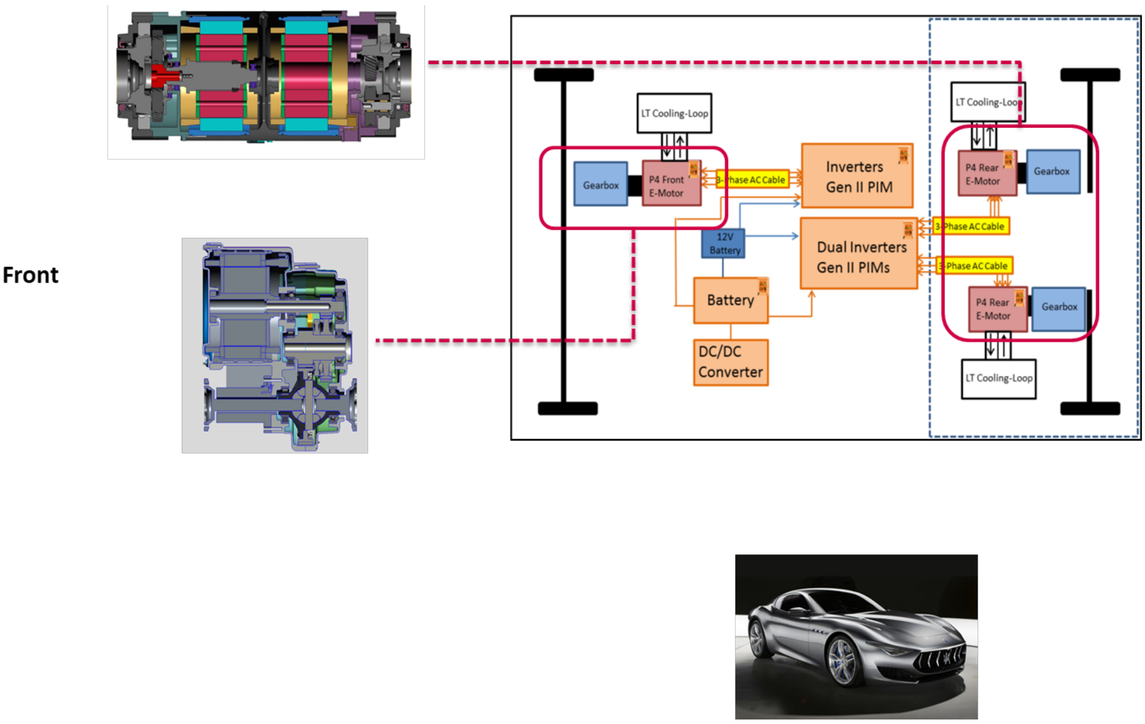


Figure 72: Block scheme of the electric transmission (Adapted from FPT Industrial, 2019)

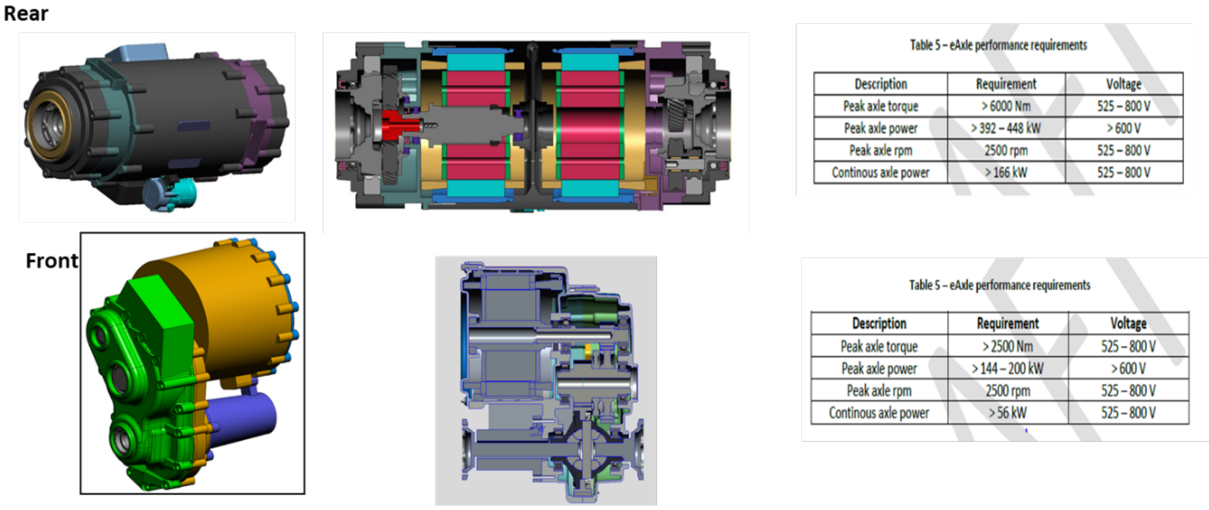


Table 5 – eAxle performance requirements

Description	Requirement	Voltage
Peak axle torque	> 6000 Nm	525 – 800 V
Peak axle power	> 392 – 448 kW	> 600 V
Peak axle rpm	2500 rpm	525 – 800 V
Continous axle power	> 166 kW	525 – 800 V

Table 5 – eAxle performance requirements

Description	Requirement	Voltage
Peak axle torque	> 2500 Nm	525 – 800 V
Peak axle power	> 144 – 200 kW	> 600 V
Peak axle rpm	2500 rpm	525 – 800 V
Continous axle power	> 56 kW	525 – 800 V

Figure 73: Main characteristics of the electric transmission (Adapted from FPT Industrial, 2019)

Dimensions and masses:

Target mass for the complete e-Axle (including oil and fluids) is 70 kg for front and 120 kg for rear

- Max 40 kg for the Electric Motor (for rear each of 2 Ems)
- Max:
  - Front: 30 kg for the geartrain including differential, housing, fluids, plugs, breather and flanges, parking lock
  - Rear: 40 kg for the geartrain including housing, fluids, plugs, breather and flanges

Gear reduction ratio: Gear ratio in the range 6.0 – 10.0.

Lubrification For life.

During the development of a new product, the company does not gain profit as the product is not yet available for sale. The main goal of Early Product Management is to build robust and effective manufacturing processes that lets a rapid industrialization of new products with as less stops as possible. This is enabled by a correct adoption of available tools in order to forecast any potential risks before the prototyping phase that characterize lasts phases of the product launch, so when product modifications have low impact both economically and time concerning.

4.2. Workplace Integration activity

Workplace Integration (WPI) is a process within WCM method to drive the management of the project launch. WPI manages the project to plan, assess, eliminate losses and integrate the product to the shop floor. WPI facilitates Concurrent Engineering and engages all WCM pillars.

The WPI process is divided into 8 loops and in itself drives continuous improvement. Front Loading methodology and lessons learned enable reduction of losses experienced in the launch process and bring improvements to Safety, Quality, Cost and Delivery.

Key Performance Indicators (KPI) and Key Activity Indicators (KAI) provide the attention to measure success at each station. It is important to have a constant visual check of information and indicators that aids in guiding the working teams.

World Class Manufacturing utilizes a pull system to provide the correct quantity of materials at the right time accordingly the WPI process must be conducted in the same manner where the needs of the customer are satisfied by the plant, and the needs of the plant are satisfied by the design. This ensures that all activities will be at the correct level at any given point in time as required.

In addition to continuous improvement, innovative product and process designs are achieved when the cross-functional teams work together as internal supplier-customer with common goals and enhanced communication.

WPI can also be used for Early Equipment Management (EEM), Change Review Board, model year changes (Mròz, 2018) (Mròz A. , 2019).

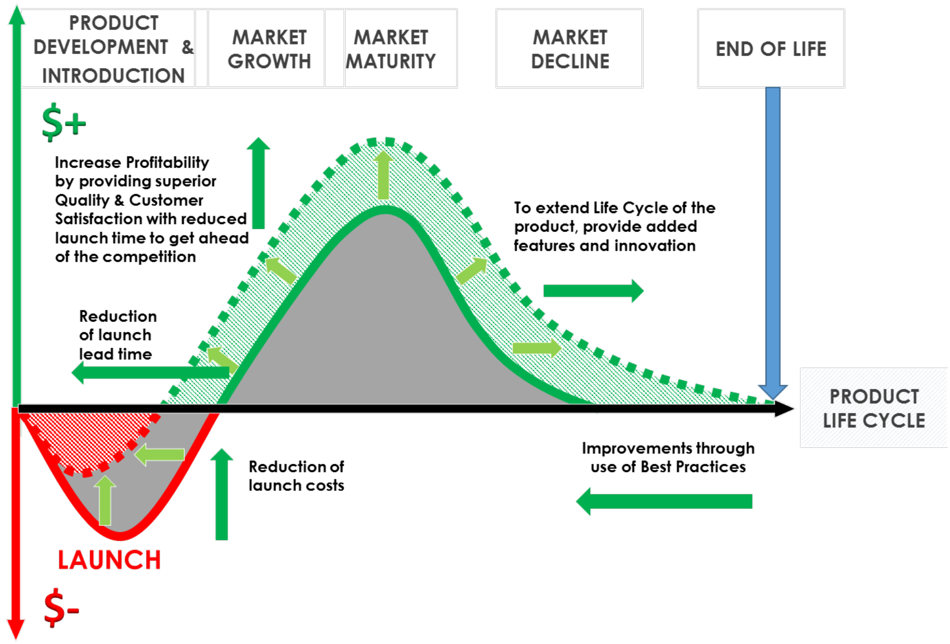


Figure 74: Product Lifecycle (Adapted from FPT Industrial, 2018)

4.3. 8 loops method application

This section contains the description of the 8 loops needed to complete the launch of the product. Each refers to the four main pillars involved in the industrialization, hence the Quality pillar, the Logistics, the Workplace Organization and the Safety one.

4.3.1. Loop 0 – Project preparation

Loop 0 is the kickoff of the WPI project. In this loop, the planning for the entire project begins. The initial WPI team is organized based on the information that is available with respect to the program needs, the mission and targets of the project are initially set. Manufacturing engineering department drafts a high-level timeline to align with the program timing. In this starting loop the WPI room is created, a dedicated room where to meet and collect all documents and to monitor progresses of the activities. It is important to set up the management system that is used to drive all the WPI activities and WCM Readiness.

Loop 0 is closed when the necessary activities of the loop have been completed and the Program Initiation milestone is approved.

The team sets up the initial timing plan or launch calendar including production schedule, WPI loops and main gates. This view is also known as a Level 1 timeline. The Level 1 timeline is the basis by which upper management and the platform team assess alignment of the functions for the program [5].

In the specific case of the Maserati transmission the product characteristics and specification (high rotating speed, low noise) require severe assembly process control to guarantee axles alignment, bearing correct fitting, 0 leak. Therefore, the Manufacturing team set the tooling approach deciding to proceed with a manual assembly operation with technological device and semiautomatic equipment to guarantee full process control and traceability of key characteristics (pressing fittings, screwing sequence, assembly sequence), to operate leak tests and final NVH tests.

Hance, the team proceeded by assessing necessary tools, in particular assembly tooling considers the gear housing with differential gear train and shafts groups preparation standalone manual assembly benches (#3 assembly benches), with semiautomatic equipment for bearing and gears fittings (electric press with load and stroke control); screwing's by electronic nut runner with process control and traceability. Moreover, the transfer box complete assembly and electric motor assembly was set on trolleys - #2 assembly stations with electric screwdriver with torque and angle control and screwing sequence control, handling and manual tools.

In order to guarantee customer requirement also end of life (EOL) tests are needed and accordingly a specific equipment is set in this phase of the WPI, therefore leak test equipment, backlash test, oil filling device, complete group (including electrical motor) final test with drag torque, parking brake, NVH, and electric motor control according to customer requirements and no inverter memory flash station are foreseen to be installed.

Another critical point is the Logistic point of view, the LCS pillar needs to study proper kitting area, trolleys for kitting and subgroups handling and the workplace logistics.

Once the team is equipped with the preliminary information about the project, they are able to proceed with some initial set up.

As an advanced tool, WPI utilizes a Project Management Methodology, particularly the Work Breakdown Structure (WBS) is a project management tool that is adopted to divide a project into smaller components and to organize the work into manageable pieces (Project Management Institute, 2006).

The team selects the WBS elements from the overall file that will be filled to guide them during all the loops of the project. During this selection of elements, the team also decides whether the Basic, Intermediate or Advanced level of the element will be applied based on the capability of the WPI team.

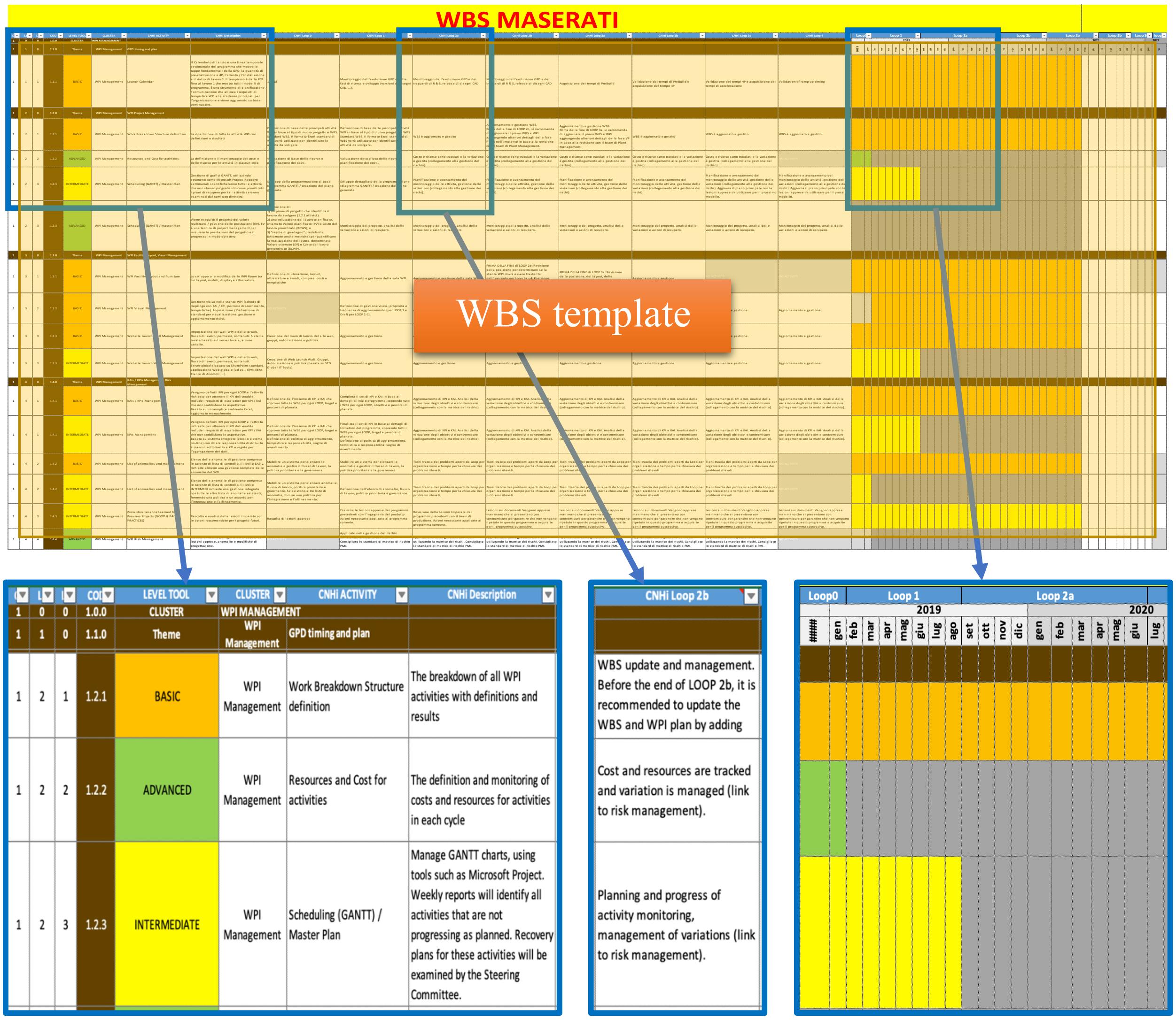


Figure 75:Work Breakdown Structure model

The reported figure 72 represents an example of the WBS adopted during the WPI for this project. The table has the left three columns where the classification of the activity is expressed, so the cluster, the group and the number of the activity are defined, then the fourth column indicates the type of the tool, it can be a basic, an intermediate or an advanced one. Following columns contains the overall description of the activity to be performed and what actions are expected in each loop of the WPI. In the right part of the table the utilization of the tool throughout the product launch is represented in order to monitor the progresses of the activities.

Pie charts in figure 76 summarize the tool adoption according to the category.

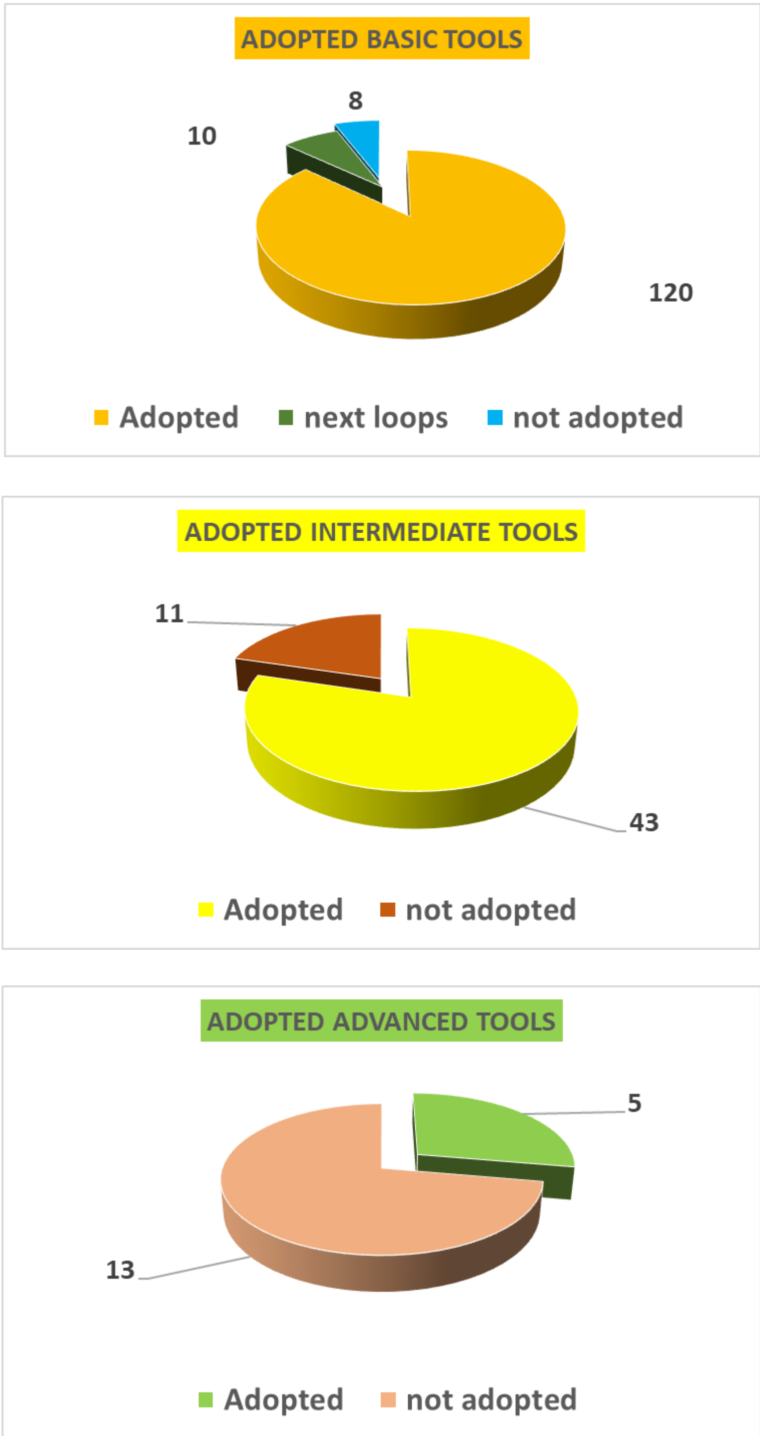


Figure 76: Pie charts with adopted tools

The information that the team has is at high level and it is preliminary, but it is used to start compiling the resources and cost for the project. This is the initial plan and will be refined with more details and accuracy as the project matures until the Program Approval milestone. Even at the initial stage, the planning of resources should be compiled by loop. Certain resources will be required for the entire WPI project, while others will be required at strategic times during the project.

From the launch calendar, the next level of a Master Plan is developed. This plan will be a GANTT chart that provides more detail to the high-level activities required to deliver on the project to satisfy the launch program. The timing displayed in this plan has finer resolution than the launch calendar. The launch calendar might be displayed in years or quarters, while the Master Plan is generally displayed in months. The Master Plan is also known as the Level 2 timeline.

This timeline is one of the tools used to identify any activities that may not be progressing as planned. The recovery plans for those activities are reviewed at the steering committee to determine the successful outcome of actions to get back on track, or assistance required to remove any roadblocks.

In the Level 2 timeline (figure 77), more details are provided for each phase on the activities for particular teams. For example, the Manufacturing Bill of Material will be processed from X date to Y date. This again can be used as a management tool to monitor the progress of the new product launch.

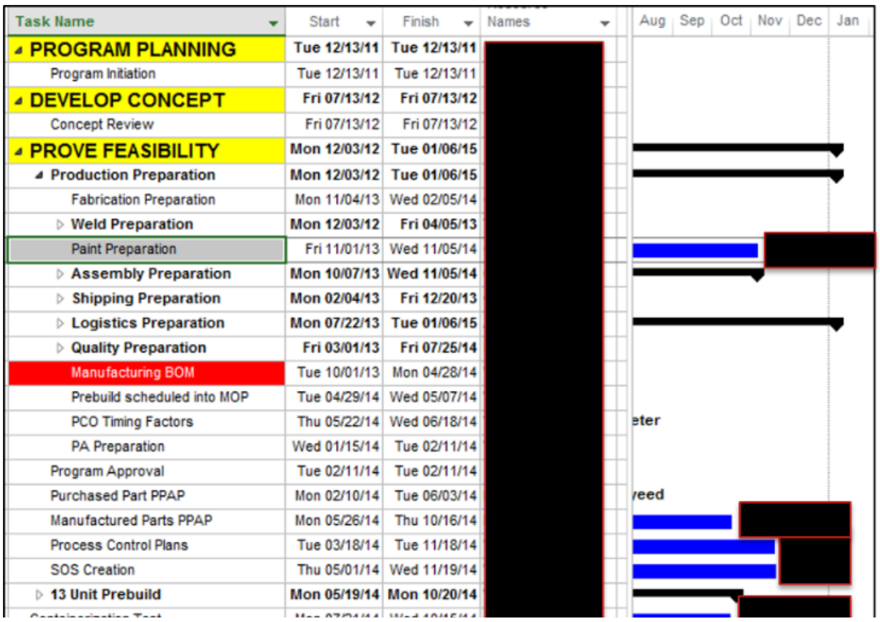


Figure 77:Level 2 timeline

The WPI Room is the central control and an area for the teams to work together. The plant may have a WPI Room from a previous project that may require some modifications due to the project or lessons learned from previous projects.
This will enable shop floor personnel from the area to participate more effectively rather than having to walk over a long distance and lose valuable time. It also allows the team to reduce wasted time when an investigation or other activity in the shop floor is required.
In the **advanced** execution of the Master Plan, Earned Value Project Management (EVPM) is used. It is a technique for measuring the project performance and progress. To use Earned Value Project Management, in Loop 0, the team must identify that work that needs to be accomplished.

The planned value (PV) also known as Budgeted Cost of Work Scheduled (BCWS) is determined in this loop. PV describes how far along the project work is supposed to be at any given point in the project schedule and cost estimate. During the project, the team tracks the Actual Cost (AC) to understand what has been spent for the work that has been accomplished. The team must also determine the Earned Value (EV) of the work completed. EV is also known as Budgeted Cost of Work Performed (BCWP). Charting these three factors will provide a visual indicator of the status of the project (figure 78).

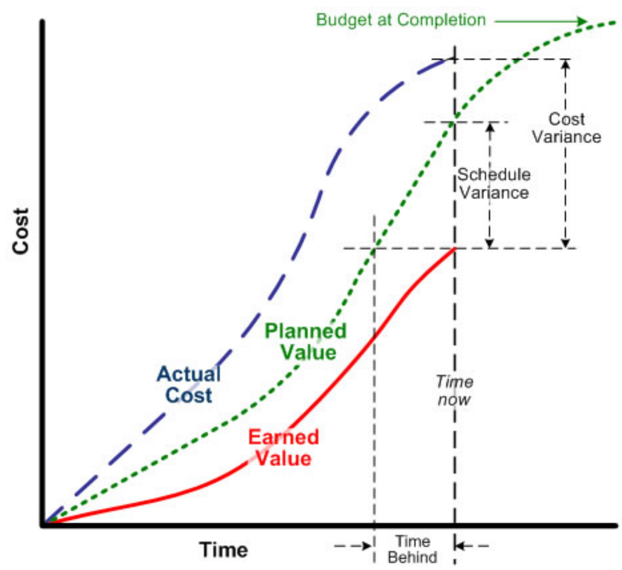


Figure 78: Costs over time diagram (Adapted from FPT Industrial, 2018)

A SharePoint location to compile information necessary for the project is opened in Loop 0. All the information necessary for this project will be stored here. Permissions will need to be granted to the team members.

As with any project, KPI and KAI are important elements in the WPI project. Targets must be set for each pillar and by loop. Some KPI and KAI might benefit from a "glide path" to achieve the desired result for the project.

QC	O&R Red	0 point	Planned Status
QC	# lines of defect in QA Matrix/1 minute of work Cycle	5 lines	Planned Status
QC	# lines of defect in QA Network/OP	3 lines	Planned Status
EPM	#EPM Info Implemented vs.Generated	80% after DR	Planned Status
EPM	Design Changes - After DR	<10%vs. #pn	Planned Status
EPM	WBS BASIC	80% (168 tool)	Planned Status
EPM	HPU Reduction	10% vs. Initiative	Planned Status
SAF	Risk Assessment- High	0%	Planned Status
SAF	Risk Assessment- Moderate	5%	Planned Status
SAF	Risk Assessment- Low	95%	Planned Status
WO	MURI Red	0	Planned Status

Figure 79: KPIs and KAIs by pillar

In addition, the frequency at which KPI/KAI must be updated is defined and they could be updated manually in the WPI Room.

A further important step is to list the anomalies included in the KPI/KAI and Risk Management and to develop how these anomalies will be addressed and the actions to eliminate a repeat in future projects finally to establish a document where the team will collect and track all the opportunities on the new product coming from different inputs: Lessons learned, EPM info, Cost Deployment, DFMA (Design For Manufacturing and Assembly) on current product, and product Analysis.

In addition to the WPI team, gather a steering committee that conducts a weekly meeting to discuss the top issues encountered by the WPI team. The steering committee should be made up of personnel that are stakeholders, able to make decisions in a timely manner and affect decisions in the plant. In this weekly meeting, the steering committee reviews the status of the KPI/KAI, deliverables, top priorities of the project, and requests. The requests are approved or rejected by the committee.

This committee will keep a kaizen journal to track issues, impact to timing of the project, solutions, timing, and costs.

In the advanced execution of WPI, a loop sign-off is completed for every loop. This sign-off is scheduled at or within a couple of weeks before the end of the loop. The sign-off will include a report out for the achievement of the KPI/KAI and deliverables for that loop. The sign-off is required before the team moves to the next loop and it is based on readiness and not calendar.

Lesson learned from previous projects are collected based on safety, quality, cost and delivery related to the product and process design. EPM Info that have not been converted to design standards or checklist items can be used here. Any items that have not been documented as EPM Info should be documented and submitted for feasibility review.

In Loop 0, the WPI team investigates models to be developed to determine opportunities for part/component communization. A review to analyze any product weaknesses and opportunities is carried out. The target for E-HPV (electric – Hours Per Vehicle) is set and prospective benchmarking identified. The EPM Product CD is used to set and achieve E-HPV target.

Application of design standards to provide solutions is a key to the success of the project. During the project, existing standards may be updated for improvements as needed and others created during the launch process.

The selection of a manufacturing engineer that is dedicated to the project enhances and focuses the support for the list of activities, adherence to design standards and adherence to the feasibility analysis.

The initial WPI team is selected in Loop 0. Based on the needs of the project, the required team members and the list of competencies for each member of the team are drawn up. The current state is assessed and the target skill level for each is assigned.

The list of competencies consists of WCM, technical and other skills required for the project moreover, the gap between the target and actual for each is reviewed. With this information, an action plan to close the gaps is developed. Some competencies will be required early in the project, while some might not be needed until later in the project.

The team will review the needs of the product and manufacturing methods. At this stage, the information available is high level, but the planning process for manufacturing must start as it has a bearing on budget, resources, timing and more. Dependent on the needs of the customer, which may be translated through the product design, there may be needed modifications to existing manufacturing processes, or acquisition of new manufacturing processes. It is always advisable to stay with existing core competency processes where possible.

If a new process might be required, careful investigation should be completed to determine whether the “new” process is absolutely the only solution, or it is possible through product and/or process design to use existing once or modified existing ones. Another option may be to outsource and allow subject matter experts partner.

The EPM Product CD is a tool that is used as well as others like benchmarking and teardown, armed with information from sources like lessons learned, best-practices, MP (Maintenance Prevention), as reported in the figure 80, and EPM Info, identify areas to be prioritized to achieve the HPV (hours per vehicle) goal.

CNH INDUSTRIAL	Maintenance Prevention Information				Date	25/05/2018	MPInfo name	WO - LINEA 2018 - 024
					Creator	WO pillar leader	Phone	
PLANT	Operative Unit	LINE	OP.	MACHINE	MACHINE SUPPLIER	COMPONENT		COMPONENT SUPPLIER
Turin Driveline	Montaggio Ponti	UTE 9	90	LINEA SPR HD POST.CARICO		Ponte EPB HD COMBINATO		
SOURCE PILLAR	WO	IMPACT	Quality	EEM STEP FOUND		STEP 1 - PLANNING		STEP 5 - INSTALLATION
						STEP 2 - BASIC DESIGN		STEP 6 - TRIAL RUN
						STEP 3 - DETAILED DESIGN		STEP 7 - INITIAL FLOW
						STEP 4 - MANUFACTURING	x	
PROBLEM					SOLUTION			
STANDARDIZATION / POSSIBLE EXPANSION	☐ All ☑ Assembly ☐ Finishing ☐ Logistics ☐ Machining ☐ Paint ☐ Press & Shear ☐ Stamping ☐ Welding							
EEM QUESTIONS STEP:	Step1							
	Step2							
	Step3							
	Step4							
Manufacturing Engineering Office					Cost	Benefit	B/C	Attachments
Department:								1 2 3 4

Figure 80: Maintenance Prevention Info themeplate

Step 1 of EEM is performed in Loop 0 to assist in the manufacturing process development, the pillar works closer with the other pillars to determine the current state, future state along with actions and timing to attain that future state. This team working on the manufacturing process should be conducting mostly preventive and proactive activities. Remember to strive for the highest possible and feasible step of each of the pillars when developing the manufacturing process. It is a waste to bring in a new product only to have to immediately after launch get into reactive problem solving.

Approved Best Practices are a great source of opportunities for application on a new product or process. Every pillar should review the current approved best practices for their pillar and identify the ones that are applicable to this project. It is necessary to generate a list and classify each as Analyzed, Applicable, Not Applicable, Applied, Rejected. During the project, pillars will also create new best practices based on improvements and solutions.
WPI checklists are used for all pillars and workstations to validate readiness by loop. The sign off of the completed checklists are one element that is used by the steering committee in the loop buyoff.
Each pillar will be responsible to track their readiness based on the KPI/KAI targets set to strive toward a world class product launch. Participation in the concurrent engineering of the project will assist in bringing this closer to realization.

What Went Right / What Went Wrong is another practice that is valuable in continuous improvement. In Loop 0, the quality pillar collects WWR / WWW information. It is recommended that the source of this information be the three most recent launches.
Once compiled, the team analyzes the information. For items that are in the WWR category, these should have already been documented and standardized in some manner. Also, items that are in the WWW category should have had countermeasures documented and/or standards created to eliminate the recurrence of those undesired situations.
At this stage an action plan is generated to complete any of the open tasks as well as application of solutions. It is also needed to include the person responsible and the timing.

The Quality Control pillar instead is responsible for the Launch QA Matrix. The Launch QA Matrix consists of three components: Reactive, Preventive and Proactive issues and it is created at the start of the launch and is updated through the launch as new information becomes available from sources like warranty, FMEA (Failure Mode and Effect Analysis), and so on. For prioritization, the severity classification is the driver.
The Reactive issues are items that have occurred and have not yet been solved but may impact the new product. This list might include items that were well down in the prioritization of reactive issues and were never addressed. Any reactive issue that has occurred should be in the pool when assessing risk to the new product.

The Preventive items are reactive issues that have been eliminated through solutions and are applicable to the new product. These reactive issues may come from within the plant itself on the same or other products the company manufactures, sister plant experience, competitor experience, supplier experience or another industry. The best manner in which these would be addressed is that they have been documented as design standards, but if not, they will still need to be highlighted and addressed to reduce the risk in the new product.

The Proactive issues are populated from “theoretical” issues that could impact the new product. Input sources for proactive issues are tools like FMEA, O&R (occurrence and release) and others.

In Loop 0, the quality pillar prepares for many other activities to follow. At this time, the team for FMEA activities is defined. These will be the people that will participate in the DFMEA and PFMEA for this project where the “D” stands for Design while “P” refers to the process. Examples of these tools will be presented in the following subchapter where they will be effectively applied.

In the case of new equipment, QC needs to be a member of the EEM initiatives. QC needs to be aware of any potential new machines that will be purchased and have representation on the team when the sourcing documentation is developed. The QC representative(s) will need to ensure that any known and potential issues that could lead to defects are addressed in the early planning stages.

The QC team also needs to provide input into potential resource needs for control plans, QA network, O&R that will be part of the launch project.

The Quality pillar will identify any cross over timing between the current and new product, highlighting any potential risks and for any carryover components from the current to the new, QC also will help to drive improvements to guarantee quality and reduce costs.

4.3.2. Loop 1 – Product Concept Optimization

Loop 1 works on the concept for the new program. The design engineers propose a number of concepts to satisfy those customer needs along with business needs. With the selection of the concept for the new product, more information is available for manufacturing to refine and align budgets, timing, processes, targets and resources.

The high-level layouts are conceptualized in Loop 1 and this will include any potential new equipment and the elimination of obsolete once. The E-HPV proposal is studied to determine any further actions required to achieve this target.

Certain activities from Loop 0 are maintained, monitored or updated in Loop 1 and later loops either through the entire project or to the loop where the activity is no longer required. There are also activities that begin in Loop 1. One of the key pieces of information is the Launch calendar.

In this level of master plan, the resolution of the timing moves from monthly in Level 2 to a weekly or even better, daily. Planning for the activities to bring the product to the shop floor as well as the builds are included in this detailed plan.

By the time this loop is started, the WPI Room should be ready for use. Allowance for the co-location of key members of the WPI team has been addressed and team is co-located. If any further definition of the visual management for this project is required, it must be addressed at the beginning of Loop 1. From this point on, the information in the room is updated and managed.

Pictures in figure 81come directly from the WPI room properly created for this product launch.

Figure 81: WPI room

KPI/KAI are finalized for all the pillars and loops and tracking begins.

With an advanced application of WPI Management, Risk Management begins, and the team will need to identify, assess and prioritize the risks to the project.

It is recommended that a risk matrix similar to the one pictured in the figure 82 has to be used as part of the risk management process. The team needs to set definitions for the assessment of Probability and Impact that each item will be scored on.

For example:

Probability

- High – Greater than *70%* probability of occurrence
- Medium – Between *30%* and *70%* probability of occurrence
- Low – Below *30%* probability of occurrence

Impact

- High – Risk that has the potential to greatly impact project cost, project schedule or performance
- Medium – Risk that has the potential to slightly impact project cost, project schedule or performance
- Low – Risk that has relatively little impact on project cost, project schedule or performance

Risks that fall in the RED and YELLOW require risk response planning which could include risk mitigation and contingency planning. There are a variety of similar matrices that can be used. All provide the same focus to attack risks.

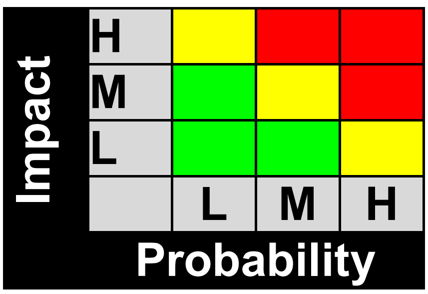


Figure 82: Risk evaluation matrix

Lessons learned that were collected in Loop 0 are reviewed with product engineering. Necessary action items are highlighted and applied to the new program.
The weekly steering committee meetings continue, and the risk management process will become part of it. Also, the loop buyoff process for the advanced application of WPI is scheduled in advance of the end of the loop.

The lessons learned and other information collected in Loop 0 are applied into the concept of the new product and process design. Other sources could be from benchmarking or virtual manufacturing. Design standards need to be applied to the project where relevant and risk management can be used during this process as well.
The make/buy analysis is initiated, and it is worth to pay particular attention to long lead parts and tooling. This may be a situation where the relationship of EEM to the other steps and milestones may take a slight deviation on alignment. Again, the decisions need to be based on risk management.
Design failure mode analysis (DFMA) begins, so that the communization potentials identified in Loop 0 and the achievement of the E-HPV and HPV targets can be achieved. Carryover components from the current product as well as new components must undergo the DFMA process. This is where the co-location of product design, manufacturing engineering, production and other functions improves the execution and reduces waste in the design process.
The PD pillar and the project leader review the gaps in required skills for the WPI team and identify trainers for each. A training plan is drawn up to ensure that the gaps are filled and at the appropriate time.
During the concept review, any additional equipment requirements or modifications to existing equipment must be highlighted and addressed along with manufacturing process changes. The application of Knowledge Management and benchmarking is used to align equipment specifications with the product definition and HPV targets keeping in mind requirement coming from autonomous maintenance, preventive maintenance and quality.
Virtual Manufacturing (VM) at this early stage is helpful when developing a plan for acquisition or modifications. Initially, VM is conducted on carryover parts. The virtual manufacturing provides feedback for Muri, Mura, and Muda, so for the sources of wastes in the workstation.

Keeping in the theme of WPI, focus to the workstation level. Ensure that the impact to the HPV is contemplated and does not create a negative impact on this target.

For what quality aspects concerns, in addition to the plant's list of WWR / WWW, it is important to collect WWR / WWW items from other plants. This can include issues or best practices that have just occurred. It is beneficial to learn from the positive and not so positive experiences of other plants. Moreover, a modification of action plan accordingly with any newfound information that will help to improve your project is required.

With the Launch QA Matrix that was initiated in Loop 0, the team assigns the severity classification to each item and develops an action plan to address the applicable issues. The Launch QA Matrix is updated throughout the project until it is completed, the issues that arise become part of the Reactive QA Matrix.

The Quality pillar should by this point be aware and engaged in the process of any potential new equipment for the project. These new machines need to be classified based on the transformation that occurs using the quality severity classification. The quality pillar must ensure that certain activities and documents will be included in the sourcing package for the new equipment, furthermore, Q Points must be identified, and AM/PM calendars need to be generated, the formers are areas of the work center that have to be properly addressed because they represent check points that the operator must periodically control to be sure he is working with the required level of quality. The WBS file for the minimum requirements based on a Basic, Intermediate or Advanced execution of WPI have to be steady consulted.

Working with the Logistics pillar, document historical problems with packaging and kitting that have caused quality issues have to be collected because they will be used when planning for the new product and participating in failure mode analyses.

At this stage of the project, the team needs to get ahead of the risk due to Human Nature. The team will decide what Human Nature risk assessment tools to use. Some are Emotional Load, 10 Common Features and Occurrence & Release.

The application of the Occurrence and Release tool will be presented in the following subchapter where it was effectively applied.

About logistics instead, having the LCS pillar engaged at this early stage will bring back many positive returns for the future of the product. Using the list of suppliers, estimate the inbound logistics costs for the new product. It is important to ensure that <u>all</u> costs are captured right to the point of delivery to the line.

The logistics flow design is initiated in Loop 1. The team conducts the Plan For Every Part (PFEP) on families of components and the figure 83 reports a part of the analysis PFEP.

N° Disegno (Beta 2)	Descrizione / Part Name	Luogo di pres	LRB Si/No	Peso KG	Q.tà x Complessivo	Q.tà ipotiz. x singolo mdr (*)	Tipologia MdR Packaging	Disposizione	Preconfezione	Rivestimento	Imballi per UDC	Note
8873208	VITE TORX - TESTA SVASATA 10.9 (piastrine out.sha)	I		0,004	25	250	3147	Sfuso	No	No		
16689125	VITI A TESTA CILINDRICA CON ESAGONO INCASSATO - IS 11-0140 - M 6X16	I			9	250	3147	Sfuso	No	No		
16689425	VITI A TESTA CILINDRICA CON ESAGONO INCASSATO - IS 11-0140 - M6X31	I			3	250	3147	Sfuso	No	No		
16750135	DADO E AUTOFRENANTE CON FLANGIA - M5	I		0,003	1	250	3147	Sfuso	No	No		
16866073	ANELLO ELASTICO DI SICUREZZA PER ALBERI - A	I	SI		1	200	3147	Sfuso	No	No		
16867173	ANELLO ELASTICO DI SICUREZZA PER ALBERI -	I			3	200	3147	Sfuso	No	No		
16868374	ANELLO ELASTICO DI SICUREZZA PER ALBERI - ANELLO ELASTICO DI SICUREZ ...	I			1	200	3147	Sfuso	No	No		
16993012	TAPPO FILETTATO (FILTRO OLIO) MASCHIO - TAPPI FILETTATI CON ESAGONO DI MANOVRA EST	I			2	200	3147	Sfuso	No	No		
16997711	TAPPO FILETTATO CONICO CON ESAGONO INCASSATO - M22X1.5 taper - 5.8 Livello olio	I			I	200	3147	Sfuso	No	No		
17094801	ROSETTA PIANA - 8X15 - 140 HV - 778 - Hvil	I			6	250	3147	Sfuso	No	No		
17094834	ROSETTA PIANA	I			15	250	3147	Sfuso	No	No		
5802755832	SPINA CILINDRICA 8x50	I	Si	0,003	1	200	3147	Sfuso	No	No		
17253270	SPINA ELASTICA 3x30	I	SI		1	200	3147	Sfuso	No	No		
17281980	GUARNIZIONE TOROIDALE	I			4	250	3147	Sfuso	No	No		
~~17281981~~	~~O-RING RACCORDO POMPA~~	~~I~~			~~4~~	~~250~~	~~3147~~	~~Sfuso~~	~~No~~	~~No~~		
17318514	TAPPO FILETTATO CONICO CON ESAGONO INCASSATO - OTTURATORE per ispezione	I			2	250	3147	Sfuso	No	No		
18064750	GUARNIZIONE A SEZIONE RETTANGOLARE - Tappo scarico olio	I			2	200	3147	Sfuso	No	No		
18297025 18296925 ?	VITE TC RIBASSATA ESAGONO INCASSATO - I.S. 11-0138 - M8X30 - 8.8	I			3	250	3147	Sfuso	No	No		
500382599	SENSORE TEMPERATURA - WATER/FUEL/OIL	Eur		0,03	2	100	3147	Sfuso	No	Politene		
5802507719	PIASTRINA - FISSAGGIO CUSCINETTI	I	Si		2	200	3147	Sfuso	No	No		
5802507759	*ALBERO PRIMARIO - Z=19*	*RC*	*Si*	*0,84*	*1*	*12*	*4280*	*Verticali*	*Strutt. ad alveare a perdere*	*Sacch. Politene*		*ERA(come va in linea?)*
5802507759	ALBERO PRIMARIO - Z=19 TORNITO	RC	Si	0,84	1	160	4700	Orizz.li/Separatori	No	Sacch. Politene		
5802507812	GUARNIZIONE - FREUDENBERG D58xD72x7	D	Si		1	96	3147	Ordinato	No	No		
5802507888	BOCCOLA - D.INT.68-D.EST.78-LUNGH.17.3	I	Si	0,107	1	90	3147	Sfuso	No	No		
5802507890	ANELLO - BOCCOLA	I	Si	0,171	1	60	3147	Sfuso	No	No		
(5802507891) 5802857679	VITE TORX - M8x35	I	Si		15	250	3147	Sfuso	No	No		

Figure 83: Plan For Every Part table

At this stage the team needs to start making assumptions of material flow by using dynamic simulations to suppose material flows and look for issues to resolve or opportunities to improve.

Supplier containers and internal packaging are factors that must be considered in the logistics flow and may be influenced by the product or process design. In turn, the containers and internal packaging may be used to influence the product or process design.

Although expansion of footprint is not a common occurrence in launches, the logistics team still must calculate space and transport route requirements. This may bring opportunities for some improvements to the existing footprint. It may also influence the need for external warehousing, which usually is not a desired circumstance. It is necessary also to calculate the area required for kitting based on the new product. An example is reported in the figure 84.

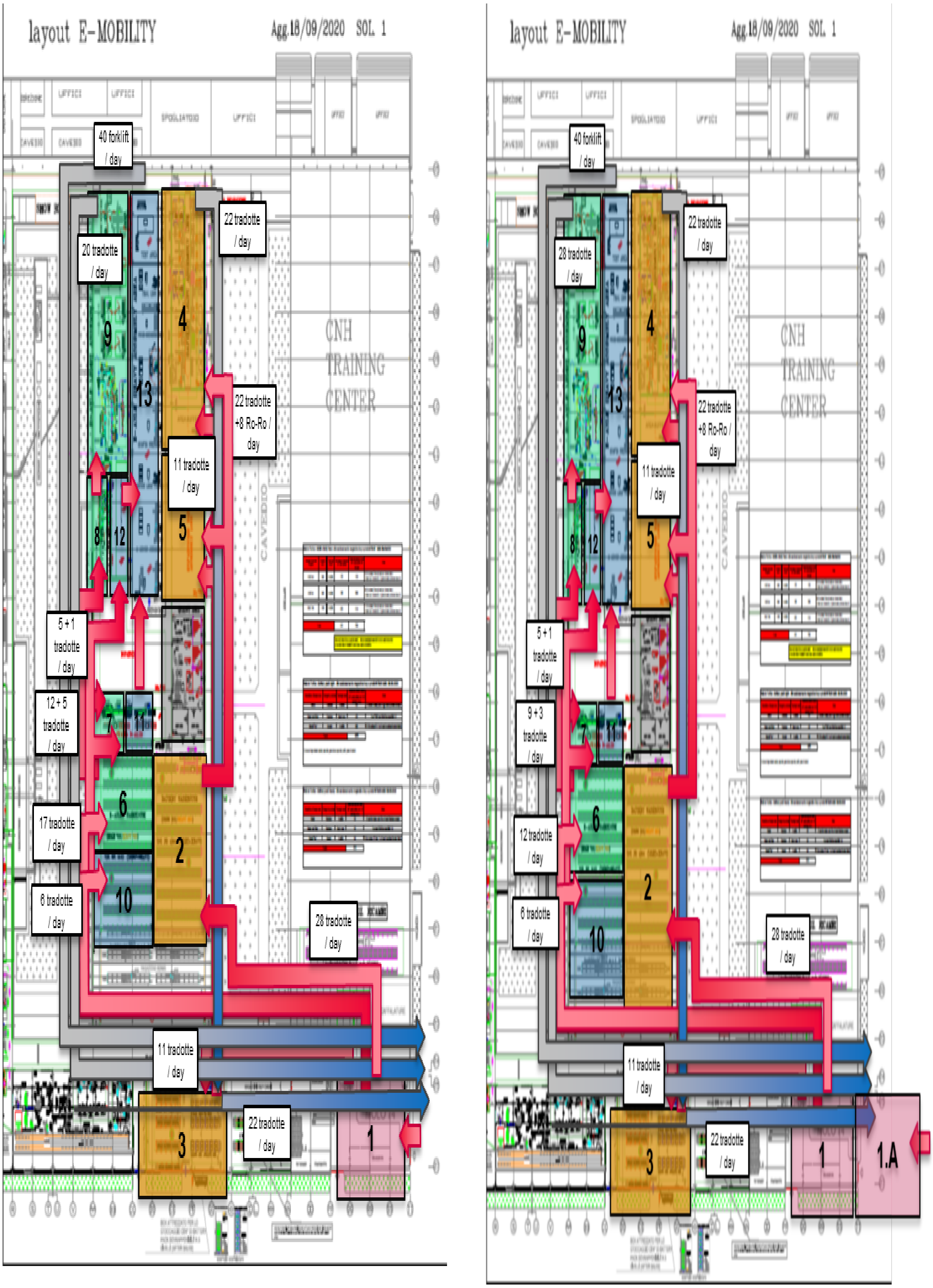


Figure 84: Logistic flows hypothesis (Adapted from FPT Industrial, 2020)

The two layouts represent the alternatives according to the volume of production, red arrows indicate all materials classified as BUY products so they enter directly on the assembly line and they do not need any machining process but just to be assembled, the blue flow instead indicate the finished product path once they are completed. The layout has been hypnotized in order to face the fast increment of product request therefore, as the image suggests, an expansion of the sipping area (1.A) has been foreseen.

Moreover, a proposal for the inbound logistic has been developed at this loop, the computation has been conducted considering the two possible scenarios of production volumes as well as the layout study. The LCS pillar suggested that considering the high number of suppliers and their spread location, the solution was to have a level of truck saturation of 40% in order to satisfy the delivery requirements. Tables reported in figure 85 represent the developed analysis to the computation of the number of trucks, they contain also data about new products that will be located in the same area of the plant entirely dedicated to products related with e-mobility because the Maserati project enters in a larger electrification program.

Truck for finished Axle/ Battery - Solution with 3.900 Maserati E-Axle				
Family	Finished goods / day	Udc /day (finished goods)	Udc / truck	Truck /day
Daily	48	24	60	0,4
Maserati Front	16	8	40	0,2
Maserati Rear	16	8	40	0,2
Nikola	40	40	8	5,0
E-Battery eDaily + eBus	88	88	80	1,1
				6,9

Truck for finished Axle/ Battery - Solution with 8.000 Maserati E-Axle				
Family	Finished goods / day	Udc /day (finished goods)	Udc / truck	Truck /day
Daily	48	24	60	0,4
Maserati Front	32	8	40	0,4
Maserati Rear	32	8	40	0,4
Nikola	40	40	8	5,0
E-Battery eDaily + eBus	88	88	80	1,1
				7,3

Truck for buy components - Solution with 3.900 Maserati E-Axle				
Family	Udc / day	Udc / truck	Extimated truck saturation	Truck / day
Daily	23,66	20	40%	3,0
Maserati Front	6,90	20	40%	0,9
Maserati Rear	8,55	20	40%	1,1
Nikola	20,00	20	40%	2,5
Moduli e-Battery eDaily + e Bus	44,00	20	90%	2,4
Buy e-Battery eDaily + e Bus	113,69	20	40%	14,2
				24,0

Truck for buy components - Solution with 8.000 Maserati E-Axle				
Family	Udc / day	Udc / truck	Extimated truck saturation	Truck / day
Daily	23,66	20	40%	3,0
Maserati Front	13,80	20	40%	1,7
Maserati Rear	17,10	20	40%	2,1
Nikola	20,00	20	40%	2,5
Moduli e-Battery eDaily + e Bus	44,00	20	90%	2,4
Buy e-Battery eDaily + e Bus	113,69	20	40%	14,2
				26,0

Figure 85: Number of trucks computation analysis

It results evident as the low level of saturation belongs to a huge number of trucks needed per day hance the conclusion was to adopt an external logistic provider that leads to a consistent decrement of the number of incoming trucks per day but it guarantees the level of incoming material.

For what the Safety team concerns it needs to address the legal compliance of the project. For CNHi, some of this is usually the responsibility of a group in the design engineering department. This not only includes the product and manufacturing process, but also includes any suppliers that will be involved with the product. There may be certain countries where the product will be marketed that have directives or technical standards that the product will need to be compliant to.

It is necessary to conduct a risk assessment of the product design, manufacturing process and suppliers as required to highlight areas that may need attention or mitigation.

4.3.3. Loop 2a – Design optimization (Basic Design)

Once the product concept has been selected, the launch team initiates the basic design of the product and process and the initial workstations layout and designs. Loop 2a is complete with the release of all the Step 3 CAD models. For this reason, the Step 3 CAD milestone shows dashed arrows on either side as various part models will be prioritized to be completed sooner than others. Step 3 CAD models are mature enough to conduct Development Builds and testing, but not mature enough for production tooling.

The timing of the launch and status of KPI are monitored during this loop. Any deviations are root caused and resolved. Manufacturing requirements, DFMEA, lessons learned, benchmarking, teardown and DFMA are inputs into the basic design.

In Loop 2a, the WPI room continues to be the glue of project. The team continues the Concurrent Engineering activities while updating the KPI/KAI and all other visual management of the room. Issues and variances to the plan are subjected to the actions necessary to mitigate or eliminate.

Loop 2a is representative of Step 2 in EEM. The manufacturing process team leads the basic design of the equipment to successfully attain the needs of the program. The exploded diagram of the product will be used in the basic design of the equipment and process. Virtual manufacturing, once again, is a great tool to guide the team. Due to the "virtual" environment, validation and tests on theories can be much quicker and lower cost resulting in reduced losses. The workstation can now begin to develop with a slightly higher degree of detail. The cross-sheet is a tool to be used in this process. Every workstation will have a cross-sheet that is used to identify and track issues.

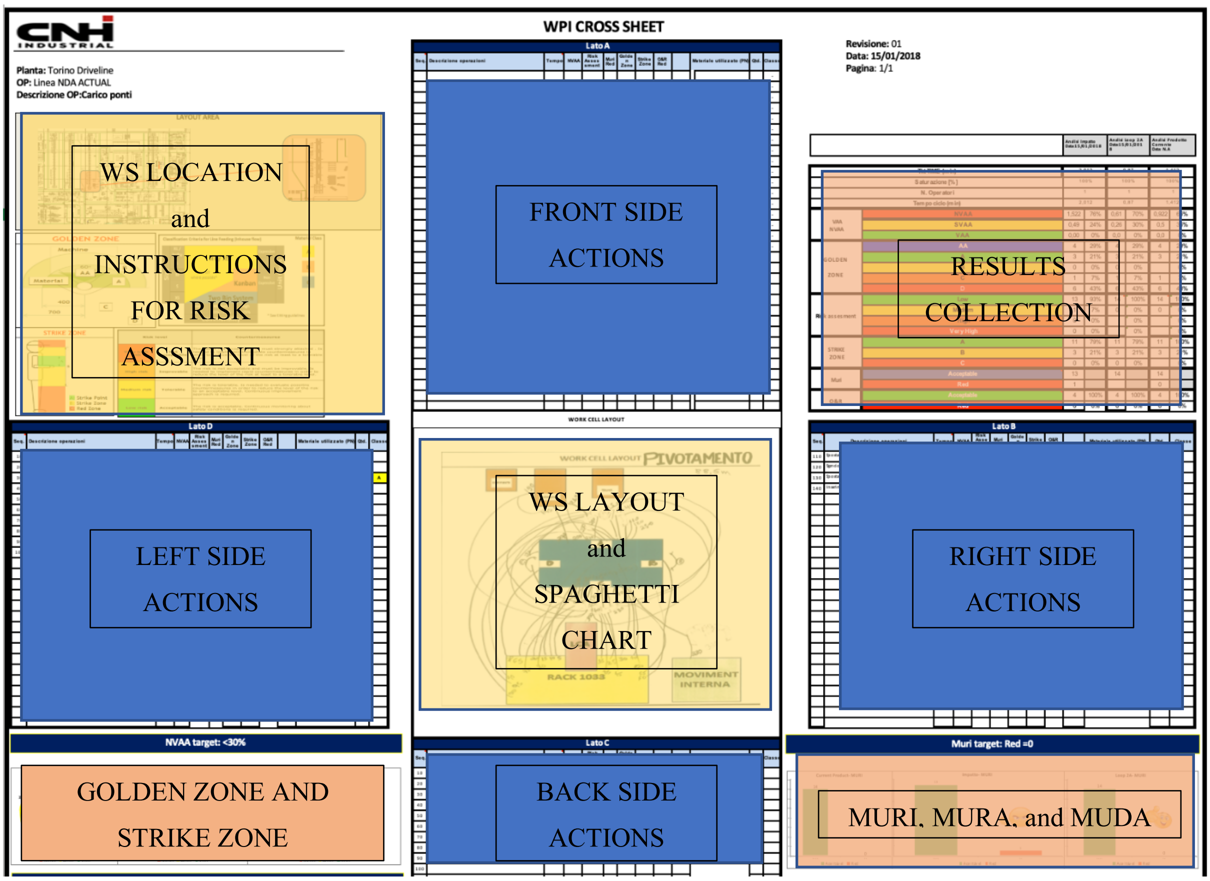


Figure 86: Cross-sheet template

In the figure 86 is reported the template of the adopted cross-sheet, usually a cross-sheet analysis has three pages, in the first spreadsheet there are all information that comes from the workstation observation, the second is the action plan to mitigate issues coming from the previous sheet that does not meet the targets, the last spreadsheet needs to allocate the cross-sheet analysis into the WBS and to represents its progress by loop.

The logic of the cross-sheet is to position the WS at the center of the sheet and to observe each action taken from the four sides of the station in order to deploy all movements of operator and materials and to address possible risks in terms of NVAA and ergonomics.

The table at each side of the sheet contains information like the operation time the work sequence and the risk assessment that can be low, medium, high or very high or rather there could be no risk as well. Then there are three columns dedicated to Muri, Mura and Muda classification, it is important also to indicate whether the operator stays in golden zone and to address the strike zone, finally there are information about the part number/equipment of the operation and the logistic material classification. In the center of the cross usually the workcell layout is reported with the relative spaghetti chart that helps in the visualization of movements and finally it is common to find diagrams about indicators and targets that enables a fast check of the status of the workstation.

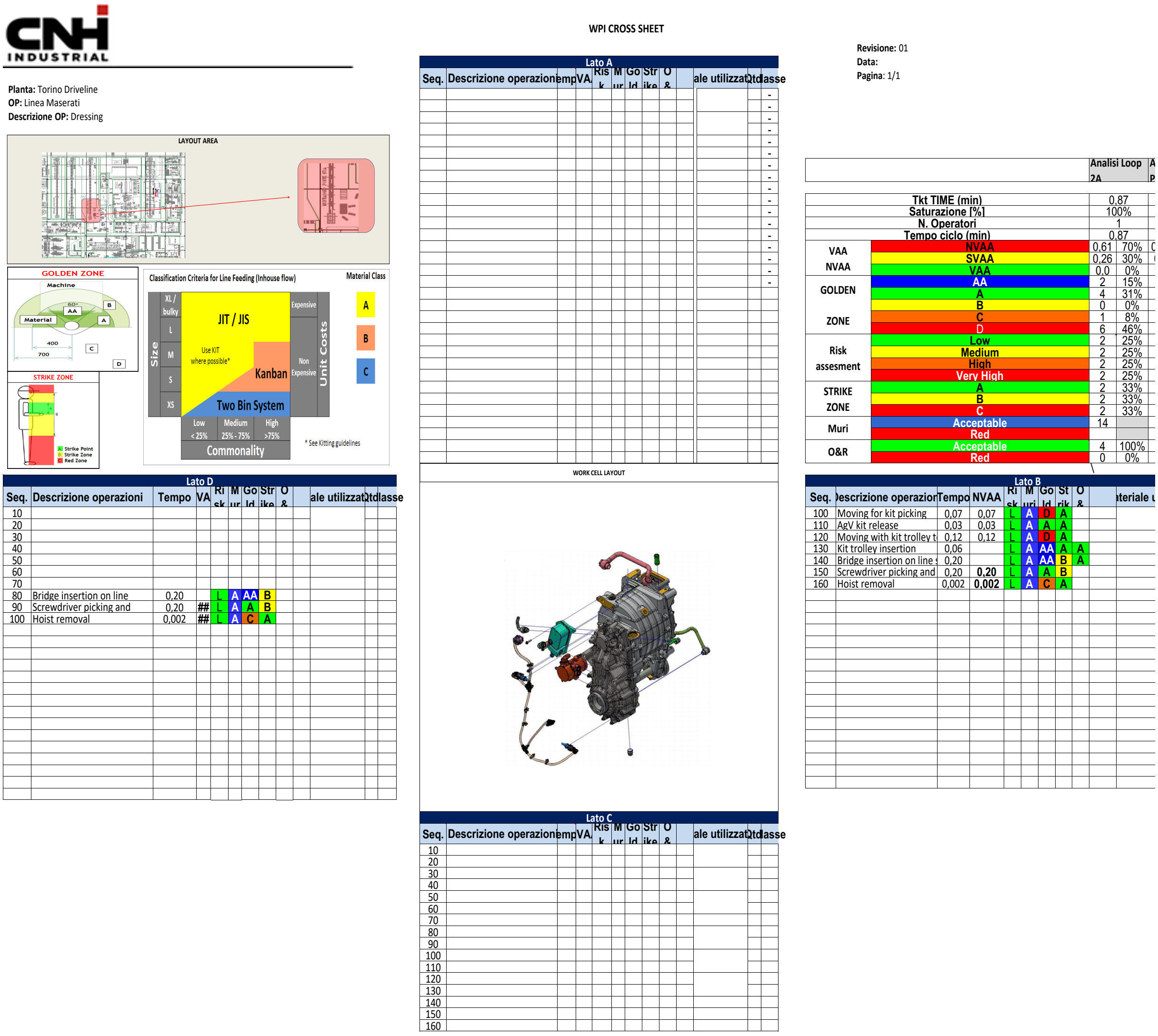


Figure 87: Example of deployed cross-sheet

One of the developed cross-sheet is reported in the figure 87, it represents the analysis about the OP. 70 so the dressing operation of the electric transmission. The work-sequence observation highlighted the presence of some risks, mainly related with ergonomic issues like the movement to get the kit that results far from the station, and this is out from the golden zone because it enters in the D classification.

Diagrams in figure 88 summarize cross sheet's outcomes.

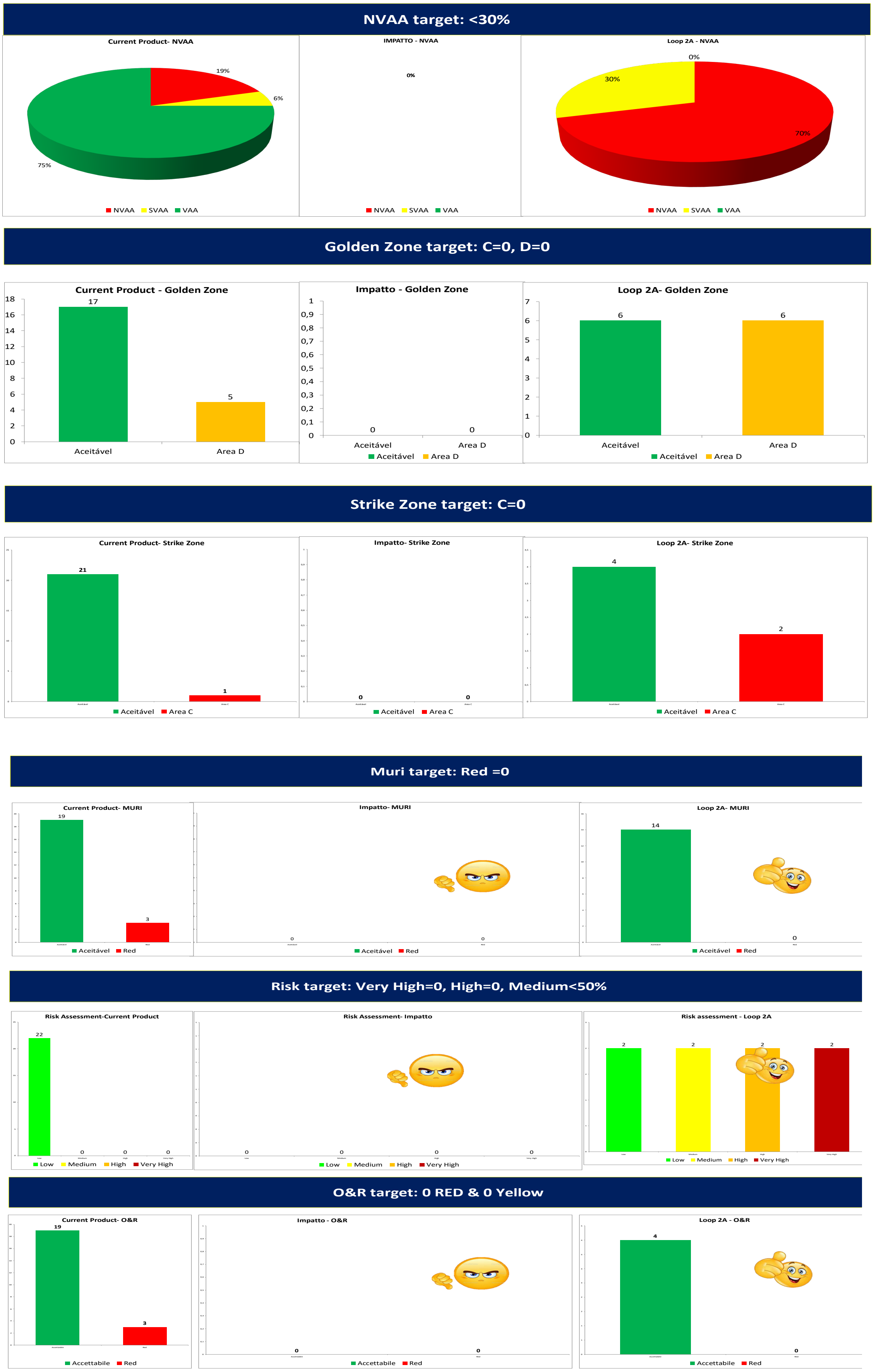


Figure 88: Cross-sheet analysis outcomes

Once obtained the classification of each operation, the action plan is produced in order to set starting points and deadlines to solve or at least to reduce issues that figured out.

The E-HPV and HPV are steady monitored. As required, countermeasures are applied to maintain the targets.

The specifications for the equipment are defined in this loop. Utilization of tools like EEM Cost Deployment, EEM Standards, Design for X, Quality Function Deployment (QFD) and Machine Failure Mode Effect Analysis (MFMEA) will focus to reduce the losses associated with the equipment and process. It is necessary to ensure that the EEM Issues List is maintained for future continuous improvement.

The best practices chosen by the pillars in Loop 1 to achieve the product definition are applied into the basic design of the product and process design. WPI targets by loop are reported and actions are taken, if necessary, to get KPI/KAI back on track.

For what concerns the quality pilar, at this stage it performs the Launch Matrix in order to identify any potential processes to apply PFMEA (process failure mode and effect analysis) and to arrange them in descending order of priority. It refers to the WBS checklist for the Basic, Intermediate and Advanced applications to determine the scope of application for the project and it has the role to assign team members to participate in the PFMEA.

If there will be any new equipment purchased for the project, the pillar has to validate the skill level of suppliers and team members in WCM tools and to train those with skill gaps as required.

One of the actions of this loop is to generate the Launch QA Network/Control Plan to the station level. This will include manpower requirements, compulsory and non-compulsory characteristics list. Compulsory characteristics are those that are defined by engineering as non-negotiable as safety shields. Additional sources of information for the Launch QA Network are PFMEA, O&R, and current QA Network. The plan for Q-Gate and any potential quality verification stations are published in his phase and the quality team must be aware of any new tooling and their requirements for the QA Network/Control Plan.

The quality team begins the plan for supplier readiness in Loop 2a. they define the scope of what will and what will not be supported by the Proactive 8 Stages, and they define a timeline for the application of the 8 stages for this project.

One of the most adopted tools is the Occurrence and Release (O&R) because it is a simple, but very beneficial for the reduction of quality defects. Usually, the team refers to the WBS file to determine the minimum actions to apply for O&R for a Basic, Intermediate or Advanced application of WPI and to define the timing plan for completion by loop.

In order to develop the O&R analysis it is necessary to fill a table that contains the peculiar description of the operation that is carried out at each station of the lined and accordingly a description of potential risks that may occur along the line or at the release, then it is important to categorize the level of the impact and the status of the defect, so whether it has been already solved or not. The table in figure 89 represents an abstract of the O&R analysis conducted by the quality pillar about the assembly line of the front electric transmission for Maserati.

OCCURRENCE & RELEASE - LINEA MASERATI FRONT

OPERATIONS				ANALYSIS		ASSESSMENT					RISCHIO			
Line	Station	DESCRIPTION AND MACRO-ACTIVITY	SINGLE ACTIVITY DESCRIPTION	POTENTIAL DIFECT EFFECT	DIFECT CLASS AA-A-B	OCCU RREN CE		RELEA SE 1-2-3-		notes: (justify the reason of attribution of Occurrence e Release Scor	EFORE		AFTER	
FRONT	Differential Box preparation	PICKING AND POSITIONING CONE BEARING ON EQUIPMENT	Loosen picking of the bearing	Functionality	A		1		1	Poka-Yoke: Stop next operation execution	0	ERRORE	1	V
FRONT	Differential Box preparation	PICKING AND POSITIONING CONE BEARING ON EQUIPMENT	uncorrect insertion of the bearing (180° rotated)	Noisy/Functionality	A		1		1	Poka-Yoke: Equipment properly designed to allow just one compliant side	0	ERRORE	1	V
FRONT	Differential Box preparation	DIFFERENTIAL BOX PICKING AND POSITIONING	Loosen picking of the differential box	impossible to proceed	C		1		1	Poka-Yoke: Stop next operation execution	0	ERRORE	1	V
FRONT	Differential Box preparation	DIFFERENTIAL BOX PICKING AND POSITIONING ON THE PALLET	uncorrect insertion of the bearing (180° rotated)	Production loss	C		1		1	Poka-Yoke: Equipment properly designed to allow just one compliant side	0	ERRORE	1	V

Figure 89: Abstract of O&R analysis

Then, once the table is compiled OR matrices are automatically filled, one for each classification class with the number of possible defects that enter in that category, each with its own probability level to happen. If some actions fall in the red area of the matrix they have to be suddenly analyzed and fixed otherwise the loop cannot be concluded. Tables in figure 90 represent the OR matrices for AA and A categories of operations.

Operations class	AA		RELEASE			
			1	2	3	4
63	OCCURRENCE	1	48			
		2	15			
		3				
		4				

Operations class	A		RELEASE			
			1	2	3	4
96	OCCURRENCE	1	50		14	
		2	29			
		3	3			
		4				

Figure 90: O&R matrices for AA and A machines

At this stage the pillar has to adopt the Quality Maintenance process to define a list of what will be measured or monitored for capability and a prioritization based on the quality severity classification standard is necessary.
With the list of historical packaging and kitting problems identified in Loop 1, quality and logistics will work together early on proposals to reduce the risk to parts due to the logistics process. Items to consider are loading sequence, pat contact, part movement, unloading, debris in kits, and so on.
Starting in Loop 2a, the quality team defines the Supplier Table, it is a process that is used to communicate supplier problems on the shop floor and it facilitates rigorous resolution of material issues while measuring effectiveness of the supplier and shop floor during the process. Supplier table has 3 KPI: Response time from the supplier, how often the plant blames the supplier when it is not a supplier issue, and number of issues on the supplier table by week or month broken down by CSL1, CSL2, CSL, where CSL stands for Control Shipping Level. The figure 91 reports the supplier table process flow.

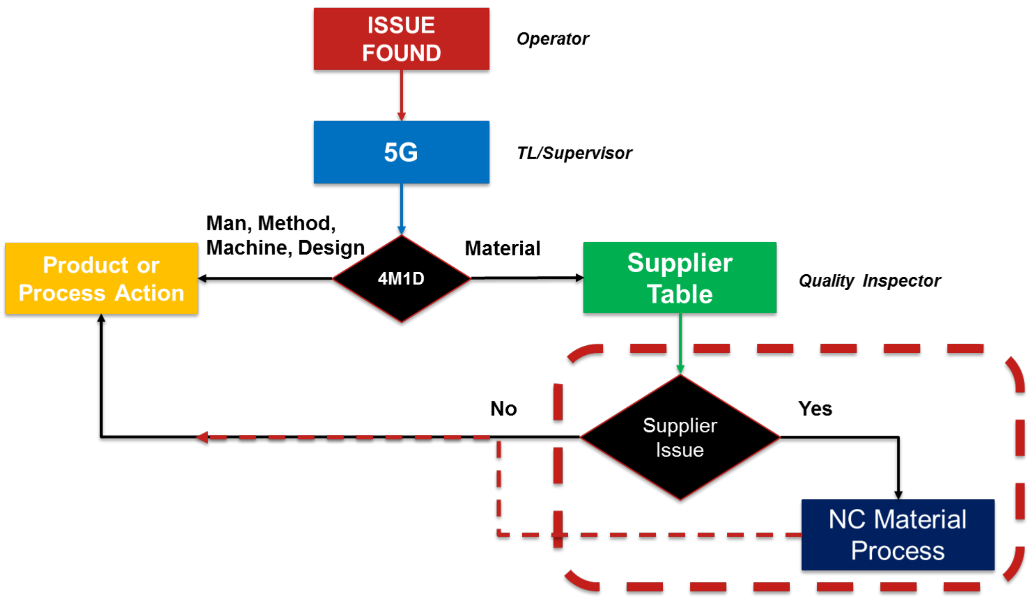


Figure 91: Supplier table process flow

The supplier is a key partner to the success of the product launch. The quality team works closely with them to ensure that parts received are of the uppermost quality. There will be information shared from the plant to the supplier and from the supplier to the plant to make this happen.
In accordance with that, the quality team has to generate a prioritized list of key purchased component suppliers. The ranking of the priority is based on historical difficulty related to

handling damage, installation damage, and PPAP (Production Part Approval Process). New technology could be considered where the previous items pose a risk to selected components. In order to guarantee that the suppliers are able to partner successfully with the plant, it is necessary to be confident that they have the tools required, therefore the quality team will define the list of training needs. The suppliers could as well be integrated into the working teams for early collaboration into the basic design.
Moreover, this is the phase of the project to identify the extended team that will be required to support the Human Nature activities, this is enabled by the RASIC process (Responsible, Approves, Supports, is Informed, is Consulted) to clarify responsibilities. Generally, Safety, Workplace Organization, People Development and Quality work together on Human Nature. All findings related to Human Nature are added to the open list for the launch.
In Loop 1, KPI/KAI for quality were defined, here in Loop 2a, these KPI/KAI are refined as necessary, and targets defined. Certain KPI/KAI may need a glide path for the launch.
For any new technology, in Loop 1, the team acquired lessons learned and issues with the new technology and added them to the Launch QA Matrix.

For what concerns the Logistic team, it monitors the requests sent out to potential suppliers and ensures that any long lead parts or parts with long lead tooling are prioritized.
The PFEP is completed to the component level and the list of new parts is obtained from the eBoM (Engineering Bill of Material). The material classification for parts that are released is completed in this loop. Internal and external flows are also defined by the logistic team that develops a conceptual layout for the material handling.
It results interesting to report the analysis developed about the material handling flow and the decision process that led to adjustments and proposals to optimize the logistics. Starting from the production requirement that are presented in the figure 92, it is possible to deploy the sequence of operation from the unloading area to the shipping one.
The flow is reported in the figure 93 and each operation requires different typologies of material handling equipment as the table in figure 94 shows.

Type	Volumes KY	Shift/day	Pcs/day	PCS/shift
FRONT	9	2	45	23
REAR	3,7	2	19	10

Figure 92: Prduction requirements

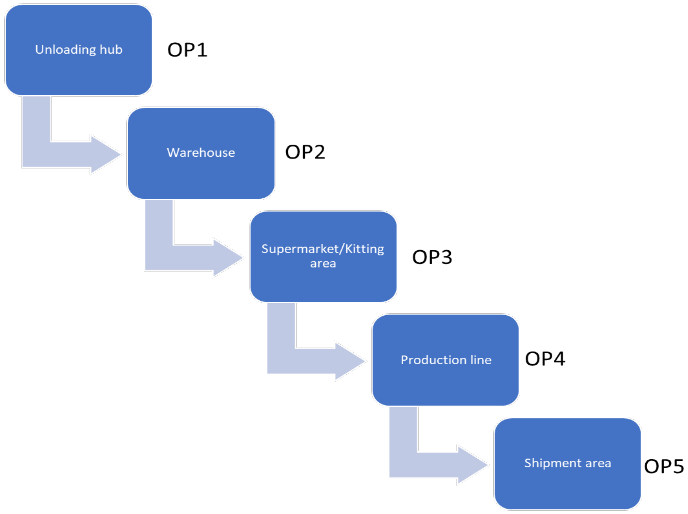


Figure 94: Production Flow

Operation	Equipment
OP1	1 Forklift + 3 RO-RO
OP2	Manual + Forklift
OP3	Manual + Forklift + RO-RO
OP4	RO-RO + Dolly
OP5	3 RO-RO + Forklift

Figure 93: Material Handling equipment to each operation

The number of equipment has been established by the logistic pillar according to carrying capacity and volumes of materials.

The analysis proceeded by producing several solutions of layouts and possible routes for material movements, the flow has been deployed operation by operation and each segment has been quantified in terms of time needed to complete it. Two of the investigated proposals are reported as example.

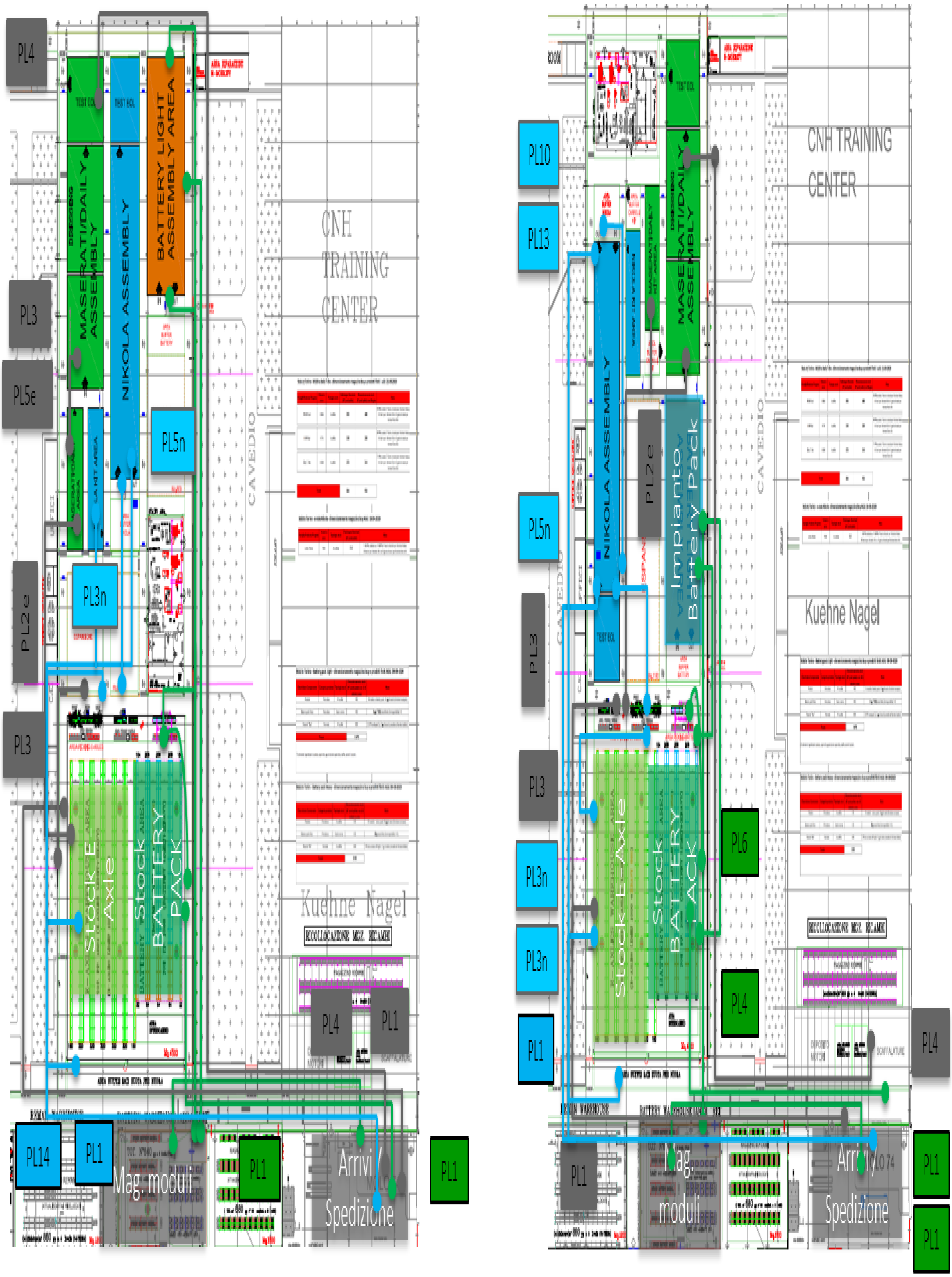


Figure 95: Possible Layout scenarios for material handling (Adapted from FPT Industrial, 2018)

The two possible scenarios (figure 95) have been investigated in terms of material handling routes and distances and based on the time needed to cover each path, the pillar computed the number of indirect operators that would be necessary to satisfy the logistic flow. Particularly, the result was that at least 15 operators are needed to cover the daily production, 5 per each assembly line.

If the calculations in Loop 1 warranted and the program has budgeted for the construction of additional warehousing and docks, the design should begin in this loop hance it is necessary to calculate floor space to support the kitting process and the manpower that will be required for the kitting cells. Begin the design and build of kitting prototypes.

In this loop the safety pillar has the goal to predict any potential risks for Unsafe Acts and providing countermeasures during the design phase. The countermeasures could be technical, procedural or protective.

Therefore, it has to review the list from Loop 1 and make any necessary refinements to meet legal compliance. Review the documentation to understand any risks.

Safety conducts the proactive Risk Assessment. All risks related to mechanical, workplace, equipment, and chemical hazards must be analyzed and reduced to the minimum level. The first assessments are performed in Loop 2a by consulting the risk matrix as a tool during the analysis of before and after. The safety team members will be also part of the group of people to review the initial layout for minimized risk and adherence to safety requirements.

The safety team reviews best practices and MP Info in order to adopt proper countermeasures to make equipment intrinsically safe. The use of poka yoke devices should be considered wherever possible. Preventive procedural countermeasures can be used in addition to technical countermeasures. Moreover, the team has to analyze any potential procedural or organizational countermeasures to add to technical countermeasures in order to reduce risks. Protective countermeasures like Personal Protective Equipment (PPE) may also be considered to reduce risks related to hazards in the workplace.

4.3.4. Loop 2b Design Optimization (Detailed Design)

In Loop 2b, the team continues and further details the design. The Development Build that occurs during this loop will provide input into these details as required in addition to any required modifications to the design. During this loop, the Step 5 CAD models are created based on the maturity of the design (figure 96). Loop 2b is completed with the Design Release milestone.

Figure 96: CAD models of the trasmission

The Manufacturing Bill of Materials (MboM) is generated as the design matures. KPI, KAI and timing continue to be monitored as deviations addressed as required to keep the project on track.

The WBS continues to guide the team through the project. Costs, resources and activities are tracked while any variations to the plan are managed.

Before the end of this loop, a decision with respect to whether or not the WPI room needs to be relocated must be finalized. Preferably, this decision would have been considered in Loop 0 and finalized in Loop 1 so that expenses related to a move would have been budgeted. Lessons learned are documented so that good practices are carried forward into future projects and countermeasures to issues are as well.

The weekly steering committee meeting continues as before.

Lessons learned from the development build are applied to the detailed design of the product and process. New EPM Info are documented for future use. The BoM is validated to the CAD models and drawings. Ensure that existing design standards are applied into the detailed design. New design standard might be generated through lessons learned.

All throughout, the team must remain mindful of Safety, Quality, Cost and Delivery.

Training and assessment of skill levels continues. PD pillar ensures that radar charts and accurate and up to date. Any additional resources added according to the original project plan must be brought up to the required skill levels for tools that they will require. PD pillar will need to keep track of movement of personnel and their respective required and actual skill levels.
People Management continues to update and manage rewarding the team for success.

Loop 2b is representative of Step 3 in EEM. The manufacturing process team leads the detailed design of the equipment to successfully attain the needs of the program. The exploded diagram of the product continues to be used in the detailed design of the equipment and process.
The concepts of the workstation are now developed with more detail.
Process documentation is also starting to develop using the Development Build. Some initial timing may be determined to measure Value added and Not Value added (VA/NVA) activities. Muri are tracked as attackable and not attackable. Spaghetti diagrams can be used to identify opportunities for improvement.
The best practices chosen by the pillars in Loop 1 to achieve the product definition continue to be applied into the detailed design of the product and process design. New Best practices are documented as they are developed.
Station Readiness is validated by used of the WPI checklists at each loop. WPI targets by loop are reported and actions are taken, if necessary, to get KPI/KAI back on track.

Also in this loop, the quality pillar is involved and particularly the Quality Maintenance process is initiated in Loop 2b. The team determines the required capability for each piece of equipment. This team also will resolve problems associated with gaps between the required and actual capabilities.
Working with Logistics, identify potential sources of Human Error related to the kitting design. Historical performance and lessons learned can be used here as well as potential issues identified proactively.

Specifically, the logistics team monitors the requests sent out to potential suppliers. The next level of sourcing is executed.
By this time, there may be some packaging and handling for long lead parts available. The buyoff and certification process for these must be completed to ensure that no issues occur in production.

However, in this phase it has been conducted the Life Cycle Cost (LCC) analysis by comparing several proposals from customers in order to assign the construction of the assembly lines for the products. For the analysis, four suppliers have been taken in consideration, each of them must be compliant with technical requirement of the equipment in order to satisfy all issues coming from each pillar. Then, the proposal of each supplier has been deployed in terms of cost's voices. An example is reported for the supplier 1 in the figure 97.

	SUPPLIER 1	
Equipment Initial Cost	$ 60.000,00	$ 60.000
Other Initial Cost	$ 5.000,00	$ 5.000
Operating Cost	$ 3.000,00	$ 30.000
Maintenance Cost	$ 1.500,00	$ 15.000
Cost Deployment	$ -	$ -
Total Recurrent Cost		$ 45.000
Total Initial Cost		$ 65.000

Figure 97: Economical proposal by supplier 1

Once this kind of cost deployment has been conducted, it was possible to make a comparison among suppliers' life cycle cost referring to a period of ten years. The figure 98 reports the cost forecasting of each supplier, and the diagram in figure 99 highlights the trend along years, and it makes evident that even though the first supplier requires a higher initial investment it has anyway the lowest Life Cycle cost and for that reason the construction of the equipment has been commissioned to that company.

Initial Investment:		$65.000	$54.000	$64.000	$61.500
Annual Recurring Cost:		$4.500	$7.200	$5.000	$5.500
Year		***SUPPLIER 1***	***SUPPLIER 2***	***SUPPLIER 3***	***SUPPLIER 4***
2020	***1***	$69.327	$60.923	$68.808	$66.788
2021	***2***	$73.487	$67.580	$73.430	$71.874
2022	***3***	$77.488	$73.981	$77.875	$76.763
2023	***4***	$81.335	$80.135	$82.149	$81.464
2024	***5***	$85.033	$86.053	$86.259	$85.985
2025	***6***	$88.590	$91.743	$90.211	$90.332
2026	***7***	$92.009	$97.215	$94.010	$94.511
2027	***8***	$95.297	$102.476	$97.664	$98.530
2028	***9***	$98.459	$107.534	$101.177	$102.394
2029	***10***	$101.499	$112.398	$104.554	$106.110
Life Cycle Cost-		***$101.499***	***$112.398***	***$104.554***	***$106.110***

Figure 98: Costs forecasting

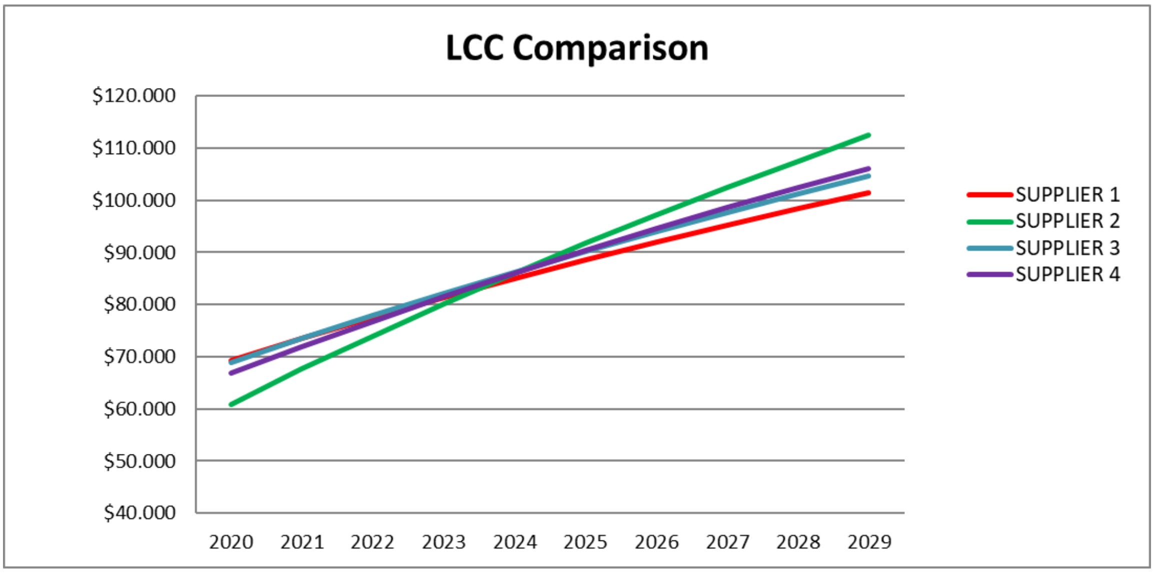


Figure 99: Costs' trend along years

For what the safety pillar concerns from the hazards' assessments, it has to identify all the risks to the task for existing and new situations by using Best Practices and MP Info as countermeasures where possible keeping Intrinsic Safety Design in mind. Poka Yoke solutions should be applied for the best countermeasures.

4.3.5. Loop 3a – Manufacturing Process Optimization and Validation (Before Prebuild)

The end of Loop 2b aligns with the Design Release milestone. This signifies the readiness of the design to begin industrialization. The focus now shifts from the product design to the process design and implementation. Loop 3a aligns with EEM Steps 4 and 5 where the manufacturing process is constructed and installed. This loop involves activities in preparation of the Pre-Build. The team begins to see the virtual world come to reality.

During this loop or the next, the decision is made to discontinue the build of the current product.

The completion of Loop 3a indicates readiness to execute on the Pre-Build. This includes a minimum of 80% production tooling and process availability.

As with all the loops, the WBS continues to guide the team through the project. Costs, resources and activities are tracked and updated while any variations to the plan are managed. It is important to keep the lessons learned activity current so that any other programs can benefit from the countermeasures.

The MboM is verified in preparation for the Pre-Build. The team ensures that actions from PFMEA and O&R are applied into the optimization of the process. The status of the HPV is monitored and necessary actions taken.

All throughout, the team must remain mindful of Safety, Quality, Cost and Delivery.

The manufacture of the process related tools and equipment is monitored for timing and deliverables. Results from the QFD (quality function Deployment) and MFMEA are validated during the construction. A buyoff during the manufacture must be completed prior to the installation. This is to ensure that the equipment will deliver the expected results for the project.

Process documentation is refined from lessons learned in the development build. Workstations are optimized to reduce WO related waste.

All relevant supporting documentation must be delivered at the time of installation. This will include AM/PM calendars, X and QM Matrices, training documentation, etc.

During this loop, the Quality pillar tracks the progress of activity from previous loops to ensure they are on track and as required.

The controls for issues found during the PFMEA and O&R are tracked. Validation of the Quality Network for the alignment of defect codes is performed. Quality validates that the AM and PM calendars and X and QM matrices are updated according to the required timing and that the necessary Q-points are present.
Further activities with the logistics pillar are conducted. Issues and solutions to prevent damages due to stacking of parts, kitting, dunnage, or handling are addressed. Some issues may reflect back to design of the logistics process and will need to be addressed in a timely manner.
The PCPA (process control plan audit) is conducted to evaluate the readiness of the production process.

The logistics team monitors the requests sent out to potential suppliers while the remaining parts are sourced.
The buyoff and certification process continues for material handling containers, it is fundamental to ensure that any new or changed parts are included in the design of the containers and the validation.
The logistics areas should be reflecting activity in preparation for parts in the Pre-Build. Some kitting, line side delivery and other material handling may need to be reassessed and adjusted.

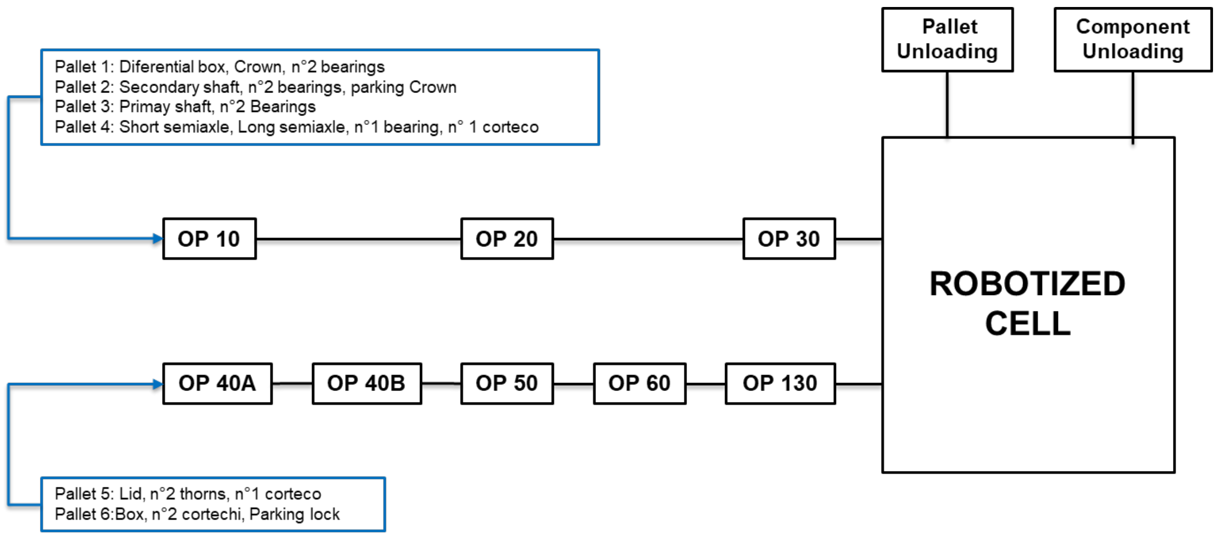


Figure 100: Pallet flow (Adapted from FPT Industrial, 2021)

4.3.6. Loop 3b – Manufacturing process optimization and validation (Prebuild)

In Loop 3b, the Pre-Build is conducted. The Pre-Build is the first build that manufacturing is responsible for. In this loop, the manufacturing process gets validated and fine-tuned based on the amount of the process that is ready. All pillars are involved in workstation fine-tuning where solutions are proposed, tested and evaluated. The manufacturability of the design is also scrutinized and improved as required.

The process closer reflects the full production process. The activities from previous loops, KPI, KAI for the program and each pillar continue to be updated and managed as required. Manufacturing Engineering and Design Engineering support the Pre-build. The Q-Gate plan is revisited for any potential adjustments and the QC pillar also ensures that necessary tools like QA Network, AM calendar, PM calendar are available and updated according to the plan. In particular, this phase was conducted in a close contact with suppliers. The company that obtained the task to realize the pre-build of the assembly lines needs to keep a constant communication with the manufacturing engineering department, therefore main characters of this loop are both people from the plant and people from supplier companies. The deadline for the delivery of the pre-build, according to KPIs and customer requirements is set for September 2021, previous month are consequently crucial because the plant must be sure that all requirements previously defined have been satisfied. For that reason, weekly online meetings are organized in order to review each part that will be delivered and eventually to adjust misalignments. To those meetings are involved experts from manufacturing department, experts from quality, logistic, workplace organization and safety from the plant and specialists from external companies that have worked on the project.

A representative example is the analysis conducted on each workstation according to the 3D models delivered by suppliers. Each operation has been deployed minute by minute of operator movement in order to identify any issue related with tool position, time losses and ergonomics that may lead to not approve the final result and to postpone the deadline of delivery with consequently customer disappointment and economic loss. The figure 101 represents the 3D model of a sequence of workstations in which the front transmission is assembled so passages like pressing, dressing ad screwing are operated, for each of them it has been developed a list of uncompliant actions or objects that need to be revised and fixed by the supplier before proceeding.

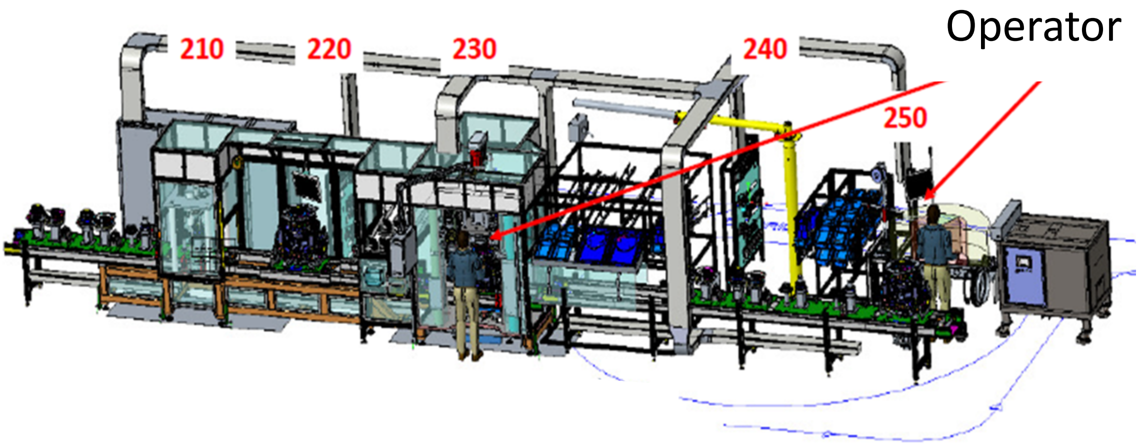


Figure 101: Workstations sequence for transmission assembly

The general overview of the work sequence belonged to the results reported in the figure 102.

n. OF ACTIONS IN GOLDEN ZONE					n. OF ACTIONS IN STRIKE ZONE			WASTE CLASSIFICATION (n. OF ACTIONS)			ACTIVITY DEPLOYMENT (s)		
AA	A	B	C	D	A	B	C	MURI	MURA	MUDA	VAA	SVAA	NVAA
0	4	2	3	1	7	0	3	3	1	1	49.87	30.64	1.10

Figure 102: Work sequence movements outcomes

The most relevant are the action in the D zone that means an action that require a physical movement and then it has to be classified from an ergonomic point of view, as well as the three actions in the C area of the strike zone that are dangerous for the spine of the worker and finally the 3 MURI should be reduced in order to further optimize the workstation's performances.

Similar analyses have been conducted for all the line and several adjustments and suggestions raised. Improvements and modifications will be evaluated in the following loop where physical simulations on workstations are disposed.

4.3.7. Loop 3c – Manufacturing Process Optimization and Validation (4P)

Loop 3c, validates the remaining production process and tools that were not validated during the Pre-Build in addition to any changes made due to issues encountered in the Pre-Build. Before the final installation of the lines part of the team of the plant has been invited by the supplier to test the workstations in order to finalize the implementation and to evaluate last open points of workplace organization. The team produced several video recordings that allowed to observe single movements of operators so highlighting possible remaining issues. An example is reported for OP. 230 in figure 103.

n.	OP.230	
	ISSUE	**IMPACT**
230.1	Movement to reach the parking lock and pick it	NVAA
230.2	Movement to reach the piston and pick it	NVAA
230.3	Movement to reach the bushing	NVAA
230.4	Movement to reach the smaller bushing	NVAA
230.5	Confirm the operation 2 times per cycle by means of a button	NVAA
230.6	All the workstation is tall to enable the transmission passage	ERGONOMICS
230.7	**Piston fixing by means a common key**	**ERGONOMICS**
230.8	**Spine-hole centering by means of a tool**	**ERGONOMICS**
230.9	**Spine inserting**	**ERGONOMICS**

Figure 103: Table of remaining critical movements from recordings observation

Most critical operations are highlighted in red, the 230.7 refers to a closing action without any measurement tool so the effectiveness is totally due to the operator and this is not acceptable to guarantee always the same level of quality as the customer requires and also because the torque to be applied is unmeasurable and then the related ergonomic impact, instead the other two 230.8 and 230.9 refer to thin and very precise operations that may stress the worker and they can cause repetitive attempts impacting the total time of the operation.
Those critical points are reported in pictures in figure 104 directly form video recordings of the operation sequence.

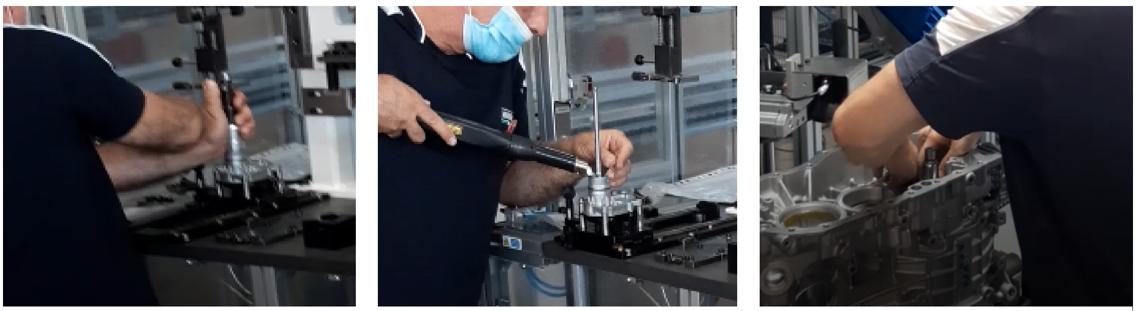


Figure 104: Critical worker postures

Loop 3c aligns with and is reflective of EEM Step 7 this means the confirmation that all actions for every pillar are in place, required documentation like X matrix and Q-Matrix posted at workstations. Preparation for supplier table complete for Job1. The plant reviews final preparations for the ramp up from Job1.

4.3.8. Loop 4 -Production Ramp Up

The Loop 4 is the ramp of the production that starts with the Job1 unit. Further monitoring of the program and pillar KPI/KAI continues to ensure that the needs of the program are met or are better.

Loop 4 ends 3 months after the “OK To Sheep” (OKTS) approval. At this point, certain activities move from the launch to regular reactive activities like QA matrix and plant cost deployment.

4.4. Activity results

To conclude, it is worth to summarize some important results achieved thanks to the Workplace Integration activity carried out.

Each step has its own objectives that needs to be completed at the right moment in order to ensure the cheapest product launch and to avoid redesign or reworkings. The first step forward was to carry out a robust risk analysis that, as the figure 105 reports, allowed 17 risk sources reduction so avoiding quality, safety and working issues.

BRFORE LOOP 1				
Risk Level	G = 1	G = 2	G = 3	G = 4
P = 1	7	6	2	
P = 2	3	4	1	3
P = 3	3		2	2
P = 4	2	1		1

AFTER LOOP 1				
Risk Level	G = 1	G = 2	G = 3	G = 4
P = 1	11	10	1	
P = 2	12	2		
P = 3	1			
P = 4				

Figure 105: Risk analysis comparison

In the loop 2 the focus moved towards the optimization of workstations, still in the design phase.

Here it was fundamental to exploit the cross-sheets tool, each of them led to Muri, Mura and Muda identification at each workstation, hance action plans have been set to reduce or eliminate those not ergonomics or NVAA actions figured out, some of them will be then tuned in the 3b loop when workstation prototypes will be available.

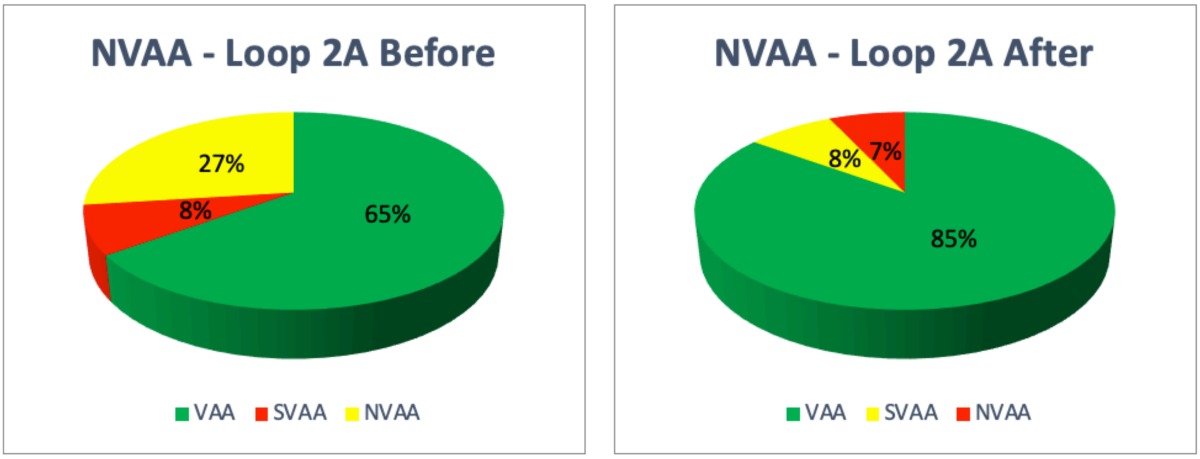


Figure 106. Value added action percentage comparison

Pie-charts in the figure 106 reports the improvement, in terms of value-added activities, achieved in the 2a loop, the result can be converted in terms of minutes of work saved and hance to an efficiency improvement.

The other important contribution was the analysis conducted for the selection of supplier in charge to produce assembly lines according to the company request, to the layout and to the logistic flows inside and outside the plant.

Last approved layout of the line is presented in the figure 107.

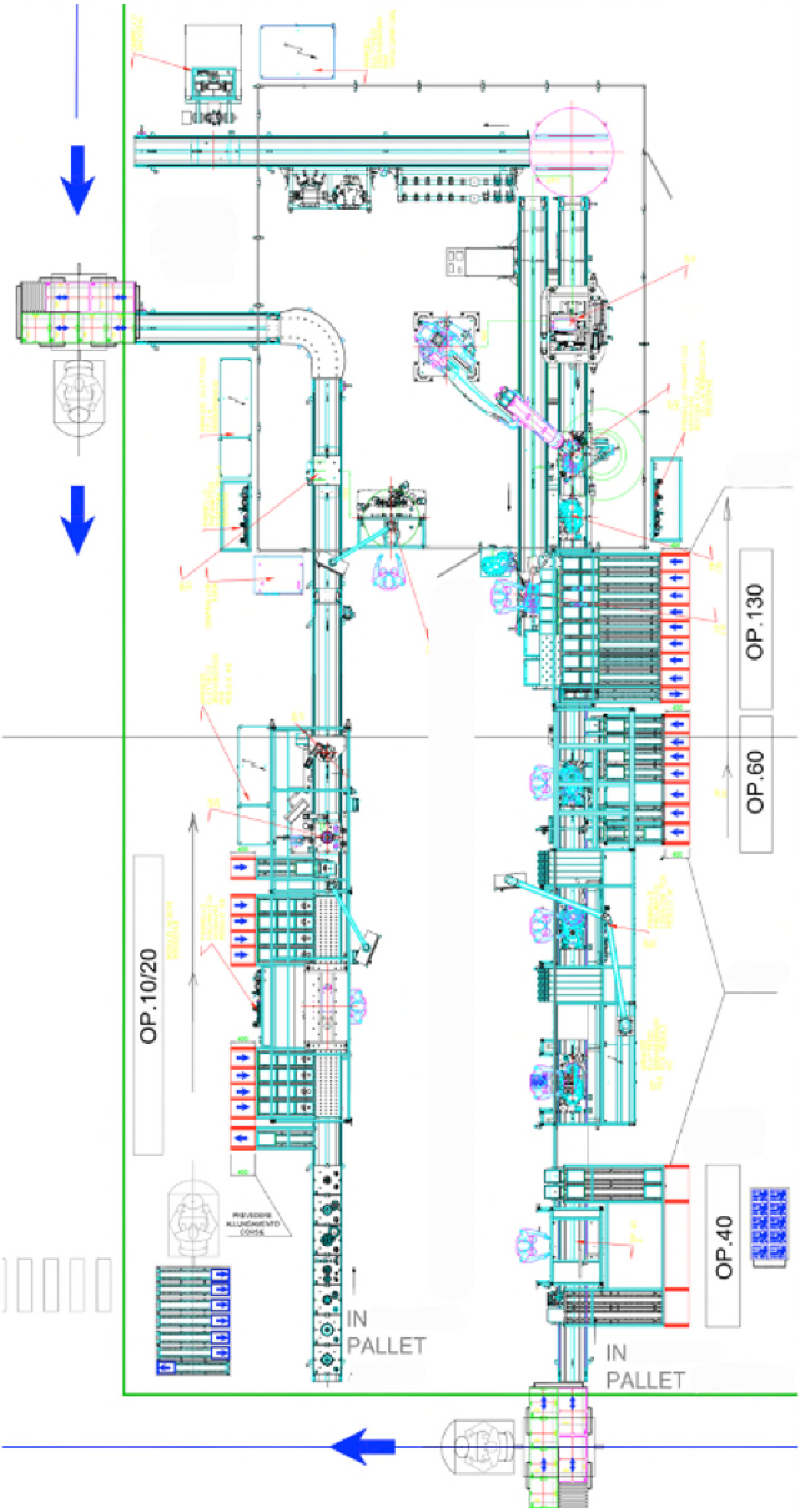


Figure 107: Final accepted Line Layout (Adapted from FPT Industrial, 2021)

The final tuning concerned the optimization of the lines that was carried out directly at the supplier plant, a dedicated team was in charge of observing any remaining problems in terms of ergonomics, quality and safety before the final installation of the lines.
In conclusion, it definitely must not be overlooked the professional growing of people involved in the activity, their improvement was evaluated by the People Development pillar leader and most significant radar charts are reported here in figure 108.

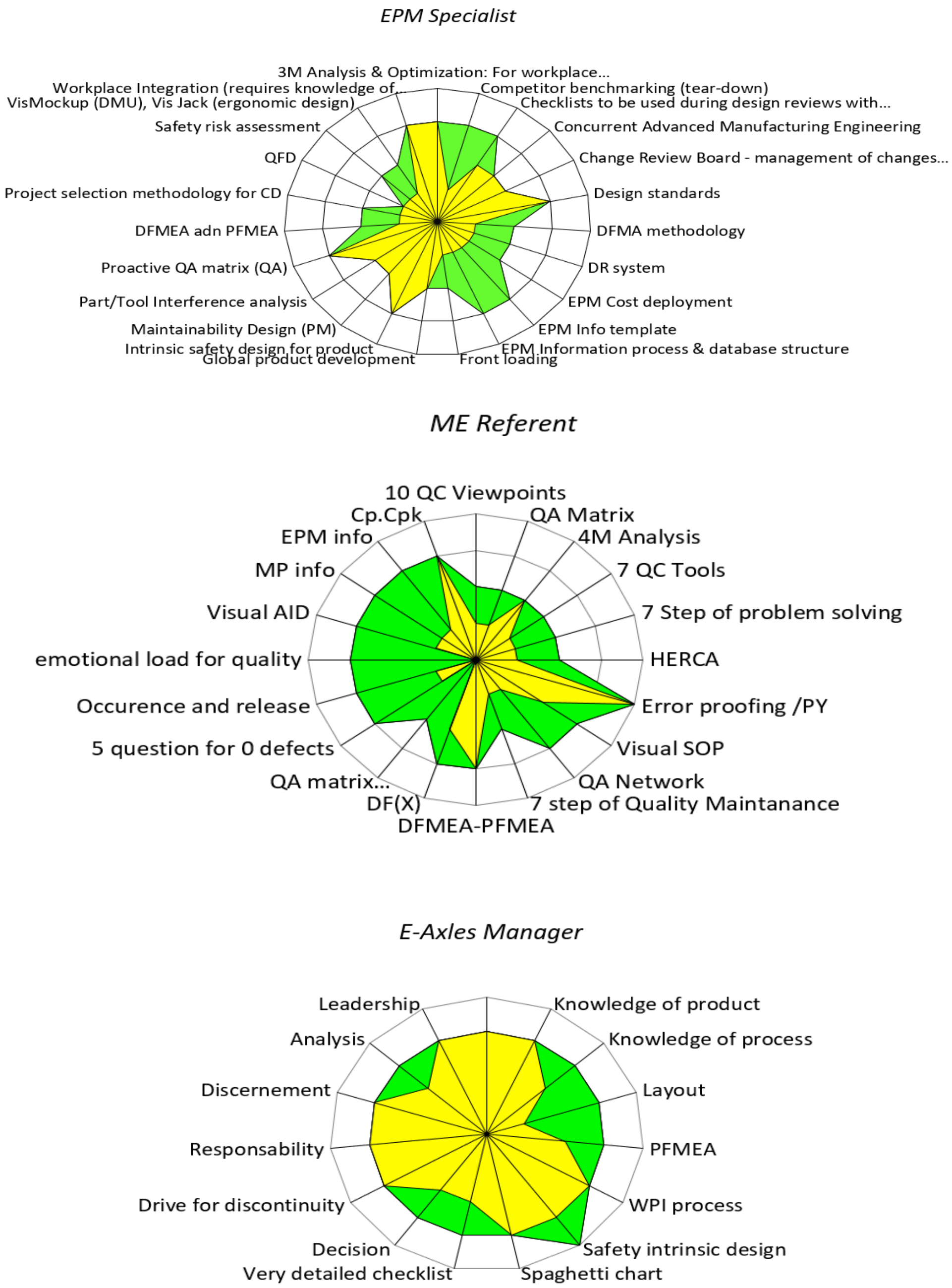


Figure 108: Relevant radar charts for people development progresses

5. Conclusions

To conclude, it is worth to investigate the main aspects of the work going through the positive and negative impacts of the WCM methodology, focusing on both direct results coming from WCM activities, but also on the human impact of the system on workers. This is fundamental because workers' involvement on problem solving teams, on total quality systems or on working teams, essentially depends on the effective management of human resources about training, the workplace safety, enhancement, and rewards.

5.1. Benefits of the thesis

The two main themes delt with in this work are about the activity developed at the transmission plant with the Autonomous Maintenance (AM) Pillar, since the company come from a static period in which recent events such as the economic crisis and previous administration issues, where the WCM activities have been neglected, last two years, comprehending the lockdown period due to the Covid-19 pandemic contributed to drop into the WCM activities and move the market, therefore the company needed to reorganize and to proceed as before, when the machinery capacity were saturated and then operations need to be as efficient as possible to avoid any kind of waste source. Moreover, this static period of about eight years led to a progressive degrading of workplaces and machineries hance the AM pillar was one of the main characters that contributed to the regrowth from a competitive point of view in the market of the company and to reestablish a common culture in the plant among workers. In particular, since nowadays the Turin's plant is evaluated as a silver plant in terms of WCM audit system, but it runs for the gold graduation, this means to have a total mark higher then 70 due to the sum of all pillars achievements. This year, thanks to the deployed activities and the work of the pillar the comment of the auditor was "The AM pillar has already achieved the mark needed to get the gold evaluation, this is a prove of the effective work of the pillar along years and that the team has understood the methodology and the way of working".

The correct exploitation of the autonomous maintenance leads to a complete involvement of all factory actors, this allows the collection of ideas toward the continuous improvement of the process and the product. By applying such an approach at all levels, the increase of quality improvement proposals was registered.

As far as the second important aspect of the work, main results and benefits are related to the respect of due dates, the correct adoption of the WPI tool led to constant monitoring the progress of activities and then to be sure to respect the time sheet. Moreover, what figured out from the WPI activity was a high number of best practices because any tool adopted highlighted limitations of the production processes both for the new and the already existent one, therefore it was occasion to make improvements at whole company levels. Also, the WPI activity was evaluated by the external auditor, he appreciated the effort that the company spent on being rigorous in the method application anyway a further improvement may be to better exploit this kind of tool to improve the skill of risk forecasting because the team based its study more on the internal experience rather than on what the modern industrial world offers.

5.2. Thesis limits

Despite a wide number of activities have been proposed as a result of the present thesis project, they need to be approved from an economical point of view and sometimes a benefit over costs ratio is not enough to guarantee the project approvement. Moreover, each activity requires people have been adequately trained and prepared to develop it. This means a large resources' investment, both from the worker side and the economic one. As far as the Autonomous Maintenance aspect, the company was evaluating the possibility to install modern software on the majority of the machines in order to create a solid structure of data collection, reliable statistical analysis, failure prevention and performance evaluation. Although consultants and providers have been involved with meetings and visits on field, at the moment the activity have been stopped for productive priority reasons.

Another impacting project concerns the review of the material supply for lines of the electrification plant, the activity was intended to improve the material flow, by inserting 4.0 solutions, like AGVs or cobots, and to better exploit resources so improving times for product transformation and movement. It would be a further improvement for those lines where the Autonomous Maintenance was already at a high level. Anyway, the volumes increment limited the project evolution even though it will be considered in the route for improvement of 2022.

For what the electrification program concerns, the Covid-19 pandemic and hence the reduced chance to travel prolonged some activities, for example test benches needed to be checked directly in the final plant and some assembly lines being already installed before the end of the 2021 but they have been postponed and accordingly the product launch.

5.3. Future Steps

For what the AM pillar concerns, new goals have been set because of the extremely positive evaluation from the WCM auditor, that means the pillar leader is daily working with the team toward the consolidation of methods, projects, proposals, and activities, passing through the involvement of workers that covers the most critical point to this pillar activity. Therefore, over the straight application of the standard, the leader supported by the team is working to establish a common view of the autonomous maintenance responsibilities among all level of the production chain. The next step is to bring all work centers at least at the step 4, so that the company is enabled to effectively monitor the efficiency of the production plant in order to cover those gaps that cause higher losses in terms of quality, safety, ergonomic or logistic that are then translated into economical losses. Finally, the objective is to get the gold evaluation in the audit system as soon as possible, to payback all efforts of the team, the workers, and the company.

About the other main theme dealt with in this work, the WPI activity in the wider project toward the electrified automotive world, the company is still working on the implementation of the plant dedicated to the electrification program, lines have been checked from all points of view hence they are ready to be installed in the new plant. The production will start from the beginning of the 2022 and it will represent an important step forward for FPT s.p.a. that modifies its historical core business of engines to follow the new market requirements.

By and large there are currently wide margins of uncertainty about the WCM program, and it is necessary to review some managerial strategies and their effectiveness towards workers in order to guarantee a common point of view among all levels of the company, only this way can lead to consistent results and further improve the quality of the company. Obviously, not being able to count on coercion and the exercise of excessively pervasive forms of control, the company needs to focus on opening opportunities and perspectives to workers to increase consensus and ensure a faster and more effective implementation of the WCM program.

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