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Scrap rate analysis for the automatic stations of an engine assembly line

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Abstract

In the FCA assembly plant of Termoli has been decided to start the production of the new firefly engines (code name “GSE” (Global Small Engines)) to replace the older Fire with 8 valves, currently produced in this plant. The new engine includes two different models (a naturally aspirated and a turbo engine) that must be assembled on the same line. Then the two models can be divided into many different final engines depending on the components that can be mounted on them. Since the production is done in batches, it is fundamental to increase line efficiency and ensure a perfect match with the feeding system. In addition to that, given the highest number of automatic machines installed in production processes, and the quality requirements and safety needs, it is necessary to study the effects of machines scrap rates on the production system and how they affect line outputs. The object of this study is to analyze those data, implementing them into a simulation software, to understand their effect on the designed production process and identify possible critical sections.

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Introduction

Objectives and Approach

The issue of stations scrap rate in manufacturing process is not new; however, competition growth in nowadays markets, simultaneously with the introduction of Lean Manufacturing techniques, increased their importance for the cost reduction objectives. In addition, even if technological progress has made automatic machines more and more reliable, scrap rate issue is particularly felt since it results in a reduction of production capacity and, if it is not faced in the right way, can be destructive for company revenues. Luckily, Industry 4.0 helps today's companies in trying to solve those problems, increasing machines interconnection (The ability of machines, devices, sensors, and people to connect and communicate with each other) and Real-time data processing (the abilities of computer systems and machines to continuously and automatically process data and provide real-time outputs and insights).

The thesis project is developed together with FCA - Powertrain Assembly department with the purpose of analyze automatic machines scrape rate data, coming from the monitoring process of different FCA assembly lines, understand their effect on the designed production process and identify possible critical sections implementing those data into a simulation software.

Firstly, a general introduction about production systems will be presented. Then, focusing on assembly process, the kind of stations involved in the scrap rate analysis (repair stations) will be introduced. In Chapter 2, the GSE project will be described with a short presentation of the products involved and of the process design parameters. Chapter 3 will analyze plant layout and more in detail the different sections from which it is composed, taking into account kind of station adopted, their arrangement and different transportation methods used in the line. Chapter 4 will define the logics behind back up and repair strategies, introduced in Chapter 1, considering the different scenario that can be faced in assembly processes. Afterwards, a description of the feeding system adopted, follows in Chapter 5 since it is strictly related to the issues coming from out of line repair strategies. Here will be described the implemented logistic process to underline the effect that the repair operations of few products can have on the entire line. Chapter 6 will be dedicated to the simulation software used for the analysis. A short description about the software and discrete events simulation will be presented in addition with some example of software implementation for line optimization. Chapter 7 will analyze deeply the case study, focusing on the scrap rate analysis and data collection process, with a further study on scrap rate and repair time model sensitivity, simulation analysis and results presentation. Finally, Chapter 8 will be intended for conclusions and further possible researches.

1 - Production System

In the most general way, it is possible to consider a production system as a "transformation process" [1].

In such a system, resources are combined and transformed to add value considering all the requirements and measures defined in the design phase. There are three main components belonging to a process:

- Inputs, that represent all the structure of the production system, such as raw materials, machines and manpower;
- Transformation process, including the activities needed to get the final product from raw materials. It is possible to have manual or mechanical activities helped by several supporting activities such as material storage and transportation, planning and testing;
- Outputs including the final product. [1]

1.1 Mass production

When a production system is considered, one of the most important manufacture methods is Mass production, in which machines are arranged in a line or product layout. It is defined as the production of large amounts of products in which there is the application of the principles of specialization, tasks division and standardization of parts [2]. Production facilities are arranged so that it is possible to execute the sequence of production operations. The items are carried through the sequence of operations through material handling devices such as conveyors or transfer devices. The person who first applied these concepts together creating a modern mass production system, was the U.S. industrialist entrepreneur Henry Ford together with his colleagues at the Ford Motor Company, where in 1913 a moving-belt conveyor was used in the assembly of flywheel magnetos. With the application of this solution, the assembly time was cut from 18 minutes per magneto to five minutes. The approach was then applied to automobile body and motor assembly [2].

In summary, the main principles that characterize mass production are [2]:

- The implementation of minimal handling of the products involved, the division of production operations into relatively simple tasks, concurrently with highly repetitive motion patterns. This solution allows the development of human motion patterns that are rapidly performed with almost zero unnecessary motion;

- The standardization of product parts so that they can be easily shared among different products in the mix without adjustment. The implementation of other standards (e.g., dimensional, parts location, material, common fasteners) on all parts of the product further increases the production system efficiency;

- The use of specialized machines, materials, and processes. The selection of materials and development of tools and machines for each operation minimizes the amount of human effort required, reduces the number of off-standard units produced and reduces raw material costs.

Based on the principles presented above, this production system is justified in the following situations:

- One or few standard products: the production mix is characterized by a single product or few variations;
- High production volume for each product with a high level of product and process standardization;
- Possibility to achieve a good production balance: each station can process the same number of parts in one time-unit;
- Short cycle time (CT) of production with an automatic material handling process.

In addition to lowering cost, mass production system implementation, has led to improvements in quality and parts consistency. Standardized design, materials and processes facilitate statistical control and inspection techniques to monitor production and control quality. This approach allows achieving quality targets without incurring in large costs that would be necessary for detailed inspection of all products.

The table below in conclusion summarizes all the advantages and disadvantages of a mass production system:

ADVANTAGES	DISADVANTAGES
Reduced total production time	Breakdown of one machine will stop an entire production line
Increase product quality	Line layout can require a complete redesign if there is a change in product design
Reduced total material transportation cost	High investment in production facilities
Low process inventory	Product differentiation is limited
Reduced human error	The cycle time is determined by the slowest operation (Bottleneck)
Low Manufacturing cost per unit	Low flexibility

Table 1 Advantages and disadvantages of a Mass Production system

1.2 Assembly line

The most relevant application of Mass production systems is the assembly line. An assembly line is a manufacturing process in which the parts belonging to the final product are added in sequence while the semi-finished product moves from a station to the next one until the final assembly is produced.

The process is organized in activities. All the activities need to be performed in sequence creating a cycle that represent the whole transformation process that should be performed in the line. Then the activities are shared among the different stations belonging to the production system. As is possible to see shown in the figure below a station can be considered as a black box that take as input the output of the previous one, perform all the activities assigned to it and deliver the “transformed” resources to the next station.

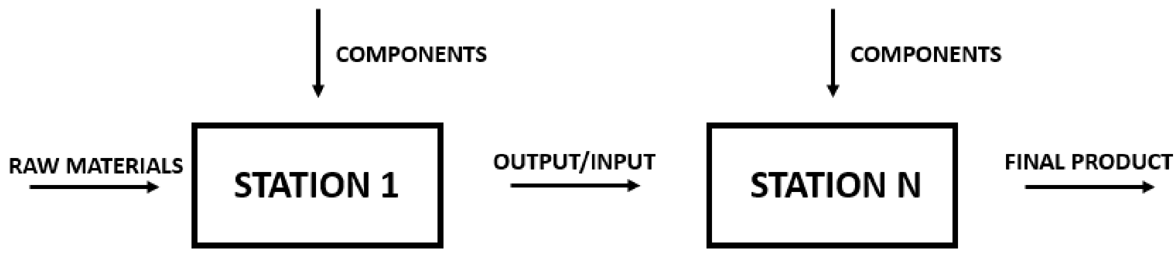

Figure 1 Schematic representation of an assembly line

It is important that all the stations involved are well balanced and synchronized so that the production system involved can ensure a higher efficiency and low in process inventory.

Being a mass production application, an assembly line is a very high efficiency system in which most of the tasks performed in a station are basic and easy-to-execute operations (such as push a clip, screw a screw or insert a gasket). In that situation, it is possible to hire low-skilled workers, and also to reduce the training hours needed for each worker reducing the initial investments, and to automatize the major part of the stations. The robots become an important part of assembly lines when factors like job safety, ergonomics and overtime are considered.

Since in an assembly line the objective is to add systematically all the parts belonging to the product, an important point to be considered is the feeding system definition, and more in general the presence of a well-integrated Logistic system.
Several different assemblies can be on the same line simultaneously, and then a complex system of scheduling and control ensures that the appropriate part to be assembled, the right product and the right consumables are present in the station at the same time, to make the desired combinations.
Considering all the parts involved (machines, human workers, logistic and support systems) is important to collect feedbacks about the activities, which is essential to control and improve system performances:

- Controls to detect possible fails or breakdown in the process and act quickly to solve potential problems;
- Improve performances if a change in the production is needed.

From now on, all the arguments presented in this thesis will be referred to an assembly lines application.

1.3 Automation

As far as the industrial automation is considered, it is possible to define the automation as the completion of an operation or procedure without human assistance by utilizing control systems, such as computers or robots, and information technologies for handling different processes and machinery.
In a mass production line, the adoption of a very low cycle time in which many activities are compressed, in addition to a strong presence of ergonomics norms that govern these activities, required that a higher and higher number of automatic machines has been used to replace manual ones.
An automated production line is comprised of a series of workstations linked by a transfer system and an electrical control system. Each station performs a specific operation and the

product is processed gradually as it moves along the line in a pre-defined production sequence.

In principle automation can be divided in 4 categories: [3]

- **Hard Automation**: also called fixed automation, it refers to the use of special purpose equipment in order to automate a given sequence of processing or assembly operations. Each operation performed is usually simple, involving perhaps a plain linear or rotational motion or a combination of the two.

  This solution is characterized by a low unit cost and a high production rate, but it is relatively difficult to implement changes in the product design and require a high initial investment;

- **Programmable automation**: the equipment here is designed to be able to change the sequence of operations to allow different product configurations. Using a coded language, read by the automatic machine software, it is possible to program and control the operation sequence. This category includes Computer Numerical controlled (CNC) machine tools and industrial robots. In this case, it is possible to manage product design variation, and then is compatible with a batch production system, but a lower production rate in comparison with fixed automation is achieved;
- **Soft automation:** also called flexible automation, includes a material handling system that links together different tools and a central computer that control all the system components. This arrangement grants a fast tool change allowing a flexible approach capable of producing a variety of parts with virtually no time lost for changes in the configuration. This is the category of the robot arms that can be programmed to assume multiple tasks, such as screws insertion, weld, rivets insertion or painting on an assembly line. With this solution, it is possible to allow a continuous production of variable product mix but with a medium production rate and high initial investments.

- **Collaborative automation**: also known as Cobot and widely used in assembly lines in the industry 4.0, involves machines aimed to “collaborate” with a human operator, in a shared environment and in safety conditions. This solution contrasts with traditional industrial robots, which are designed to work autonomously with safety assured by isolation from human contact. They can have many roles from logistics robots that transport materials within a plant or perform machine-feeding operations, to industrial robots used to help a human worker in not ergonomic tasks such as carrying heavy parts. With that kind of solution, it is possible to speed up manual operations with a relatively small initial investment.

If a general assembly line is considered, automatic machines perform several operations historically performed by human operators. These operations often present safety or ergonomics issues or used in fields where machines surpass human performances:

- operations that involve the application of a high level of force;
- operations in which a high weight must be handled;
- operations that involve a not comfortable posture for the human operator;
- operations in which operator safety is not granted.

The use of automated assembly stations significantly reduces production and labour costs and minimizes human errors, ensuring production consistency and quality. In addition, it frees up people from the dangerousness of repetitive tasks, replace human labours in tasks done in dangerous environments and perform tasks that are beyond human capabilities of weight, speed and endurance [3].

Since a real assembly line generally consists of multiple stations, a Hybrid system can be applied, whereby automatic sections of the line feed areas where there are just manual stations and vice versa. In a hybrid system, a different level of automation can be assigned to each station, depending on the type of operations executed.

1.4 Back-up stations

As stated in table 1, of chapter 1.1, one of the main disadvantages of mass production is the interconnection among stations in the line and more precisely, line shot-down in presence of a station breakdown.

In modern production systems, the massive presence of automatic machines increased exponentially line vulnerability. These machines are necessary since a high quality and process consistency level must be ensured, and also to protect human operator from possibly dangerous or harmful activities. In addition, a line stops even if for just a few hours can have a huge impact on the budget of the company since the time in which the line is stopped can be easily transformed in part not produced in the considered time:

$$Part\ not\ produced\ [pcs] = \frac{\text{time the line is stopped [s]}}{\text{cycle time [s/pcs]}}$$

Equation 1 Part not produced in a given period

Then by allocating a cost for all the parts not produced, the revenue lost can be also evaluated. To mitigate this problem, it is necessary to implement the so-called back-up stations. When the automatic station stops, it will be replaced by a temporary station able to perform its activities, to prevent line from stopping.

When it is possible, a manual back-up station is used, where an operator is able to perform the activities of one or several stations in case of one of them stops working. If a manual back-up it is not applicable, then another automatic station is needed to replace the stopped one.

Here below an automatic station is shown and it is compared with its corresponding back up:

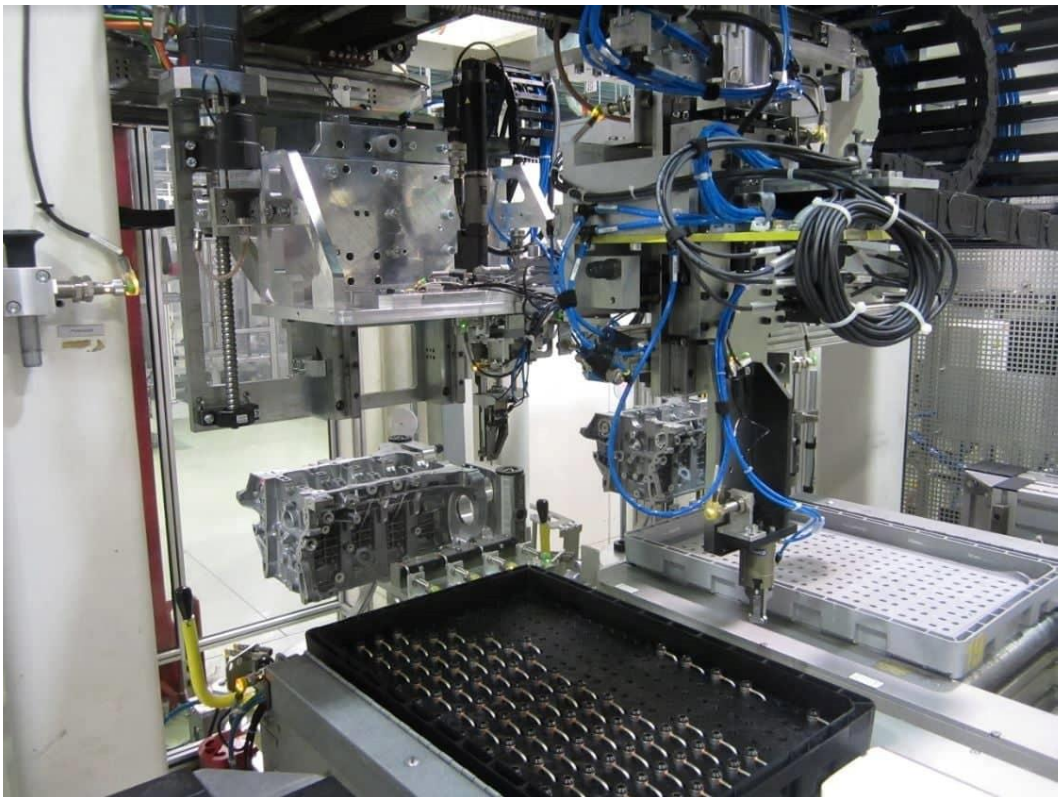

Figure 2 Automatic station example

More in detail, the station is installed in an engine assembly line and is in charge of assembling three or four oil injectors. Their number depend on the type of engine to be produced (one in each cylinder) and are designed to lubricate the inner surface of the pistons (the one not facing the combustion chamber).

In case the automatic station has a breakdown and must be stopped to be repaired, the backup station starts working.

Figure 3 Back-up station example

In the figure above the corresponding back up station is shown. Since the operations that have to be execute are basically screw tightening, this station is equipped with all the tools needed to perform a manual work ensuring the same level of quality. In order to do that, the operator uses the two items black and orange shown in figure to fastening and adjust the oil injector angle. Obviously, the manual operations performed here, are significantly slower in comparison with the same automatic version and then, since such a station is just a temporary solution, cycle time is not taken into account

If needed, these stations can be used like in-line repair stations following the strategy shown in the following chapter.

1.5 Repair stations

Nowadays manufacturing companies are more than before facing the challenge of performing their manufacturing processes ensuring high production rates, limiting the use and waste of resources.

Even if the reliability of modern machines is very high, this aspect is still particularly critical in a scenario where products characteristics are becoming highly demanding in terms of quality and performances. For this reason, in the factories, a well-designed quality inspection strategy must be implemented in order to identify nonconformities.

A huge number of sensors are assembled on each station, to ensure the correct monitoring of the process. If this strategy should not be sufficient, an operator, in particularly critical sections of the line, can perform manual or visual check. This is particularly true when final tests and inspection are executed.

In such a situation, scraps are rapidly identified and blocked before the next operations are carried out. The policy is not to throw out the product, wasting money, but is to repair the detected failure (when it is possible) and repeat the operation. In a repair station, product inspection and repair are performed in the same process stage. However, in doing so, there is an impact on the overall line productivity since the product must be worked again. Two possible strategies are widely implemented when repair stations are considered: in-line and out-line.

In-line: in this repair strategy, the station in charge of repairing the scrap produced by previous stations is placed on the line.

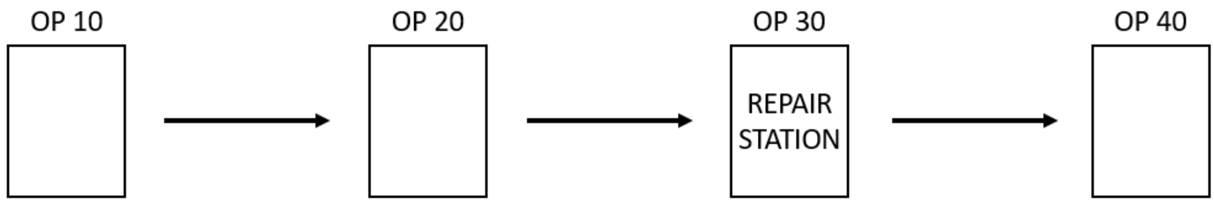

Figure 4 In line repair station scheme

In this way, both good and scrap pieces produced will pass through it. Since production is stopped during the repair process this solution is desired for fast repairing operations.

Out-line: while in the previous strategy the product is repaired in the following station, with this solution, when a defective part is detected, it is deviated from the main flow and enter in a repair loop.

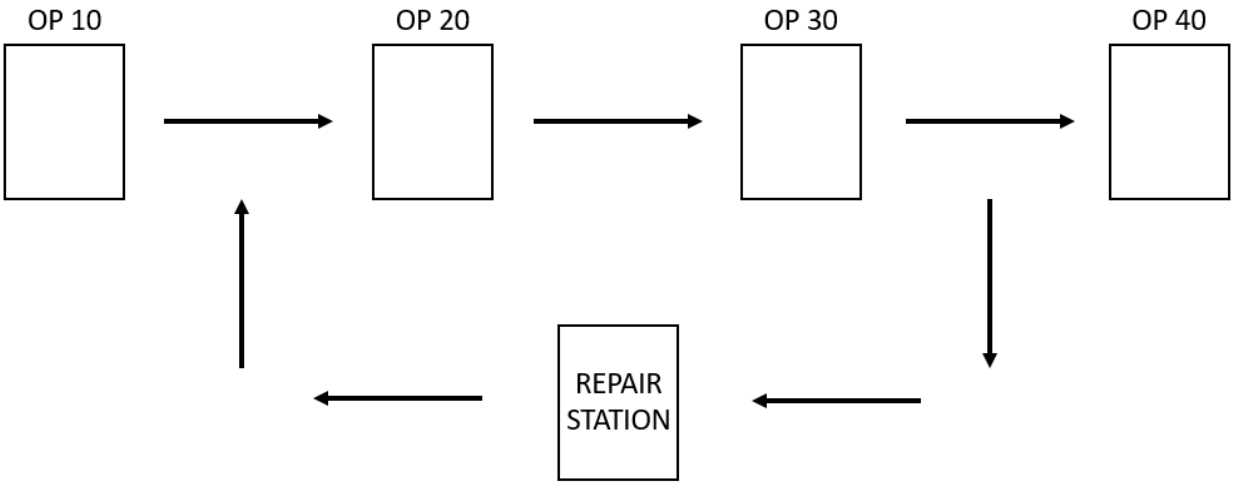

Figure 5 Outline repair station scheme

Here the product is received by a dedicated station and can be analysed without disturbing the natural line flow. Certainly, considering the effort involved and flow management needed with this strategy, it cannot be used for every station but just for particularly critical situations. After the product has been repaired, it can be reintroduced in the line and the assembly operations restart.

2 - General info about GSE (Global Small Engine) project

FireFly (also called GSE, Global Small Engine) is a family of four stroke gasoline engines with 3 or 4 in-line cylinders and a front transverse configuration, produced by Fiat Chrysler Automobiles (FCA) starting in 2016. They are vertical engines with aluminium cylinder heads and blocks, and they present two or four valve per cylinder with variable valve timing. [5]
This project is born to face the exponentially stricter standards regarding engines emissions, by increasing product efficiency and at the same time starting a downsizing strategy to reduce engine size.

2.1 Products

This new FCA product is characterized by 5 variants and a modular design with the same displacement in each cylinder. In particular, all the different versions present a unitary displacement of 333cc. The modularity of the architecture allows to share different components such as pistons and connecting rods, so they can be produced on the same production line decreasing capital investments for the lines.
The production first started in Brazil, in the assembly plant of Betim, and has been implemented in several cars reserved for the local market. In Betim plant, two naturally aspirated versions are produced, called N3 and N4 according to their number of cylinders: the first present 3 in-line cylinders, 1000cc and 72 HP, the second 4 in-line cylinders, 1300cc with 101 HP. [6]
For the European market, FireFly engines production started two years later in the Polish plant of Bielsko Biala, in which were produced the older 900cc TwinAir and the 1400cc MultiJet. In this plant, two different turbocharged versions are produced:

T3 (1000cc and 120 CV)

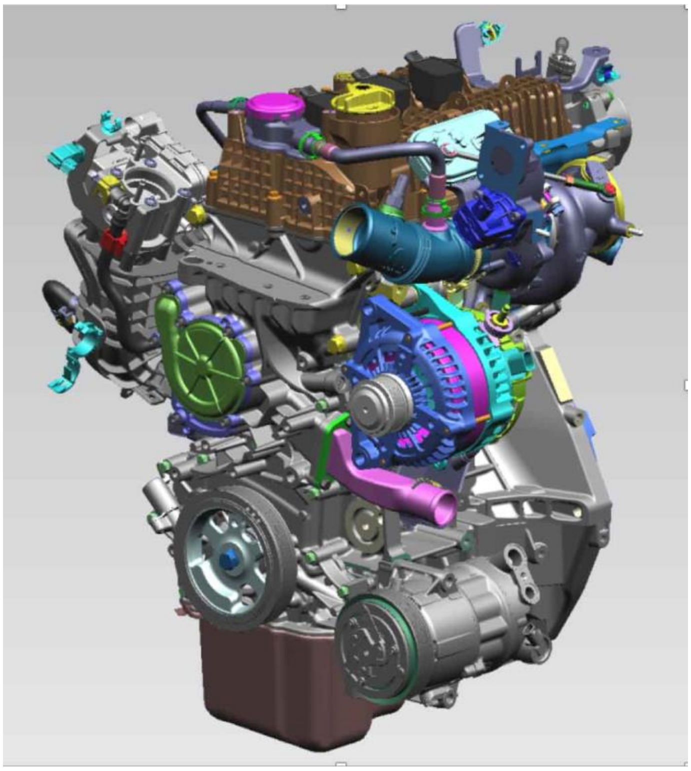

Figure 6 FCA FireFly T3 model 1000cc

T4 (1300cc and 150 or 180 HP):

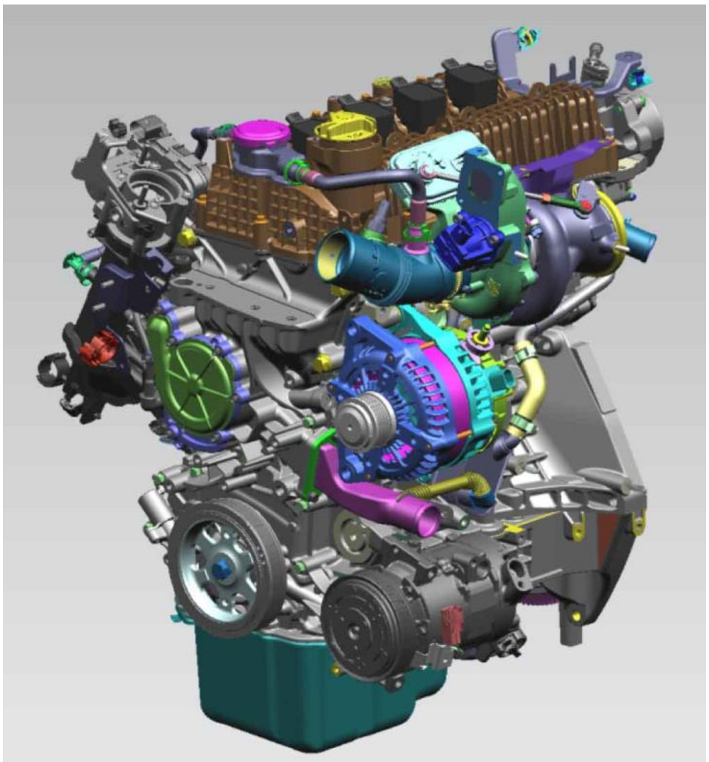

Figure 7 FCA FireFly T4 model 1300cc

Also in this case, the number of cylinders characterizes their name. The same product mix is also reserved for the APAC (Asia-Pacific region) market and produced in China.
Finally, the last and newest engine assembly plant is the redesigned plant of Termoli. It began operating in 1972 and, since then, two of the most iconic FIAT engines have been produced there: the two versions (8 and 16 valves) of the FIRE. After more than 30 years of career, their implementations on new car models started to be limited. In addition, the increasing demand related to the new FireFly models has made it necessary to increase their production volume for the EMEA (Europe, Middle East & Africa) market. Due to its strategic position, close to many chassis production plants, the Termoli plant was the best candidate, among the other European assembly plants, to carry out this task. Here, FCA will produce the naturally aspirated N3 model, already produced in Brazil and just adapted to the European legislations, and a new turbo version called in code “DOHC”.

2.1.1 DOHC Model

This new model, based on the T4 design presented in the previous chapter, reflects the need of decreasing production costs related to T4 engines. At the same time a performances optimization has been introduced implementing an additional camshaft.
An overhead camshaft (OHC) engine is an engine where the camshaft is located above the combustion chamber, in the cylinder head, in contrast with the oldest overhead valve (OHV) engines, where the camshaft is located below the combustion chamber in the engine block and only the valve system was located in the top section. A more advanced version is the double overhead camshaft (DOHC) engine, which has two camshafts per bank of the cylinder head: one for the intake valves and the other for the exhaust valves. Most DOHC engines have four valves per cylinder; however, there are also few example with just two valves.
A DOHC design allow a wider angle between intake and exhaust valves than in SOHC engines improving gas flow through the engine. A further benefit is that the spark plug can be placed at the optimum location since the space in between the two shafts, right in the central point of the cylinders, is now free, which in turn improves combustion efficiency. [7]

2.3 Line design parameters

In this chapter, we will analyse the design parameters that characterize the assembly line of Termoli: line productive capacity and Cycle time.

2.3.1 Line productive capacity

Once plant and product mix have been selected, it is important to set line productive capacity. For this reasons, sales data are collected starting with already available pieces of information referred to old engines or starting new marketing research related to engine performances or based on vehicles on which these engines will be implemented. With this data it is possible to evaluate the production volume needed to fulfil the theoretical demand as well as the productive capacity of each single plant.

Considering the previous introduction, the initial line productive capacity has been set equal to 400,000 engines per year and in particular, equally divided between the two products: 200,000 units of N3 and 200,000 of DOHC. Then this annual production has been shared among the different days and shifts, after an analysis of the available working days. Just to be precise, a theoretical percentage of the products should be considered as scrap and then, in order to fulfil the demand, the line productive capacity should be set equal to 410,678 units per year.

Initially three different situations have been analysed, respectively considering 280, 265 and 246 working days per year.

PCS/YEAR	DAY/YEAR	PCS/DAY	PCS/SHIFT
410,678	280	1467	489
410,678	265	1550	517
410,678	246	1669	556

Table 2 Different line productive capacity strategy.
(For the calculations has been considered 3 shifts each day)

In the first line, 280 working days per year are considered divided in eighteen shifts and 6 days per week. In this case, it is required by law to stipulate specific employment contracts allowing employees to work on Saturday.

In the third solution, the minimal working capacity is considered. It is divided in 5 working days and 15 shifts per week and consequently 246 Working days per year.

PCS/YEAR	DAY/YEAR	PCS/DAY	PCS/SHIFT
410,678	265	1550	517

Table 3 Selected line productive capacity strategy.
(For the calculations has been considered 3 shifts each day)

The second row shows data in between the two solutions just presented. In normal operating conditions, the line production is set on just five days per week, with the possibility to work, when needed, on Saturday. In this case, it is possible to work sometimes six days per week (by law at maximum eighteen Saturday during the year) without stipulating special contracts like the one compulsory in the first solution. Since the latter scenario is the most flexible, the line has been dimensioned on it. Finally, it is possible to evaluate the number products to be produced per day and per shift by simply dividing the yearly production by the number of day per year considered and the number of shifts per day.

Contemporary with this solution, an increase of production capacity to reach 600,000 units per year has been designed. In order to do that machines must be modified in order to get the lower cycle time needed (also the layout has been prepared to host such as production increase by leaving empty spaces in particularly critics line sections).

In some cases, machines can just be prepared to work quicker without acting on the equipment involved. Most of the times this solution is adopted for machines performing simple operations, like engine rotations or quality controls.

In other cases, the operations involved are not so simple, and then the station must be modified in order to increase its productivity. An example can be screwing stations. In these cases, it is possible to increase the number of screw drivers, redesigning completely the production cycle. In alternative, if the operations involved are not connected, it is possible to add a further position inside the station itself and split the job in two, doubling the station productive capacity.

Finally, if none of the two previously presented solution can be adopted, the machine must be doubled. This final case is obviously the most expansive and is adopted only if nothing can be done as alternative option. It is intended for those complex operations that cannot be

separated and the only way to reduce the cycle time is perform them in parallel with two machines. An example is timing setting for cam and crank synchronism. In this case, since the station involved perform just this operation with a cycle time already high to fulfil the demand of 400,000 units per year there is no other solution than adding another station in parallel.
By the way, the starting point, as already sad, is 400,000 units per years and those changes in the production have not been implemented yet.

2.3.2 Cycle Time

The same analysis performed above can be defined also for the cycle time definition. The productive capacity considered is also in this case 410,678 units per year as already explained. To determine the cycle time needed to fulfil the demand in the three different solutions shown in the table 2 it is necessary to set additional design parameters involved in the calculations. First, let's introduce the OEE (overall equipment efficiency). It is a percentage indicator that measures the overall performances of a production process. It measures the overall efficiency of monitored installations (cell, machine, production line, systems) giving indications of the gaps between the real performances versus the expected target [8].
This parameter can be evaluated as the calculation of three factors that represent the three main loss cause: technical availability, performance, quality.

- **Availability**: takes into account unplanned stops. An Availability score of 100% means the process is always running during planned production time;

$$A = \frac{Actual\ running\ time}{Planned\ production\ time} * 100$$

Equation 2 Availability losses in percentage

- **Performance**: takes into account slow Cycles and Small Stops. A Performance score of 100% means when the process is running it is running as fast as possible;

$$P = \frac{Actual\ output}{Target\ output} * 100$$

Equation 3 Performance losses in percetage

- **Quality**: takes into account Defects (including parts that must be reworked). A Quality score of 100% means there are no Defects and consequently only Good Parts are being produced.

$$Q = \frac{Good\ parts\ produced}{Total\ parts\ produced} * 100$$

Equation 4 Quality losses in percetage

Finally, the OEE can be evaluated by multiplying those three percentages:

$$OEE = A * P * Q$$

Equation 5 Overall Equipment Efficiency

Since the overall equipment efficiency is time dependent, it should be measured periodically on sufficiently long period to have a representative average value. Best producers can reach and maintain an OEE around 85% that represent the “word class” objective being able to count on standard processes and products.

Once the OEE has been defined it is possible to evaluate the target cycle time for the line. For this study, the standard time available in a shift has been considered, then 8 hours with three breaks of ten minutes each.

PCS/YEAR	DAY/YEAR	PCS/SHIFT	MIN/SHIFT	OEE	CT (min)	CT (s)
410,678	280	489	450	85%	0.78	47
410,678	265	517	450	85%	0.74	45
410,678	246	556	450	85%	0.69	41

Table 4 Different line productive capacity strategy, CT definition
(For the calculations has been considered 3 shifts each day)

Having the number of product to be produced per shift, it is simply a matter of dividing it by the product between the minutes available per shift and the OEE:

$$CT\ [min] = \frac{\text{OEE} * \text{Available minutes per shift}}{\frac{Pcs}{shift}}.$$

Equation 6 Cycle Time definition

As already said the line has been designed based on the second solution, and then the target CT is 45 seconds.

3 – Plant Layout

In general, a layout is the project of the spatial location of machines, utility systems, auxiliary services, people, and materials.

Among the possible layout strategies, in assembly processes a product-based layout is preferred since it is the most suitable when one or few standard products must be produced, and a high production volume is requested. In particular, a fixed assembly line is what is widely implemented. A number of automatic or manual stations, into which the assembly operations are performed, characterizes this system. They are linked by a transportation system that after a certain time (cycle time (CT)) transfers a sub-assembled part from a station to the next [4]. This layout strategy is also used in the engine's assembly plant of Termoli.

The whole plant extends for an area of 1.3 million-m2 split in transmission and engines production. The latter comprises a smaller line dedicated to the last production phase of the older Fire engine, and all the operations needed for the complete production of the engine in analysis:

- Cylinder head machining;
- Engine block machining ;
- Crankshaft machining;
- Assembly line;
- Testing.

3.1 Assembly line Layout

Focussing on the assembly line, its layout can be divided in 5 sectors according to the figure below:

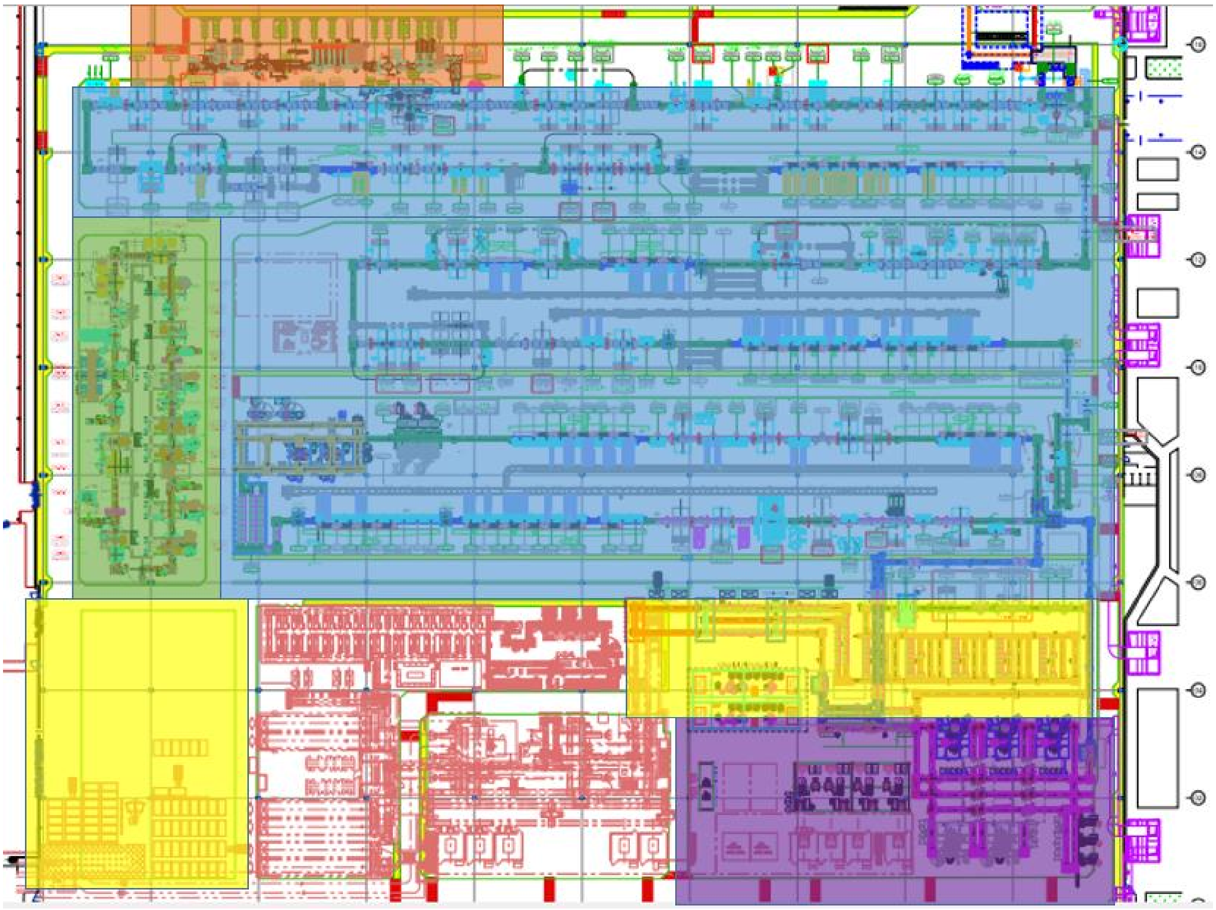

Figure 8 Assembly line areas

The 5 sectors are: the main assembly line, two smaller lines that converge in the main one in charge of assemble two subcomponents (piston/rod and cylinder head assembly), testing and shipping area.

- **Piston/rod sub-assembly line**:

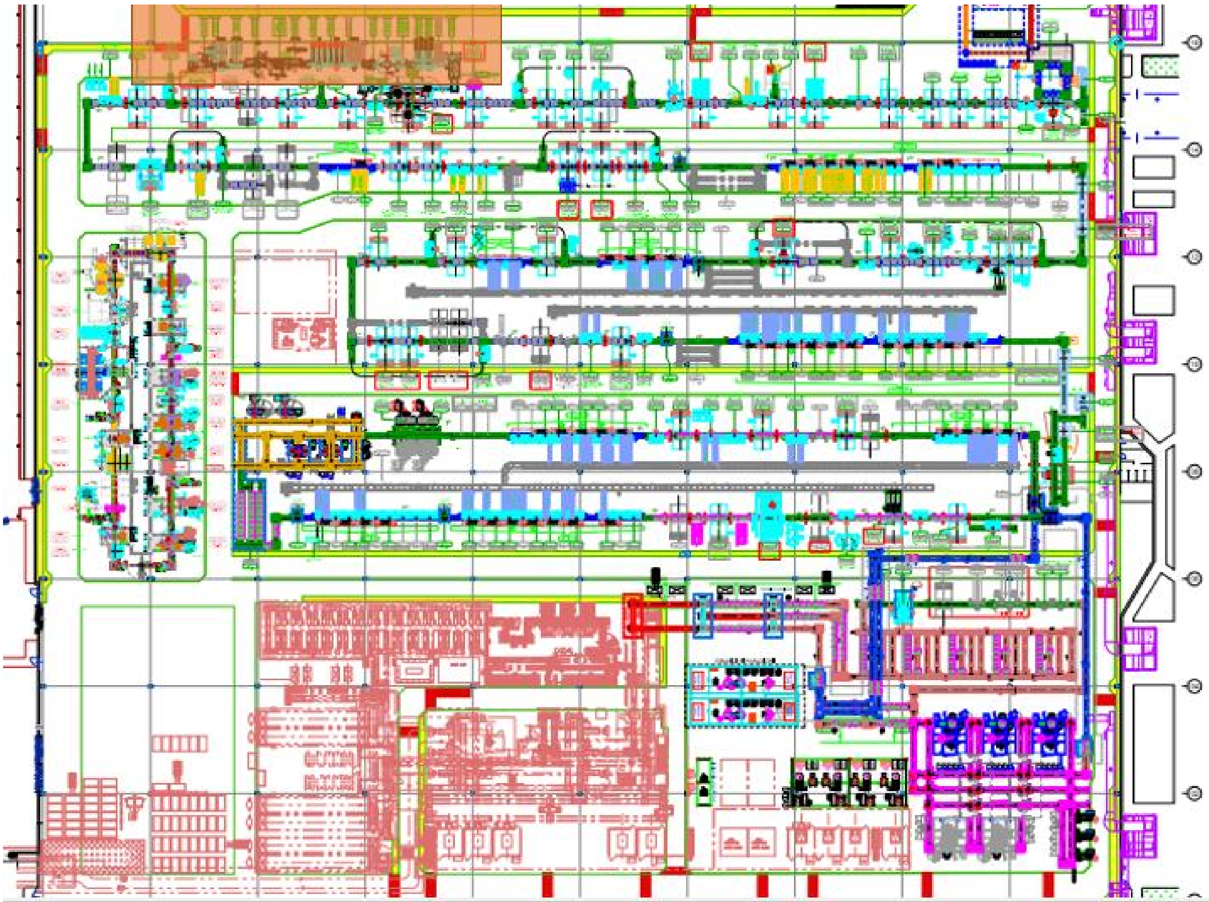

Figure 9 Piston/Rod assembly line

This small line is positioned above the main one in order to ease the connection between the two according to the product assembly cycle. It is mainly composed by automatic stations that assemble components coming from the warehouse and deliver the subassembly to the main assembly line. The stations are in charge of connecting the piston and the connecting rod, applying all the gaskets needed, removing the rod caps and placing the rod cap bearings.

- **Cylinder head sub-assembly line**:

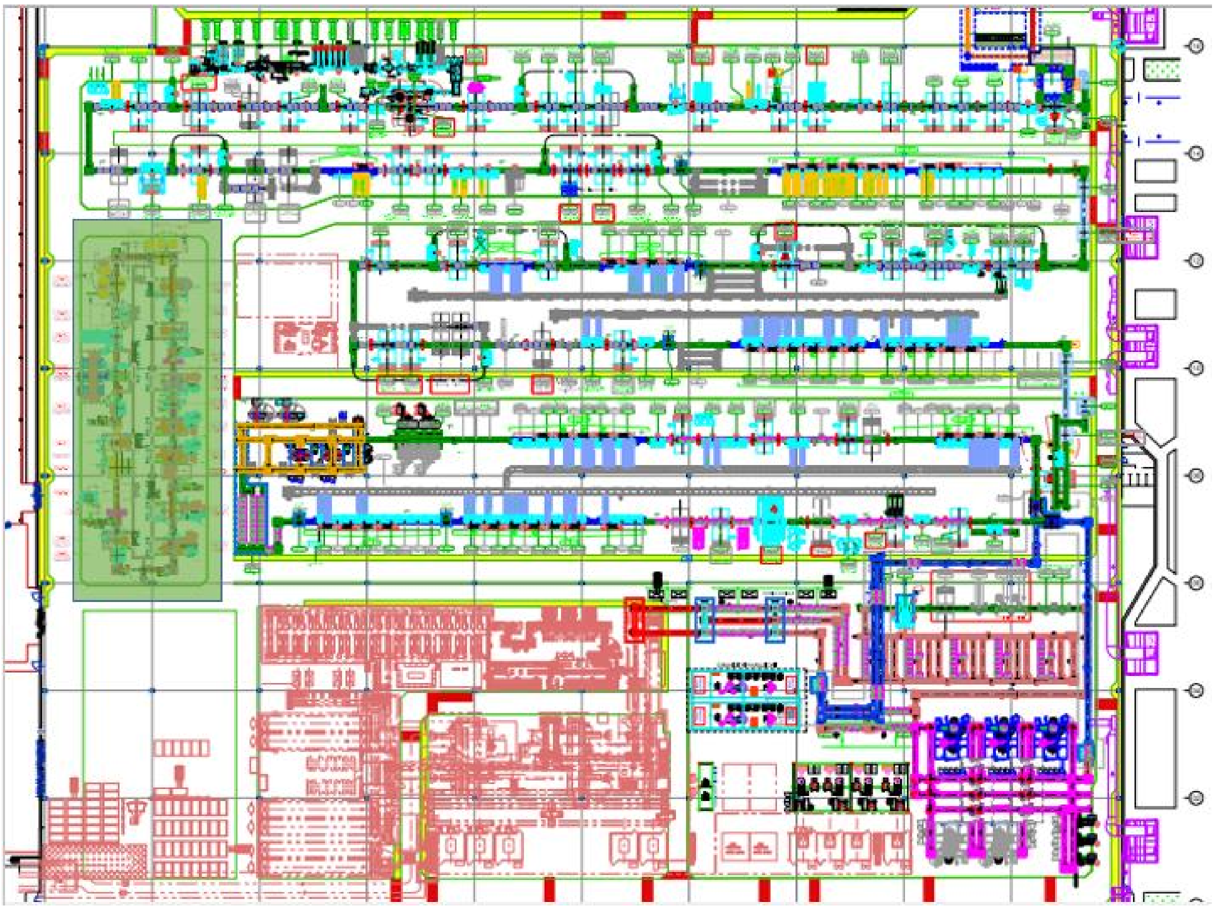

Figure 10 Cylinder head assembly line

This section is in charge of assembling the cylinder head system. Also in this case the cycle is fully automated. The operations start with the finished cylinder head block loading, coming from the machining area of the plant. Then, only the engine valves system is assembled since the other components will be mounted later on. Finally, the assembled system is sent to the main line where is sealed and fastened with the cylinder block.

- **Main line:**

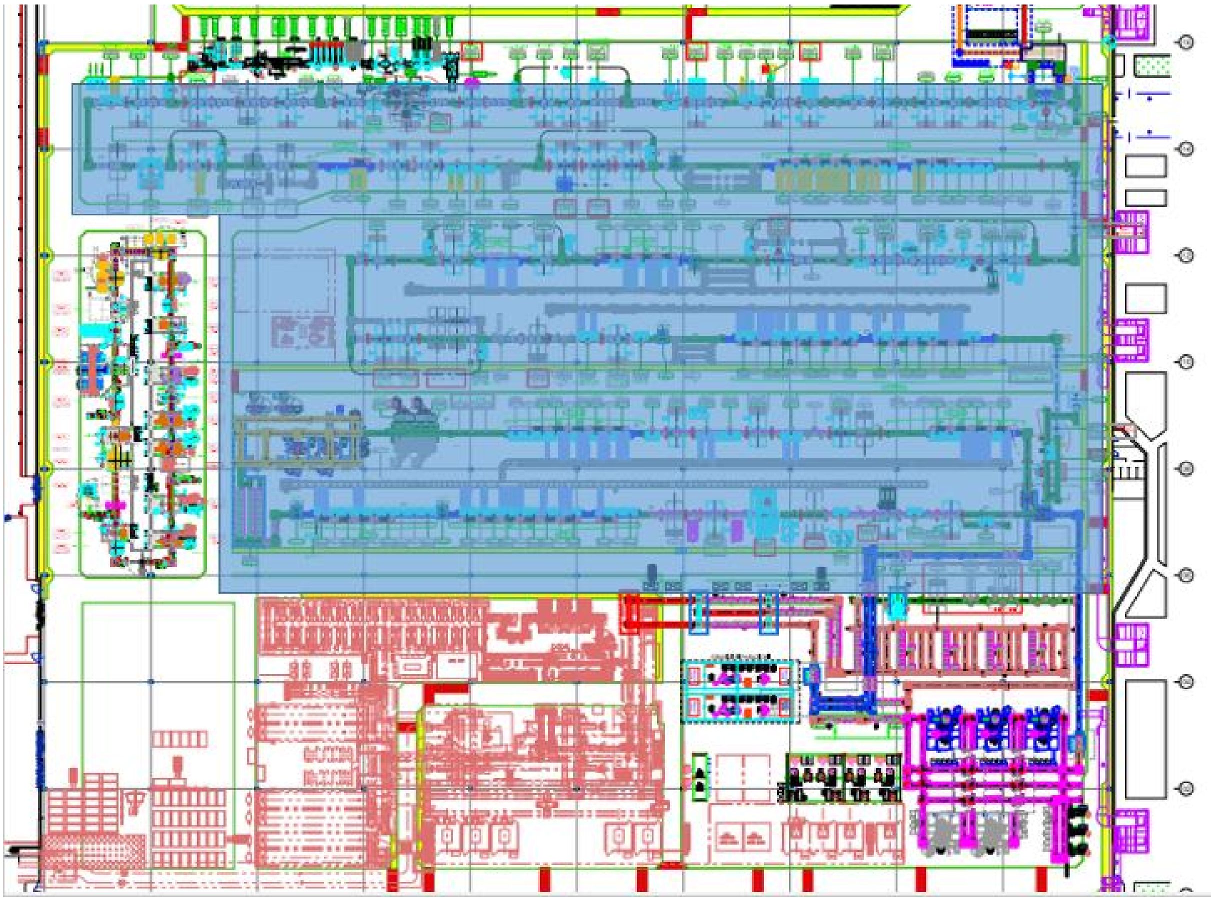

Figure 11 Main assembly line

Figure 11 represents the main assembly line where the biggest part of the assembly process take place. It is divided into two sections, respectively short and long block, according to the used transportation method. It is a hybrid configuration in which alternate automated and manual sections (in particular continuous moving assembly methods considering the manual one). Once completed the engine will be ready for the testing process.

- **Testing area:**

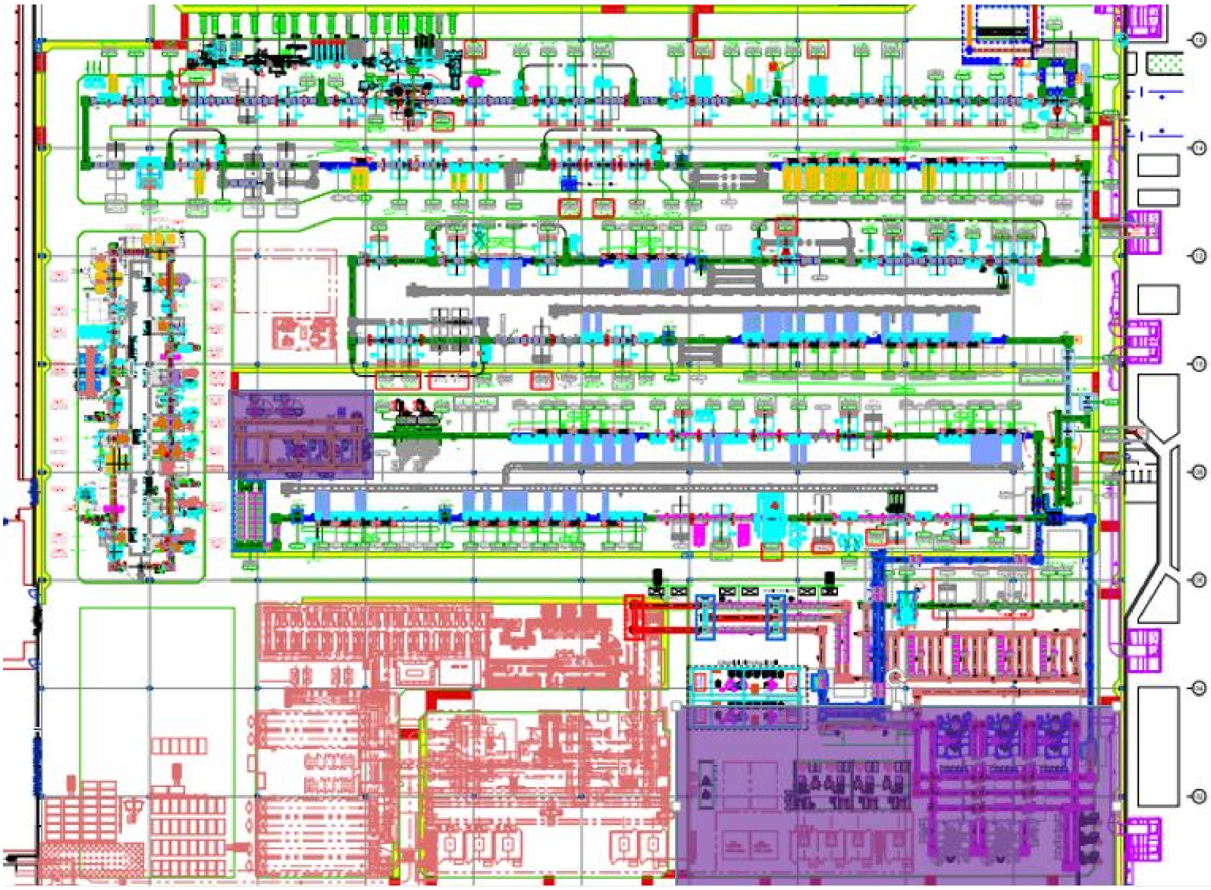

Figure 12 Testing area

Final product tests are performed in this area. It is mainly divided in three parts: leak tests, cold tests and hot tests. Leak test must be executed on every engine produced and it is implemented just before the final section of the line, when the assembly process is completed up to 80%, to allow measurement system installation on it. Here oil, water and low pressure EGR (if present) circuit leakproofness are checked to validate the assembly process of gaskets, tubes and surface connections.

The next testing area is dedicated to cold tests: tests during which the engine is not switched on. It is placed in the last section of the line where mechanical and electric tests are performed using the same transportation system involved in the assembly line. Here are checked breakaway torque, turbo performances, timing and electric connections. In this case, as well as for leak test, 100% of production will pass through it and it represent the final quality gate of the line.

Finally, the last testing area (not enlighten in the plant layout since it is external) is related to hot tests. The engine is connected, for approximately 45 minutes, to all the systems needed to work (electric, fuel, oil…) and through a test bench, that set the same boundary conditions of an engine generating power on a car, its performances are measured. One of the most important is engine torque and power measurement, and in particular, if these parameters are in between design tolerances. Since those tests employ a high quantity of time and resources, the number of engines analyzed decrease during all the process phases. At the beginning, all the engines will be investigated due to process unreliability, then the number decrease up to 5% in very advanced production phases.

- **Shipping area:**

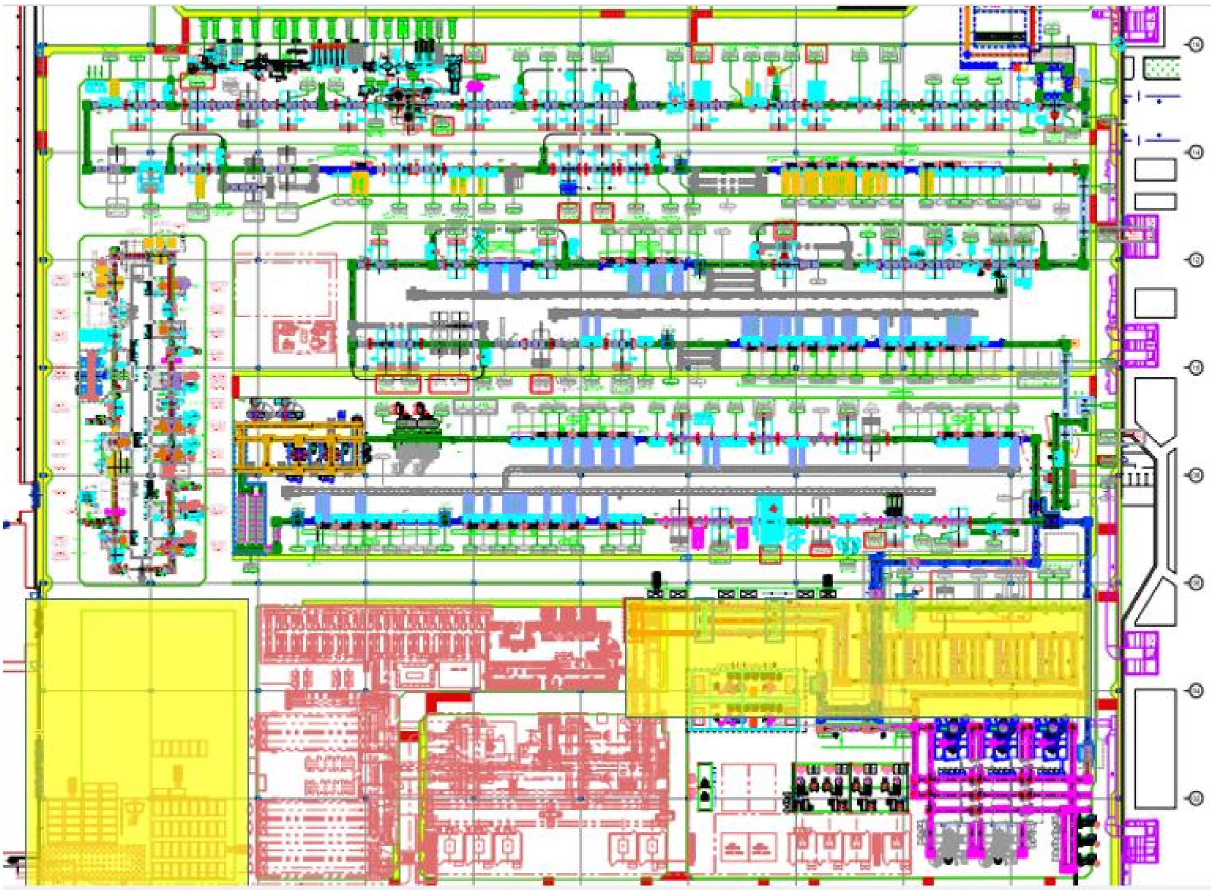

Figure 13 Shipping area

This represents the final area of the assembly line. Here the engine undergoes a final check in which the coherence and position of particularly important assembled components are inspected. If no anomalies are detected, the engine is carried in the final section where it is packed, loaded on a wooden pallet and stored in the final product warehouse waiting for the orders.

3.2 Manual stations

The manual stations involved are typically individual workbenches, equipped with tools needed to perform the desired operations, used by a human operator. In particular, both continuous moving (CM) and Stop-and-Go stations can be found. In a standard manual station, the product enters the station and is secured into it, according to the best position relative to the operator, preventing all possible unwanted movements. At this point, the operator has an amount of time equal to the CT to perform the assigned operations. After time has passed, the product starts moving without the intervention of the operator.

The continuous moving system is very different. In such a system, the product never stops and the operator is forced to handle parts moving at constant speed and walking parallel to the line. By using this system, it is possible to set the product crossing time equal to the cycle time balancing the entire line.

If the operator must perform complex operations, position a critical component or reach a difficult position, the Stop and Go Station is best suited to this task. In this case, the product in the station is stopped waiting for the operator signal. Once the operations have been performed, the product is released. As can be deduced there is not a cycle time that define the line speed but is just a matter of operator working speed. This solution helps the worker blocking the product right in front of him but may lead to line unbalancing.

Regarding the main assembly line of Termoli, 66 manual stations have been implemented, they are divided in 49 continuous moving and 17 Stop-and-Go spread over the whole line. Since the equipment needed to install a continuous moving station is very expansive, they are collected in specific section of the line in order to share the same conveyor.

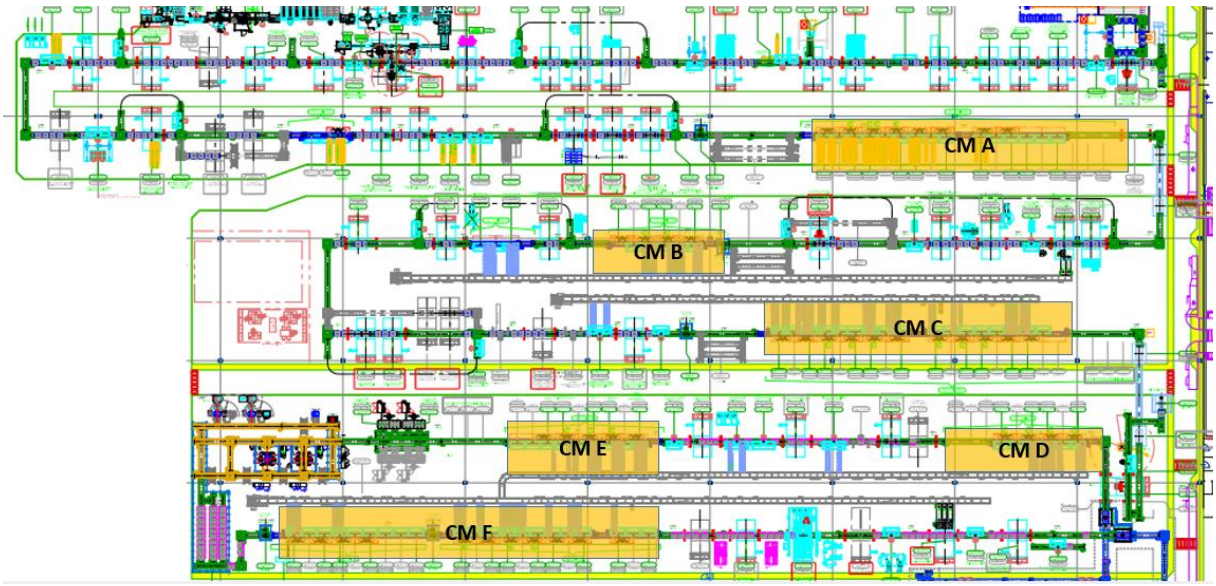

Figure 14 Continuous moving stations location

3.3 Automatic stations

Together with the manual stations presented above, this line presents an important number of automatic and semi–automatic stations. They mainly consist of soft or programmable automations in charge of performing critical operations.

The fully automatic system does not require human interaction. This means the product is loaded into feed systems or can be transferred from another system that will automatically load into the next step of the assembly process. If there is human interaction, it can be as simple as responding to system prompts.

In the semi-automatic arrangement, the cycle in not fully automated but can include a small help from an operator, such as manual loading and/or unloading of the system or manually actuated signals to allow the automated conveyor to continue down the assembly line. The key concept in this assembly station type is that it includes both manual functions as well as machine-aided assembly operations.

Focusing on the Termoli assembly line, there are 45 automatic stations which are mainly used when precision, heavy duty or quality controls are performed. The most iconic examples are sealing and fastening operations. In order to ensure a perfect surface connection, it is important to set a specific level of torque and angle, when the latter operations are managed, and of silicon, when the first are considered. For this reason, an automatic machine allows to monitor in real time these parameters allowing an equal output for all the products worked.

3.4 Transportation method

Factory automation has been a key driver behind the improvements of any manufacturing company. These improvements included the product transportation system in production lines. For this reason, pallet conveyor systems continue to be a vital component for virtually every manufacturer that tries to improve efficiencies, flexibility and consequently profits.

The greatest part of manufacturing facilities has some sort of system that uses a platform, carrier, or pallet lying on a conveyor to carry the product as it is being assembled. These systems are often referred to as a Palletized Loop; as they include an empty pallet return upon completion or transfer to another type of carrier system. The product may be heavy and hard to handle manually, or small and delicate. The pallet system allows having a perfectly stable working surface, able to carry heavy loads and a dimensional control equipment to ensure accurate alignment with the facility's tooling.

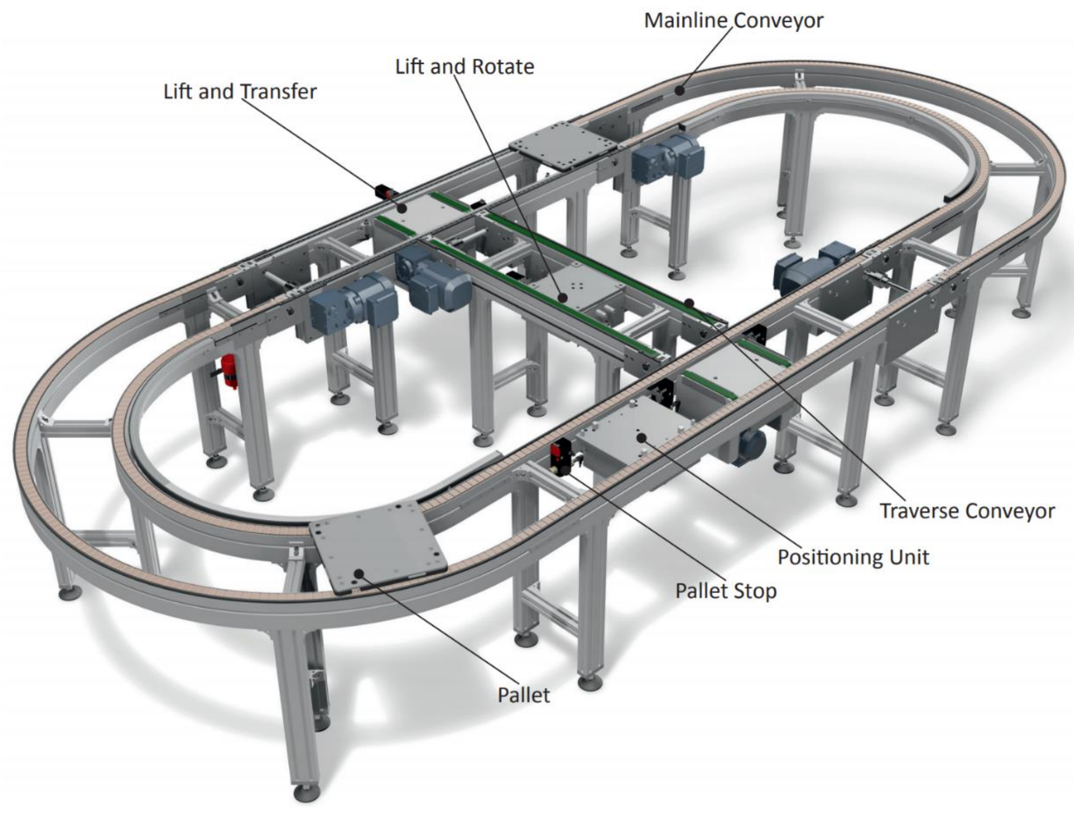

Figure 15 Conveyor System Example

Pallet conveyor systems deliver several important benefits. They can continuously move materials from point to point, handling them every item in the same way. It is possible to eliminate operations not adding value (operations that are carried out by an operator but do not add value to the product). For example, a pallet conveyor can rotate its pallet, and consequently the parts placed on it, by means of a rotary plate. Having the product in the desired orientation, the next step in the production process can be applied immediately. This results in greater throughput and lower costs. In addition, because conveyor systems are designed as modular components, changing elevations and around corners manoeuvres can be performed easily.

It is easy to understand that the pallets involved in those systems are not just like wooden slotted pallets used in shipping. They represent a high investment for the company, and then is important to have an optimal number of them within the loop. This aspect will be explained in detail in the simulation software chapter.

We will now analyse the system implemented in the assembly main line of Termoli. In that particular case, two different pallets are involved.

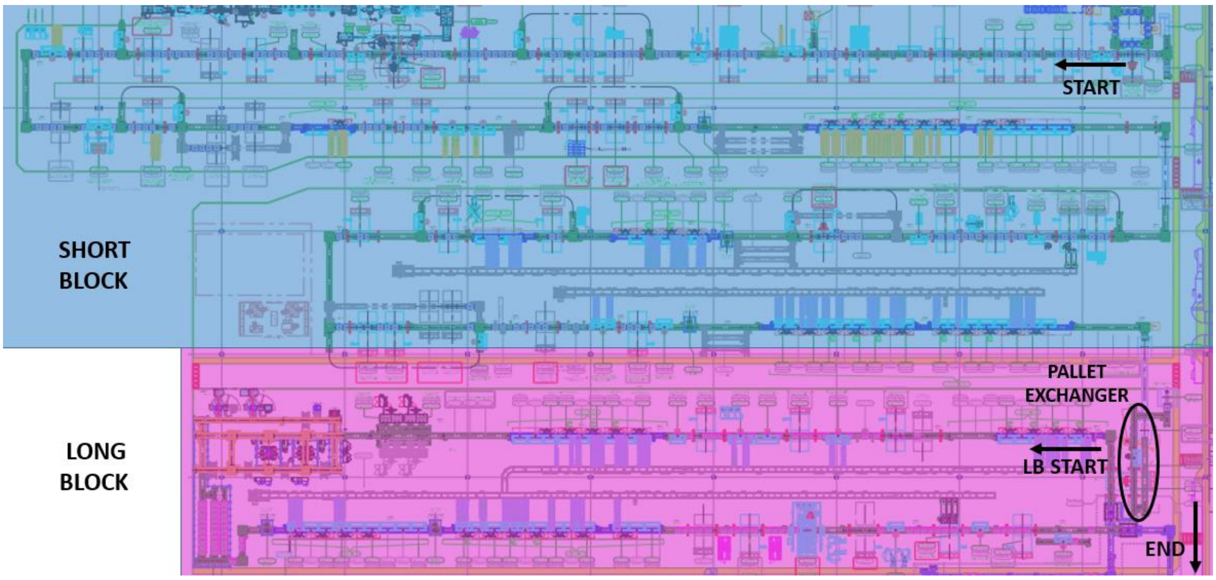

Figure 16 Short and Long block, main line division

The first line section in called “short block”. This name come from the shorter pallet involved. Even if it is smaller, it is even more expansive in respect to the other pallet used in the line, due to its design complexity, then for this reason its implementation should be limited only to specific operations.

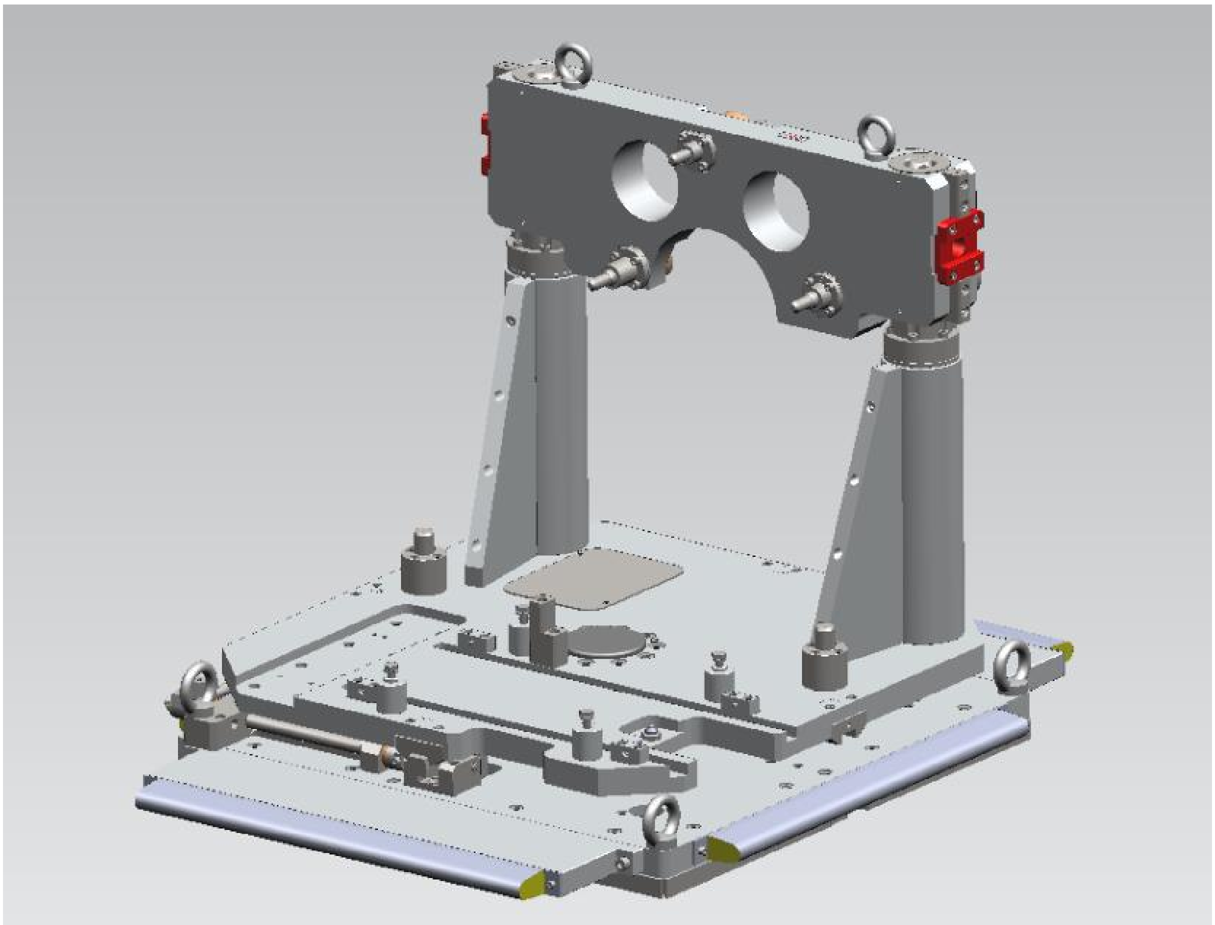

Figure 17 Short Block Pallet

The primary use of this pallet is for assembly operations that require engine rotations in every direction, making access possible to all different surfaces of the product. To ensure all those degrees of freedom, the engine does not just lie on the pallet but is physically connected to it from his lateral surface using a flat plate. It has also two holes on each side allowing the system to be extracted and inserted again, in a different position, rotating the engine. Implementing this solution, it is possible to work on every surface of the engine, except the one screwed on the plate that will be treated later. This transportation method is then suitable for the initial phases of the process.

At a certain point in the cycle, there is no longer the necessity to ensure such a high number of degree of freedom. In this case, it is better to leave the shorter and more expansive pallet and implement another solution. The engine is then picked up, using a crane system, and loaded on the so called "long block" (since the pallet used is much longer) section of the line. The shorter one then is being transported back at the beginning of the line and used again for another product.

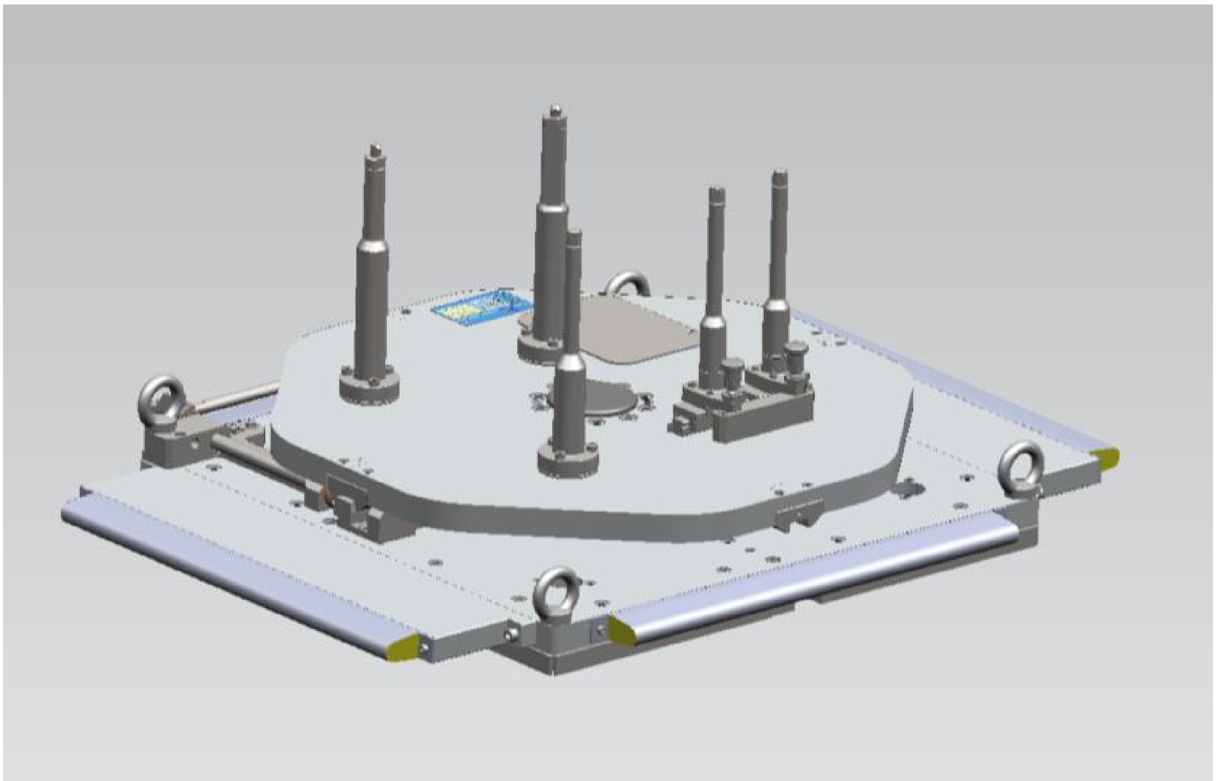

Figure 18 Long Block Pallet

The new pallet is simpler, and then cheaper, in respect to the other since it has just five support points for the engine that is locked on it in a vertical position (oil cup in contact with pallet surface). This configuration just allows a vertical rotation of the engine and not an horizontal one since is no more necessary to work the lower engine surface after the assembly of the oil cup. The "long block" section continues for the rest of the line when the assembly process ends and starts the shipping operations.

4 - Back – up and Repair logics

As already introduced, back up and repair stations are indispensable for a proper and efficient line functioning. Of course, they can be implemented with different logics depending on the products involved.

4.1 Back – up logics

Regarding back up stations, since they are ideally a perfect manual replacement of the main automatic system, they are not directly involved with production process, as long as the automatic station work properly. For this reason, in order to limit investments, one backup can be dedicated to several automatics.

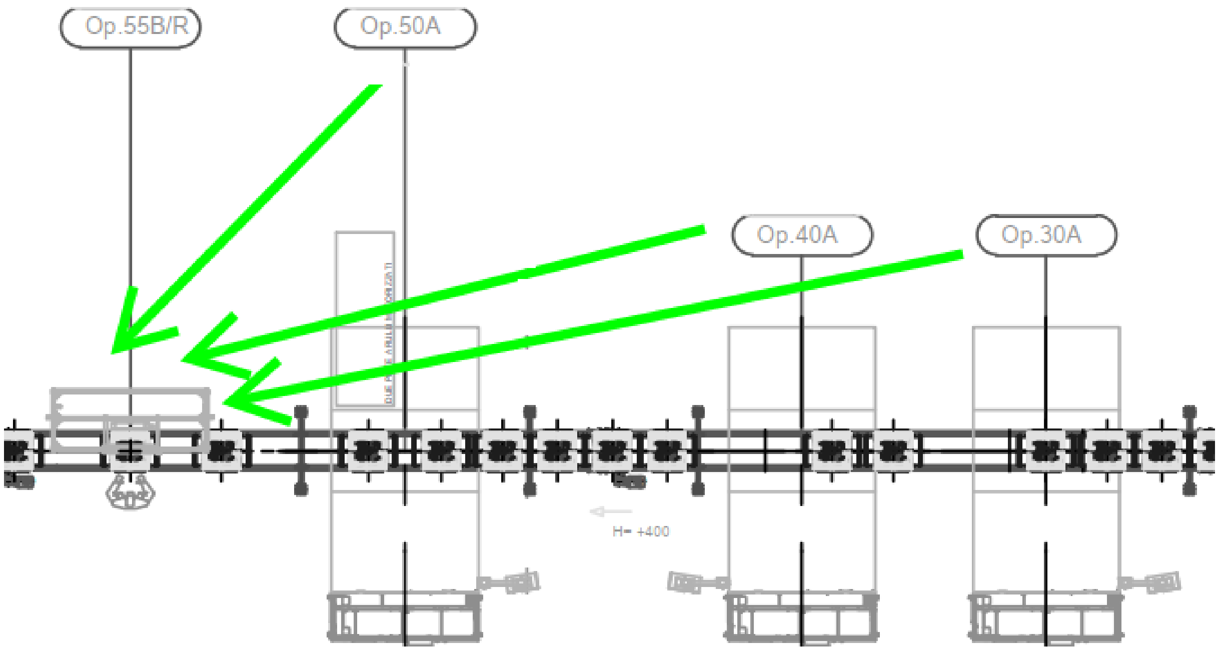

Figure 19 Back up strategy schematization.
In this example, station 55 will replace station 30, 40 and 50.

By the way, this number is relatively small since many limitations may arise:

- In the station should be present all the items needed to perform all the operations involved, consequently one of the main drivers is the space available in the operator working zone;

- If two stations have to be excluded, for example due to an equipment breakdown, all the operations performed there, will be carried out by the backup station. In such a scenario, even if cycle time is no more considered, time spent by a product in the station will be a lot higher, with the possibility of line saturation.
- Assembly is a high-interconnected process in which components are added gradually and most of the time must be considered the so called "process constrains". They refers to operations that must be performed in sequence and then without the execution of the first one, the others cannot be carried out. To visualize such a production limitation, it can be related to figure 19. If there were a process constrain among these three stations, OP 55 could not be a backup for OP30, 40, 50. In particular, if station 30 stops working, the operation completed there will be moved on station 55 located after station 40 and 50 not respecting the process constrain.
- In backup stations will converge all components assembled in the others. Even In this situation, an efficient and ergonomic material feeding system must be allowed.

That kind of stations are usually placed later in the production process, in respect to the main automatic solution, to do not affect production flow. However, the opposite arrangement can also be implemented in particular situations.

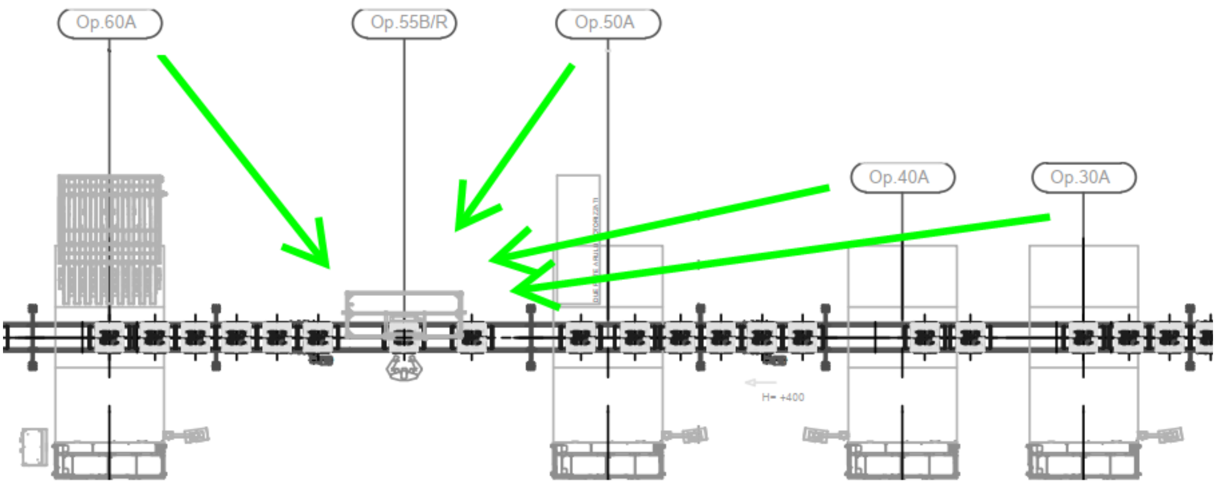

Figure 20 Back up strategy schematization.
In this example, station 55 will replace station 30, 40, 50 and station 60 in advance.

In the example above, station 55 is equipped to replace station 60 as well. The problem with this system come out when the automatic station is switched off, since engines in between OP60 and OP55 cannot be handled. To face this situation those pallets will be sent in to the next repair station in which can be managed and completed. For the reasons presented above, this arrangement is preferred in situations in which a backup is already installed right before an automatic station and it is impossible to introduce one of them in the following line section, within few production steps.

In the Termoli assembly plant, 13 back up stations are implemented and in particular, 21 automatic machines are assigned to them.

4.2 Repair logics

When an assembly process is considered, an infinite number of product nonconformities could be faced. For this reason, it is important to apply different repair logics in order to react in the quicker and most efficient way, depending on which of them show up. In particular, in this case study, two different logics are planned depending on where the repair operations are performed, if in-line or out-line.

4.2.1 In line

That kind of repair strategy is the most common when assembly lines are involved. The logic behind is very simple: one or more automatic stations in the line are assigned to a specific repair station, obviously placed in the following line steps. They must be equipped with all the items needed to perform all the possible cases of product reparations that could show up. Since the items involved in repair operations are often similar to the one needed to station back up, the same area can be dedicated to both the operations.

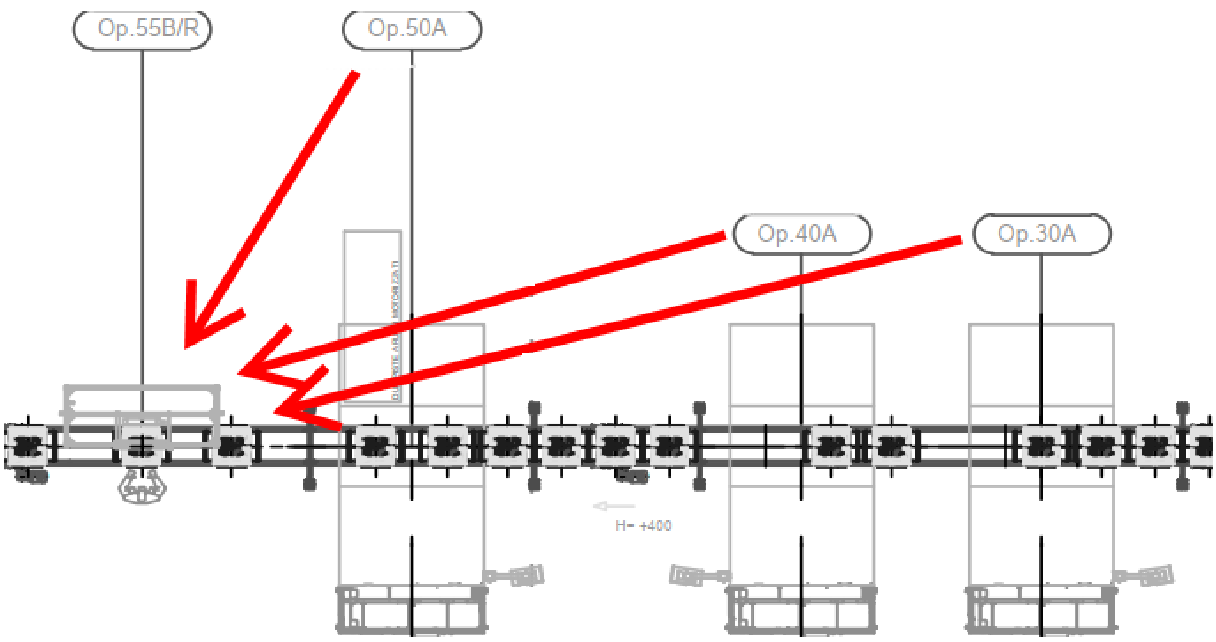

Figure 21 Repair strategy schematization.
In this example, station 55, introduced before as a backup, will be also used as a repair for the same stations.

4.2.2 Out of line

This last strategy is based on secondary loops in which repairs operation are executed before reintroduce the product in the main line flow.

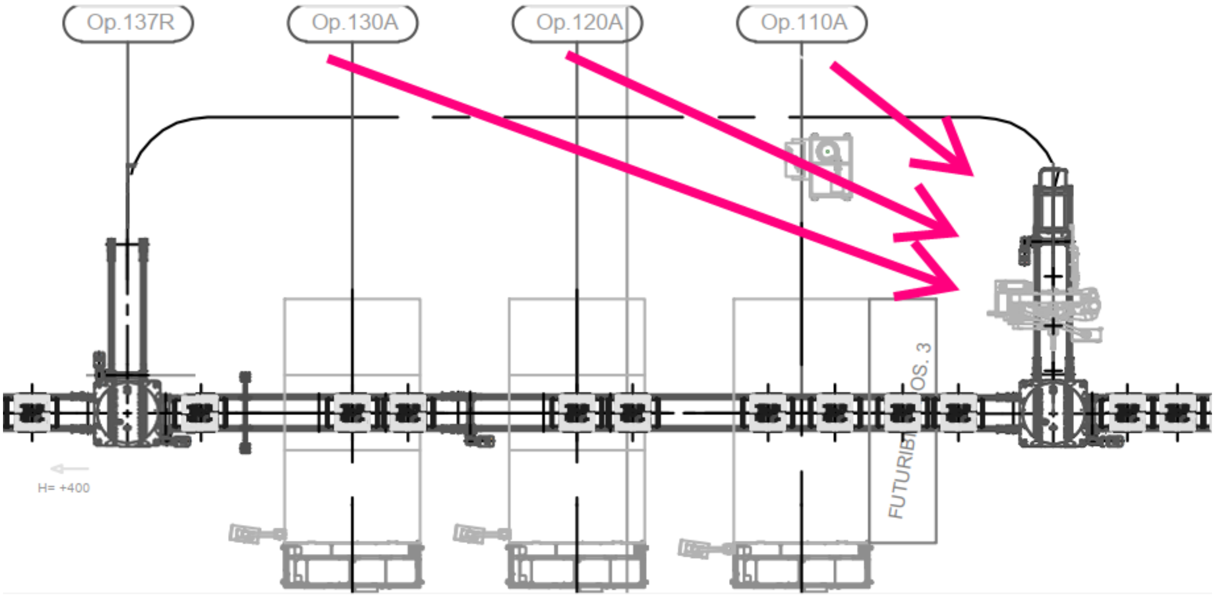

Figure 22 Repair strategy schematization.
In this example, non-conformities detected in stations 110, 120 and 130 are repaired in the repair loop 137.

After an engine, assembled by a station inside a repair loop, is recognized as a waste from the processing, it is sent to the following extraction gate in which, by using a rotary plate, it is picked up and transported to the near repair station. The station is placed just before the reintroduction gate. In this way, after operator objectification, the engine will be reintroduced neglecting all possible problems related to transportation.

Such a logic is implemented when difficult or numerous repair operations are necessary or if the engine must be restored to initial conditions. In the first case, the operator will fix the problem, and the engine will be reintroduced without being worked by the automatic machines. In the second, the operations performed must be cancelled to allow the automatic stations to perform them again. This logic is primary used when perishable items are involved, such as silicone, where the engine must be cleaned up before being re-worked, or when the operations performed includes a critical control phase and are so long and elaborate to do manually that is not convenient to implement a further equipped station. In those cases, it is better to reset initial engines conditions and let the automatic machine work again the product. The engine is then reintroduced in the main line flow just before the first station inside the loop.

Since an additional line path is established, it is essential a perfect line flow management to grant a high system efficiency. In particular, to better match components feeding system, for the reasons that will be presented in chapter 5.6, it is necessary, when possible, to reintroduce each engine within the same production batch.

In the stations presented above, not every production waste can be repaired. If such a condition shows up, the engine is reintroduced in the line and will not be processed by the following stations, until the end of the line is reached. Here the product is extracted and transported to a dedicated section of the plant called “Grandi riparazioni” where those cases are managed. In that area the engine can be completely dismount and deeper analyzed in order to recover it. If the product can be recovered, it is marked as unrepairable and scrapped.

5 – Logistic Management

In 1991 the Council of Logistics Management defined logistics as: "the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements." [9] It is a general term that encompasses both planning and execution of all the key aspects related to transportation, distribution, warehousing and purchasing. Starting from the first temporal phase, purchasing in an assembly plant is related to all the operations related to the purchased materials and used on the line.

For each part that is supplied there is a different supplier placed all over Italy and all over the word. Time and costs are obviously the main drivers behind their choice. In particular, costs are different between two suppliers according to travel time, and so according to the supplier position, and the chosen transportation method (by truck, train, ship, plane …). Lead-time (time between order placement and order reception) is also an important driver since the less the lead-time is, less goods must be stocked in the company warehouse, reducing WIP materials.

Another important driver is packaging: two different costs and management systems are needed if the so-called "one way" boxes must be handled, which can be thrown away, or boxes made of other materials that must be managed and sent back to the supplier to be used again.

Once all the suppliers have been chosen and the order has been sent, after a defined lead-time, goods will arrive to the raw materials warehouse where it will be collected and registered, becoming property of the plant. Then, at this point, a software will manage all the parts registered and the production can be set according to the parts present in the warehouse.

5.1 Materials warehouse

A warehouse is a building for storing goods [10]. A raw material warehouse, is considered a place in which all materials intended to be used in production are temporary stored waiting for customer orders (in that situation the customer is the production line). [6 warehousing]
Considering size of that building, it should be in a sector of the plant where it does not interfere with material flows. Simultaneously, thinking about the activity that must be performed inside it, not so far from where trucks can be received and unloaded or from the stations in the line.
Among these activities, some can be unlighted [4]:

- **Receiving**: trucks containing goods ordered from suppliers are received and parts registered in order to build the inventory;
- **Storage**: materials are then stored to protect them and ensure an efficient location;
- **Order Picking**: a software is used to collect the orders coming from the production line to have a list of parts to be prepared;
- **Packing\kitting**: parts are located inside logistic boxes or kits;
- **Shipping**: finally, parts or kits prepared are sent to the right station in the production line.

These operations must be strictly connected, and then a perfect warehouse management is fundamental since it has something to do with the main line efficiency. In addition, due to today's competitiveness companies need to offer a wide range of different products. As a result, a typical line configuration is the multiple mixed-model assembly line system in which the line is dedicated to a product family but is also able to produce several different models belonging to it [11]. For this reason, a single part may have different variances depending on the characteristics of the engine to be produced and this result in an even more difficult warehouse management.
Another widely used solution consist in the implementation of two warehouses between which the operations presented above are shared. In the bigger one, trucks are received, and materials registered and stored just as explained before, then another smaller warehouse is placed near the line fed by the biggest one. It is just a decentralized storage area used as intermediate warehouses for parts required by the production system. While the first have a

very high storing capacity, the second can just manage some hour of production. By implementing this solution, it is possible to isolate the main warehouse excluding it from that operations related to the feeding system. This task will be managed in the smaller warehouse directly connected to the line.

After trucks containing all the parts purchased, have been received and unloaded, materials are stored waiting for assembly line orders. When production starts, the parts needed are selected and prepared according to the feeding system and parts packaging which best fits the station.

5.2 Material Packaging

Packaging is employed to delivery parts to the assembly line. Parts need to move from the raw materials warehouse to the stations in which they are assembled with ease, with efficiency, safety and positioned in the right functional position for operators in the assembly line. In addition, packaging parts improve workflow practices and reduce logistics mission frequency since parts are not sent one by one. In particular, the so-called “Golden Batch” is defined. In that case, parts are sent in submultiple or in equal number in respect the set production batch. What is used to move them are plastic (or other materials designed for special purpose) boxes designed to flow in the transportation system or to be fit in the logistic vehicles. It is possible to adopt three different approaches: the so-called “one way” boxes, standard boxes or ad hoc designed boxes.

In the first case, the boxes are made of hard cardboard or thin plastic materials. This holding solution is often provided by suppliers and once used they are thrown away since they are easily deformed.

Figure 23 Disposable holding solution

The second solution consists of a box, produced with hot stamping operations, with standard external size and geometry. As can be seen in the figure below this solution is slightly flexible. What can be changed is the internal surface in which there are some bulkheads. They are designed to hold components and depend on the parts to be packed.

Figure 24 Standard holding box (engine pistons)

In this example, the internal surface has been designed to hold engines pistons. Differently from the previous solution, the company provides these boxes to suppliers, which will use them in the shipping operations. Another difference is the recycling loop. Once used the empty boxes must be managed in order to be used again.

In the third situation, the box is entirely designed to hold the part. This solution is certainly more expensive since is not a standard equipment and are often used softer and lighter materials (compressed expanded-polypropylene). For this reason, it is used when geometrically complex or expansive components are involved.

Figure 25 Compressed expanded-polypropylene holding box

As it can be seen the box is completely customized for a specific component. This solution allows designing the holding surface to hold different components in the same box. In this way, it is possible to integrate packaging systems for kits. In addition, in this case the recycling loop must be managed.

Material packaging is selected considering the materials to be sent and the type of station for which it is intended: automatic or manual.

- Automatic: this type of station is particularly critical since some constrains must be considered. The assembled parts must be sent in a precise position in the space and with the right orientation since a robot has to get and process them. In addition, the quantity of parts inside the box must be designed in order to reduce as much as possible the logistic missions and at the same time not so much to prevent to manage not empty boxes.

- Manual: what is relevant here is manpower presence. A man has more degree of freedom in respect to a robotic arm but at the same time, ergonomics (weightlifting, arms and back position (torsions)) and safety issues must be considered. The part to be assembled must be packed and oriented in order to maximize ease of handling and processability even if the presence of a person in the station allow different handlings and a reaction to part position and packaging.

5.3 Feeding system

When all the parts to be assembled have been received, registered and prepared, a system must be designed in charge of transport materials from the warehouse to each station in the assembly line. There are two different methods: traditional and automatic.

5.3.1 Traditional feeding method

This method was one of the most used in assembly processes in history, given the ease with which it can be implemented since there is no physical structure between warehouse and stations where materials flow. There is the necessity to design a dedicated zone in the warehouse where the parts can be adjusted in the specific box. Once the boxes are ready to be transported, they are loaded on the logistic vehicles and through designed routes are sent to the assembly line stations. Here the boxes are unloaded using gravity or motorized conveyors and the empty boxes are picked up and transported in the warehouse where they are prepared again for the next mission. This zone is also called Supermarket.
The presented feeding system is characterized by its transportation system. The worldwide used material handling vehicles are forklifts, but for several years, they are not used in FCA plants because of problems related to operator’s safety. For this reason, AVG logistic vehicles and bulls are adopted.

AGV stands for Automated Guided Vehicle and it is used to name all the vehicles, primary implemented in industrial applications, used for parts transportations inside the plant. [12]

Figure 26 AGV System

This type of vehicle automatically transports loading units without the necessity of human presence and can connect different material handling systems within the warehouse as well as warehouse itself with the assembly line for parts feeding. This result in time, energy and space savings within the company logistics. Rapid development of technology allows a rapid development of AGVs, especially for what concerns driving methods.

The first implemented driving system was by wire: an electric signal flowing through a wire positioned just below the floor of the plant, contemporary with solenoids and simple electronics, is used to drive these vehicles. Such a method is still used in application where dirty environment is involved.

More advanced methods have been developed over the years and in particular, some of the most used inside an assembly plant are magnetic and coloured bands driving systems. The first one is based on magnets placed below the floor and, unlike the by wire method, less work on the floor has to be performed since just few holes on the surface are needed. In the latter case, coloured bands are used and an optical sensor is in charge of sense the path. This method requires even less time to be implemented because the bands are glued on the floor, but more maintenance is involved since the bands must be clean to allow the optical sensor to read them.

For what concern power supply mainly, batteries are used, in that way the vehicle is able to perform all the needed logistic missions, but a recharge station must be implemented. [13]

STRONG POINTS	WEAK POINTS
Low running costs	High initial investments
No indirect workforce involved	Maintenance and spare part costs

Table 5 Strong and weak point of AGV system

BULLS consist in several logistic carts connected and led by an operator on a vehicle such us the one in the figure below.

Figure 27 BULL System

The different here is the presence of the indirect workforce needed to be implemented, and then such a station feeding system is intended for plants with a high number of indirect workers in order to saturate their working time. In addition, while the company often bought AGV vehicles, bulls are leased and then they are not a property of the company. In this scenario all the cost for special and ordinary maintenance, and therefore cost related to spare parts, are included in the rental price.

Just to summarize the choice between these two kinds of vehicles depends on the plant: if it is already involved a high number of indirect workforce, it is likely more convenient implement a bull strategy trying to saturate their working time; if these people must be hired then is likely better to implement an AGV system

5.3.2 Automated feeding system

Manufacturers in industries like Automotive are always looking for efficient production with high accuracy and quality. Automated feeding systems help increase consistency and efficiency of the line by automatically managing line orders. They are more efficient than a corresponding traditional feeding system and can be completely customized to meet the requirements of virtually any application.

An automated system is in charge of selecting, routing and positioning the parts to facilitate and enable their subsequent handling and assembly. It consists of a buffer placed in the warehouse, in which parts are collected waiting for shipping and their quantity is maintained above a minimum value. A software designed to collect the orders coming from the line and routing the boxes in the right station and finally an articulate system of routs in charge of connect warehouse and the point of use.

Since the automated arrangement is desired when high feeding frequencies are involved, it is often coupled with the traditional one. In particular, the latter is often in charge of feed special parts that require few feeding missions, for instance screws and nuts.

5.4 Flow racks

This represent the final part of the feeding system: once the boxes have been rooted it is in charge of handling components to the automatic machine or to the operator if a manual machine is involved as well as to collect the empty boxes waiting for replacement.

Motorized or Gravity Flow Racks (GFR) (SAG in Italian: scaffali a gravità) are the most used solutions in those applications. By using this simple equipment, it is possible to optimize the effectiveness of the just in time production system [14].

Figure 28 Gravity flow racks

Flow racks are also known as first-in-first-out ("FIFO") racks since they enable containers to flow from the back, where they are rooted by the feeding system, to the front, where they are used, thanks to inclined racks where gravity naturally forces parts to be consumed on a first-in-first-out basis.

The lower shelf is inclined in the other direction to receive the empty boxes and make them accessible to the operator or the automated system in charge of replace them.

5.5 Kit feeding system

This is the last parts feeding policy used in Termoli plant. It refers to a particular feeding system that consists of delivering parts to the assembly stations in predetermined quantities and placed together in *ad hoc* designed containers.

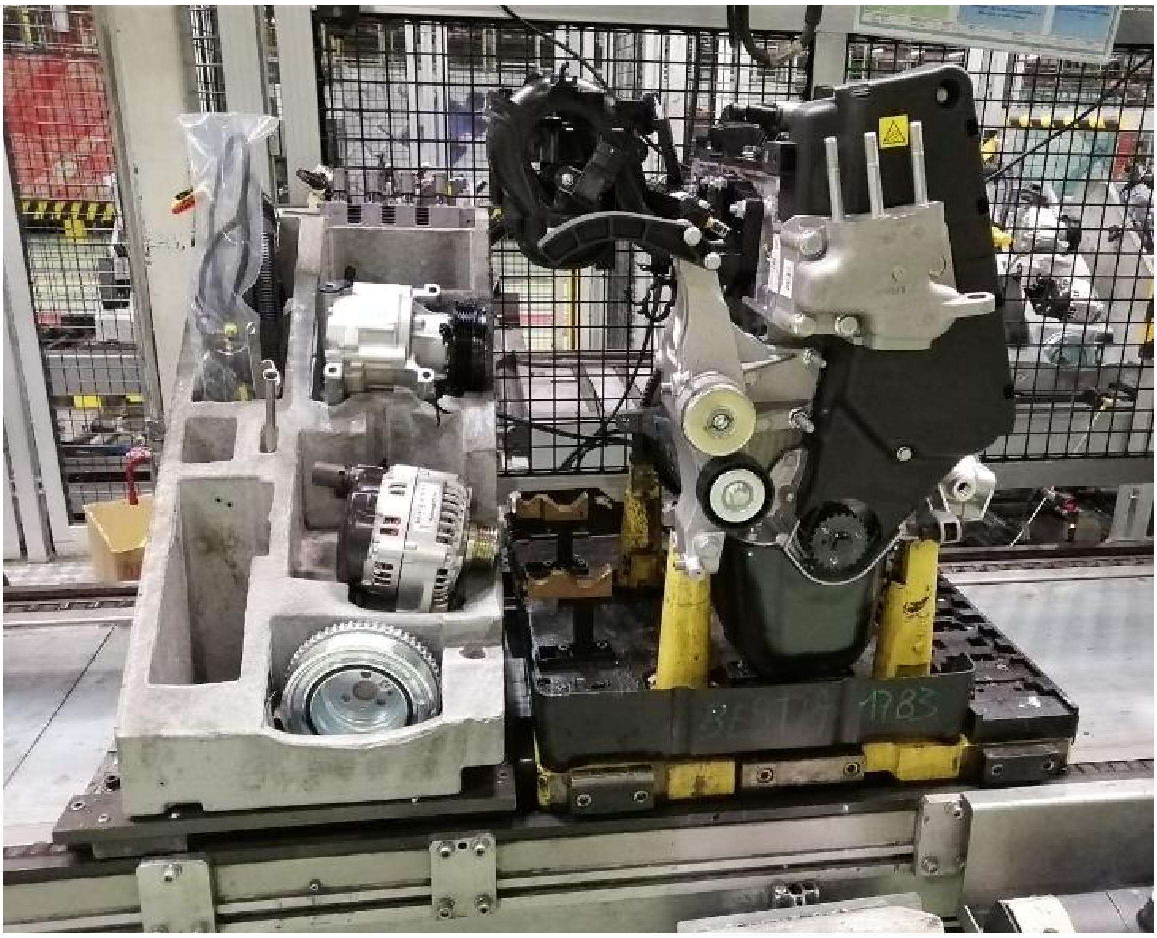

Figure 29 Kit feeding system.
In this example, each the engine is followed by its kit in which all the components associate with It are contained.

As stated by Johansson & Johansson (1990) a kitting system is preferred when products consisting of many parts number must be processed, a production system must ensure a high level of quality and when high value components must be handled. All these characteristics belong to an engine assembly plant. [15]

The kit is prepared by putting the required parts into a designed container in a dedicated part of the materials warehouse. The kit is then delivered to the assembly line in the correct

sequence. Once it is received by the line, kits are placed on the same pallet holdings its corresponding engine and together are transported through the line.
This solution is adopted in the continuous moving sections of the line, when manuals assembly operations are performed. Those are manual stations in which the product is not assembled in a stationary place, but the engine continues to move as the operator assemble parts on it. Since the engine is not stopped, static flow racks are very inefficient, and kits are preferred. One of the constrains that this feeding system strategy must face is that, in order to allow the operator to prepare the kits associated to specific engines and transport them to the line, a minimum of engines sequence must be respected. Then, when the sector in which the kits will be used began, the logistic system must be sure that the kits already prepared will match their engines. This is not always true since, as already explained, there are many points in which a product can exit from the line and be reintroduced later. In particular, for this case study, the logistic team has calculated that a 12 engines sequence must be respected.
Other strong and weak points are summarized in the following [16]:

WEAK

- **Double handling:** kits must be prepared. Parts received must be unboxed and placed in the right kit handling them once more, increasing the non-adding value activities;
- **Dedicated warehouse area:** the operations presented above must be performed in a dedicated area of the warehouse increasing its area;
- **Dedicated packaging:** each kit may have a particular layout due to the different parts it can hold, this will increase the investments due to packaging design.

STRONG

- **Reduces human error:** since parts of the right type and in the right quantity are fed, it reduces errors related to operator distractions;
- **Lean line:** offer a better shop floor control by just handling the kit containers instead of containers belonging to each component;
- **No management of not completely empty boxes:** since the kit is connected to one product, this solution is more flexible when production changes are involved.
- **Sequence constrain no more necessary:** every kit is assigned to a particular engine, then it is not necessary to ensure batch of production in line sections in where kits are implemented.

5.6 Importance of a sequence

The feeding system is relatively simple if it is possible to send all the parts to the line and start a mission when the materials in boxes are near the minimum level. Unfortunately, due to the limited space dedicated to each station and to the material packaging size, just some of those components can be available to the operator. This happens for example, when several variants of the same components are designed (different types of turbocharger, cables …) and so will be inefficient if one SAG for each one of them would be allocated.
With such a constrain it is fundamental a sequence strategy: the feeding system is in charge to send to the station the right components and in the right quantity (several missions if the box contains a submultiple of the golden batch) in relation to the engine to be assembled. In particularly critical situation, for example if the station is too far from the stores, buffers can be designed in order to be quicker if a component is needed.
To understand which type of product must be processed in the following stations, the warehouse "communicates" with them, receiving such information. In particular, when an operation has been performed, starting from engine loading on the pallet, the data related to the product and the operation itself are registered. Then in strategic points of the line, there are the so-called transit points that collect those pieces of information and send an order to the warehouse with the right components needed. At this point, the automatic feeding system software, through algorithms, is able to evaluate the time needed for each box to get the right station considering distances and queues. Luckily, in this case study, the space available in the manual and automatic stations in addition with the few models assembled in the line, make it possible to guarantee every component accessible to the operators and robots. In the future, this will not be possible anymore if the product mix will change.

6 – Simulation software

A simulation software is a program that allows the user to observe a phenomenon through simulation without having it in reality. It is based on modelling a real phenomenon with a set of mathematical formulas. Then, in theory, any phenomena that can be reduced to mathematical data and equations can be simulated on a computer. More practically, it can be used to forecast the future behaviour of a system, by what may be influenced and how the system evolves when those phenomena occur. For this reason, many companies widely use it in the product and process design phase so that the final results will be as close as possible to design specifications without expensive modifications in the following phases of the product development. [17]

With the technological progress, simulation software become more and more precise and reliable establishing itself as an essential tool in product and process development.

6.1 Software introduction

In this chapter, we will introduce the software used to perform the simulation. It is named Plant Simulation and is a computer application developed by Siemens for modeling, simulating, analyzing, visualizing and optimizing production systems and processes, the flow of materials and logistic operations. Using Plant Simulation, users can optimize material flow, resource utilization and logistics for all levels of plant planning from global production facilities, through local plants, to specific lines. We will now review why this kind of software is suitable for a production line analysis and the different applications it can have when the objective is line optimization. [18]

6.1.1 Types of simulation models

To classify the different types of simulation models Law (2006) uses three characteristics:

- Static or Dynamic: if a model is considered static it's like have a photo of the system and considering it at that fixed time; when is dynamic the system evolves over time.
- Deterministic or Stochastic: In a deterministic model, no randomness is induced during the time in which such a model is studied; when a model is stochastic one or several randomness sources are considered.
- Continuous or Discrete: these two types of simulation are used to study the evolution of a dynamic system in time. When a model is continuous, the change of the system state is calculated continuously. They are used to model a wide variety of physical phenomena like ballistic trajectories, electric motor response, radio frequency data communication, steam turbine power generation etc. When the system state changes at certain intervals, the model considered is called discrete. In that case, if an event is considered as a change of state of the system, the simulation observe it and create an events chain assuming that between consecutive events, no change in the system occurs [19] [20]

Figure 30 Events chain scheme

In order to link the presented characteristics with an assembly line model, several key performance indicators must be identified. Because of them, it is possible to determine the simulation characteristics that better fit the systems involved.
Let us consider the most important characteristics:

- LEAD TIME: time spent by the product to flow through the line;
- THROUGHPUT: "the amount of work done or people, materials, etc. that are dealt with in a particular amount of time" [21], it is strictly related to line productivity [pieces/h];
- WORK IN PROGRESS (WIP): pieces actually present on the line.

In order to get these indicators, it is not possible to analyse the system at a given time, but it is fundamental to observe its variation over time. This means the model should be dynamic since a static system would not generate useful data.
As it has been introduced in chapter 1.4 and 1.5 machine failures and operation scraps must be considered when a deep analysis of the system it is performed. That introduce stochastic elements due to the percentage in time of machines availability and the percentage of good pieces due to machine efficiency. As a result, the model cannot be deterministic but stochastic.
Finally, in an assembly line what characterize the system are the changes of state performed in each station and the transportation time spent between two consecutive stations. What really happens between them is not important since system state does not change. Then it is not necessary to have a model in which changes in state are analysed continuously but will be faster if a discrete time is considered [22].
Such a simulation is widely used in the early design phases of assembly lines and logistic systems. Its application is fundamental to analyse different scenarios:

- by simulating an existing line, can be seen if a line variation has a good or bad impact on the production;
- evaluate the maximum productivity the line can achieve;

- how machine failures and scrap impact on productivity since the simulation typically keeps track of the system's statistics (acting on parameters such as MTBF (mean time between failures), MTTR (mean time to repair) and machine efficiency);
- bottleneck individuation;
- production mix analysis;
- evaluate the so-called Golden Batch by varying the pieces composing the batch and simulating it trying to get the target productivity;
- evaluate the maximum number of pallets present at the same time on the line, in order to get the highest line efficiency;
- …

Let us analyse some of these applications, to understand the huge impact that the simulation can have on the project.

6.1.2 Optimal Pallets number identification

Most manufacturing facilities have a system that uses a platform or pallet to carry the product as it is being assembled, and while it is passing through the line. These systems are often called Palletized Loop as they include an empty pallet return system upon completion or transfer to another type of carrier system.
The pallet usually consists of dimensional control equipment to ensure accurate alignment with the facility's tooling and to handle easily the product while it is flowing throw the line. This is a huge investment for the company so it is important to manage the optimal number of pallets within the loop in order to prevent a desaturation of the line due to lack of pieces to be processed, in case of too few pallets in the system, or on the contrary a complete saturation with queue issues. For this reason, palletized loops need room to expand and contract to ensure optimal throughput and delays due to downtime or changeovers can degrade performance. It is vital to ensure that an empty pallet is available and ready for the next build, yet not blocking the transfer machine and contemporary the entire line. Simulation is the best solution for visualizing the palletized loops and all the interconnections and consequences that it can have on the entire production. [23]
The first step is to create a model, representing the production line to be analysed. This is the most critical phase since all the stations belonging to it must be modelled, considering the operation performed and the cycle time related to them, as well as the logics that govern product flow inside the line.
Once a realistic model has been built, it is possible to proceed with the simulation phase. The objective is to obtain the optimal number of pallets in the system. It is simply possible to run the simulation several times changing the number of pallets each run, for example considering a logical step size of ten pallets per run and analyse how the system respond to these changes. When all these simulations have been performed, it is possible to build a table where results are collected, using as inputs data, for instance, the variation from one hundred to two hundred pallets. The performance criteria of the simulation are often based on maximizing line throughput but can also keep track of the performance of buffers between lines or between stations.

Let's consider the real application of GSE assembly line in Termoli. Since the assembly line is composed by different line sections (piston-rod, cylinder head, main assembly line…) a simpler analysis can be performed for the cylinder-head line which have just one pallet type and then enlarged to the main assembly line in which two different types of pallet are employed. Performing such an analysis, the following graphic is obtained:

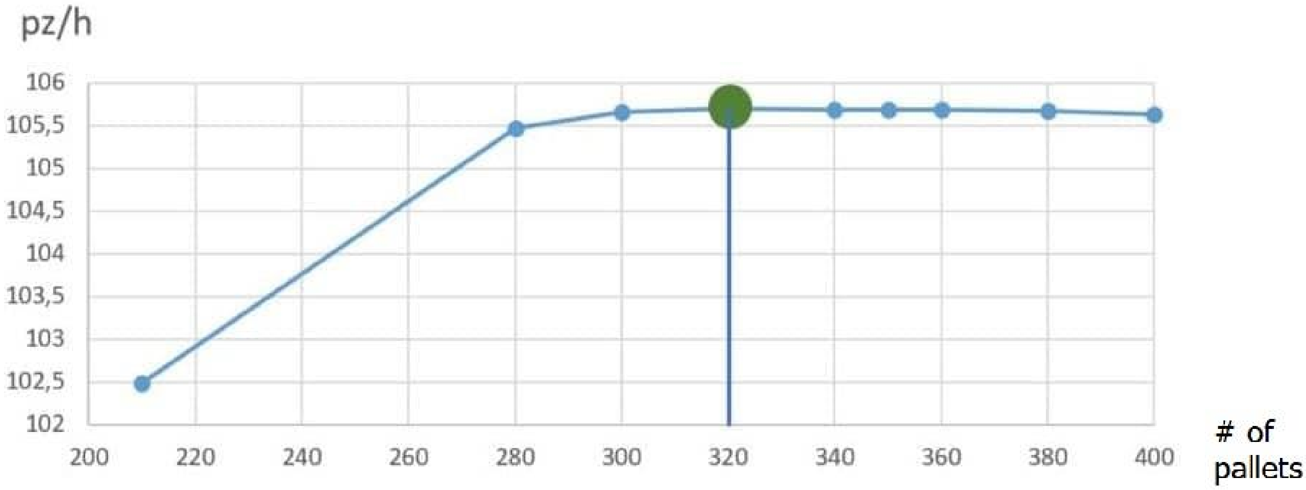

Figure 31 Optimal pallets number

In the graph, the throughput (in the y axis) is analysed as a function of the number of pallets (in the y axis). When the number of pallets is too low the throughput decreases since the lack of pallet forces the stations to stop and wait for the next pallet. If the number of pallets is too high, the throughput decrease as well since the line is too saturated and queue start to manifest before the stations. By analysing the curve, a maximum throughput point can be found, and the optimal number of pallets can be selected for the assembly line.

If the same analysis is performed for the main assembly line, an additional differentiation must be done due to the differences between short and long block pallets. The analysis result in a system with two variables represented by the two pallet types itself and then also the results will be represented by the throughput varying as a function of them.

In the following table, an example with the most significant data is presented:

	Pallets short block	Pallets long block	Throughput per hour	Efficiency	Min. Efficiency
Exp 1	260	250	74.43	93.03%	92.94%
Exp 2	270	260	74.47	93.08%	92.97%
Exp 3	280	270	74.50	93.12%	93.00%
Exp 4	290	280	74.52	93.15%	93.02%
Exp 6	300	290	74.54	93.18%	93.05%
Exp 7	310	300	74.56	93.20%	93.07%

Table 6 Parameters optimal pallets number relative to the main line

Results previously collected in a table can graphically generate a three-dimensional graph creating a sort of heat map where on the x and y-axis there are respectively the number of short and long block pallets. Generally, just a few experiments are simulated since it is possible to notice data drift towards a specific result. As it is possible to see the efficiency and throughput increase when the number of pallets increase. A further increase of them will affect negatively the performances. Since the experiments allow stochastic variables, in the last column show the minimum efficiency value registered in the different simulation runs started with the same input parameters.

6.1.3 Buffers position and dimension

The most problematic aspect of Termoli assembly line is the presence of Continuous Moving (CM) sections since in each CM area there are more than ten manual stations. Each micro-stop of each manual station will stop the entire CM causing production losses in that specific area but also blocking the automatic stations that are upstream the CM, since the following stations are busy, and keeping the stations downstream waiting for the completion of the previous operations. This behaviour will decrease the overall efficiency of the line.

A possible solution for this problem is to try to reduce the micro-stop almost to zero but this is an ideal target impossible to reach. A real improvement can be achieved by using the simulation. By changing line layout, it is possible to reduce the influence of micro-stop increasing the interoperational buffer size between each station. In practice, the simulation shows how the efficiency and throughput change varying the space between two consecutive stations and using it as a buffer between them. This distance directly relates to the number of products that the conveyor connecting two stations can hold.

Let us consider the section of the line in the following figure.

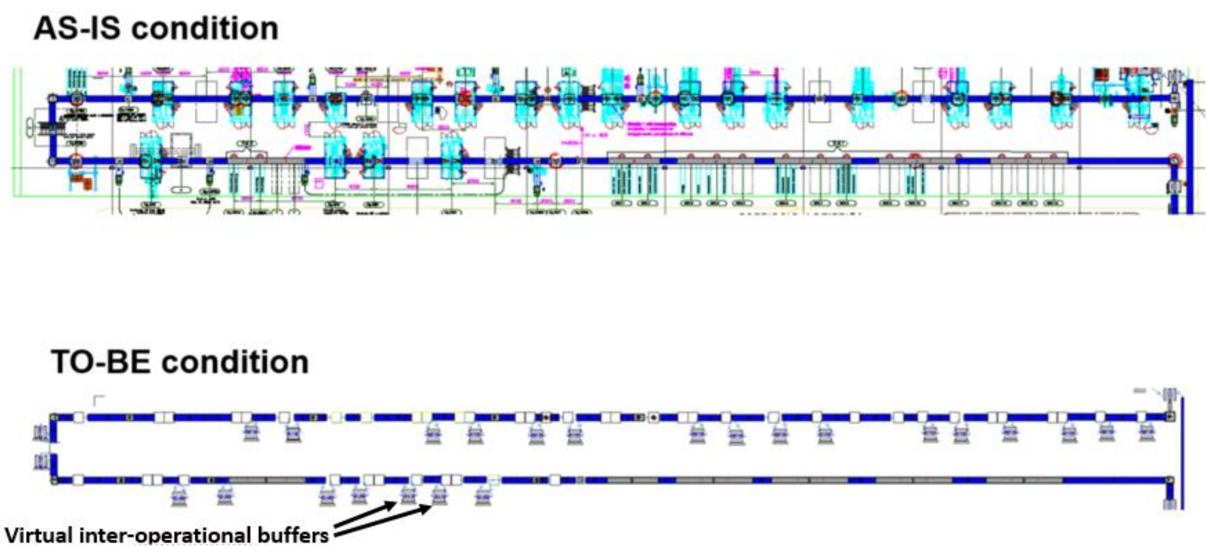

Figure 32 Line optimization, as-is and to-be conditions

It consists of n machines in series and (n-1) buffers located between them. Each machine is characterized by three parameters: the processing time, the time between failures and the time to repair and there is a maximum buffer size due to a maximum length that the line can have. The virtual inter-operational buffers are parametric, so it is possible to perform a DoE (Design of Experiment) to optimize each one of them. As can be seen in the optimized layout, the stations inside the CM area are arranged in a different way according to the buffer needed by each station to get the maximum throughput. Implementing this solution, with almost zero investment, the production losses have been reduced of 4% increasing consequently the line productive capacity.

In a similar way, it is possible to simulate the impact of repair stations, for both in-line and out-of-line cases, on the overall line throughput that is the object of this study.

7 – Case study analysis

Once the main systems and characteristics has been introduced, it is important to analyze the data already available in the project and the strategy adopted to collect and discriminate the not available information.

7.1 Scrap rate

When a new line is designed, it is important to understand the impact of production scraps on the normal production schedule since such a product must be processed again increasing the time spent in the line and then decreasing its efficiency. The issue with this type of data is that it is impossible to get them for a new plant and the only solution is to adapt the results coming from similar systems. For this case study, it was decided to analyse the scrap percentage of the machines installed in the assembly lines of Bielsko Biala in Poland and Betim in Brazil. Data related with the latter plant are even more relevant since its design has been taken as point of reference for the one in Termoli.

First, let us analyse the data acquisition system implemented in the majority of the FCA assembly plants. Every pallet is linked to a different product since the beginning of the process, when the engine block is loaded on it. At the same time a magnetic support, the so-called "tag" is assigned to both the engine and the pallet and will travel with them during the entire cycle. It is an industrial object where it is possible to write and read information. Every station is provided with a reader/writer that reads data contained in the tag and write information and results, in particular, are programmed to interact with the so-called "Tag Maps" (a well-defined template where a lot of information are coded). In this file there are all the information the stations need to recognise which type of product just entered and consequently to perform the right operations. To visualize those maps, it is easy to think of an excel file in which every row represents a coded data. At the end of the process, all the stations results will be stored in the tag map. Such a template can be divided in different sections depending of the type of information stored:

- **Biographic section**: is the first area and contains data related to product machinability (this is the first row since if the engine cannot be worked the station will let it pass through without wasting time reading the other rows), engine serial and homologation number;
- **Components biographic section**: here all the drawing numbers relative to each component that will be installed on the engine block (cylinder head, crankshaft, flywheel...) are collected.
- **Process data section**: In this area, there is the information about the production process and in particular, about every operation that will be performed in the line. The key information encoded here is about operation scraps. Indeed, after an operation is performed, the writer installed in the station, will write in this area if it has been performed correctly or if the engine must be processed again because something went wrong. If the latter case shows up the engine is marked as not processable, and it is sent to the nearest repair station without being worked by the others. When the product is repaired, the scrap information saved in the specific operation area is deleted, is encoded the information "repaired" and the engine can go on through the following stations. The system has a high level of detail since for example in a screwing operation in which more than 10 screws are processed at the same time, it is possible to know which screw does not meet the design parameters.
- **Quality data section**: there are the measures that must be granted as operation results. For example, in a screwing operation will be encoded the measures of torque and angle to be respected to get a good product.

When the engine receives the final clearance all those maps are registered and saved into the main data storing system called PMS (Production Management System) that collect them and create a huge database which contains the maps belonging to all engines produced. It is a sort of a cloud system used to collect information. By consulting the PMS relative to a specific line, tag maps can be accessed by the "Engine history" section. Such a database was born to certify the quality of the product since contains the report about every operation performed, but a deeper analysis can be used to check, for each station, how many engines have been repaired, in a given period. By relating this number with the total number of engines produced in the same period, the scrap percentage for the machine can be evaluated. A limit of this analysis is the availability and reliability of the data, due to the differences between the lines and since they refer to stations that, in some cases, perform many operations in series that are different from the one carried out by the machines in the case study. To mitigate the effect of this problem, it has been decided to do not consider each operation as a stand-alone system, but to group those who belong at the same type and use as scrap rate the mean value. For example, if in the line are installed 10 screwing machines, they will be grouped together and the scrap rate associated to this type of operation will be the mean value of the scrap rate of the single machine. In such a way it is possible to assign a value to the stations not present in the PMS and to mitigate the effect of random events on the single scrap rate.

In particular, 12 different groups of operations have been selected:

- Screwing (1 / 2 screws);
- Screwing (3 / 6 screws);
- Screwing (>6 screws);
- Cylinder head screwing (stand-alone group due to complexity of the operation);
- Press-fitting;
- Sealing;
- Lubrication;
- Free rotation;
- Leak test;
- Check;
- Assembly and screws insertion;
- Timing.

To each one of them has been assigned a correspondent scrap rate. It consists in the mean value of the scrap rate of the operations grouped in the class and collected considering a period of two years of production. At this point it is possible to implement those data in a simulation software, in order to understand if scraps can have a significant impact on the normal production and how to solve possible problems that may arise.

7.1.1 Sensitivity analysis

An assembly line is a complex system composed by different entities and governed by many logics and parameters. For this reason, can be interesting to perform a sensitivity analysis with the aim of understanding the most relevant differences in the system outputs, by changing one by one the input parameters.

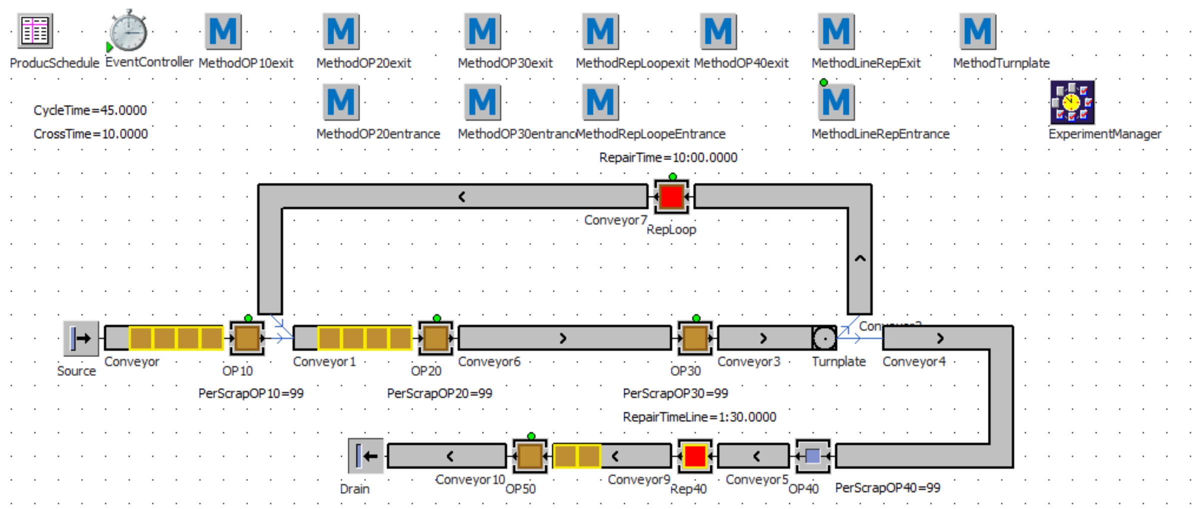

Figure 33 Schematic simulation line model

The image above shows the implementation of a simple line, in the simulation software, in which all the characteristics related to the scrap rate analysis can be tested. It represents a line composed by five operating machines (OP10, OP20, OP30, OP40 and OP50) and two repair stations, one out-of-line (RepLoop) and one in-line (Rep40). The first is in charge of manage scraps generated by OP10, 20 and 30, which are leaded by the turn plate in the repair loop and reintroduced in the main line, before OP20, to be worked again; the second manages scraps generated by OP40, while is just crossed by other products. Source and Drain entities, placed respectively at the start and at the end of the line, are in charge of create and delete the product simulated by the software. Products are represented as brown boxes and the red one are the products that must be repaired.

At the top, the square icons with the M are called methods. They define the logics that the stations must follow to replicate real stations behavior and must be arranged using the programming language of the software.

```
is
    dice :real;
    color :integer;

do
    if @.isOP10scrap= true then
        @.move;
    end;
    if @.isOP10scrap= false then
    dice:= z_uniform(1,0,100);
    if dice > PerScrapOP20 then
        @.isOP20scrap:= true;
        color:= @.Vectorgraphicscolor;
        @.coloreprec:= color;
        @.Vectorgraphicscolor:= 255;
    end;
    @.move;
end;

end;
```

Figure 34 Simulation method example

Figure 34 represent an example of method and in particular, the one dedicated to the operations executed by OP20 and repaired by the repairing loop. The commands implemented here are in charge of defining station scrap rate, the color change of the box in case of failure of the operation and other logics related to products traffic.

Once the model has been designed, it is possible to run the simulations. For this case study, has been decided to vary one by one three input parameters (machines scrap rate, in-line repair time and out-of-line repair time), maintaining the other two constant, and analyze the effect on the number of products produced in one hour.

Machines scrap rate variation

The first group of simulations have been run changing simultaneously the scrap rate of the analyzed machines in a range of zero - 10% to analyze the behavior of the line when the repairing operations become more frequent. Starting from 0%, this percentage has been increased by 0.5 every subsequent experiment, until the target of 10% was reached, keeping constant at 90sec and 5min the in-line repair time and the out-of-line repair time.

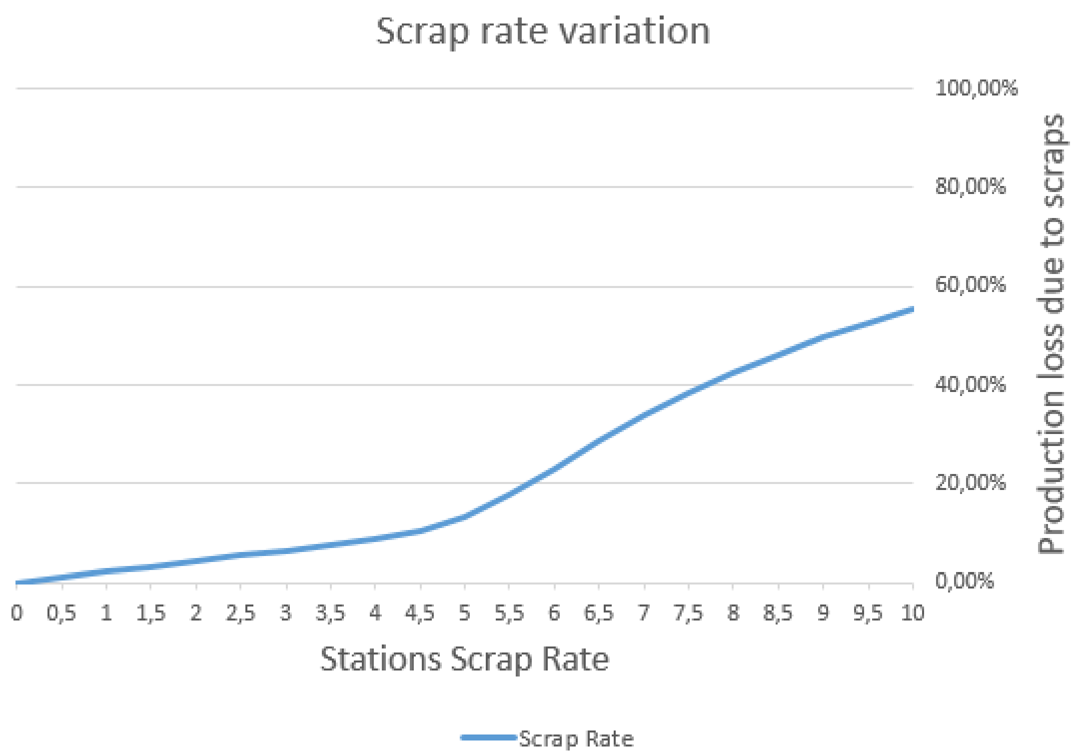

Figure 35 Graphical results of scrap rate variation

The graph above collects the obtained data. On the y-axis, it is represented the production loss evaluated as:

$$Production\ loss\ [\%] = 1 - \frac{\text{peaces produced considering scraps } \left[\frac{\text{pcs}}{\text{h}}\right]}{\text{peaces produced not considering scraps } \left[\frac{\text{pcs}}{\text{h}}\right]} * 100$$

Equation 7 Production loss calculation

As it is easy to imagine, by increasing the scrap rate, the production loss increases as well. The interesting result is that the slope of the line is almost constant until a certain scrap rate is reached, where the effect on the production become strong.

In-line Repair time variation

The second group of simulations is dedicated to time needed by station Rep40 (in-line repair station modelling) to perform all the repair operations. This parameter has been changed in a range of 3-10 minutes with steps of 20 seconds. Also in this case the out-of-line repair time is keeping constant at 5min. As regards Scrap Rate, several scenarios have been considered to study the connection between the variations of those parameters.

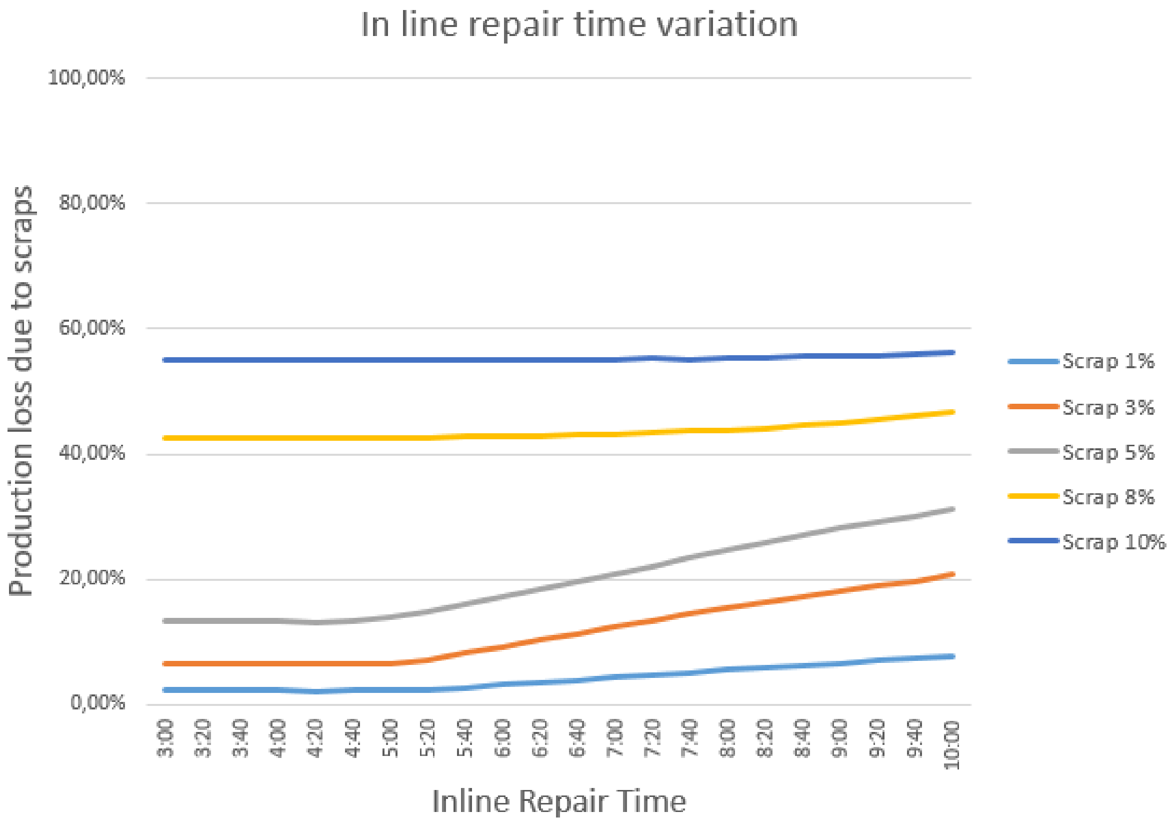

Figure 36 Graphical results of In-line repairing time variation

Also in this case the graph shows an increasing in production loss for both scrap rate and in-line repair time growth. In addition, can be noticed that for a higher percentage of scraps, the time needed to repair them is not so meaningful since the high number of line stops impact dramatically on production outputs. On the other hand, if a scrap rate between 1 and 3% (typical automatic station scrap rate) is considered, the production loss is constant up to a particular repair time in which it starts to increases linearly.

Out-of-line Repair time variation

Finally, in the last simulations group, the time needed for repair operations in the out-of-line station (RepLoop) has been varied. Just like the previous group, this parameter has been changed in a range of 3-10 minutes with steps of 20 seconds keeping constant at 90sec the in-line repair time. A maximum of five products (plus one inside the repair station) has been considered as buffer for this station.

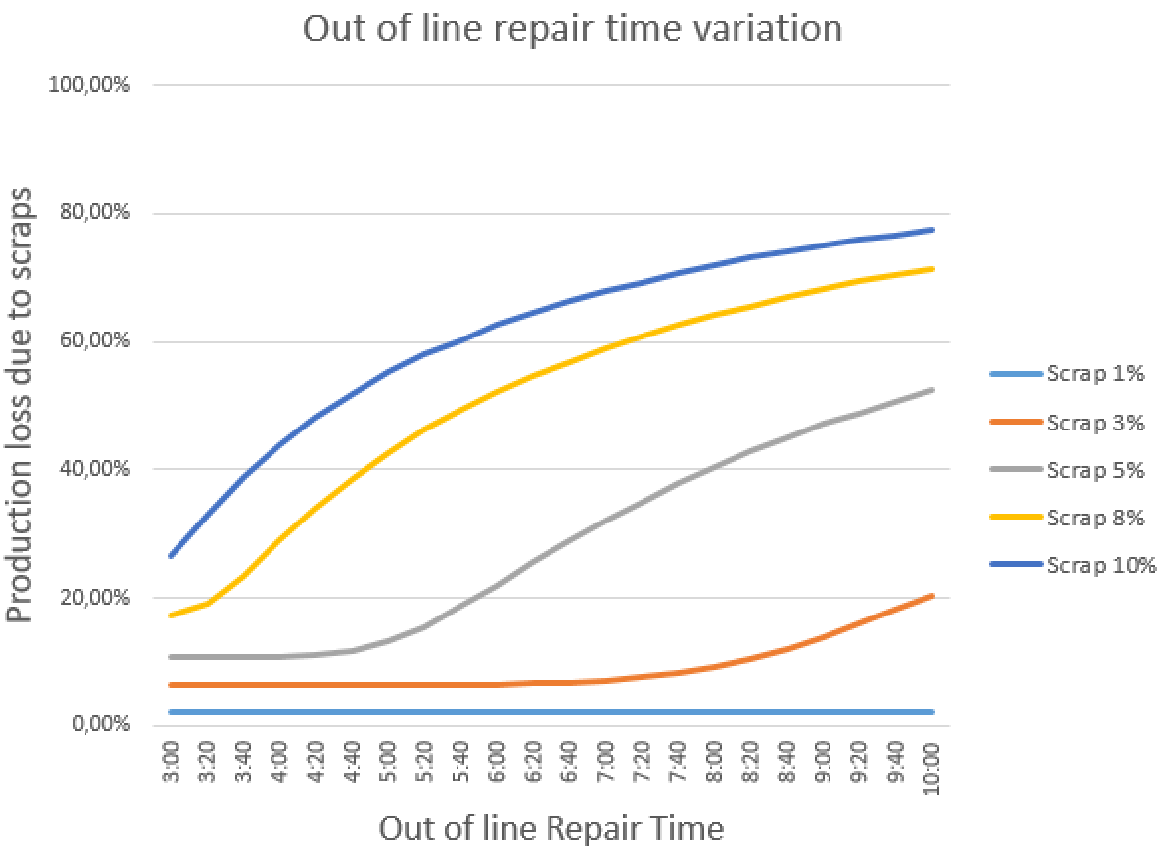

Figure 37 Graphical results of Out-of-line repairing time variation

Just like the previous case a high scrap rate value, violently affect production capacity even for short repairing time. Instead, when a lower scrap rate value is considered the repairing time acquires less importance since production loss are almost constant, and start to increase just for longer operations. Finally, can be underlined that the effect of out-of-line repairing time variation start to have a relevant effect on production loss for longer repairing time in respect to the in-line analysis (5 minutes for in-line and 7 for out-of-line stations).

7.1.2 Scrap analysis main model implementation and simulation

Is now possible to implement the scrap rate analysis, introduced in the previous chapter, in the main line model. Just like in the simple example presented, the 7 repair loops and the 13 in line repair stations, installed in the Termoli assembly line, has been modelled and their working logics has been programmed. At this point, the model has been validated by comparing its results with the ones of the validated simulation runs.

In this new analysis, the real stations implemented in the line are considered. For this reason, it is no more needed to vary the scrap rate of the stations since the values collected, for each type of operation in the scrap rate analysis can be used. The only two parameters to analyze in this model are then the time needed for the out of line and in line repair operations.

Two types of production loss have been implemented in this model: scraps, and consequently the repairing time, and station failures (in this case, a design parameter of 3% of probability has been considered). The latter refers to a situation in which machines stop unexpectedly, for an unknown failure, and some time is needed to repair it.

First, the model has been tested applying those two characteristics and maintaining constant both the in-line and out-of-line repairing time (3min).

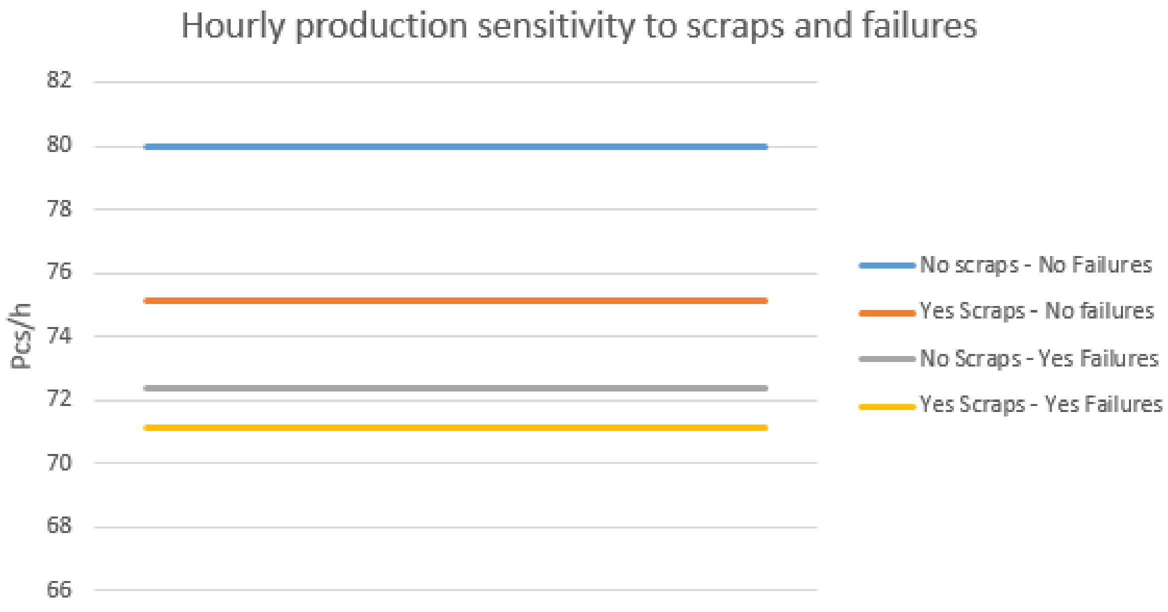

Figure 38 Hourly production sensitivity to scraps and failures

In the figure above the result of such an analysis has been shown. The blue line represents the simulation results considering 0% machine failures probability and scrap rate, and it define the higher hourly production that can be reached by a production line with cycle time equal to 45sec, 80 pcs/h. Obviously, when loss sources are introduced, the throughput of the line decreases, as depicted by the other lines. In particular, the gray one, representing a model in which only machine failures are considered, shows that this is the higher source of loss since a lower hourly production is reached in comparison with the experiment with just machine scraps (orange line). Finally, it is interesting to notice that scraps and failures are not two additive loss sources; in fact, the yellow line shows how the line hourly production does not differ too much from the one evaluated in the experiment with machine failures. This characteristic results from the higher probability and repair time of machine breakdown that mitigate the negative effect of scraps.

After having proved and quantified the negative effect of scrap rate on production capacity, it is important to analyze the effect of the repairing time for both the in line and out of line repair stations.

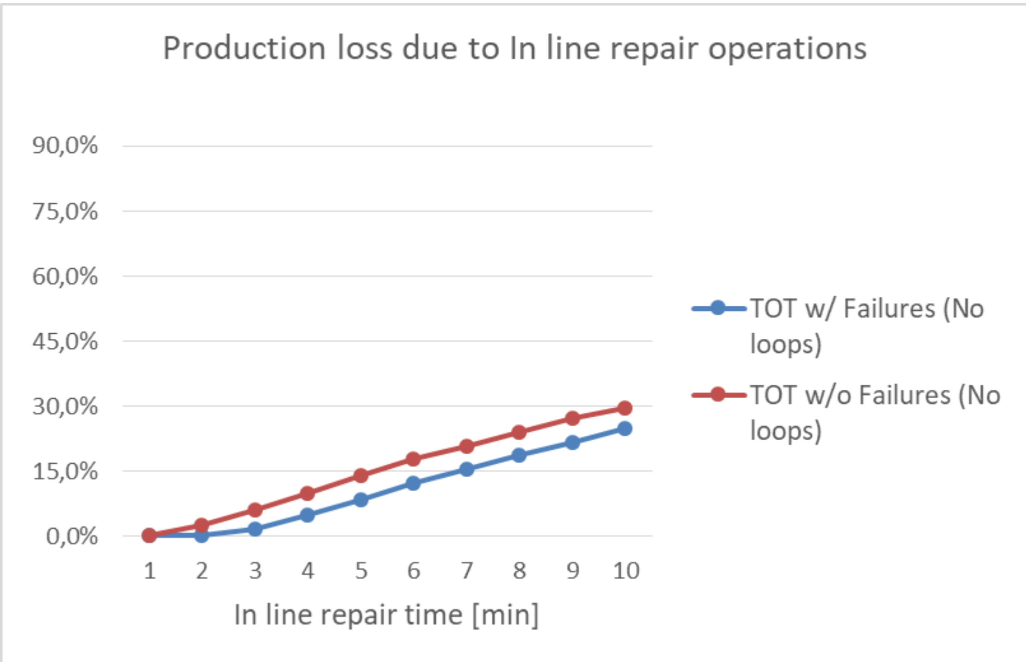

Figure 39 Production loss due to in line repair operations

First, let us analyze the in line repair stations effect. As a first study, a model without repairing loops has been simulated both with and without machine failures and its result has been collected in Figure 39. It shows the percentage (in respect to the data coming from the experiments described in figure 38) of production loss when the in line repairing time increases. Here can be noticed again, the dominant effect of failures on machines scraps since the production loss, registered in the case in which failures are considered, is lower in respect to the opposite case.

In addition, a trend for the in line repair time can be found. By analyzing the experiment with both sources of loss (blue line), that represent the most relevant one since it refers to the real application, a decrease in production lower than 3% is shown for in line repairing time lower than 3 minutes. For values greater than this threshold, loss percentage start to increase rapidly to unacceptable values. This 3% is a design parameter, considered as the greatest loss percentage that can be accepted when machine scraps are considered.

At this point, repairing loops can be added in the model to analyze the overall contribution. In this experiment the in line repairing time has been set equal to 3 minutes, as a result of the previous one, and the out of line repairing time has been changed in a range of 3 – 15 minutes.

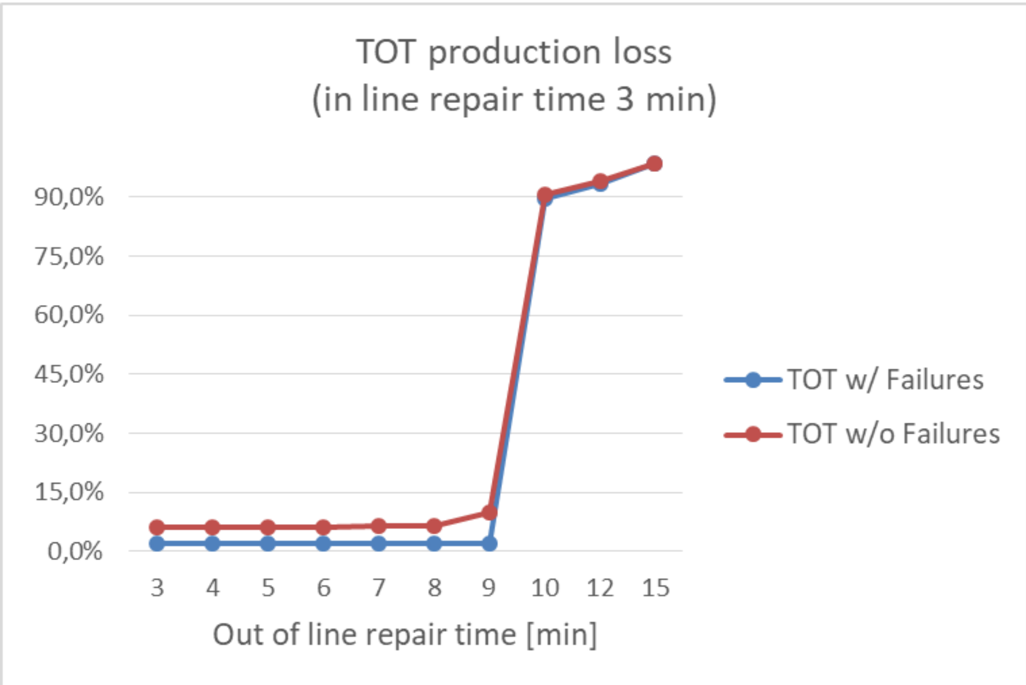

Figure 40 Total production loss.
(In line repairing time equal to 3 minutes)

In figure 40, it is clearly visible the acceptable out of line repairing time; until the repairing operations do not last for more than nine minutes, the percentage of production loss is lower than 3% and then can be accepted. When this time is exceeded, there is a sharp rise in the production loss due to a dead loop condition of the model that shows up when the buffer placed before the repair station is full. This condition does not occur with the same characteristics in every loop, but there are some more critical than others. In particular, the most crucial will be those with the highest number of stations managed by the repairing loop and the highest machines scrap rate. By the way, this topic will be analyzed deeply in the following pages.

Is now possible to have a comparison between in and out of line repair strategies, and then study the production behavior when loops are introduced or not, with different values of repairing time. In particular, in this experiment, three different out of line repairing time (3, 6, 9 minutes) has been tested and their results has been collected in the following graphs for both with and without failures conditions.

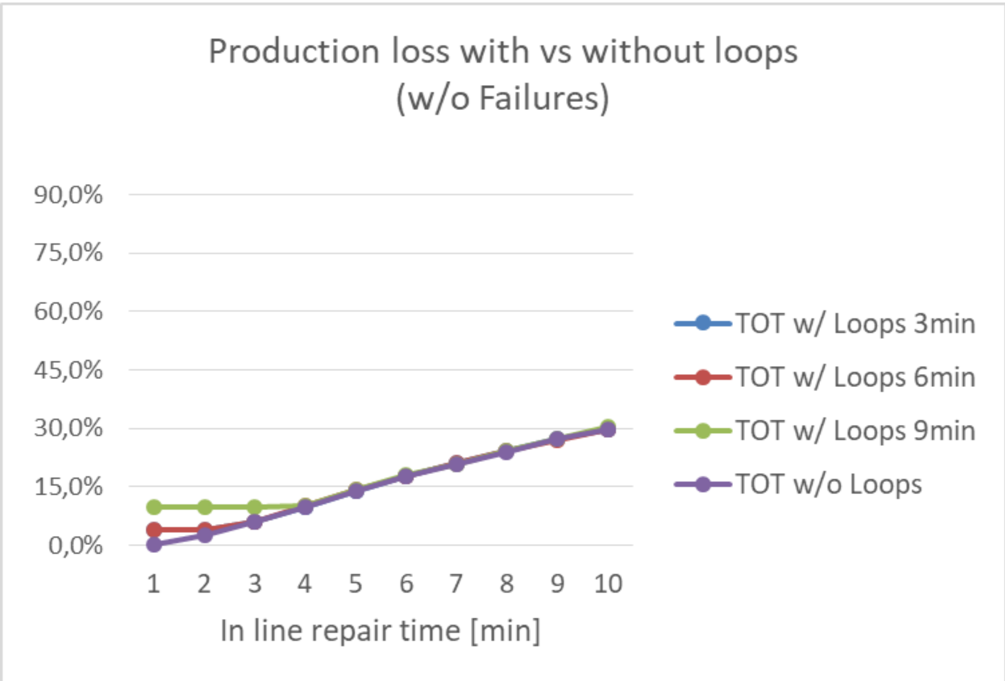

Figure 41 Production loss variation with vs without repairing loops. (Experiment without failures)

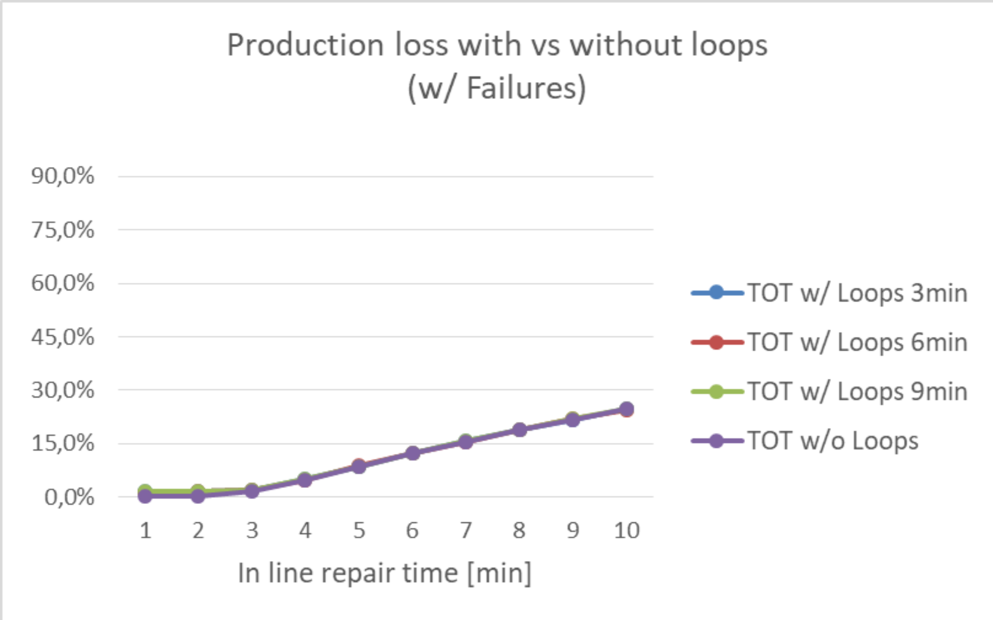

Figure 42 Production loss variation with vs without repairing loops. (Experiment with failures)

What is summarized in figure 41 and 42, is that for low value of in line repairing time, the higher production loss input is due to repairing loops, in particular when longer out of line repair operations are considered (9 minutes). On the other hand, increasing in line repairing time, the loops contribution disappears and the dominant effect is due to in line operations.

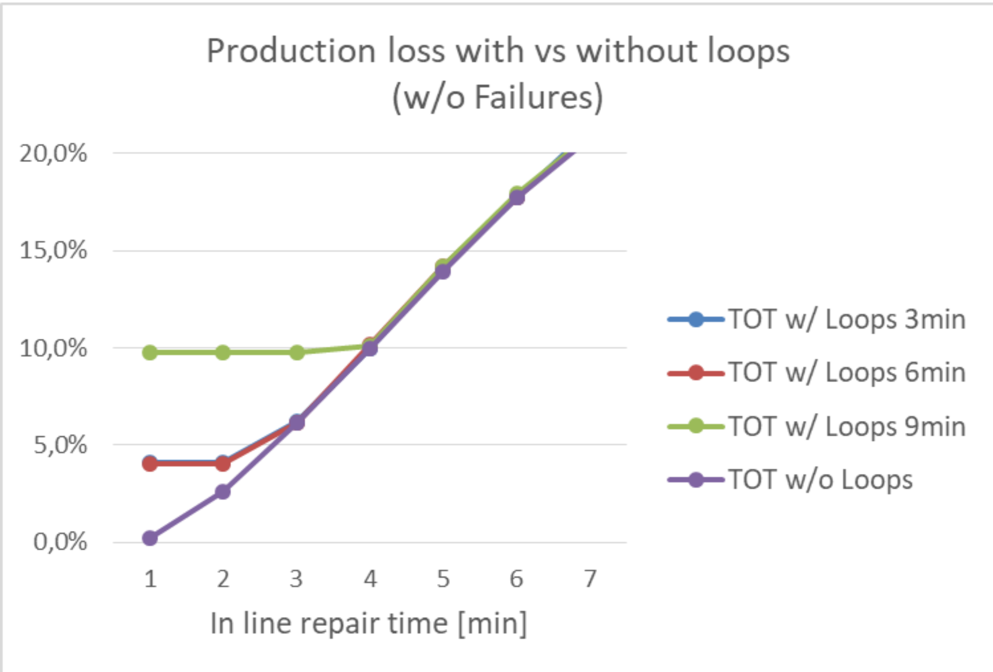

Figure 43 Production loss variation with vs without repairing loops. (Experiment without failures) ZOOM

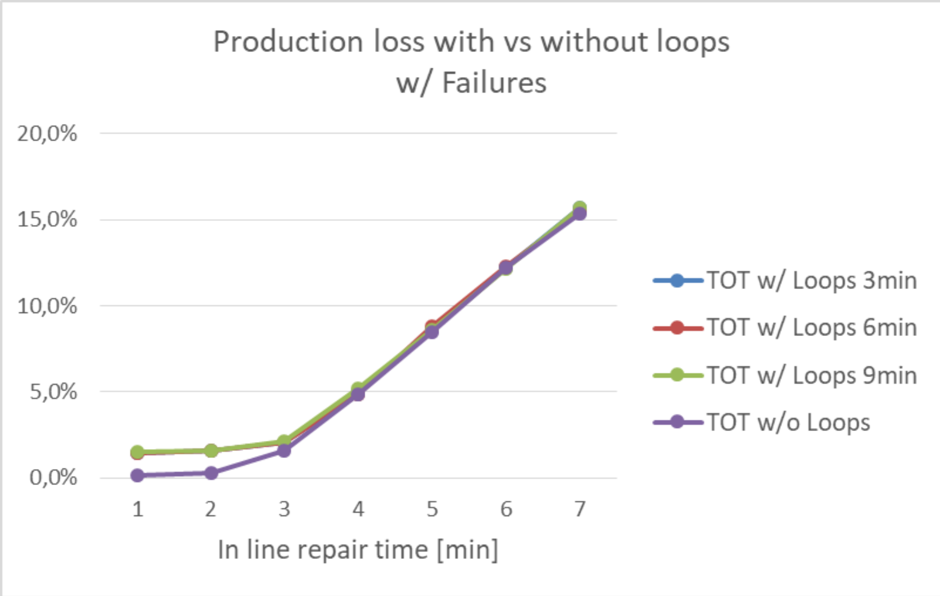

Figure 44 Production loss variation with vs without repairing loops. (Experiment with failures) ZOOM

By zooming the previous graphs, the impact of repairing loops can be more easily appreciated, especially for higher out of line repairing time. Even if machine failures mitigate a lot their effect, the production loss coming from repairing rings cannot be neglected. This experiment also remarks the importance of spend at maximum three minutes for in line repair operations. Finally, let us analyze the contribution of each loop on the overall production loss in order to identify the most critical situations.

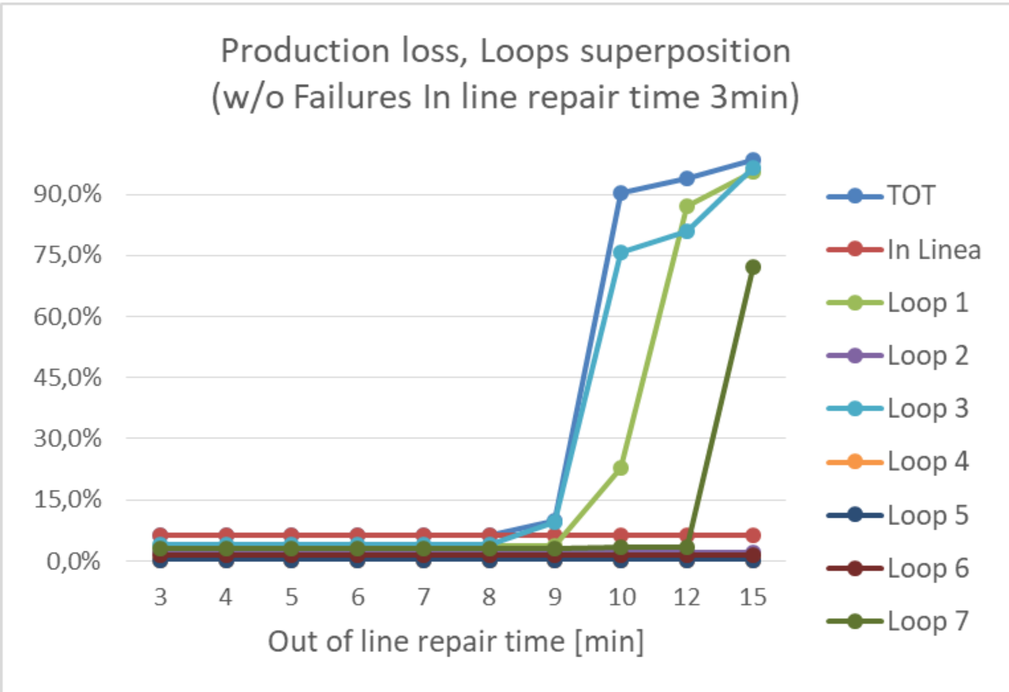

Figure 45 Production loss, loops superposition (Experiment without failures, 3min in line repairing time)

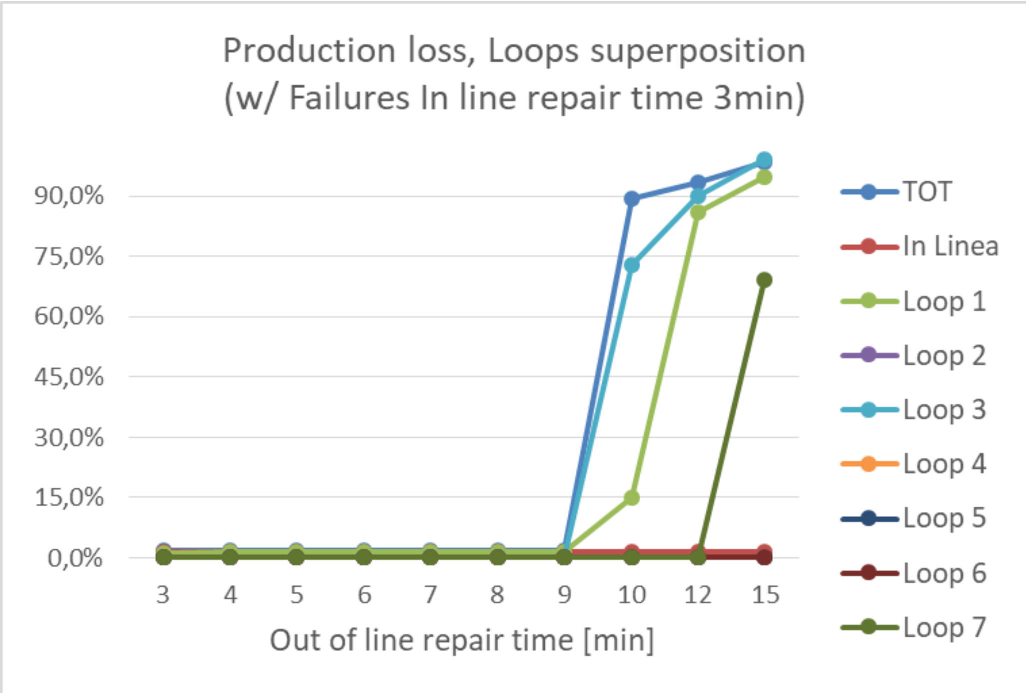

Figure 46 Production loss, loops superposition (Experiment with failures, 3min in line repairing time)

In those two final experiments, the in line repairing time has been set equal to 3 minutes. The blue line represents the total production loss when all the scrap sources are considered and the other lines stand for each scrap source existent in the model. In particular, the constant red line represents the production loss due to in line repair operations when no loops are considered and for repair time equal to three minutes. The other lines stand for a system where no machines scrap rate are considered except for the stations within the analyzed repair loop. In figure 45 and 46 it is possible to notice, as already introduced with the other experiments, that for out of line repairing time lower than nine minutes the greatest contribution for production loss, is represented by the in line repair stations. What characterize this investigation, it is its behavior when this threshold is exceeded; in fact, in line repair operation are no more predominant, and the most critical loops in the line can be observed. For this case study, repairing operations for loops one, three and seven (when a repairing time higher than 12 minutes is supposed) should be monitored and managed in a dedicated way trying to not exceed their threshold time.

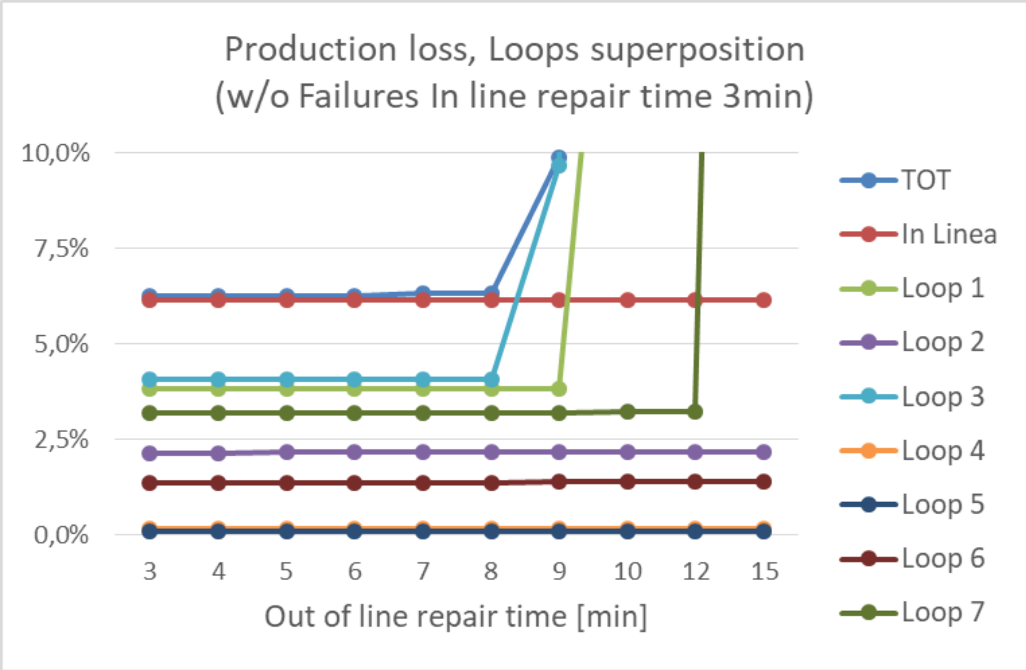

Figure 47 Production loss, loops superposition (Experiment without failures, 3min in line repairing time) ZOOM

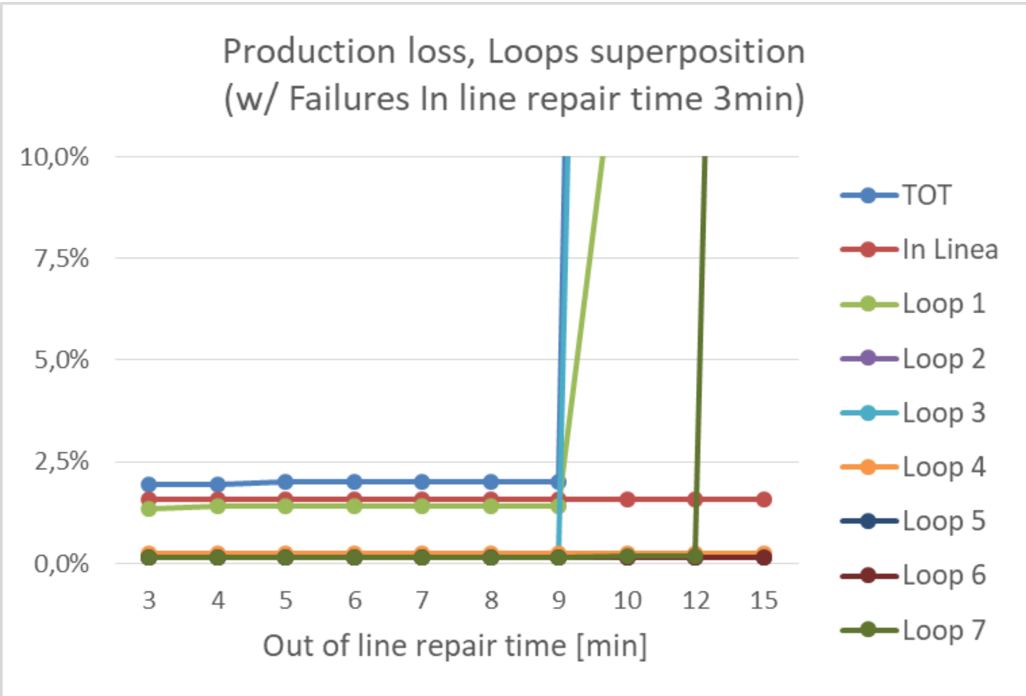

Figure 48 Production loss, loops superposition (Experiment with failures, 3min in line repairing time) ZOOM

Zooming in on the lower part of the graphs, can be noticed that even for lower out of line repairing time, loop one is still critical and its design should be analyzed to avoid unwanted production problems.

Possible solutions

As it has been proved in the previous chapter loops one, three and seven show a critical behavior for longer out of line repairing time. Analyzing the scrap rate of the stations included in the loops, can be noticed that the loops that manage the stations with the higher overall scrap rate, coincide with the critical loops presented in the previous graph.

Trying to solve this problem, two possible solutions have been developed. In the first solution, the size of the buffer placed right before the repairing station has been increased, in the second, the loops have been divided in two parts, when possible, reducing consequently the overall scrap rate managed by the repairing loop.

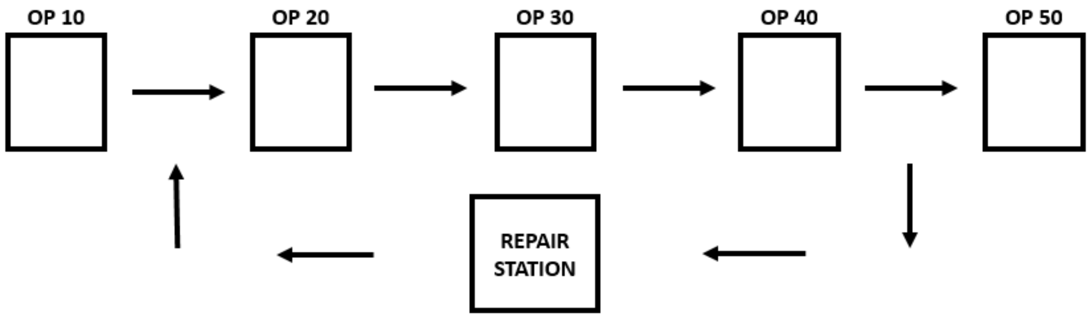

Figure 49 First loop design

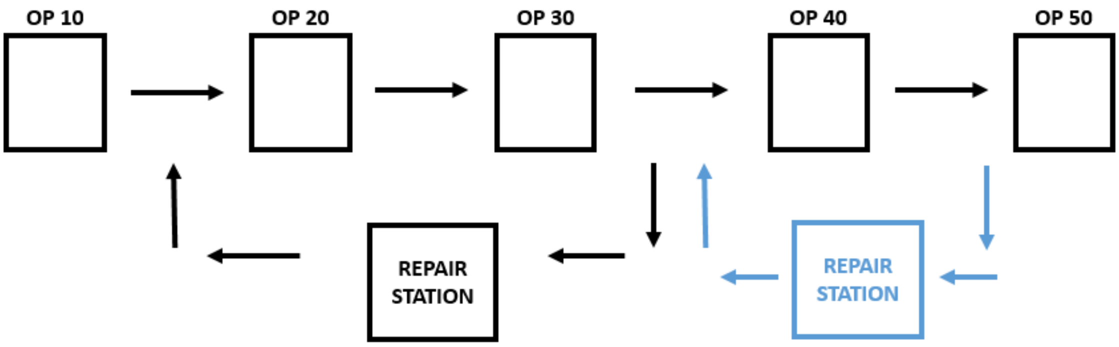

Figure 50 Optimized loop design

Both solutions has been simulated just for the critical loops and their results has been collected in the following graphs.

The blue line represent the results presented in figures 45 – 48 and stands for the current solution. The other two represent the optimized systems.

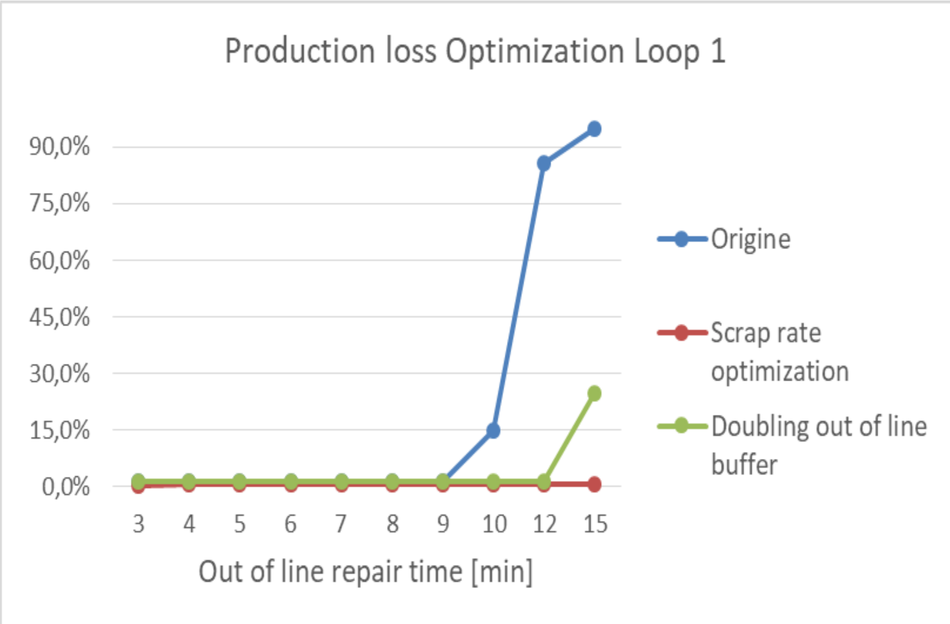

Figure 51 Production loss, Loop 1 optimization

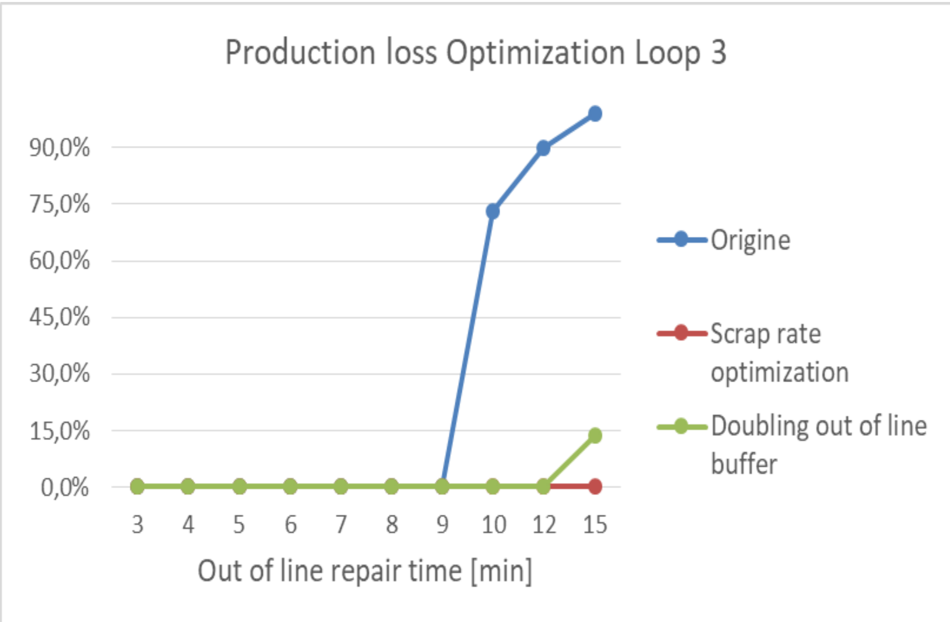

Figure 52 Production loss, Loop 3 optimization

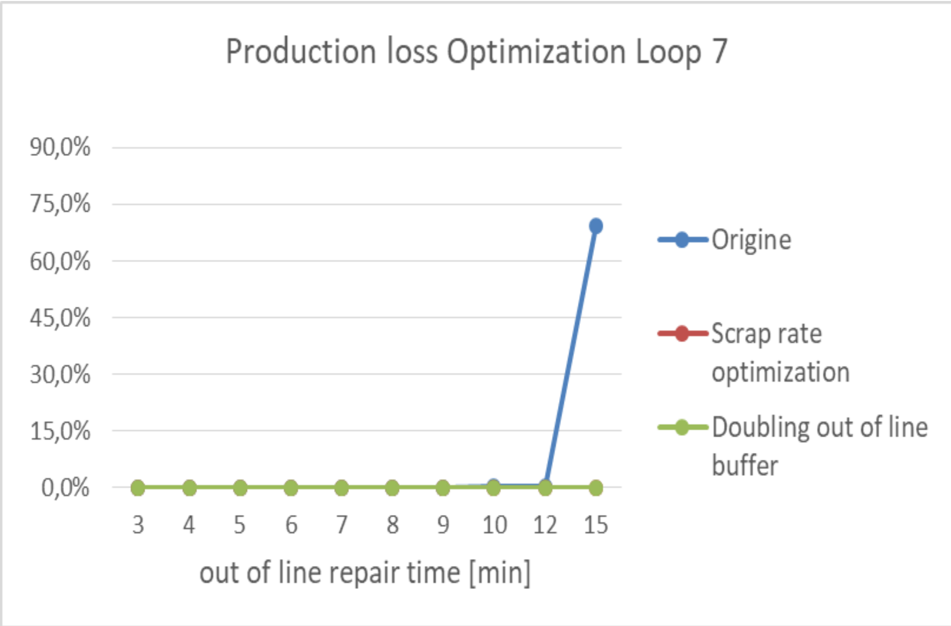

Figure 53 Production loss, Loop 7 optimization

Both solutions show an improvement in terms of production loss, even if, how can be noticed, increasing repairing stations buffer size move the critical section of the graph for higher out of line repairing time (from 9 to 15 minutes). On the other hand, decreasing loops scrap rate helps the line to absorb the queues created right before the repairing stations.

8 – Conclusions

This study helped to analyze the behavior of an assembly line when machines scrap rates are considered and, more in detail, their weight in terms of production loss, introducing important results for the design phase of a production process. A further step shown the contribution of both the in line and out of line repair operations, also identifying the threshold time values beyond which the system will not work properly. Finally, has been recognized the most critical repairing loops for which a deeper analysis should be performed.

Further research and applications

This study can have an infinite number of application even if it refers to a specific assembly plant. The reason for this is that machine scraps impact on every existent production process.

- Since the design phase of GSE assembly line is not concluded yet, this thesis can be updated in any phase of the project, following its evolution. Furthermore, the simulation model implemented in the software can be applied and shared among different assembly and production line, proving a more complete analysis not only for this case study but also for every FCA product.
- After production starts, the scrap rate analysis can be repeated for the stations installed in the Termoli plant providing more precise results.
- Right now, just two engine versions will be produced in the presented line, but in future, other type of engines could be added. This study can help the analysis of batch mix when out of line repair operations are involved. Then the Logistic department will also use these future results, to design correctly the line components feeding system.
- A further application could also be the exact dimensioning of repair loops. Right now, they are all designed in the same way, considering the same buffer behind the repair station. A deeper analysis could be started with the aim of dimensioning every loop on the basis of the real use of the repair station.

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