Sabelt case study: overall plant continuous improvement actions

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1. Introduction

Recently the manufacturing industry has started to widely apply the concepts of the Industry 4.0. This important shift has interested the whole value chain of a product but also the information flow and the material flow. In parallel, some companies in particular business sectors have the need to increase their flexibility, creating production lines that should be able to switch rapidly from one product to another one.

This is the case of Sabelt. A world leading company for premium cars seats. On one side there is the need to digitalize the information and material flows, increasing the efficiency on the other side to increase the flexibility of their processes to adapt to a continuous changing market.

This thesis project tries to connect those two aspects: flexibility and digitalization.

In the second chapter there is an overview on Sabelt history and an insight into the various products and the related manufacturing processes.

The third chapter proposes a SMED technical solution in order to make more flexible the production lines, with some suggestion to optimize the changeovers operations.

In the fourth chapter a theoretical analysis about Manufacturing Execution System standards and design requirements.

In the fifth chapter, Sabelt information flow system is analyzed. A MES like tool is developed and applied to this system. In this chapter it deeply analyzed.

In the sixth chapter an AGV theoretical analysis is held, with the scope to describe and finding out the key element for an AGV fleet implementation

In the seventh chapter, the AGV fleet is designed and the buffer at the end of the lines are dimensioned through the help of discrete event simulation software: FlexSim.

2. Sabelt history, product and production processes

In this chapter, a brief, but necessary, foreword about the company history, product and production processes will be performed.

2.1 Company profile: Sabelt

Sabelt was founded in 1972 by Piero and Giorgio Marsiaj. The name stands for Safety Belts. At that time, the core business of the company was the seat-belt production, destinated to the passenger cars market. Despite seatbelts were not mandatory in the cars at that time, an increasing interest and awareness about the importance of passengers' safety was arising and developing.

During the 1970's seatbelts started to become mandatory in the car. Czechoslovakia was the first country implementing this measure in 1969 and many others countries followed. In Italy, only in 1976, belts became compulsory to be mounted in the car . This sea change helped Sabelt build up his role as market leader in the automotive safety field: in late 1970s the company entered the motorsport sector and started supplying belts for rally cars. Afterward, Sabelt began providing safety belts also for the F1 teams (Alfa Romeo, Williams, Ligier and Ferrari), becoming their official supplier in 1989

In the late 1990s, the company leadership decided to expand the production of new products which have not been considered so far: suits, sets and other accessories for motorsport. Nevertheless, the 2000 was the actual turning point for the company, which developed and produced the first OEM seat for Ferrari. It was the beginning of a new business. Since then, Sabelt has fulfilled the ambition of becoming one of the world leaders in the production of high quality seat and safety equipment for the automotive sector. Among the list of top car manufacturers supplied by Sabelt we can find: Ferrari, Aston Martin, McLaren, Abarth, Seat, Porsche, Jaguar, Alfa Romeo. The business is in continuous expansion due to the high quality and the excellence of the products. In this regard, in 2018, Sabelt was awarded by McLaren by the Supplier Excellence Award for its seat's high-quality standards.

2.2 Seat product

The seat is a fundamental car component for various reasons. First, as a safety measure it has to satisfy strict and complex regulation in order to be enrolled in the vehicle and sell on the market. Second, as an aesthetical component in the car interior it has to be comfortable for all the car users (both drivers and passengers). In the automotive market, and specifically in the sector of sport and premium cars, we can find a wide variety of seat types which will be concisely analysed in this paragraph.

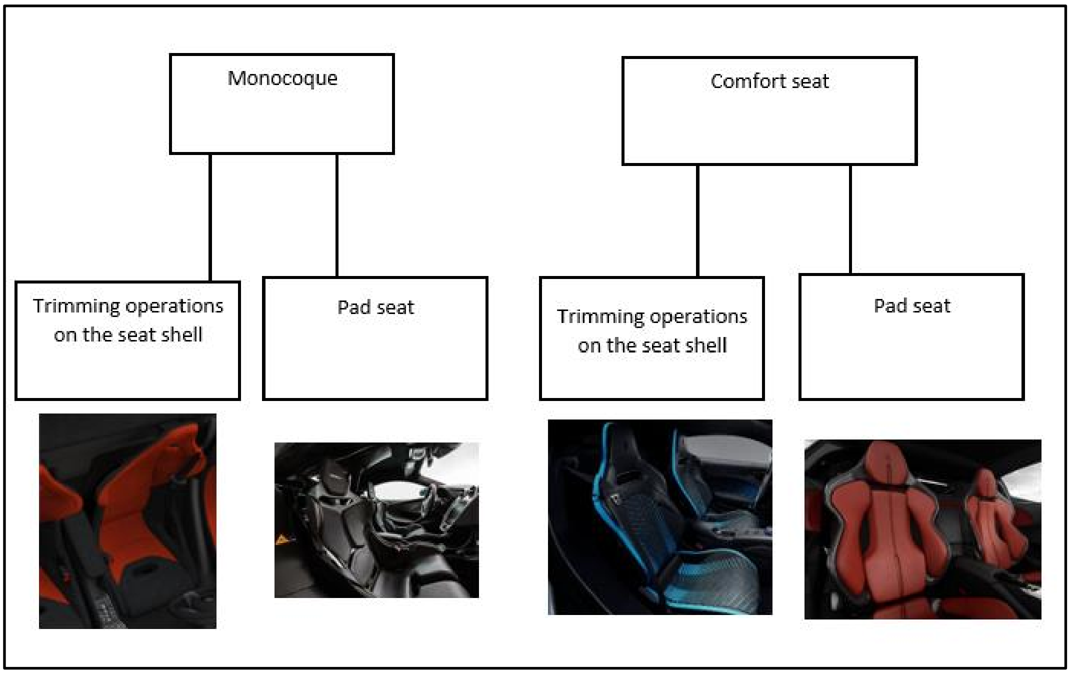


Figure 1: Seats variants

As we can observe from the table above, a substantial distinction is made between the Comfort seat and the Monocoque one. The basic difference lies between the two is that the former is made of two shells one for the backrest and one for the cushion while the latter is made of a unique shell.

Figure 2 Maserati MC20 Comfort seat

As we said they are made of two shells, on which it is positioned a foam and then the cover, that is the aesthetical surface of the seat. It can obviously be made of different material, from leather to Alcantara.

Then we have the Monocoque seats. They are simply made out of one frame, that can be made of carbon-fiber or fiberglass. They follow the a similar trimming operations of the previously mentioned Comfort seats.

Figure 3 McLaren Monocoque seat

Then there is another range of products: Pad seats. There is still the difference between Comfort and Monocoque, but the trimming operation is not performed on the seat, but on the Pad. A pad is an assembly of a frame, usually made of carbon-fiber or fiberglass, a foam and a liner that are glued together. There are various type of pads, one for every area of the seat: cushion, backrest, shoulder, headrest area. The pads are then mounted on the seat shell.

Figure 4 McLaren lightweight monocoque PAD seat

Figure 5 Ferrari Comfort Pads seat

2.3 Seat manufacturing process

In this paragraph the different production processes behind each type of seat will be described. In this analysis we will start by the Maserati Mc20 seat process.

Operation	Description
Kitting	Kitting operation
010	Cushion pre-trimming
020	Cushion trimming
030	Backrest pre-trimming
040	Backrest trimming
050	Cushion and Backrest aesthetical finishing
060	Marriage station
070	End of line checks

Table 1 Maserati MC20 routing

The starting point of the line is the kitting station, were the operator collects the components that have to be mounted on the seat and put them on a cart. Every component of the seat is equipped with a label, on which the following information can be found: serial number, part number, lot number and a bar code/QR CODE. These informations are fundamental for the traceability of the components when the seat is delivered to the final customer, in case of defects or problems.

The kitting station, as all the stations of the line, is equipped with a pc and a monitor. The operator reads on the screen the components to be taken, frame the bar code reported on the part and position it in the cart. Once the kitting is complete, the operator moves the cart to the station 010, the cushion pre-trimming workstation.

In this station, all the pre-trimming operations are performed. The operator takes the shell from the cart, positions it on the structure and blocks it. Then the foam and the liner are taken and positioned in this order on the cushion frame. The liner is secured to the foam using the hog ringer, that allows to clamp the metal rods that are inside the liner and the foam. Once the operation is finished the cushion can be moved to the trimming station. In the meanwhile, some additional operations are performed such as the mounting of the following components: cables, heating pads or the sensor of presence (SBR), in case of passenger seats.

The semi-finished product is then moved to the next station. The cushion is positioned upside down on a trimming stump. In order to facilitate the operation, the cushion is pressed down.

Figure 6 Trimming operation

Here the proper trimming operation starts. The operator has to insert the latex profile of the liner inside the conduit of the cushion shell, as visible in the Figure 6. On some critical points of the trim some metal clips are positioned, in order to secure the blocking of the liner. The operation is finished when all the latex profile is inserted inside the conduit of the cushion shell.

The same operations, pre-trimming and trimming, are performed on the

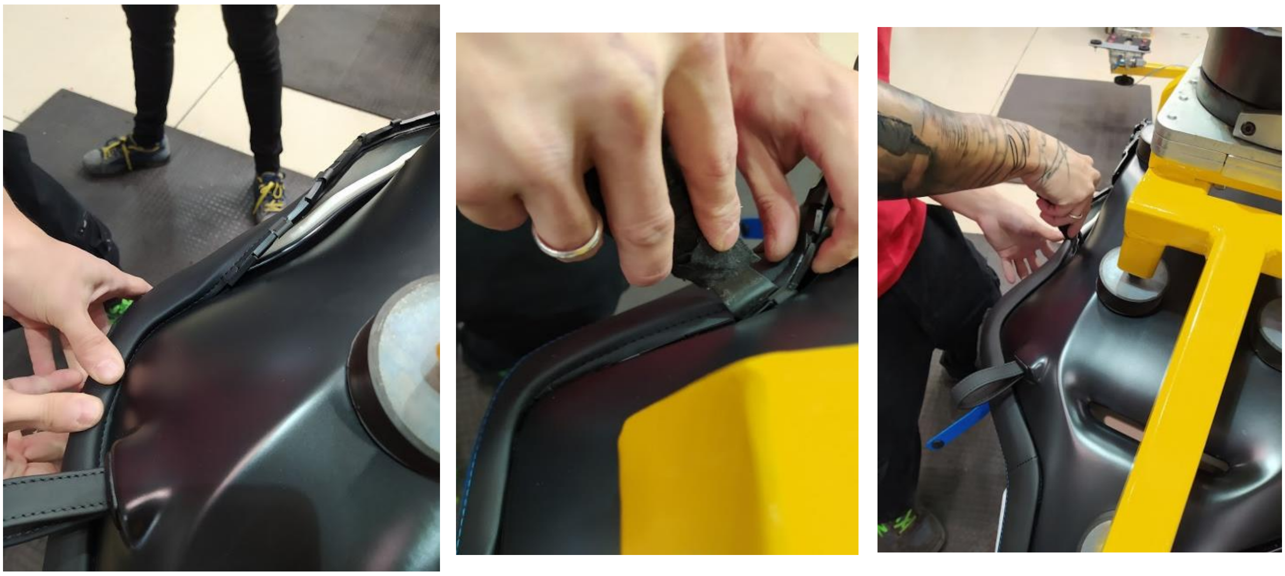


Figure 7 Backrest trimming operations

backrest frame. As happens for the cushion, during pre-trimming operations, there is the necessity to mount between the backrest frame and the foam some additional components: such as heating pads, lumbar support motor, backrest recliner mechanism. Therefore, at the end of that assembly operations, the metal rods of the foam and of the liner are clamped together, through the use of the hog ringer. The semi-finished part is then positioned on the trimming station, 040.

The process and the equipment used are the same of the station 020, with the exception of the stump that is different in shape because it is designed starting from the backrest frame internal shape.

At the end of the trimming operations, cushion and backrest are positioned on the structure of the following workstation, the aesthetical finishing one, as we can see in the Figure below.

Figure 8 Aesthetical finishing station

Here the operator with a dryer eliminates all the defects from the surface of the liner. Since most of the seats liner are made of leather, in some cases some wrinkles can appear, resulting in aesthetical defects. By heating the area, the leather stretches and the defect is no more visible. Once this treatment is over, the cart is moved to the next station: marriage station.

This operation is called “Marriage station”, because for Comfort seats the backrest and cushion semi-finished parts are assembled together and mounted on the metal sheet structure. The structure is essential in order to mount the seat and fasten it to the vehicle chassis. In this station some additional operations are performed: cable routing and mounting, buckle belt fastening, seat movement command mounting.

When the operation is finished, the seat is moved to the End of Line station, where some functional and electronic tests are performed: for example the correct mode of operation of the buckle belt, sensor of presence, electrical movement of the seat, both vertical and horizontal, lumbar support correct functioning and heating pad functionality. At the end of those tests, the seat is ready to be moved to the shipping area, where it will be packed and sent to the carmaker.

Now we can focus on the monocoque seats, with trimming operations inside their routing, so not equipped with PADS.

Operation	
010	Seat preparation and trimming operation
020	Marriage station
030	End of line checks

Table 2 Monocoque seats operations

The significant difference compared to the Comfort seat process previously described is in the trimming operation. The trimming occurs just once and for all the seat. In operation 010, the foam is positioned on a the monocoque frame, and then the liner on it. The metal rods of the foam and of the trim are clamped together and the trimming process can start. For all those operations, the seat remains in the same position on the station structure.

Once performed the semi-finished product is ready to be mounted on the metal structure. For certain seats the metal structure arrives already mounted, for some is yet to be assembled. For example, for all the McLaren monocoque seats, it has to be assembled on the operation 020. Once the structure is mounted, the monocoque is fastened on the metal structure and after some additional operations the seat is ready to be moved to next workstation: the EOL.

Here the functional checks are performed and at the end of these, the seat can be packed and transferred to the carmaker.

Now we can focus our attention on the PADs seat. As previously said the trimming operation is not done on the seat but on the single pad that is then mounted on the seat frame.

OPERATION:	Description
010	Pad trimming
020	Pad mounting on the seat frame
030	EOL

Table 3 Pad seat operations

The pads are manufactured in the upholster area of the plant, that is equipped with tables and with a ventilated cabin where it is possible to spray glue on the different component of the pad. In the following paragraph we will describe the conventional process for the pad manufacturing. The seat is composed of different pads with different shapes, according to the area in which they are mounted: cushion, shoulder area, backrest or headrest.

Firstly, the operator has to take the Pad frame, generally made of lightweight material such as carbon-fiber or fiberglass. The frame has to be sprayed with glue and then has to stand some minute in the air in order to solidify a bit. After that period of time, the operator can position the foam on it, painting some glue on its edges and making sure they are well close-fitting to the frame.

Now it is possible to start the trimming operation on the pad, by positioning the liner on the semi-finished product and then gluing the edges on the back of the frame. Since the process deeply relies on the manual skills of the operator, its experience and know-how are fundamental. The trimmed finished product is amazingly more similar to the result of a hand-crafted process rather than a manufacturing one. Once all the pads are trimmed, they can be mounted on the monocoque of the seat, in workstation 020, by jointing them using Boellhoff pins present on the structure. Then seat is mounted on the metal structure and then it is ready to be checked in the end of line station.

The last type of seat we will describe in this analysis is the one mounted on the new Ferrari SF90. It is a PAD comfort seat. The substantial difference with the previously described ones is that the PADS are not trimmed internally but supplied by a tier 2 company.

Operation	Description
010	Marriage station
020	Robot gluing
030	EOL checks

Table 4 Ferrari Pads seat operation sequence

In the first station, some mounting operations are performed on the backrest shell and on the cushion one. Afterwards they are assembled and mounted on the metal structure. From this point on the semi-finished product is moved to the next station, where a robot sprays the glue on the shells and then the PADS are positioned. Once the solidification period of the glues is ended the seat is ready to be moved to the EOL station where functional and aesthetical checks will be performed.

Figure 9 Ferrari Comfort seat with PADS in EOL station

2.4 Summary

To sum up we can observe that the premium car sector, in which Sabelt is dealing with is in continuous growth and the seat, as a product has several variants, affecting and complicating the production routing and material management.

For those reasons, the whole value chain needs to increase its flexibility and reconfigurability to adapt to a fast-paced changing market, needs to increase the availability of information, in order to take quick and rapid decisions. One way to speed up this change is to apply the Industry 4.0 and intelligent manufacturing principles, transforming the physical world into digital twin, combining the production system with intelligent one and increasing the cooperation between machines, sensors and humans.

3 SMED operations

The acronym SMED stands for "Single minute exchange die". It is one of the lean tools to reduce waste during the conversion of the equipment from one product set up to another one.

This method was born in Japan in the 1940's in the Toyota metal sheet stamping shop. Differently from Ford's facilities, where there was a higher availability of machines, one or two for every component to be produced, in Toyota they had fewer machines. They had to change the tools in order to set-up the machine for the following lot of components. A stamping die is a huge block of steel, that has to be positioned with precision in the machine in order to make good parts. Due to the complexity of the operation, the time for the changeover could last from 2 to 8 hours. Hence it results in a big lot size and high inventory level. Therefore, there was the necessity to decrease the set-up time and Toyota started a program aimed at reducing it to less than 10 minutes. In the 70's they were able to change dies in 3 minutes. This incredible increase in efficiency allowed to have a smaller lot size, less inventory and a higher flexibility.

The following analysis will be backed up by Shingo Shigeo techniques for SMED application, from his book: *Shingō, Shigeo - A revolution in manufacturing_ the SMED system* and by Hiroyuki Hirano guide for Just In Time Manufacturing.

3.1 Sabelt case study

As we have seen there are types of seats that have a common structure and hence a similar production routing and assembly sequence. In particular, this is the case of the following three type of Comfort seats:

- Maserati MC20 seats, whose project name is M240;
- McLaren P16 seats;
- McLaren P13/P14/P22 seats.

These commonalities are reflected also into the workstation equipment. All the three lines are provided with similar structures. This is due to the fact that, prior to the development of the MC20 and P16 seats, McLaren P13, P14 and P22 seats production was run on three different lines, than due to the introduction of new models and the decrease of the production volumes, two lines were adapted to produce P16 and MC20 seats, while running P13/P14/P22 seats on just one line.

Until now infact, in Sabelt the best practice was to have a dedicated production line for every project, with its own dedicated equipment, shelves and tools. As we can see from the plant layout below, there are three lines, one for each seat type listed above.

Figure 10 Layout

The project is to run the aesthetical finishing, pre-trimming and trimming operations for backrest and cushion on just two lines, instead of the current three and providing for changeover operations to move from one product set-up to the other one. For what concerns the kitting and the three marriage stations, these will be kept as they are today. As we can see, from the layout, the workstations highlighted by a red rectangle are the ones to be removed.

The final goal is to allocate the free surface to new business opportunities and to have a higher equipment saturation. Infact, with the current layout the three lines work simultaneously, in the same shift, 8 hours a day and so corresponding to 480 minutes, minus 20 minutes for collective breaks, so 460 minutes.

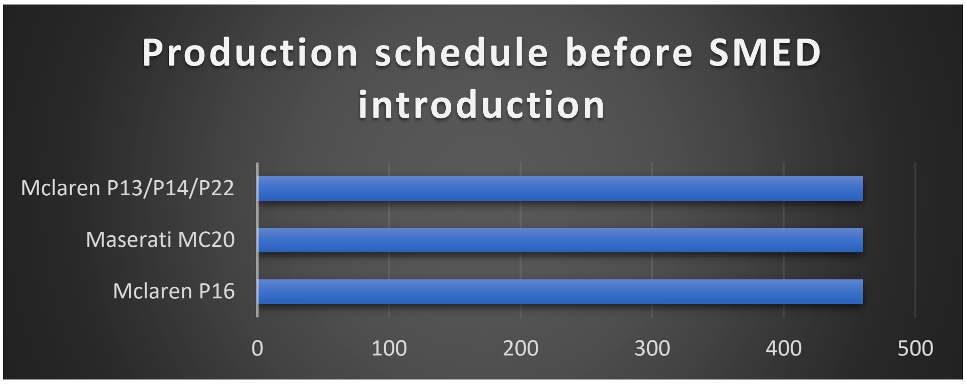


Figure 11 Production schedule before SMED introduction

Supposing now to organize the production of the McLaren seats on two different shifts and to perform changeovers in between the two shifts, the following situation is obtained:

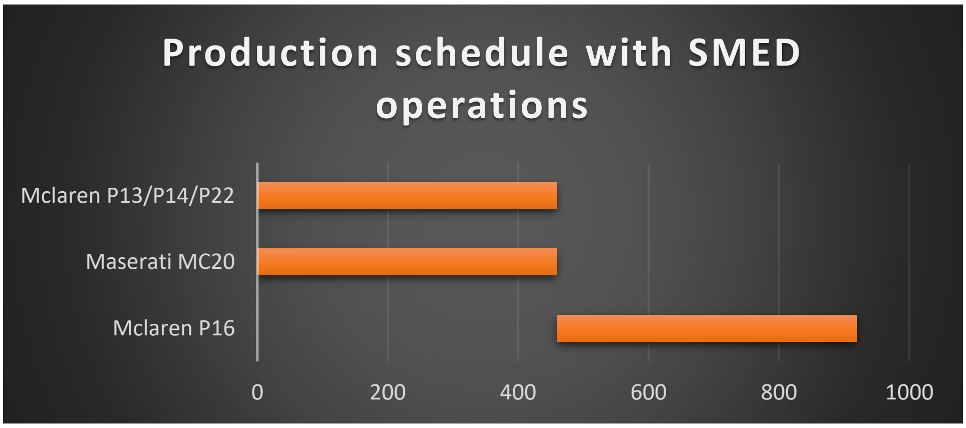


Figure 12 Production schedule with SMED operations

The results in terms of equipment saturation are shown in the table below:

Results			
3 lines solution		2 lines and changeovers	
AWT [min]	1440	AWT [min]	1440
PWT [min]	460	PWT [min]	920
U	32%	U	64%

Table 5 Equipment saturation

For this brief analysis an available working time (AWT) of 1440 min is considered, corresponding to 8 h shift, multiplied by 3, that are the number of shifts available in a day. The considered planned working time (PWT) lasts 8 hours minus 20 minutes for collective breaks. The equipment saturation is given by the ratio between PWT and AWT. As we can notice from the table, we have a notable increase in the equipment saturation.

3.2 AS IS analysis of the changeover operations

Firstly, it is required to analyse the equipment that are involved in the changeover, in order to find out which are the sequence of operations to be performed. As suggested by Shigeo Shingo, in the analysis it is necessary to distinguish between internal and external changeover. The sum of those two is giving the overall changeover time. The internal one gathers all those operations performed when the machine is stopped, reversely the external ones can be performed while running.

3.2.1 Cushion pre-trimming station

As said in the previous chapter, the cushion frame is positioned on a structure in order to perform all the pre-trimming station.

The cushion pre-trimming station is composed by a metal shape framework, that is specific for the cushion frame, that is hinged to the underlying structure. Therefore, in order to perform the set-up operations, it is requested to substitute the top metal frame with another one.

Maserati MC20 and McLaren P16 seats have the same cushion shell and resulting in the same metal interface: as we can see on the left figure below, the framework has a H shape. Instead the McLaren P13/P14/P22 seats have another cushion shell and hence it requires another framework to be hinged to the underlying structure. For this reason, in order to switch from MC20/P16 arrangement to the P13/P14/P22 one, it is necessary to perform changeover operations.

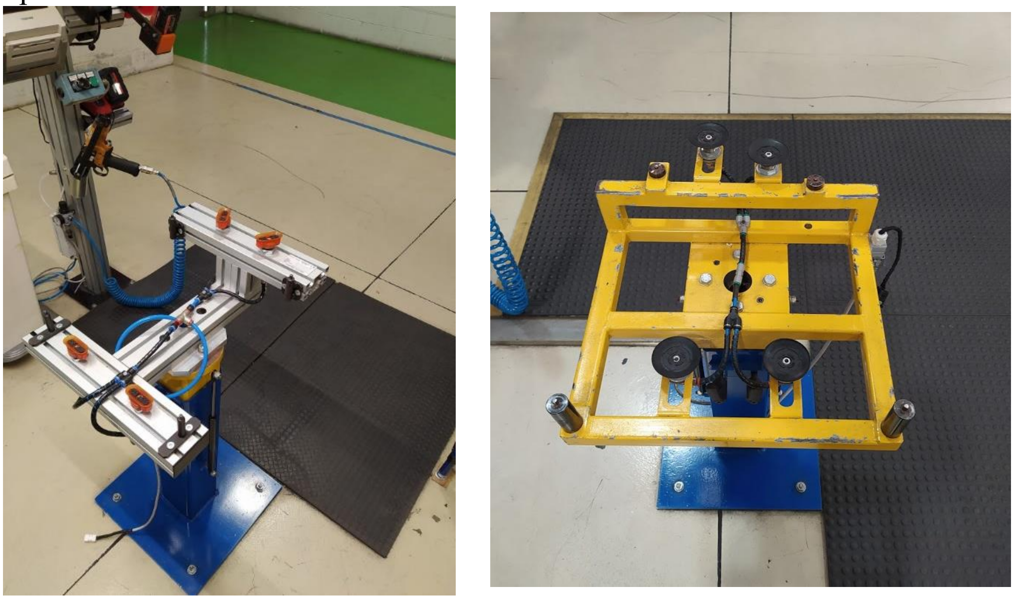


Figure 13 Cushion pre-trimming workstation

As we can notice, in both of the two workstations, there are some air compressed suction cups, that guarantee the blocking of the cushion during the pre-trimming.

To sum up, in order to switch from the P16-MC20 set up to the P13/P14/P22, as highlighted in the figure below, it is necessary to:

- Remove 4 bolts;
- Disconnect the compressed air quick coupling;
- Change the metal structure;
- Connect the compressed air quick coupling.

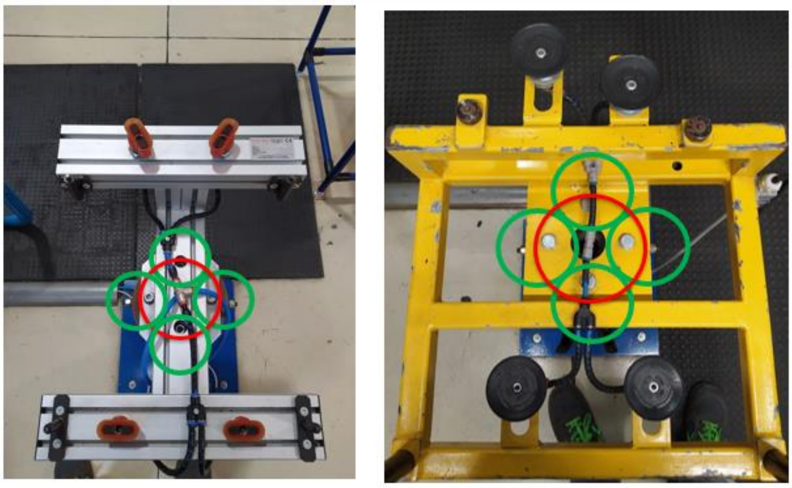


Figure 14 Changeover operations at cushion pre-trimming station.

3.2.2 Backrest pre-trimming station

The same commonalities between the MC20 and P16 are also found in the backrest pre-trimming station. They share common dimensions of the backrest and hence it means that the supporting framework of the workstation is the same. On the contrary, we have a different framework for the P13/P14/P22 seats.

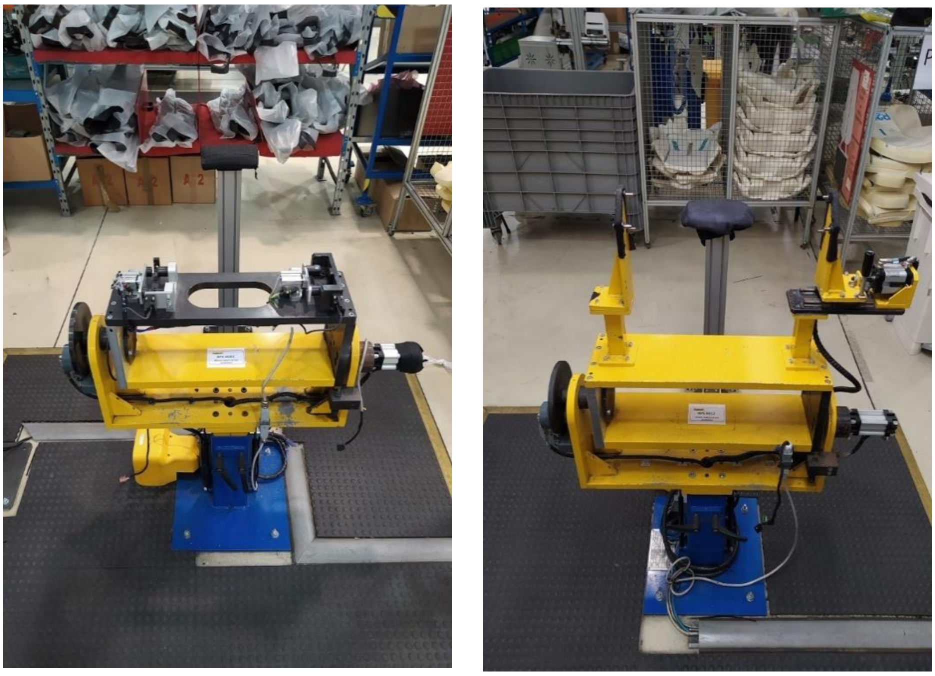


Figure 15 Backrest pre-trimming stations

On the left side there is the MC20/P16 workstation arrangement while on the right side, there is the P13/P14/P22 one. Both workstations have pneumatic actuators to block the backrest hinges on the workstation.

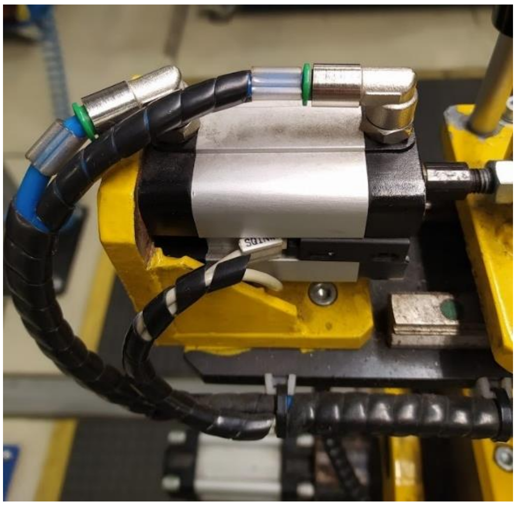


Figure 16 Pneumatic actuator

In order to switch from one arrangement to the other one, it is necessary to:

- Unscrew 8 bolts;
- Disconnect the electrical interface;
- Disconnect the compressed air interface;
- Change the framework;
- Fasten the 8 bolts
- Connect the electrical interface and the compressed air interface.

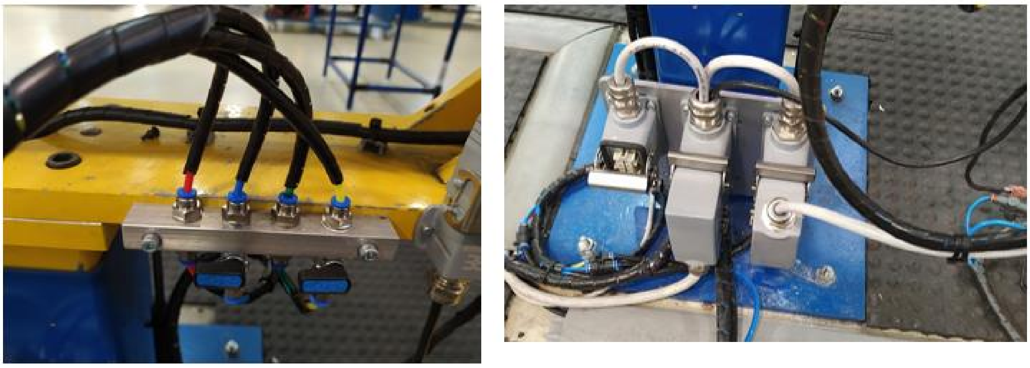


Figure 17 Electrical and compressed air interfaces

3.2.3 Trimming stations

All the trimming stations, both the ones for the cushion and the ones for the backrest, are built in the same manner; therefore, it is possible to gather them together while performing the analysis. The trimming station is composed of a stump and a pressing metal structure, like the yellow one in the figure below.

Figure 18 Trimming station

The metal structure under the stump has two guides on which the stump has to slide. In order to block this movement during the trimming operations, a bolt is fastened on the bottom side of the stump.

The yellow metal part on the top of the trimming station slides on two guides and it is fastened through two bolts, to limit its movements during the trimming. According to the seat to be trimmed we have different stumps and yellow metal parts for each of the three variants.

3.2.4 Aesthetical finishing station

As we said before, in this station the aesthetical finishing operations are performed. As for the pre-trimming stations, there are commonalities between the MC20 and P16 seats. Reversely there are some differences with the P13/P14/P22 structure.

Figure 19 Aesthetical finishing stations

On the left side we have the MC20/P16 structure while on the right side there is P13/P14/P22. We can notice that the main differences are in the way in which the backrest is fastened to the workstation, in the left side arrangement, it is blocked with some quick closing levers, while on the other one there are some air compressed suction cups, hinged on a metal structure. For what concerns the cushion there is a different height of the frontal part of the cushion, due to the different dimensions of the cushion shell.

In order to switch from one arrangement to the other one, it is necessary to change the backrest support, by removing the pin and extracting the support, by making him to slide long the two guides. In case it is connected to the compressed air, hence it is requested to remove the air- junction.

As far as the cushion is concerned, there is the need to adapt in height the pin, until they guarantee a perfect stability of the cushion frame, as we can see from the figure below.

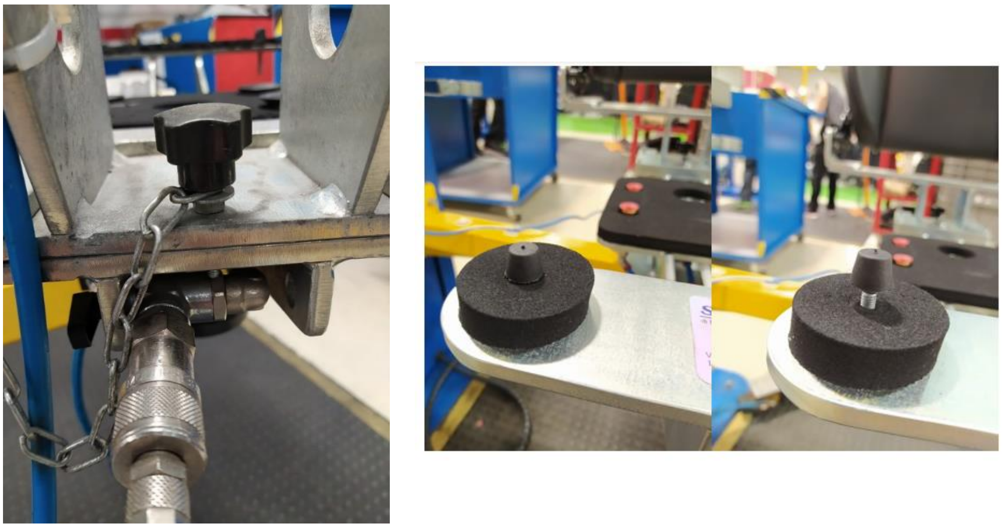


Figure 20 Aesthetical finishing station

3.2.5 Time analysis

Once performed this analysis we can proceed with the time evaluation of the changeover operations. Every single operation for all the workstations has been video-recorded and then a list of operations has been created, with an associated time duration. In the appendix, it is possible to find all the list for the five workstations.

The obtained result is the following:

Workstation	Description		SMED time AS IS	Minutes
10	Cushion Pre-trimming		410	6.8
20	Cushion trimming		344	5.7
30	Backrest pre-trimming		624	10.4
40	Backrest trimming		344	5.7
50	Aesthetical finishing		166	2.8
	TOTAL [sec]		1888	31.5

Table 6 Changeover time evaluation

From the table above we can see that in order to switch, for example, from the Maserati MC20 arrangement to McLaren P13/P14/P22 arrangement, it is required approximately 32 minutes. An important aspect to highlight is that all the work-instruction and assembly cycle that is guiding the manufacturing of the product can vary between different types of seats in terms for example of operation order or of the working parameters such as the tightening torques. In our case, all those information are saved in the industrial pc that is available in every workstation, and they don't need to be changed and set every time a changeover operation is run.

By looking more in details at the output of our timing analysis, we can divide the changeover operations in three large categories:

- Tightening operations
- Transport operations
- Other

By gathering together the similar operations we can observe:

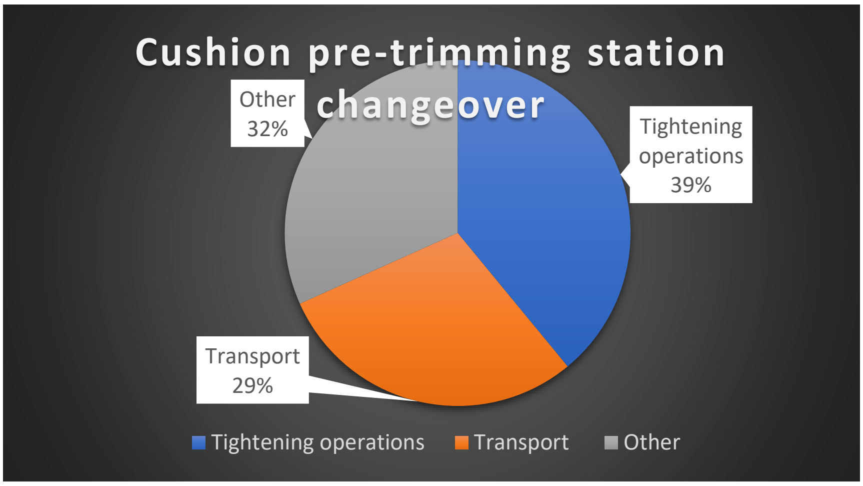


Figure 21 Cushion pre-trimming station changeover

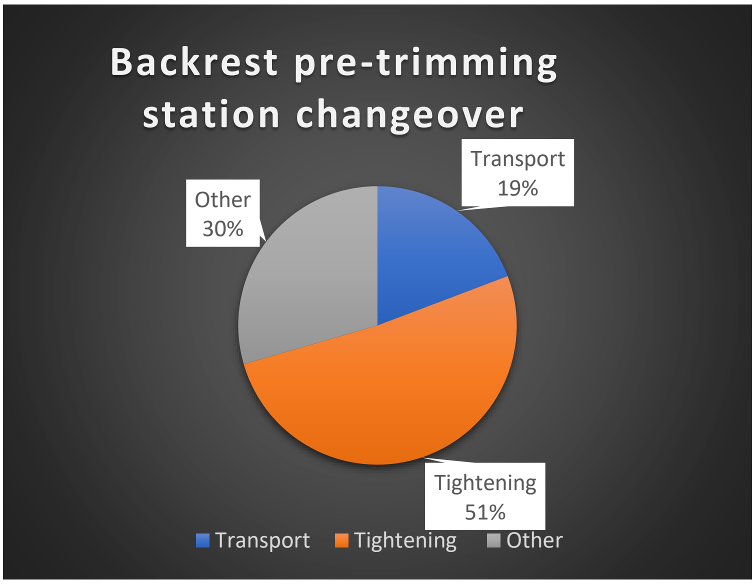


Figure 22 Backrest pre-trimming station changeover

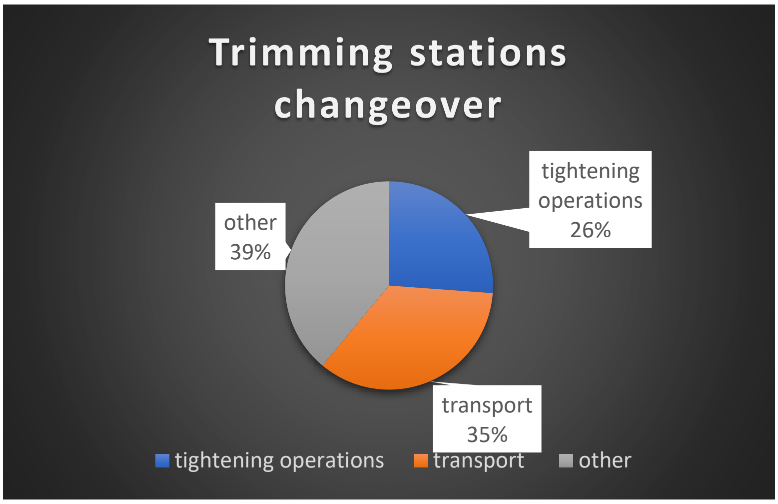


Figure 23 Trimming stations changeover

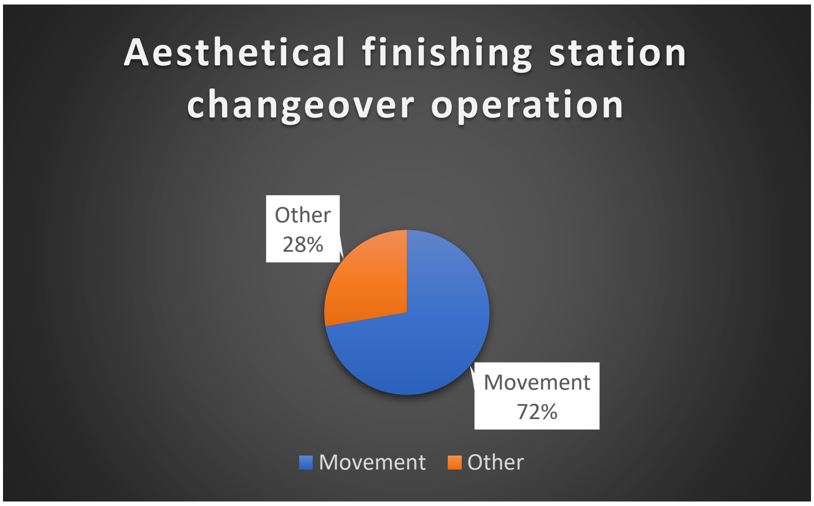


Figure 24 Aesthetical finishing station changeover

Description	Percentage	Duration [seconds]
Tightening	35%	660
Transport	32%	600
Total		1888

Table 7 Changeover time details

As we can see from the figures and the table above more than one third of the time is devoted to the tightening operations. While one third of the time is spent for transport activities, e.g. moving cart to the shelves where to lay down the removed stump or framework.

As Hiroyuki Hirano said in his book: “Most of the waste created during replacement of dies and blades is related to removing and fastening bolts. We should regard to bolts as our enemies. When necessary, they are our enemies, when unnecessary we should find a way to eliminate them.” The table above confirms that tightening operations have to be studied carefully in order to reduce the tightening operations time or even to remove unnecessary bolts.

In the following paragraph some an optimization analysis will be performed and a cost-benefits analysis of the suggested improvements will be held.

3.3 Changeover optimization

3.3.1 Use of an electric screwdriver during the changeover operations

The first improvement step can be to reduce the time for fastening the bolts. The previous time tightening and unscrew operations were done manually. A possible time-cutting improvement can be the use of an electric screwdriver. A simulation of the changeover is run and by using an electric screwdriver the fastening time is reduced approximately of one third, significantly reducing the tightening time.

In the table below we can notice the significant improvement obtained using a screwdriver. The overall changeover time is reduced of 23 %, lasting only 24 minutes, from the initial 31.

Workstation	Description	AS IS [seconds]	TIME [minutes]	With Screw-driver [seconds]	TIME [minutes]	Decrease [%]
10	Cushion Pre-trimming	410	6.8	306	5.1	25%
20	Cushion trimming	344	5.7	284	4.7	17%
30	Backrest pre-trimming	624	10.4	406	6.8	35%
40	Backrest trimming	344	5.7	284	4.7	17%
50	Aesthetical finishing	166	2.8	166	2.8	/
	TOTAL	1888	31.5	1446	24.1	23%

Table 8 Changeover duration decrease with the use of a screwdriver

Although there is a significant improvement in the changeover time, we have to consider that in order to access the screw on the bottom side of the trimming stump, it is necessary of an angular screwdriver with a particular socket wrench, allowing to the operator to have an easy access to the screw. The same accessibility problem is encountered in the dismounting of the yellow metal part on the top of the trimming press.

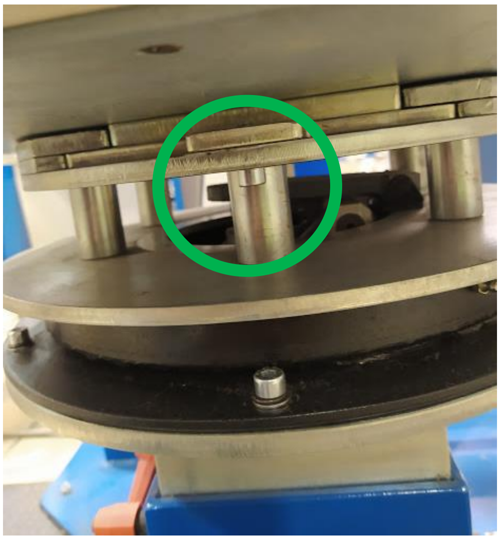


Figure 25 Screw on the bottom of the trimming stump

Supposing to run changeover operations twice a day and supposing once per each shift. Supposing to charge two operators with the changeover operations at the end of the shift, and to subdivide the operations in this manner:

- One operator runs the changeover operations on the cushion and backrest pre-trimming station;
- One operator runs the changeover operation on the aesthetical finishing station, the cushion and backrest trimming stations, where it is necessary to use the angular screwdriver with the particular socket wrench.

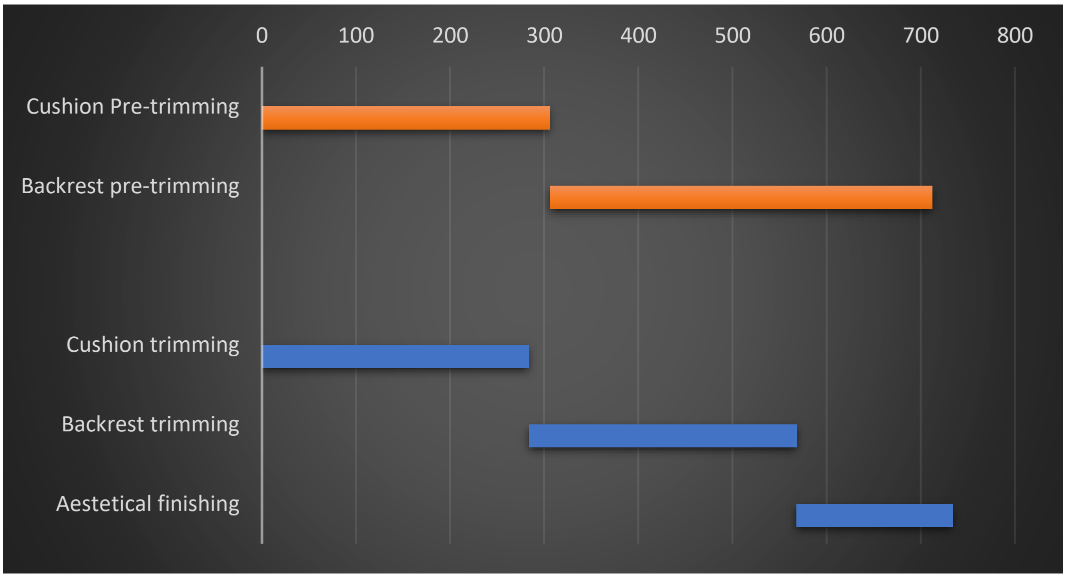


Figure 26 Changeover operations organization

If the changeover operations are organized in this manner, the operations will be completed in 734 seconds, that means around 12 minutes.

Using the screwdriver, seven minutes will be saved for each changeover operations, that means to save along a whole year 3757 minutes that if converted in costs, generates a save of 1690 euros. On the other side, the cost of an angular screwdriver and a socket is around a thousand euros.

Yearly working days	255
Saved time using screwdriver [minutes]	7.4
Yearly saved minutes [minutes]	3757
Hourly working cost [euros/hour]	27
Yearly cost saved [euros]	**1690.65**
Socket wrench cost [euro]	700
Angular screwdriver cost [euros]	300
Total cost [euros]	1000

Table 9 Cost benefit of the use of the screwdriver

That means that we will have a return on the investment after around 151 working days as we can observe from the picture below.

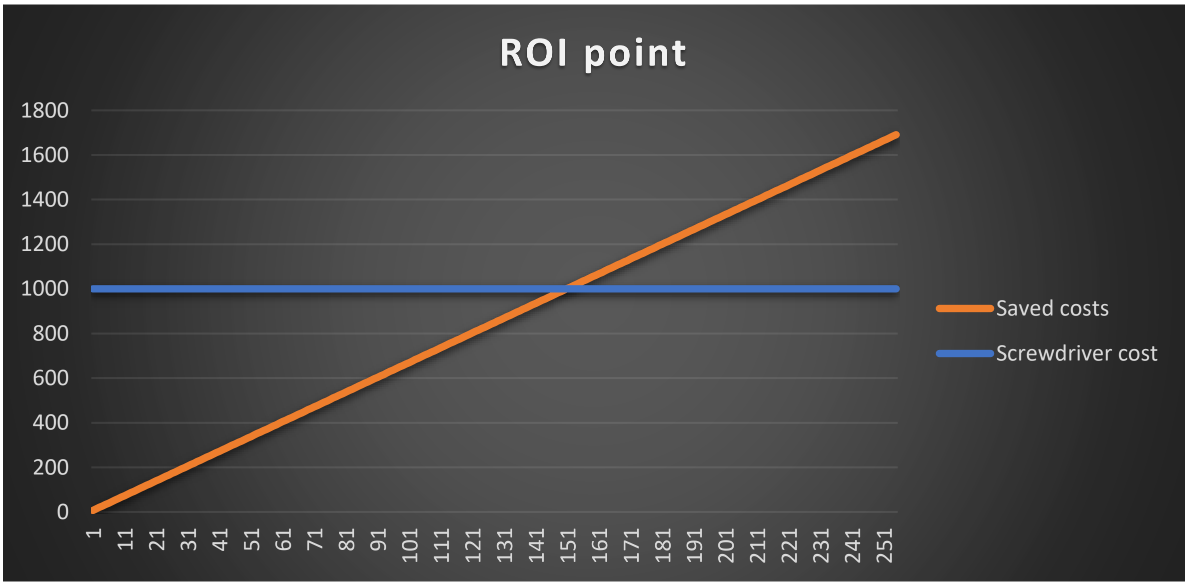


Figure 27 ROI point

3.3.2 Use of quick release levers

One possible solution in order to maintain the advantages of the electric screwdriver, but without the necessity to invest in this tool is the substitution of the screws with quick-release levers. Performing some test, it was possible to find out that the time spent for opening the three levers is really close to the unscrewing operations done with the electric screwdriver.

What has to be taken into account is the accessibility problem we encountered also in the previous paragraph. There is the necessity to differentiate between the typology of quick release levers to be adopted, one solution for the trimming press and one for the trimming stump.

Figure 28 Quick release levers

As we can notice in the figure above, there are two types of quick release levers. The one on the left side is mainly composed of three part: a plastic lever with a spring inside mounted on a threaded pin. This solution permits to fasten and unfasten two parts together in a very rapid way: rotate the plastic lever, in case it is necessary one more turn and there are some accessibility problem it is possible to complete the turn by slightly extracting the plastic lever, re-positioning it in the original position and performing the remaining turns. This solution allows to fasten two parts together in 5 seconds, without the use of the electric screwdriver.

The second quick-release lever type is quite different. It is made of a metal cylinder that is threaded into the hole of one of the component to be fastened. Inside this cylinder there is a pin and a spring connected to a plastic handle. The screwing operation is substituted by a simple and fast pulling of the handle, in order to remove the pin and separate the two components.

By looking at the trimming station, it is more convenient to apply the former type of quick lever to the metal structure of the trimming press and the latter one to the trimming stump. The main reason for that assumption is due to the limited space that there is under the trimming stump.

As said before, both the two solutions represent efficient and valid alternatives to the screwing and unscrewing operations, without the investment for an electric screwdriver and socket.

3.3.3 Removing unnecessary bolts and nuts.

Until now we mainly focused our attention just on the trimming stations. In this paragraph some improvements will be studied also for the pre-trimming stations.

As we said before, Hiroyuki Hirano suggests to eliminate unnecessary bolts and nuts and at this proposal we will find out if some tightening operations can be removed. Starting with the cushion pre-trimming station, we remember that there are four bolts that are fastening the seat interface with the metal structure below.

By studying the pre-trimming process, it was noticed that the operator does not exert such forces on the structure and after some trials the conclusion is that two over four bolts can be eliminated and substituted by two pins, that are tightened to the metal structure. The two pins are helpful during the changeover operation, operating as reference pins.

A similar reasoning can be done also for the eight bolts that are fastening the backrest support to the metal structure below. In this case, we can eliminate just two bolts, and no more. The reason for this choice lies into the pre-trimming process. The backrest during the pre-trimming operations is tilted backward and a not negligible amount of force is exerted on the structure. It is important to notice that the bolts removal is not affecting the stability and the safety of the structure, because the back rest top end is supported by a metal structure.

The table below summarize the improvements that have been done on the pre-trimming stations:

	As is	step 1	step 2
Transport	**120**	**120**	**120**
Bolts and nuts	**160**	**56**	**28**
Other	**130**	**130**	**130**
Total time	**410**	**306**	**278**

Table 10 Cushion pre-trimming station: changeover improvement

	As is	step 1	step 2
Transport	**120**	**120**	**120**
Bolts and nuts	**320**	**112**	**84**
Other	**184**	**184**	**184**
Total time	**624**	**416**	**388**

Table 11 Backrest pre-trimming station: changeover improvements

In both the tables, the step 1 refers to the use of the electric screwdriver or the use of quick-release levers for the trimming stations instead of the manual wrench, while step 2 refers to the bolts and nuts elimination and substitution with reference pins for the other stations.

By looking at the table above we can deduce that for the cushion pre-trimming station, we were able to reduce the tightening time of 82% while for the backrest pre-trimming station the reduction is of 73%.

This result is reflected into the overall changeover time, as we can deduce from the table below:

Description	AS IS [sec]	[min]	Step_2 [sec]	[min]	decrease [%}
Cushion Pre-trimming	410	6.8	250	4.2	39%
Cushion trimming	344	5.7	251	4.2	27%
Backrest pre-trimming	624	10.4	388	6.5	38%
Backrest trimming	344	5.7	251	4.2	27%
Aesthetical finishing	166	2.8	2.8		
TOTAL [sec]	1888	31.5	1140	19.0	40%

Table 12 Changeover reduction after bolts and nuts elimination

As we can observe a 40% reduction is obtained with the elimination of unnecessary bolts and nuts, reducing the overall changeover operation duration to below 20 minutes.

3.3.4 Transport time reduction

In the analysis held until this point, the transport time was not considered at all. Therefore, the transport time, as seen before, has a relevant impact on the overall changeover operation duration.

Hence an optimization analysis has to be performed on this relevant key part of the changeover operation.

In order to reduce the transport time, one solution could be the position the shelves for the stumps and the other interfaces closer to the lines. Since at the moment, they are positioned quite far from the lines on which we are performing our analysis. The shelves dedicated to the SMED operations are stocked close to the Abarth line, as we can see from the red rectangle in the bottom of the figure below.

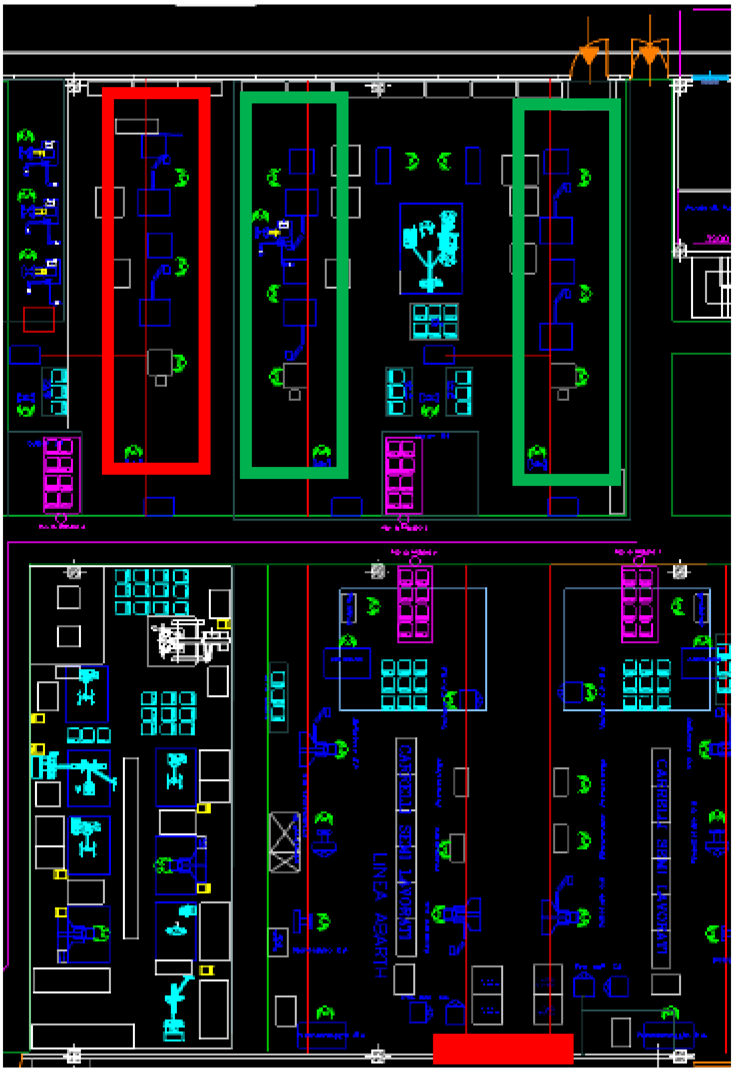
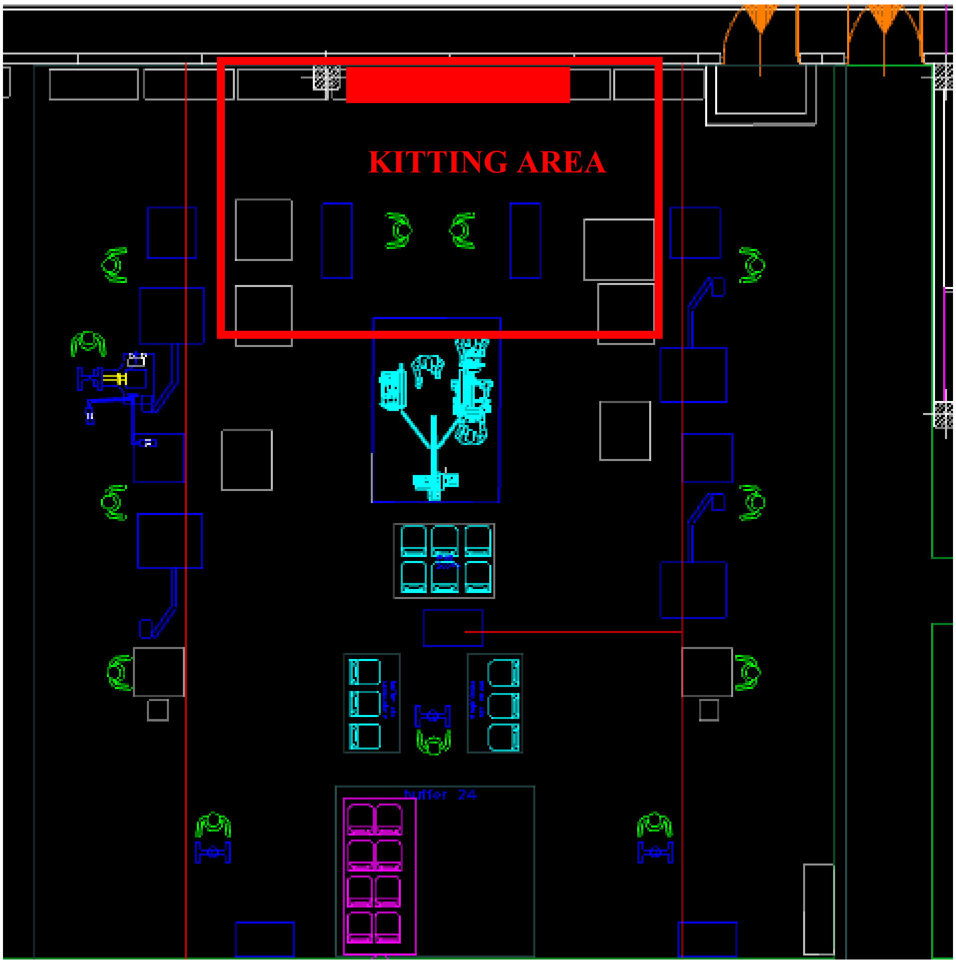


Figure 29 Plant Layout: changeover shelves location

The distance between the line and the shelves is around 40 meters, that are covered on average in 1 minute. We have to take into account that the operator is walking while pushing a cart, on which there is positioned a stump or a metal interface.

The ideal position for the changeover shelves is in between the two lines, near the kitting area. By positioning in this location, we are able to reduce the distance to just 3 meters. That means that the transport time will be significantly reduced.



The reduction in distance covered for every changeover operation is significant: from 40 m to 3 m. It means a reduction in time of around 50 seconds, affecting the overall changeover operations time, as we can see from the table below:

Description	AS IS	[min]	step 3 [sec]	[min]	decrease [%]
Cushion Pre-trimming	410	6.8	178	2.967	76%
Cushion trimming	344	5.7	184	3.067	56%
Backrest pre-trimming	624	10.4	288	4.8	81%
Backrest trimming	344	5.7	184	3.067	56%
Aestetical finishing	166	2.8	66	1.1	60%
TOTAL [sec]	1888	31.5	900	15	68%

Table 13 After changeover shelves re-positioning

By looking at the table above, we can state that the changeover operations were reduced of more than 68%, passing from more than half an hour to fifteen minutes.

One possible way of changeover scheduling and organization can be as follows in the following table:

Operator 1	**duration [sec]**	**duration [min]**
Cushion pre-trimming	178	2.97
Backrest pre-trimming	288	4.80
Total		7.77
Operator 2	**duration [sec]**	**duration [min]**
cushion trimming	184	3.07
Backrest trimming	184	3.07
Aesthetical finishing	66	1.10
Total		7.23

Table 14 Changeover organization

According to line balancing and workforce organization, four operators are supposed to work on each of the two lines. At the end of the shift, two of them can perform the changeover operations, one of them will be devoted to the pre-trimming workstations while the second one to the trimming ones and the aesthetical finishing one. By running those operations simultaneously, the changeovers will be performed. This arrangement is based on mainly two reasons. Firstly, in this way only one specific cart for trimming stump is necessary, and it is used by only one operator

Secondly, this arrangement allows to have a more balanced subdivision of operations in terms of duration and both the two operations are concluded in around 7 minutes.

4 MES overview: historical background, standards and specific functions

The acronym MES stands for Manufacturing execution system and it has as goal the management and control of production processes, starting from the production order creation and following all the production activities until the finished product is stocked in the warehouse. This kind of system enables companies to follow the industry 4.0 roadmap towards the Smart Factories of the future.

4.1 Historical background of MES development

In order to understand MES development it is crucial to analyze the context in which it was developed. In the 1970s, mainframe computers were serving a wide variety of users, and they ruled the computer world. The main issue at that time was the conversion of data from manual accounting systems to automatic and electronically powered systems. In the last third of the 1970s, minicomputers became available and affordable for medium-sized companies. This increase in availability pushed software companies to develop and sell programs to sustain the need of the firms.

Indeed, in this period some systems were developed such as:

- Production data acquisitions and machine data acquisition (PDA and MDA). At that time data were transferred manually, while using contactors controls and PLCs systems the acquisition and the transfer of data can be increasingly automatized.
- Computer aided design (CAD). In the early 80's, electronic drawing systems were developed and sold on the market, leading to a huge increase in productivity and revolutionizing the product development process. Nowadays those systems are able to virtually simulate the product, checking assembly compatibility and interferences between the different components.
- Computer aided quality assurance (CAQ). In that period those type of software started to be developed, leading to a continuous increase in the quality level of the product.

As we can notice all those systems were solutions for a specific need of a specific department. Therefore, an idea arose in the mid-80’s: to develop an integrated system able to contain all those functions. Unfortunately, the implementations often failed, due to a complexity given by the lack of standardization concepts and the inappropriateness of available technologies, insufficiently developed to sustain such a task.

Thanks to the globalization and the subsequent increasing market competition, companies were pushed to be more efficient. In the global market the companies faced a new challenge: to be faster, better and cheaper than the competitors. This means that they had to implement real-time monitoring and control activity on their production processes. It became vital to get a real-time insight on the performances of the production, in order to take prompt and timely counteractions. At this scope, the development and implementation of IT systems became a vital need, with the appearance on the market of the first production control software and MES systems.

Only in the 90’s the latter term was coined. At that time many people claimed that they have coined it. Differently from what one can imagine, it is much more than a production control system: quality, product data management, inventory and maintenance can’t be separated from the MES control domain.

The international non-profit association, MESA, was founded in 1991, in order to share knowledge and best practices for MES functions and uses. In one of their first paper they distinguished eleven functions, that can be attributed to this system, as we can see from Figure 10.

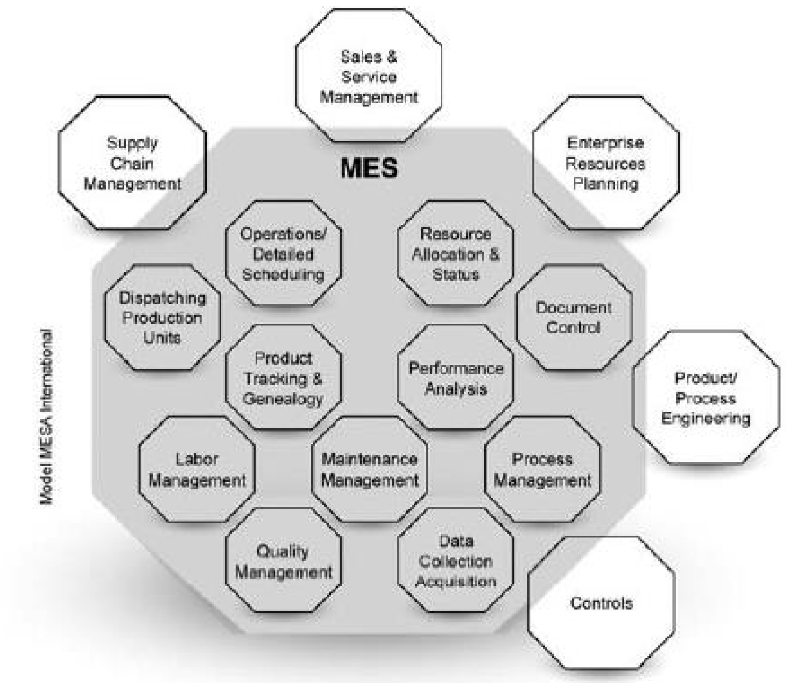


Figure 30 MES system according to MESA

This model provides a broad and clear insight into the scope of the MES. Nonetheless, this model fails to catch the links and the relations between the different functions of the system. Therefore, the model based on ISA standards appears to be more useful for the scope of our analysis.

4.2 MES according to ISA standards

ISA stands for the International Society of Automation. It is a non-profit organization whose main goal is to define standards for the industrial automation field. Furthermore, it performs training activities and conferences, while providing technical publications.

ISA 95 is a standard for developing an automated interface between the enterprise and the control systems. The aim is to provide consistent terminology and models in order to describe a manufacturing company. All the models focus their attention on the ERP-MES integration, although the ISA 95 never mentions those names. It defines the boundaries between different decision-making levels.

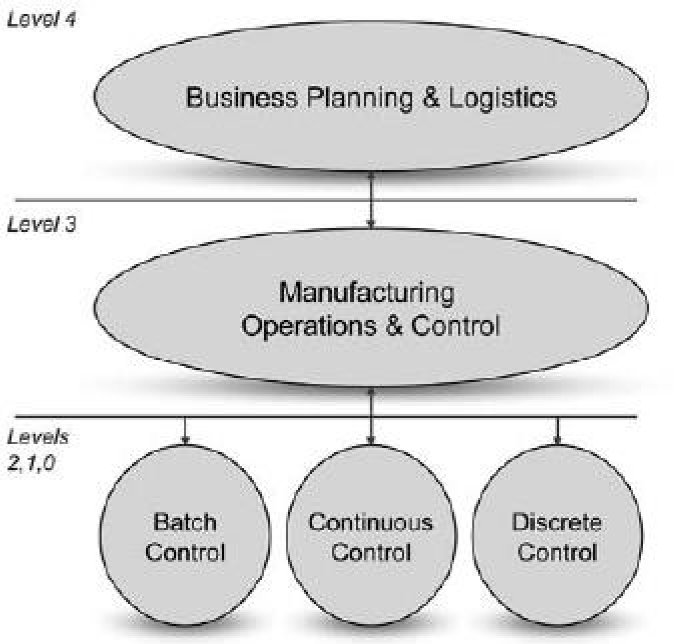


Figure 31 ISA 95: functional hierarchy model

As we can observe from the Figure 11, Level 4 considers the long-term planning, as to say months and week. The main decisions are taken on ordering materials to the suppliers, sending invoices, planning long term production and developing of new products. This layer is nowadays called ERP layer.

On the other side, on layer 3, decision making horizon is focused on a shorter term: days, hours, minutes. The effects of the decisions have a direct and immediate influence on the efficiency of the plant. As we can observe this is the MES layer. On the bottom level of the hierarchy model there are the level 2, 1 and 0. Their time horizon is over minutes and seconds. In this level production takes place.

Manufacturing companies, in the implementation of MES and related systems, generally face an overlapping between the packages, offered by different providers. Sometimes the ERP and MES functionalities are interwoven. In this sense the ISA-95 standard tries to separate and set boundaries between the different functions, setting the common interfaces of communication between ERP and MES.

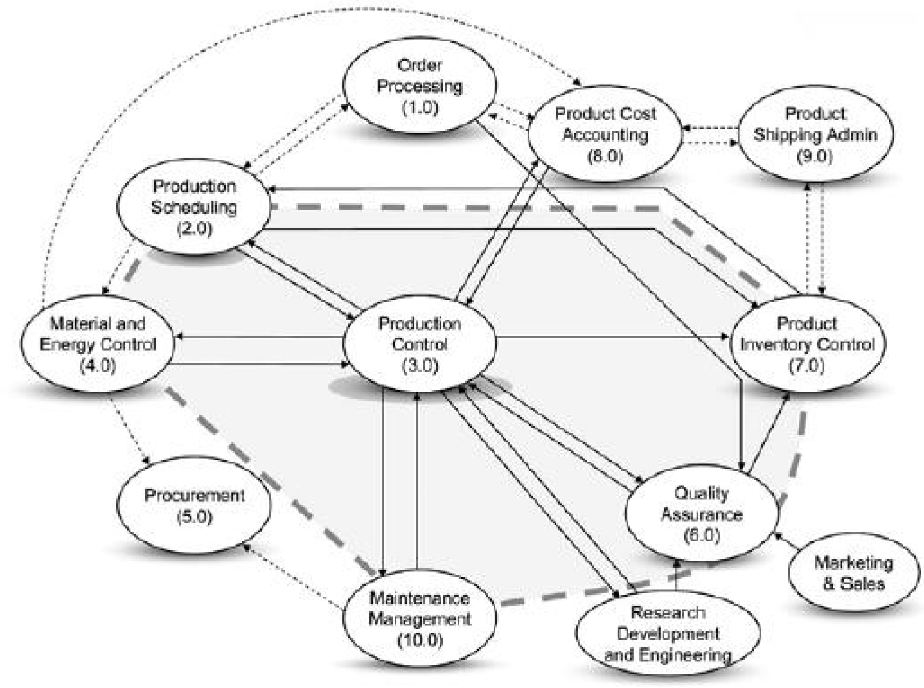


Figure 32 Functional enterprise-control model

In the Figure above, the fat dotted line represents the boundary between the Enterprise domain, and so the ERP layer, and the Control domain, the MES layer. Some functions are along this border. For example, there is a Production scheduling function belonging to both level 4 and level 3. The difference is in the layer: layer 4 refers to a long-term horizon, meaning that the right product needs to be produced and delivered to the customer on the expected/planned delivery date; layer 3 ought to fulfill the mission of producing the item efficiently in spite of the limited capacity of the production lines, e.g. finding out the right combination of orders to minimize changeovers.

It is interesting to focus the attention on the model of ISA-95, describing the activities that have to be performed into the level 3. This model can be easily applied to a production department, therefore will be taken as a reference for the following MES tool, developed for Sabelt production lines.

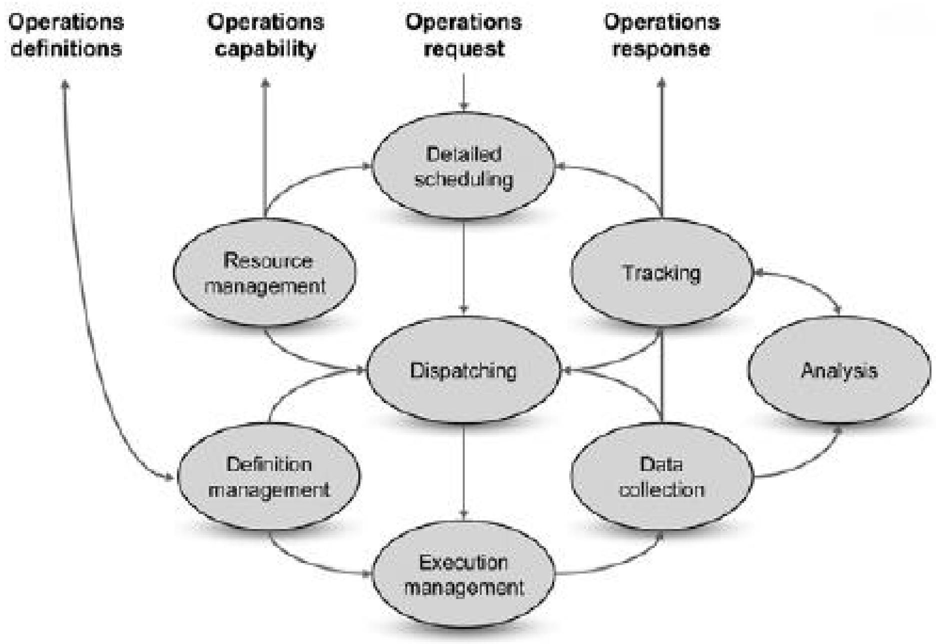


Figure 33 From ISA-95 generic activity standard for manufacturing operations

As we can observe from the Figure 13, before running the production, the information about the availability of production personnel, machines and material must be updated. In the Figure, it is called “Resource management”. That defines the so-called operations capability, namely what is at company’s disposal to produce. Afterwards, it is necessary to generate and update the SOP’s and the assembly instructions that the line operators will follow. This is called “Definition management”.

In order to produce, it indispensable to generate a detailed production schedule. Once ready, it can be assigned to the shifts, through the “Dispatching” function. The “Execution management” assures that the tasks are performed at the right time and that the components are produced in the right quantity and product mix. During all the production processes, data are collected and transformed into information, tracking the KPI. During the “Analysis” phase, that information is investigated and compared with the production target.

4.3 Target management

In this regard, every production department must deal with targets: e.g. yearly costs reduction, increase of productivity, improvement of Overall Equipment Efficiency. Those targets are generally relevant for production and should be taken under control during the production phase in order to find out possible ways of improvement.

A modern MES system needs to support the target management and even more it should represent a potential way to simplify how the target reaching path. As stated by Heiko Meyer, MES systems can be useful for

- Employee motivation;
- Target tracking;
- Analysis of target deviation.

One of the key tasks of MES system is the measurement and visualization of all data arising during the production process. The acquisition, collection and processing of data allows to measure the performance of the production system, by setting and tracking along time of KPI's. Their creation is fundamental to reduce the amount of information to a manageable amount. It should be noticed that data collection and processing procedures are not performed at the end of the shift or, even worse, days after. Data are collected and processed in real time, giving the possibility to constantly monitor target achievement along the whole shift duration and to implement short term actions to fulfill the target.

MES systems should be also able to provide possible reasons for target deviations, offering simple reports based on the data-analysis. Once those reports are generated, the useful information should be delivered to the right company department, in order to take the appropriate countermeasures.

4.4 MES workflows

In order to map the previously mentioned functions, all of them have to be allocated into the correct workflow, corresponding to the operating cycle of the production system under investigation.

According to Heiko Meyer, there are three basic workflows, where all the MES functions should be allocated:

- Production flow-oriented design
- Production planning
- Order processing

4.4.1 Production flow-oriented design

Before implementing any software solution, it is necessary to map the production process in all its details: ranging from the product definition with all its possible variants, to a description of the production flow and to the list of required resources, machines, personnel and materials.

The first step that should be performed is to collect all the information related to the item to be produced. What is necessary is the product master data, generally available on ERP or PLM systems. As we can expect, different variants of the same item can be processed along time. Every product requires resources. A variant of an item can differ from another one in terms of production routing, type of operation and features. Once defined all the operations necessary to produce a certain variant of a product, the process routing is obtained. In the routing, it is common practice to link the operation, e.g. drilling, with the equipment to be used to perform that operation, e.g. drilling machine. At the end the final result is a list, one for every product variant, with all the operations and the associated equipment. Another important piece of information is necessary to wholly describe the product: the part list, also called BOM. It contains all the components, in a hierarchical order, that will create the final product.

Now let’s consider more in detail the concept of operation. It is an activity or process that is part of the product development. In order to be performed, an operation needs some inputs:

- Material;
- Resources, such as tools and measuring equipment;

- Information.

Then once the operation is associated to the workplan, it is possible to add time data and personnel resources. Those two are a function of the selected machine type, e.g. a drilling operation can be performed through a manually activated machine or through an automatic one and obviously the required time for the operation can change and the number of required operators can vary.

For what concerns the material, we can observe that the quantity requested to produce each article depends on the master data, e.g. four bolts are necessary for one item.

It is necessary to establish a substantial difference between material types. There are the materials that are purchased externally, for example raw materials that are received from external suppliers. On the other side, there are materials that are produced internally, therefore the planning process of the final item should be organized considering the internal production of the necessary components and their process chain.

Independently of the source of the materials, this list of components is like a recipe, without which the correct process cannot take place. Therefore, it is essential to hold a careful planning of materials.

For what concerns the latter input, every operations carry with itself a certain amount of information, in the form of documents. Firstly, it is necessary to define which is their use. There can be some documents that are showed to the operator and once acknowledged they are archived. There are some documents such as the work instructions, that are acknowledged and then they are available during the execution process, in case of uncertainties. Then, there are other information that are always showed during the execution process, in order to supply a constant support during the activities. In some cases, for particular operations, work instructions can be showed on the workstation screen. They provide, for a certain article and for a specific operation, how to carry out a particular step, e.g. showing the cable layout to be obtained after an assembly operation.

Once all those inputs are available it is possible to compile for each article the workplan, or production routing, combining the operation with the machine. Heiko Meyer defines the workplan as: “the central control instrument of production”.

The basic elements of a work plan are:

- Sequence number: every operation the semi-finished product is passing through is labeled with a number, generally it is a multiple of 10;
- Operation description: here the process is described, e.g. milling or cutting;
- Machine or workstation allocation: it means where that operation with that sequence number will be run.

Here an example from the Ferrari seat production line in Sabelt:

Operation	Description	Equipment
010	Mounting together backrest and cushion frame	Marriage station
020	Pad's gluing on the frames	Robot gluing station
030	EOL checks	Eol workstation

Table 15 Ferrari seat production routing

Once performed the correlation between the operation and the equipment used, it is possible to associate time data and the needed personnel resources to the workplan. According to the Association for Work Design there are different time types, and those differences should be taken into account. For what concerns MES requirements, we should distinguish between:

- Production time t_p it is the time taken to perform the operation;
- Set up time t_{su}: what is necessary to prepare the machine or equipment for the production. It is obviously independent of the number of pieces produced;
- Order execution time given as $t_p * quantity + t_{su}$.

In the figure below, it is represented a summarizing chart about the production flow-oriented design starting point: Product definition.

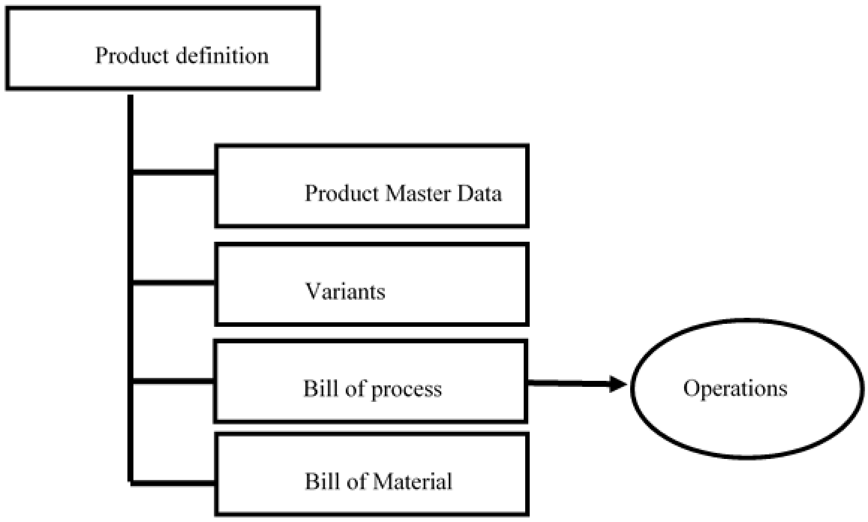


Table 16 Product definition

4.4.2 Production planning

As stated by the ISA 95 standard, there are several levels of activity, and so also for the planning one.

The first level is the tactical planning or sales planning. It is a proper strategic planning; whose time frame is long range and involves the top management of the company. It defines the production targets and estimates the volumes to be produced during the year.

Secondly, there is the rough production planning, whose time frame is long to medium range. It consists in implementing the strategic planning, taking into account the concrete requirements and constraints. For that reason, that type of schedule will be generally drawn in ERP system.

Thirdly, there is the detailed production planning that is the second-key function of MES. From the rough planning there is the first idea about the requirements for the needed resources. Based on the customer orders, that are generally maintained in the ERP system, MES has to create the production orders. Even in this case there is a common interface between the ERP (layer 4 referring to the ISA-95 hierarchical model) and MES (layer 3). With the purpose of creating the production orders, the following data are required:

- Customer order number that uniquely identifies the product that the customer expects to receive;
- Quantity;

- Delivery date or earliest possible production date: for what concerns the former it is important to distinguish between earliest possible delivery date, request date and latest possible delivery date. This distinction should increase the flexibility of the planning activity.

Once the customer orders are transmitted to and loaded on the MES, its core task is to sequence them, finding the optimum. Nonetheless, according to the type of product, business and production site, there are several ways to plan: manually, using planning boards or using fully automatic tools. The core goal is to find the optimal sequence. Two important aspects should be considered. Firstly, the customer viewpoint has to be kept clear in the planner's mind: delivery dates and quality level must be respected. Secondly, there is the cost-oriented planner choice whose main goal is to minimize production costs, e.g. setup costs or warehousing costs. Besides there is an intrinsic complexity hidden in the planning activity: the boundary conditions, linked to the company business. They can be of different nature:

- Customer order (e.g. delivery date and quality);
- Product (e.g. different variants that means different BOM and BOP and so there is a setup cost to be minimized);
- Production process (e.g. cooling times, transport times from one job-shop to the following one);
- Resources allocation (e.g. machine saturation, available personnel).

Consequently, the ranking of the most important and relevant constraints is intrinsically linked to the business and the production activity, therefore it should be imported in the MES planning tool in order to develop a system aiming at improving the entire production system.

Furthermore, the planning tool needs has to be able to face the problems of the production, that is the implementing body of the planning phase. This reality can be affected by technical problems in the facility, issues concerning the supplied materials, operators' illness or unforeseen customer priorities. Hence, it is required a certain degree of planning flexibility and a responsive attitude towards unexpected issues.

4.4.3 Order processing and control

This is the core function of the MES, the interface that directly adds value to the production process. In this sense it is important to design a user-friendly interface, able to precisely fit to the needs of the manufacturing process.

Once the order is delivered to the production line, there is the necessity to constantly monitor the progression, in order to make comparison with the detailed planning, and finding out in real time what is not going in the right direction. Therefore, through the use of MES, a permanent feedback from the production line too the offices is implemented. Generally, before this kind of implementation, the line performances are evaluated once per day, normally at the end of the shift, checking the closeness to the targets. The necessity to have a constant and closer look at the line performances is due to a faster reaction rate in case of deviations from targets: e.g. quality issues of the product or slowing down in the production rate due to a technical issue.

Besides, the workers are responsible of processing the right order in the right moment, but it is necessary to give them the possibility to work. It is crucial that materials are available at the workplace in the ordered quantity. Another aspect of this function of MES is to involve the production and materials department, providing them the information to ensure the successful order processing.

In conclusion, we can summarize the basic functions to be inserted in the order execution and MES control area:

- Material flow control and material usage: the goal is to provide the required material in the correct quantity, as previously stated. Once the order is generated, the material provision list needs to be generated and sent to the internal logistic department in order to supply the line. When the material is used, the bar code must be scanned and the status of the material changes from "provided" to "in production";
- Order processing and operating data recording (machine downtime; piece flow, quality issues): this is the MES function that records what happens in the production line, both direct value-creation functions both preparatory functions or malfunctions. Consequently, it acquires the data to generate KPI's;

- Output of the operations: it should be possible to allocate any data from the process to any order (e.g. scraps, reworks, samples to be taken to the laboratory).

5 Sabelt case study: information flow management, from production planning to the lines.

Before going in deep into the analysis of the current information flow in Sabelt and of the tool description, it is necessary to make a brief clarification about the tool and its goals.

The tool has a double aim. At first, as it was specifically designed on Sabelt material and information flows, one goal is to directly improve the production facility daily operations. Secondly, as it was developed on a rather simple and rudimentary programming application (Excel VBA), the second aim is to represent an input and a starting point for a more sophisticated MES system and obviously it is not pretending to be a complete substitute.

5.1 Information flow as is analysis

In order to better understand the development and the functionalities of the information management tool, it is appropriate to contextualize it my making an AS IS analysis.

Sabelt production planning department is the starting point of the information loop within the company. Since Sabelt supplies a wide number of carmakers, the ordering and communication flow can very from one to the other one.

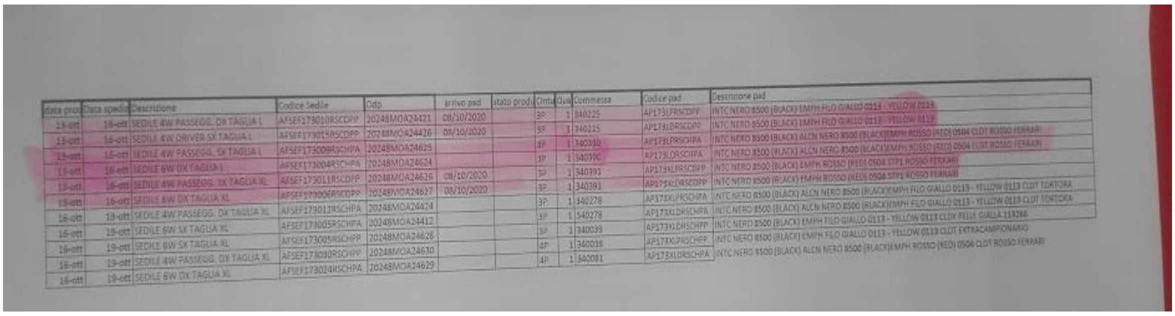
The planning department can order the components to satisfy the carmaker once it has the visibility on the production orders to be delivered or far in advance. This type of choice is generally made by considering different factors: such as lead time or the type or the features of the component. By taking as example the Ferrari production line, the cushion or backrest carbon frame has not so many variants, and so it can be ordered in advance without having a clear insight into time horizon. On the other side the PADS, mentioned before in the previous chapters, have many variants. Furthermore, for this type of seats there are the so-called tailor-made versions. By looking at the Ferrari website, it is the "*exclusive programme for those customers who want to customize each element of their car for a perfect fit*." This means that the PADs that have to be ordered and mounted on the seat have an infinite number of variants, ranging from the type of leather, color, type of pattern and so on. The variants can be completely chosen and designed by the final customer. Consequently, the order cannot be made in advance, before having the insight on the order time bucket from Ferrari.

The orders have to be scheduled in such a way in order to have all the components to produce the seat, respecting the expected delivery dates. The scheduling procedure is done manually on Excel sheets by the supply chain department, without the use of scheduling algorithms or software.

Actually the list of seats to be produced before a certain delivery date is transmitted to the production department. This is a critical passage and until now, the information is conveyed in various forms, according to the production line, the occasion and the people involved:

- By email: from the supply chain department to the line coordinator, who will print the list and give it to the line;
- Through an excel file available on the computer near the line with the list of orders to be delivered. The line coordinator or line responsible can consult it and schedule the daily production;
- By phone or verbal communications.

The line responsible has a list similar to the one below, reporting the seats to be produced.



data prod	Data spedi	Descrizione	Codice Sedile	Odp	arrivo pad	stato produ	Qnta	Qua	Commessa	Codice pad	Descrizione pad
13-ott	16-ott	SEDILE 4W PASSEGG. DX TAGLIA L	AFSEF173010RSCDPP	20248MOA24421	08/10/2020		3P	1	340225	AP173LPRSCDPP	INTC NERO 8500 (BLACK) EMPH FILO GIALLO 0113 - YELLOW 0113
13-ott	16-ott	SEDILE 4W DRIVER SX TAGLIA L	AFSEF173015RSCDPP	20248MOA24426	08/10/2020		3P	1	340225	AP173LDRSCDPP	INTC NERO 8500 (BLACK) EMPH FILO GIALLO 0113 - YELLOW 0113
13-ott	16-ott	SEDILE 4W PASSEGG. SX TAGLIA L	AFSEF173009RSCHPA	20248MOA24625			3P	1	340390	AP173LPRSCHPA	INTC NERO 8500 (BLACK) ALCN NERO 8500 (BLACK)EMPH ROSSO (RED) 0504 CLDT ROSSO FERRARI
13-ott	16-ott	SEDILE 6W DX TAGLIA L	AFSEF173004RSCHPA	20248MOA24624			3P	1	340390	AP173LDRSCHPA	INTC NERO 8500 (BLACK) ALCN NERO 8500 (BLACK)EMPH ROSSO (RED) 0504 CLDT ROSSO FERRARI
13-ott	16-ott	SEDILE 4W PASSEGG. SX TAGLIA XL	AFSEF173011RSCDPP	20248MOA24626	08/10/2020		3P	1	340391	AP173XLPRSCDPP	INTC NERO 8500 (BLACK) EMPH ROSSO (RED) 0504 STP1 ROSSO FERRARI
13-ott	16-ott	SEDILE 6W DX TAGLIA XL	AFSEF173006RSCDPP	20248MOA24627	08/10/2020		3P	1	340391	AP173XLDRSCDPP	INTC NERO 8500 (BLACK) EMPH ROSSO (RED) 0504 STP1 ROSSO FERRARI
16-ott	19-ott	SEDILE 4W PASSEGG. DX TAGLIA XL	AFSEF173012RSCHPA	20248MOA24424			3P	1	340278	AP173XLPRSCHPA	INTC NERO 8500 (BLACK) ALCN NERO 8500 (BLACK)EMPH FILO GIALLO 0113 - YELLOW 0113 CLDT TORTORA
16-ott	19-ott	SEDILE 6W SX TAGLIA XL	AFSEF173005RSCHPA	20248MOA24412			3P	1	340278	AP173XLDRSCHPA	INTC NERO 8500 (BLACK) ALCN NERO 8500 (BLACK)EMPH FILO GIALLO 0113 - YELLOW 0113 CLDT TORTORA
16-ott	19-ott	SEDILE 6W SX TAGLIA XL	AFSEF173005RSCHPP	20248MOA24628			3P	1	340039	AP173XLDRSCHPP	INTC NERO 8500 (BLACK) EMPH FILO GIALLO 0113 - YELLOW 0113 CLDX PELLE GIALLA 113266
16-ott	19-ott	SEDILE 4W PASSEGG. DX TAGLIA XL	AFSEF173030RSCHPP	20248MOA24630			4P	1	340039	AP173XLPRSCHPP	INTC NERO 8500 (BLACK) EMPH FILO GIALLO 0113 - YELLOW 0113 CLDT EXTRACAMPIONARIO
16-ott	19-ott	SEDILE 6W DX TAGLIA XL	AFSEF173024RSCHPA	20248MOA24629			4P	1	340081	AP173XLDRSCHPA	INTC NERO 8500 (BLACK) ALCN NERO 8500 (BLACK)EMPH ROSSO (RED) 0504 CLDT ROSSO FERRARI

Figure 34 Production scheduling list.

From this list, the daily scheduling should be done because generally the list provided from the supply chain departments containes more orders than the number of seats that the line can produce in one day. The daily scheduling is up to the line responsible.

Based on the scheduling, the line responsible has to communicate to the warehouse the components to be supplied to start production. Normally they compile a paper called "Lista Approvigionamento Materiali" and give it to the warehouse. As we can see from the appendix, in this table there is the P/N code, the description of the item, the quantity needed and the line that is requesting the restock.

Due to the fact that the orders list provided to the line responsible is containing more seats codes than the ones that the line is able to produce in one day, the risk is that ,most of the times, the line responsible asks to the warehouse to fill the line with all the components that are necessary for that list. This implies to have an higher amount of stock along the line rather than with the components necessary to cover only the daily production. This issue comes out notably because seats are made of bulky components, such as carbon frames, metal structure, covers and monocoques. For example, the Ferrari PADS arrives in carton boxes and are delivered to the line in this way, in order to avoid any damages during the handling. The shelves are dimensioned to host a maximum of 8 boxes, that corresponds to eight seats, that is equal to the half a shift production. This shelf should be refilled twice a shift, at the beginning and at the half of the shift. Despite nowadays all the PADS necessary to complete the list are stocked alone the line, and the situation is the following:

Figure 35 Ferrari PADS stock along the line

The causes of this phenomena can be various. One of the reasons is that there is not a simple way to communicate easily between the line and the warehouse. Usually the line responsible prefers to have more stock along the line rather than waiting material, blocking the line and missing the delivery date.

Once the line has been supplied with the requested materials, the production can start.

Each workstation is provided at least with an industrial pc, a monitor, a bar code reader, a tightening control unit and tightening equipment. At the end of each cycle a label is printed, a report is generated and saved in the machine folders. The former has to be glued on the traceability document of the seat. Both the label and the report saved in the machine folder contain the list of all the components mounted on the seat (part number, serial number, lot number, the hour, date of production and the name of the operator), for the tightening operations they also keep track the values of torque and angles.

On one side, due to the fact that the line machines and Pcs have not the internet access, there is no possibility to have a constant monitoring of the production rate. Furthermore, with the actual system there is not a structured way to immediately detect and solve issues, for example some of the most common can be the following:

- materials shortages,
- machine malfunctions,
- reworks, scraps or quality issues.

At every line stoppage, the line responsible has to compile a form, in which it is reported the amount of time of stop and the cause. One sample of that paper can be found in the appendix. This document is called "Dichiarazione di Produzione" It contains the list of the seat codes produced and the line stoppages duration and causes.

Therefore, only at the end of the shift, it is possible to count the number of seats produced in order to compare with the daily production target and with the delivery requests. This operation is generally in charge of the line responsible. In particular, in this document all the data related to the production are collected in order to build the KPI's.

In this complex document, we can see that the main data collected are the numbers of the operators on the line, number of seats produced, working time. The goal of this document is to compute the KPI's in order to track the line performances over time. An example of this document can be found in the appendix.

From the AS IS analysis held until now, some conclusions can be drawn:

- there is the need for a more practical system to communicate to the line the production scheduling and to the warehouse the list of material to be supplied;
- since the machines are collecting data and monitoring the production flows but without displaying them in real-time, it would be helpful and useful to have a constant monitoring of the production and a real time KPI's building.
- it would be useful the setting up of a simple communication method in case of line stoppage or material shortage in order to permit an immediate decision making process, e.g. in case of material shortage, a warehouse worker is immediately called and informed of the lack, for an immediate line refill.

5.2 Development of a MES like tool for information flow improvements

In this section, a MES like tool will be developed, following the principles of the ISA standards. It is a level 3 tool, linked with level 4 software and dispatching information to the 2,1,0 levels.

As stated in chapter 4, before the developing of the software a complete mapping of the production process has to be done, the so-called production flow-oriented design.

By looking on Microsoft Dynamics AX, the ERP software in Sabelt, and on the PLM software, it is possible to collect all the information for the products of interest, in terms of variants and production routing.

Taking as a reference the Ferrari line, we have the following production routing:

Workstation	Description	Equipment
010	Mounting together backrest and cushion frame plus and mounting of components	Marriage station
020	Pad’s gluing on the frames	Robot gluing station
030	EOL checks	EOL workstation

Table 17 Ferrari seat production routing

The production routing is the same for every variant of the seat, what change between one seat code and another one is in the sequence of operations performed in the workstation. Since all the workstations are equipped with a pc, by reading the different seat-code, the machine shows to the operator to perform different operations. For example for a passenger seat, the operator has to mount on the cushion frame the SBR, a sensor of presence, or it has to mount a different type of cables, while a driver seat has no SBR sensor and needs a different cable.

Since there are some differences between different seats codes in the cycle, that is managed through the creation of difference work-cycle, there are also some differences in the components to be mounted on each seat. The tool will focus mainly on the bulky components, such as the cushion frame, backrest frame, metal structures and PADs carton boxes. Furthermore, for what concerns the first three elements, the variants associated to the different seat codes is the following:

Codice	Descrizione	Comfort	SCHIENALE SX	SCHIENALE DX	cuscino 4w PASS	cuscino 4w DRV	cuscino 6w SX	cuscino 6w DX	struttura 4W	Struttura 6W
AFSEF173001	SEDILE 6W SX TAGLIA M	x	X				X			X
AFSEF173002	SEDILE 6W DX TAGLIA M	x		X				X		X
AFSEF173003	SEDILE 6W SX TAGLIA L	x	X				X			X
AFSEF173004	SEDILE 6W DX TAGLIA L	x		X				X		X
AFSEF173005	SEDILE 6W SX TAGLIA XL	x	X				X			X
AFSEF173006	SEDILE 6W DX TAGLIA XL	x		X				X		X
AFSEF173007	SEDILE 4W PASSEGG. SX TAGLIA M	x	X		X				X	
AFSEF173008	SEDILE 4W PASSEGG. DX TAGLIA M	x		X	X				X	
AFSEF173009	SEDILE 4W PASSEGG. SX TAGLIA L	x	X		X				X	
AFSEF173010	SEDILE 4W PASSEGG. DX TAGLIA L	x		X	X				X	
AFSEF173011	SEDILE 4W PASSEGG. SX TAGLIA XL	x	X		X				X	
AFSEF173012	SEDILE 4W PASSEGG. DX TAGLIA XL	x		X	X				X	
AFSEF173013	SEDILE 4W DRIVER SX TAGLIA M	x	X			X			X	
AFSEF173014	SEDILE 4W DRIVER DX TAGLIA M	x		X		X			X	
AFSEF173015	SEDILE 4W DRIVER SX TAGLIA L	x	X			X			X	
AFSEF173016	SEDILE 4W DRIVER DX TAGLIA L	x		X		X			X	
AFSEF173017	SEDILE 4W DRIVER SX TAGLIA XL	x	X			X			X	
AFSEF173018	SEDILE 4W DRIVER DX TAGLIA XL	x		X		X			X	
AFSEF173019	SEDILE 6W SX TAGLIA M	x	X				X			X
AFSEF173020	SEDILE 6W DX TAGLIA M	x		X				X		X
AFSEF173021	SEDILE 6W SX TAGLIA L	x	X				X			X
AFSEF173022	SEDILE 6W DX TAGLIA L	x		X				X		X
AFSEF173023	SEDILE 6W SX TAGLIA XL	x	X				X			X
AFSEF173024	SEDILE 6W DX TAGLIA XL	x		X				X		X
AFSEF173025	SEDILE 4W PASSEGG. SX TAGLIA M	x	X		X				X	
AFSEF173026	SEDILE 4W PASSEGG. DX TAGLIA M	x		X	X				X	
AFSEF173027	SEDILE 4W PASSEGG. SX TAGLIA L	x	X		X				X	
AFSEF173028	SEDILE 4W PASSEGG. DX TAGLIA L	x		X	X				X	
AFSEF173029	SEDILE 4W PASSEGG. SX TAGLIA XL	x	X		X				X	
AFSEF173030	SEDILE 4W PASSEGG. DX TAGLIA XL	x		X	X				X	
AFSEF173031	SEDILE 4W DRIVER SX TAGLIA M	x	X			X			X	
AFSEF173032	SEDILE 4W DRIVER DX TAGLIA M	x		X		X			X	
AFSEF173033	SEDILE 4W DRIVER SX TAGLIA L	x	X			X			X	
AFSEF173034	SEDILE 4W DRIVER DX TAGLIA L	x		X		X			X	
AFSEF173035	SEDILE 4W DRIVER SX TAGLIA XL	x	X			X			X	
AFSEF173036	SEDILE 4W DRIVER DX TAGLIA XL	x		X		X			X	

Table 18 Ferrari seat product variants

The main variants can be summarized as follows:

- the seat can be a driver or passenger one,
- the seat can be a left-hand drive or a right-hand drive,
- two metal structure can be mounted, one that can only slide horizontally back and forward, called 4W and another one that can move also up and down, adjusting the height of the cushion, and it is called 6W;

According to the variants, each seat code needs a specific cushion frame, backrest frame and metal structure.

For example, if we have to produce a seat code like **AFSEF173007**, it is a RHD passenger seat. It implies a left backrest frame, a passenger cushion frame and a 4w metal structure. Each component is labelled with a part number, identifying it unambiguously, as can be seen from the table below.

Component code	**Description**	**AFSEF173007**
AAF173122	Left side backrest frame	X
AAF173101	Right side backrest frame	-
AAF173102	Cushion passenger frame 4W	X
AAF173238	Driver cushion frame 4W	-
AAF173067	Driver LHD cushion frame 6W	-
AAF173127	Driver RHD cushion frame 6W	-
ACF173100	4W metal structure	X
ACF173093	6W metal structure	-

Table 19 Components variants

Until now the PADS carton boxes have not been considered. Every seat order from Ferrari arrives with the seat code, e.g. AFSE173007, and an order code that is labelling univocally the type of PADS to be mounted on that seat. Therefore, each seat has its own carton, labelled with the correct order code, containing the PADS to be mounted on.

Once this analysis has been performed for all the possible seat codes, it is possible to describe the production planning and scheduling system of the tool.

As it was explained in chapter 4, according to ISA 95 standard, there are several levs of activity. The first level or sales planning is not of our interest, due to its longer-range term.

The completion of this section of the tool is in charge of the supply chain department. There is an Excel paper called, weekly workplan, in which at the end of the week or at beginning of the next week, the personnel in charge of the planning, copies and pastes the orders received by Ferrari. This is a sort of weekly rough planning, those orders are not already scheduled and sent to the production.

The rough planning paper seems to add an higher complexity to system but in reality is a way to add an overall and global view on all the weekly workplan, in order to decrease the decision making process time and take more rapid decisions.

For example, sixty seats have to be produced by Friday evening, in order to be delivered the next Monday in Maranello, the planning department can schedule 12 seats each day, according to the capacity of the line, 14 seats per shift, it is sure that at the end of the week all the orders will be completed and ready to be packed. For some reasons, on Wednesday, two orders are not produced. The planner knows that it is possible to re-schedule those two orders on the following day, because the overall line capacity is 14 seats per day. In this way by a simple look at the rough planning paper, the planner knows if the addition of orders can be managed easily or if it necessary to recur to overtime production.

To properly schedule, the planner has to go into the excel paper called TMW_WP, standing for tomorrow workplan, where it is needed to select the date of tomorrow, the table is automatically reading the column in the rough planning and self-updating. In order to send the daily production list to the line, the planner has just to click on the button at the end of the page, called "*Commessa alla linea*". An email is automatically generated and sent to the pc of the Ferrari line, where it can be easily printed. Another interesting function that has been implemented in this tool is the material request sent to the warehouse, based on the daily workplan list. Infact the planner has to click on the button, called "*Approvvigionamento linea*", and an email is automatically sent with the list of items and components that are necessary for the production of the daily scheduling. In the attachment of the email, a list of bulky components is found. In the list there is the quantity of components to be delivered to the line, the code, a bar code and a description of the object. Furthermore, there is also the list of order number identifying the PADS carton boxes.

Due to some optimization plans, it was decided to refurnish the line twice a day in order to reduce significantly the amount of stock of material along the line. In the list delivered to the warehouse there is the subdivision between what has to be delivered in the first run and in the second run. An example of this list can be found in the appendix.

As we can deduce, the idea is to implement a Just In Time approach to the stock along the production line: providing the line with the right number of bulky, components that are consumed in the daily production process.

Usually the production processes are not as smooth as designed, hence the tool has to take into account the everyday problems of a line: equipment malfunctions, scraps of the components or lack of materials.

Ideally at the end of the shift, following the JIT logic, the stock of bulky components should be zero. Only in the case in which some orders for some reasons have not been processed, the materials are still along the line. In this case the line responsible has to update the table below in the section "*In Linea*", by adding the number of components present in the line. Automatically when the planner has to make the scheduling for the day after, a supplying request to the warehouse with all the components necessary for the following day production is sent, considering the number of components that are still along the line.

On the other side, there is the need of the planner and of the production responsible to monitor in real time the performances of the line and to be aware of any problems. The tool is able to track the daily trend of the line, but due to the fact that it is not linked nor to bar code readers neither to the work-cycle software it has to be updated manually by the operator by clicking on some buttons. The interface with which the operator has to deal with has been designed in order to be the simplest and most user friendly as possible.

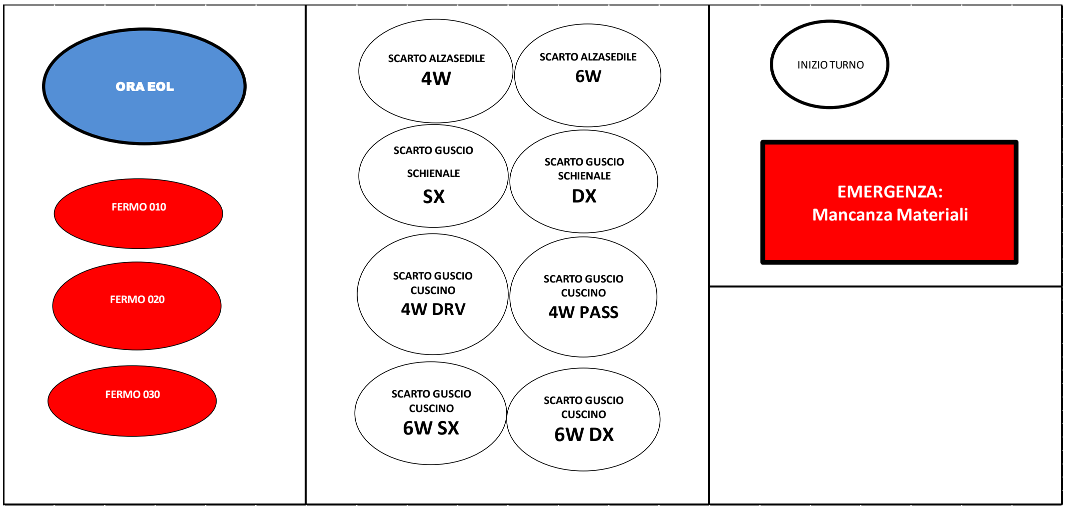


Figure 36 Line operator dashboard

Each button is associated to one Excel VBA function that perform a different operation.
On the left side of the dashboard we have the blue button. This button has to be clicked by the end of line operator when the seat is finished and ready to be delivered. The three red buttons below have a similar function but associated to the three workstations of the production routing. By clicking on these buttons, the operator is communicating to the production responsible that the line is stopped because of a problem in workstation 010 or 020 or 030. Therefore, by clicking on these buttons a mail is automatically sent to the production responsible for immediate support, in order to restart the line as soon as possible.

By clicking on the blue button, the time at which the seat has left the end of line workstation is written in the blue column below, next to the associated seat code. On the other side by clicking on the red button "*FERMO 010*" the time at which the workstation has been stopped is written in the first red column, while for the second button "*FERMO 020*" the time is added on the second one and the third one for the button "*FERMO 030*".

17/12/2020

N	CODICE SEDILE	COMMESSA	EOL	REWORK
1	AFSEF173007	340515		
2	AFSEF173003	340529		
3	AFSEF173003	340537		
4	AFSEF173010	340601		
5	AFSEF173003	340601		
6	AFSEF173028	340576		
7	AFSEF173021	340576		
8		0		
9		0		
10		0		
11		0		
12		0		
13		0		
14		0		
15		0		
16		0		
17		0		
18		0		
19		0		
20		0		

FERMO LINEA											
POSTAZIONE 010				POSTAZIONE 020				POSTAZIONE 030			
INIZIO	FINE	CAUSA	TOTALE [min]	INIZIO	FINE	CAUSA	TOTALE [min]	INIZIO	FINE	CAUSA	TOTALE [min]
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0
			0				0				0

LINEA RIPARTITA: Selezionare la casella dove si vuole inserire l'ora e cliccare il bottone

Figure 37 Line outputs and downtimes

The green button below has to be clicked when the problem is solved and the line is re-started.

Coming back to the operator dashboard, there are six white buttons in the middle of the page. Each of the them is dedicated to one of the bulky components that are delivered to the line. Since the line has to run following a JIT logic, for every component that is discarded, due to quality issues or to damages during the handling, another component with the same features has to be delivered to the line in order to complete the daily schedule. By clicking on one button an email is immediately sent to the warehouse with a request of supply, specifying the component code and description. For example, if a 4w metal structure is discarded, an email similar to the one below is sent to the warehouse. As we can notice, in the object is highlighted the extreme urgency and the needed quantity and code.

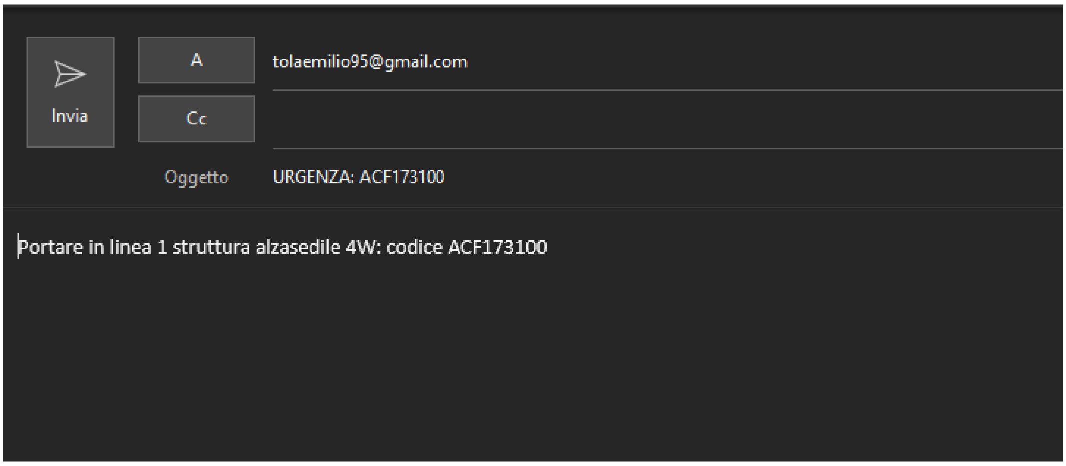


Figure 38 Email sent in case of discarded parts

By continuing to analyse the figure above, there are two buttons. The white one on the top-right corner has to be clicked at the beginning of the shift, in order to keep track of the Furthermore the big red button has to be clicked in case of an emergency supply: for example in case the line has not been supplied correctly and some elements are missing, or if the second line restock is not arriving and the line has no more materials to continue the production. Even in this case, once the button has been clicked, an email is immediately sent to the production and internal logistic responsible.

At the end of the production day, in the Excel paper about the line performances, figure 37, there is the list of seats produced, and in the orange column there is the number of seats that are produced and reworked, because of some defects. Those data are collected in the page called KPI and the key performance indicators are automatically computed.

data	07/02/2021
ore di straordinario	
operatori in straordinario	
#operatori	4
tempo ciclo [min]	90
tempo a disposizione senza pause [min]	430
Tempo di fermata:	**domenica 7 febbraio 2021**
t FERMATA 010	0
t FERMATA 020	0
t FERMATA 030	0
tempo totale di fermata [min]	0
ANDAMENTO produzione:	**domenica 7 febbraio 2021**
# sedili prodotti	1
#sedili Rilavorati dopo collaudo	0
disponibilità	100%
velocità	21%
NON qualità	0%
OEE	5%
produttività diretta	5%
WS010	
causa fermata:	
Attrezzatura	0
Approvigionamento	0
Rework	0
WS020	
causa fermata:	
Attrezzatura	0
Approvigionamento	0
Rework	0
WS030	
causa fermata:	
Attrezzatura	0
Rework	0
Causa fermi linea:	**domenica 7 febbraio 2021**
Attrezzatura	0
Approvigionamento	0
Rework	0
Scarti	**07/02/2021**
GUSCIO SCHIENALE SX	0
GUSCIO SCHIENALE DX	0
GUSCIO CUSCINO PASS	0
GUSCIO CUSCINO DRV 4W	0
GUSCIO CUSCINO DRV 6W SX	0
STRUTTURA 6W	0
Totali	0

Table 20 Input data and KPI computation

In the table above, there a wide number of data that are helpful for the KPI computation. The rows highlighted in green are automatically compiled, due to the fact that are linked to the excel page related to the line performance monitoring, that can be seen in figure 37. Furthermore, the rows highlighted in yellow are compiled by the line-responsible at the end of the shift.

This table will provide some KPI's of interest such as:

- Availability: obtained as $\frac{(T_{available} - T_{stop})}{T_{available}}$ where $T_{available}$ is the overall time at disposal of production without the breaks while T_{stop} is the overall duration of line stoppages;
- Speed: obtained as

$$(\#quality\ pcs + \#discarded\ pcs) * \frac{cycletime}{(T_{available} - T_{stop})}$$

- Non quality as the ratio between the number of seats reworked over the total number of seats produced. It aims at measuring the capacity of the line to produce according to customer quality standards;
- OEE obtained as

$$\frac{cycle\ time * \#produced\ seats}{(\#operators * T_{available}) + (\#overtime\ operators * hours\ in\ ovetime * 60)}$$

Secondly it provides interesting data according to the discarded components and the line stoppage causes.

Based on those data, some plots can be automatically obtained showing in a clearer way the line performances.

5.3 The Excel VBA logic behind the information tool

In order to describe the Excel VBA logic behind the MES like information tool, we will follow the same order of the previous paragraph.

For what concerns the first function, sending the seats orders to the production line, the button "*Commessa alla linea*" works referring to the following Excel VBA function:

```
Sub LISTACOMMESSA()
'
' LISTACOMMESSA Macro
'

'
  Dim GIORNO As String
   Sheets("TMW_WP").Select
   GIORNO = Cells(1, 1)

    Range("A1:D22").Select
    ActiveSheet.ExportAsFixedFormat Type:=xlTypePDF, Filename:= _
        "C:\Users\emilitol\Desktop\Ferrari\rev_tracciabilità\rev_1\COMMESSA.pdf", _
        Quality:=xlQualityStandard, IncludeDocProperties:=True, IgnorePrintAreas _
        :=False, OpenAfterPublish:=True

Dim outMail As Object

  Set outApp = CreateObject("Outlook.Application")
  Set outMail = outApp.CreateItem(0)



With outMail
 .To = " tolaemilio95@gmail.com "
'.CC = inCC_CC@gmail.com 'inserire la mail del destinatario in CC
'.BCC = inBCC_BCC@gmail.com 'inserire la mail del destinatario in BCC
.Subject = ("commessa linea ferrari: " & GIORNO)
.Body = ("Buongiorno, in allegato i codici sedile da produrre in data: " & GIORNO)


.Attachments.Add ("C:\Users\emilitol\Desktop\Ferrari\rev_tracciabilità\rev_1\COMMESSA.pdf")
'.Attachments.Add ("C:\test2.txt") 'inserire il percorso ed il nome del file da allegare
'.Send 'per inviare subito la mail
.Display 'per aprire e controllare la mail prima di inviarla manualmente
End With

Set outMail = Nothing
Set outApp = Nothing

End Sub
```

Figure 39 "Commessa alla Linea" function

First of all, we declare the variable "Giorno" as a string and we associate it to a specific cell inside the selected excel worksheet, called "TMW_WP". In this cell the date is reported. It is important to declare this variable because it will be reported in the subject of the email in order to simplify the warehouse task.

Then the function selects a range of cells, with the command "Range("A1:D22").Select". In this area, the list of seat codes and associated identification numbers of the PADS carton boxes are reported. Once selected, this list is saved a PDF file called “*Commessa*” in a chosen path, through the command “*ActiveSheet.ExportAsFixedFormat*”. Then it creates an e-mail, using the associated Outlook account of the PC, attaching the file just created. It compiles the field related to the subject with the command “*.Subject* “ and the body of the email with the command “*.Body*”. It compiles the address field with the needed mail. By writing the command “*.Send*” we choose to send directly the email or with the command “*.Display*” we can review it and then send it, in a second moment.

A similar code is also at the basis of the button “*Approvigionamento Materiali*”.

```
Sub PDF()
'
' PDF Macro
'
   Dim GIORNO As String
   Sheets("XTMW").Select
   GIORNO = Cells(8, 5)

   Sheets("XTMW").Select
   Range("$A$9:$A$45").AutoFilter Field:=1, Criteria1:="NOK"

  Sheets("XTMW").Select
  Range("B8:E45").Select


    ActiveSheet.ExportAsFixedFormat Type:=xlTypePDF, Filename:= _
        "C:\Users\emilitol\Desktop\Ferrari\rev_tracciabilità\rev_1\LINEA_FERRARI.pdf", _
        Quality:=xlQualityStandard, IncludeDocProperties:=True, IgnorePrintAreas _
        :=False, OpenAfterPublish:=True


Dim outApp As Object

Dim outMail As Object

  Set outApp = CreateObject("Outlook.Application")
  Set outMail = outApp.CreateItem(0)


With outMail
 .To = " tolaemilio95@gmail.com "
'.CC = inCC_CCCO@gmail.com 'inserire la mail del destinatario in CC
'.BCC = inBCC_BCC@gmail.com 'inserire la mail del destinatario in BCC
.Subject = ("FERRARI: Approvigionamento materiali per il giorno: " & GIORNO)
.Body = ("Buongiorno, in allegato la lista dei componenti per garantire la produzione nella giornata del: " & GIORNO)

.Attachments.Add ("C:\Users\emilitol\Desktop\Ferrari\rev_tracciabilità\rev_1\LINEA_FERRARI.pdf")
'.Attachments.Add ("C:\test2.txt") 'inserire il percorso ed il nome del file da allegare
'.Send 'per inviare subito la mail
.Display 'per aprire e controllare la mail prima di inviarla manualmente
End With

Set outMail = Nothing
Set outApp = Nothing


End Sub
```

Figure 40 "Approvigionamento Materiali" code

The main difference in this code is that the range of cells on the base of which the function will generate the pdf file has to be updated at each time the code is run.

This is necessary because the availability of materials along the line has to be checked and updated. For example, if there is still a backrest carbon frame along the line, the warehouse has to refill the line shelves taking into account the amount of backrest carbon frame available.

		Lista per il primo rifornimento della linea Ferrari		13/02/2021
STATU	QUAN TITY	CODE	DESCRIZIONE	BARCODE
NOK	5	AAF173122	GUSCIO SCHIENALE SX	
NOK	2	AAF173101	GUSCIO SCHIENALE DX	
NOK	2	AAF173102	GUSCIO CUSCINO PASS	
NOK	5	AAF173067	GUSCIO CUSCINO DRV 6W SX	
NOK	0	AAF173127	GUSCIO CUSCINO DRV 6W DX	
NOK	2	ACF173100	STRUTTURA 4W	
NOK	5	ACF173093	STRUTTURA 6W	
		PAD		
NOK	1	COMMESSA	340515	
NOK	1	COMMESSA	340529	
NOK	1	COMMESSA	340537	
NOK	1	COMMESSA	340601	
NOK	1	COMMESSA	340601	
NOK	1	COMMESSA	340576	
NOK	1	COMMESSA	340576	
		Lista per il secondo rifornimento della linea Ferrari		
		PAD		

From the table above, the Excel VBA function extracts the components with the left side column equal to "NOK" filtering through the ones that have the left side column equal to "OK". The components are labelled with "NOK" when the number of components in the line is not sufficient too satisfy the production plan.

On the contrary, the component that are already along the line in a sufficient number to satisfy the production line are labelled with “OK”. As it can be imagined, the quantity number needed to be supplied is obtained by subtracting to the quantity of components necessary for the daily production the number of same component that are still available along the line.

Passing to the operator dashboard, we can now consider the blue button, communicating that a seat has been produced and has passed the End of Line tests.

This button writes the time at which the seat is produced on the blue column in figure 37, and automatically in the KPI’s worksheet the number of seats produced is increased of one unity.

```
Sub CLOCK()


   ThisWorkbook.Worksheets("LINE").Select
   i = Cells(1, 22)
    Cells(i, 4) = Format(Now, "hh:mm")
    Cells(1, 22).Value = Cells(1, 22).Value + 1



End Sub
```

Figure 41 "EOL hour" button

In this function it is requested to add a parameter, “i”, that has to be increased each time the button is clicked in order to write the exit hour on the correct seat code row, and not cancelling the one written previously.

For the three line-stoppage buttons, the logic is similar. A parameter is increased for each line stoppage in order to write down the hour at which the line has been stopped each time in a different cell. Furthermore, there is the previously seen function that allows to send emails automatically.

The same coding logic is behind the green button for the line restart.

```
Sub FERMO_010()

   ThisWorkbook.Worksheets("LINE").Select
       j = Cells(2, 22)
    Cells(j, 7) = Format(Now, "hh:mm")
    Cells(2, 22).Value = Cells(2, 22).Value + 1

    Dim outApp As Object

Dim outMail As Object

  Set outApp = CreateObject("Outlook.Application")
  Set outMail = outApp.CreateItem(0)

With outMail
 .To = " tolaemilio95@gmail.com "
'.CC = inCC_PAPERINO@gmail.com 'inserire la mail del destinatario in CC
'.BCC = inBCC_PAPERINO@gmail.com 'inserire la mail del destinatario in BCC
.Subject = ("ATTENZIONE: LINEA FERRARI FERMA")
.Body = ("La linea FERRARI è ferma. Recarsi in linea per gestire il problema")

'.Attachments.Add ("C:\Users\emilitol\Desktop\Ferrari\rev_tracciabilità\rev_1\LINEA_FERRARI.pdf")
'.Attachments.Add ("C:\test2.txt") 'inserire il percorso ed il nome del file da allegare
'.Send 'per inviare subito la mail
.Display 'per aprire e controllare la mail prima di inviarla manualmente
End With

Set outMail = Nothing
Set outApp = Nothing


End Sub
```

Figure 42 Line stoppage code.

The code for the discarded material button contains an email generator code, a decreasing function of the number of item along the line and a function to increase the number of discarded components. Due to the fact that a JIT logic has been implemented, for every discarded material there is the need of a line refill with another item, replacing the discarded one. It is important to record the amount of components along the line in order to keep track along time of the quality of the supplied parts.

```
Sub CUSCINODRV4W()

ThisWorkbook.Worksheets("DD").Select
Cells(5, 27).Value = Cells(5, 27).Value + 1
Dim outApp As Object

Dim outMail As Object

  Set outApp = CreateObject("Outlook.Application")
  Set outMail = outApp.CreateItem(0)


With outMail
 .To = " tolaemilio95@gmail.com "
'.CC = inCC_PAPERINO@gmail.com 'inserire la mail del destinatario in CC
'.BCC = inBCC_PAPERINO@gmail.com 'inserire la mail del destinatario in BCC
.Subject = ("URGENZA: AAF173238")
.Body = ("Portare in linea 1 guscio cuscino DRV 4W: codice AAF173238")


'.Attachments.Add ("C:\Users\emilitol\Desktop\Ferrari\rev_tracciabilità\rev_1\LINEA_FERRARI.pdf")
'.Attachments.Add ("C:\test2.txt") 'inserire il percorso ed il nome del file da allegare
'.Send 'per inviare subito la mail
.Display 'per aprire e controllare la mail prima di inviarla manualmente
End With

Set outMail = Nothing
Set outApp = Nothing

End Sub
```

Figure 43 Discarded components function

Furthermore, in the email object, it is provided the part number of the component, in order to help the warehouse during the refilling operations.

Lastly the button "*Inizio Turno*" has to be clicked in order to reset the previously mentioned parameters and the tables of figure 37, before the start of a new production shift.

```
Sub START()
'
' START Macro
'

    Sheets("LINE").Select
    Range("D3:D22").Select
    Selection.ClearContents
    Range("E3:E22").Select
    Selection.ClearContents
    Range("G5:I22").Select
    Selection.ClearContents
    Range("K5:M22").Select
    Selection.ClearContents
    Range("O5:Q22").Select
    Selection.ClearContents
    Range("V1").Select
    ActiveCell.FormulaR1C1 = "3"
    Range("V2").Select
    ActiveCell.FormulaR1C1 = "5"
    Range("V3").Select
    ActiveCell.FormulaR1C1 = "5"
    Range("V4").Select
    ActiveCell.FormulaR1C1 = "5"
    Range("V5").Select
End Sub
```

Figure 44 "Start of the shift" code

5.4 Suggestions for future improvements

As it was stated at the beginning of this chapter, this is a working tool and it was implemented in some of Sabelt's production line, because it permits to simplify the information flow along the production site. Although its advantages, it is a simple system without the belief to completely substitute a more refined MES system. Furthermore, all the line equipment are arranged to be connected together with a ethernet cable. The actual situation can be improved in the following ways:

- Production planning: the daily schedule list can be automatically sent to the line equipment. The machine reads the list and for each seat code, it allows the operator to start the manufacturing operations. In this way, the scheduling operations is directly communicated to the production equipment, cutting down all the intermediate passages and reducing the error possibility;

- Material consumption and line restock: considering that most of the components that are mounted on the seat have a label, reporting some information such as the part number and serial number, and considering that most of them are flashed with a barcode reader during the process, the list containing the number of components along the line can be automatically updated when the bar code is read. When a certain threshold is reached a refill-notification is sent to the warehouse. The same reasoning can be applied to the discarded components. Once a component has to be discarded, the operator clicks a button on the monitor, selecting discarding intention. Then the bar-code present on the component is flashed and the component discarded.

- Line performance evaluation: considering that the line equipment are equipped with a pc and that on the end of cycle traceability label the hour of production is reported, the data are already owned by the machine, it is only a matter of aggregating them on a common dashboard where line performances are analysed.

- End of line and warehouse interactions: once the seats are produced are laid down in a buffer at the end of the line waiting for the collection from the warehouse operators. With a more structured system, a notification can be sent to the warehouse when each seat kit, driver and passenger seats, is produced and ready to be collected, in order to free the buffer area as soon as possible. Another possible way of improvement can be an AGV network. Once the kit is ready to be collected, a collection request is sent to the AGV in order to pick up the kit and carry to the warehouse. This latter way of improvement will be analysed in the following chapter.

6 AGV’s implementation

Before going forward with the analysis to dimension and introduce AGV’s into the production site, it is necessary to do a brief introduction with some key concepts. First of all an AGV is a fixed are conveyance system capable to orient, drive and steer without a direct human control. Those type of vehicles are :

- Capable to orient themselves without the being controlled by an operator;
- Able to garantee the order executions in a safe way, taking care of protecting people and facilities;
- Able to communicate with the other systems and they integrate themselves in the surrounding.

6.2 Navigation system and safety components and equipment

In order to guarantee the previously mentioned functions, those vehicles need some protocols to let them orient, navigate in a safe way. The concepts navigation and safety seem not to be so linked but in the AGV working protocols are interconnected.

First of all, navigation is the way in which the vehicle knows where it is located, where it has to go and which movements should be done in order to arrive to the destination.

Generally, the AGV’s moves in a certain area, that is represented in a fixed reference system The AGV operates only in the area defined by this coordinate system. Furthermore, a mobile reference system can be installed on the vehicle itself: useful to know the movements of the payload.

Once defined the environment in which the vehicle has to move, a protocol and a system to determine the position in the reference system has to be implemented. Two basic principles can be applied: dead reckoning and bearing taking. (Ullrich)

The former is similar to odometry and uses internal sensors to determine the position: e.g. angle sensor on the wheels or a magnetic compass. A Ullrich said, this system is imprecise by nature. It can be affected by various variables such as loss of grip under the wheels or a variation in the curvature angle due to increased payload. At this proposal, a special measuring wheel is installed under the carriage to register the most precisely as possible the movement of the AGV.

Although the trials there are still some errors in the positioning and that is the reason why it is necessary to take bearings. Those reference points can be active technologies ones, such as reference points, or fixed and passive ones, called surrounding points, such as the wall contour that can be taken as a reference.

On the AGV market we can find vehicles using different types of navigation system.

- **Physical guideline**. This type of navigation method relies on the fixtures on the floor. There are several technologies: actively inductive guidance track, passively inductive guidance track and optical guidance track. Under the actively inductive vehicle there are two coils in which there is passing a current induced by the guidance track on the floor, similar to the train railway. Each section can be switched on and off . The difference in current between the two coils measures the deviation from the guiding railway and it guides the vehicles. In the passive inductive guidance track a metal strip is on the floor. Some magnetic field detectors under the vehicle notices the metal strip and guides the vehicle. Furthermore, the optical guidance ones rely on colored stripes on the floor. The vehicle is provided with a camera that is detecting the difference in colours and that guides the vehicle by giving feedback to the motor. When there is a simple plant layout, the passive inductive or optical track is the most cost-efficient option, according to Ullrich.

- **Anchoring points on the floor**.

This type of navigation relies on dead reckoning to compute the guide line but it takes advantages of the anchor points that are present on the floor in order to take bearings. Those reference points can be of different types. They can be permanent magnets or “ quasi active transponders”. The former have a nort-south poling and they are placed in holes on the floor, where the magnet is fastened with an epoxy adhesive. The number of points depends on the AGV type and its manufacturer.

The latter type is generally used for outdoor applications. The quasi active transponders are set into the floor in place of the passive magnets. The vehicle reading unit induces energy into the transponders, that send their own identification position code to the unit and allow to the vehicle to compute its position with extreme precision.

- **Laser navigation.** This type of navigation protocol is the most well known system and permit to have the most flexible solution in terms of vehicle path and navigation. The AGV is equipped with laser scanners detecting reflectors, that are artificial landmarks, and surrounding contours, facilities landmarks. The navigation procedure is extremely flexible: new routes can be created by using particular, "teach in", training functions. The laser scanners continuously scans the surrounding environment and detecting the landmarks and references points taken during the start-up procedure computes its position in the space.

As said before, the navigation is strictly related to safety. Legislation about AGV is strict, especially in Europe. The safety equipment required for AGV's is listed in the DIN EN 1525 and DIN EN 954. The technical requirements can be summarized below:

- As the AGV is an industrial machine has to be equipped with an emergency button, that can be easily recognized and accessed by everybody. Once the button is pressed the vehicle has to stop immediately;
- The vehicle should be visible, even from a great distance. AGV's are generally equipped with luminous signs, changing colour according to the state of the vehicle: e.g. red means an emergency stop, blue means that it is recharging the batteries and green it is moving.
- The presence of a moving AGV has to be signalled even in case of places where the visibility is limited. The vehicle is generally emitting a beeping sound in order to signal its movement;

- The vehicle and the drive path should be provide with bumpers and personnel safety features in order to avoid damages or injuries in case of collision. Those features can include devices capable to stop the vehicle once detected the obstacle before the person is injured or the object is damaged.

6.3 AGV categories and typologies

On the market there are a wide variety of automated guided vehicles that can be used in production facilities to support the intralogistics of the plant and the choice of the right one can be complex. The main elements to consider are the following:

- the size and the number of vehicles in the plant;
- the complexity and the organization of the material flow within the plant;
- the load to be moved and the constraints in relation to the material handling and transportation;
- the operating conditions;

According to Gunter Ullrich the main categories are the following:

Pos.	Designation	Load	Description
1	Forklift AGV specially designed	Pallet	Floor-level load pickup, various heights, standard or special pallets or other fork-compatible containers, stackable, typical payload: 1 t. Conceived, designed and produced by AGVS manufacturers
2	Forklift AGV as automated serial vehicle	Pallet	As in 1, but: the AGVS manufacturer uses a serial product from a forklift manufacturer and automates it with the necessary AGV equipment
3	Piggyback AGV	Pallet	Usually limited to one transfer height (e.g. 1 m), side load pickup using roller tracks or chain conveyor, typical payload: 1 t
4	Towing vehicle	Trailer	"Tugger". Pulls multiple trailers, typical total weight of trailers: 5 t
5	Underride AGV	Roller container	The standard AGV in such places as hospital logistics. It underrides the roller container, and lifts it for transport. Typical payload: 0.5 t
6	Assembly AGV	Assembly object	Use in serial assembly, a substructure holds the pickup for the assembly object. Typical payload: up to 1 t
7	Heavy load AGV	Rolls, coils (paper or metal)	Transporting heavy paper rolls or steel coils up to 35 t
8	Mini-AGV	SLC	Use in large fleets, e.g. for commissioning.
9	PeopleMover	Passengers	For conveying passengers, similar to small or large buses
10	Diesel AGV	Diverse	Outdoor vehicles, usually diesel-electric or diesel-hydraulic drive. Typical payloads ≥3 t. Examples: Diesel forklifts, trucks, wheel loaders, harbor AGVs for ship containers
11	Special AGV	Diverse	Special solutions for special tasks. All AGVs that do not fit one of the above categories

Figure 45 Categories of Automated Guided Vehicles

The first seven categories are the most common in the production and in the following paragraphs a brief overview of the main characteristics of some of them will be done.

6.3.1 Forklift AGV

The main task of the first two categories of AGV's is to transport and lift loads at different heights. It is generally provided with forks, allowing to move pallets. The main difference with a manually driven trans-pallet is that the forks follow the vehicle, for safety reasons. On the market there are various manufacturers offering specifically designed solutions or automated serially designed products. The main advantage of the latter solution is a cost advantage through serial manufacturing and a proven service and replacement parts availability.

6.3.2 Piggyback AGV

This vehicle works with the traditional loading aids but differently from the vehicles previously mentioned those AGV's cannot lift loads directly from the floor. They require a certain height, generally around 60 cm. Due to their better load handling and maneuvering capacity, it is requested less space in respect to the forklifts AGV's.

6.3.3 Towing AGV

This type of vehicle permits to tow one or more carts, through the use of a hook and a series of smaller hookes between the carts. It is possible to automoatize the hooking and unhooking operations. Increasing the number of carts, the vehicle has a larger radius of curvature. For this reason the use of this type of vehicle is suggested for wider production facilities and where the distance to be overcome is significant.

6.4AGV fleet designing steps

In order to properly design a AGV system, some key steps have to be taken into account. The main parameters to be defined are: path's layouts, the number of robots and the task assignment protocol.

6.4.1 Path layout

The problem related to the complexity of an AGV fleet system can be minimized by using different types of layouts. In the following paragraph, the most important will be considered.

The first to be considered is the simplest one: the conventional one. In this layout, the AGV is free to serve every workstation and it can move along every possible path. The main drawback of this system is the increasing level of complexity with the increase in number of the vehicles. In particular, within this model, two solution can be highlighted:

- **Single loop**: this model looks for shortest closed loop that connects all the workstations. The advantage of this model is that it allows to all the AGV's present in the facility to run continuously in the same direction, avoiding collisions and reducing the traffic congestion.
- **Bi-directional shortest path**: this model on the other side look for the shortest path that connects all the workstations, it minimizes the efficiency, reducing the covered distance.

Another model of our interest is the tandem solution. This model divides the plant surface in different areas, not overlapping, each of them served by a different AGV. This model generates two big problems. The first one concerns the movement of the loads between one area and the other one. This implies to create some load exchange workstations. Another problem is related to the inefficiency of the system in the case in which one area is not completely saturating the AGV capacity. This implies a careful subdivision of the areas in order to find the best overall AGV system capacity saturation and efficiency.

6.4.2 Dimensioning of the AGV fleet

There are two main methods to determine the dimension of the AGV fleet: one is analytical while another way is performing a material flow simulation. The first method is generally used for small AGV fleet, since it has increasing level of uncertainty with the increasing number of AGV's involved. On the contrary the simulation allows to have more precise solution.

In order to dimension the AGV fleet analytically, formulas and equations have to be used. One formula that is widely used is the one developed by Fitzgerald in 1985. It is rather simple but effective.

$$C = \sum_{i=1}^{k} \frac{(N_i * t_i)}{n_i * h}$$

Where:

- C is the number of vehicles that are needed,
- N_i is the number of parts per day that have to be transported,
- t_i is the transport time, also considering the loading and unloading phase,
- n_i is the number of units to be transported in each vehicle,
- h is the number of hours in which the AGV's are working,
- i the index referring to different type of products to be transported, ranging from 1 to k: e.g. the product A is associated to i=1 while product B has i=2 and so on.

Since this dimensioning technique has a quite high level of uncertainty, it is applied to small AGV systems, while for more complex cases more refined models are applied.

6.4.3 AGVS guidance control and task assignment protocol

The VDI defines the AGV guidance control as a system consisting of a software and a hardware, that runs one or more computers, serving to coordinate the the AGV fleet and to integrate it with the surrounding environment of the facility.

In particular, wireless communication system provide the connections to various vehicles composing the fleet and also integrate various devices and other peripheral equipment.

Going more in details, the guidance control system is accessible by the user through the so called user interface. On one side it allows the interaction between the human and the machine and on the other side it gives the possibility to communicate between the vehicles through the machine-machine interface.

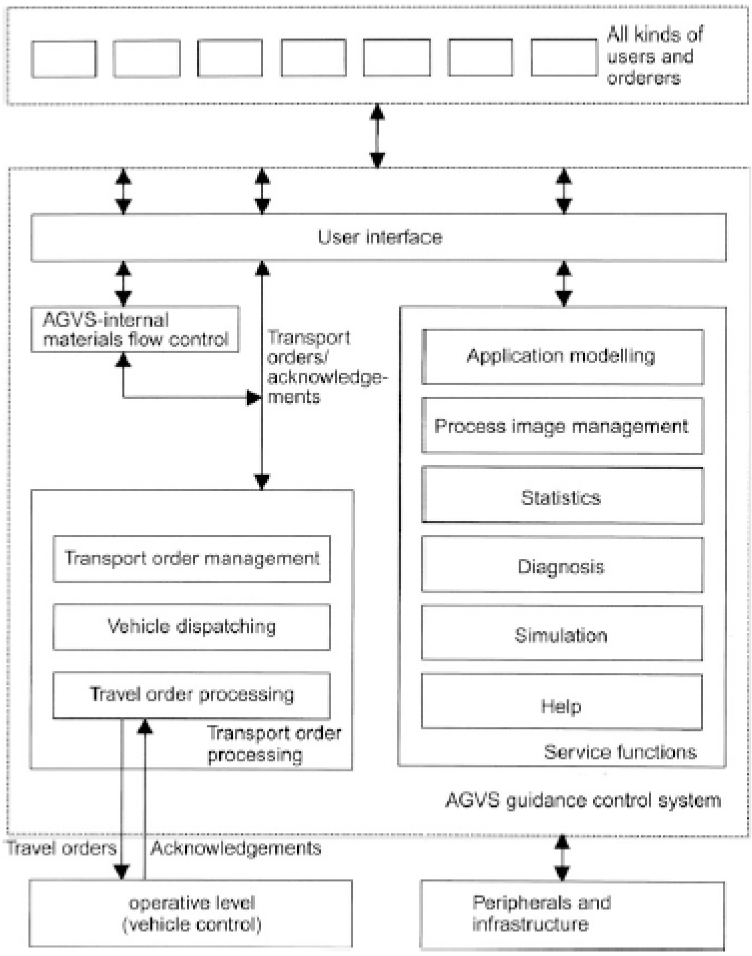


Figure 46 Functional set up of an AGV guidance control system (Ullrich)

In the table above the we can observe how the guidance control works. By starting with the need of a certain good X at workstation Y, the information that has to be given to the vehicle is to move a load from location A to location B. The internal material flow control combines the source and the sink of the with the transport relationship entered through the transport order entered by a user. It manages the order and dispatches to the vehicle. The vehicle executes the order and move the load from the source to the destination. So summarizing the key steps of a certain transport order entered by a user are the following:

- Transport administration: the transport order are received and ranked according to a certain priority, e.g. FIFO rule or LIFO;
- Vehicle dispatching: the guidance control function founds the best AGV to assign the transport order. Different strategies can be used. It can be random or some more refined protocols can be implemented: e.g. shortest time or distance to the source. In the following chapter some vehicle dispatching strategies will be analyzed;
- Travel order processing. It ensures problem free movement for the AGV especially at the intersections and in high intensity areas, preventing collisions and blockages. Generally the traffic guidance control is based on the traditional process of dividing the AGV network into blocking areas. A vehicle is generally not allowed to enter a certain area.

6.4.4 Vehicle dispatching strategies

In the AGV literature, there are two protocols that are used in order to dispatch the travel order to the vehicle.

The first one is the "**machine initiated dispatching problem**" where some AGVS are waiting for travel orders. In this case the software is deciding at which vehicle to assign the order.

The second protocol is the " **vehicle initiated dispatching problem**" where some travel mission are waiting that a vehicle is free to execute the order. In this case a list of mission will be created, according to different types of priority

For each of these strategies, different type of priorities exists, as it can be seen from the table below:

Machine initiated dispatching problem	
Random vehicle	Casually assigned
Nearest vehicle	The nearest vehicle to the load position
Farthest vehicle	The farthest one
Longest idle vehicle	Assigned to the AGV that has waited longer

Table 21 Some example of machine initiated dispatching protocols

Vehicle initiated dispatching problem	
Random machine	Randomly assigned
First call first served	The order list is generated following a chronological order. The first workstation that generates the order is served first.
Shortest travel time	The first free vehicle is assigned to the closest workstation, in order to minimize the unloaded travel time
Maximum outgoing queue size	The free robot are assigned to the workstation with the highest buffer size.

Table 22 Some example of vehicle initiated dispatching protocols

7 AGV's in Sabelt production plant

This chapter starts with a brief analysis of the finished product flow from the End of Line station to the warehouse, essential to study an AGV solution for the plant. Then the AGV fleet is dimensioned theoretically and with the support of a simulation software: FlexSim. The simulation of the material flow supports the dimensioning of the AGV fleet and consequently of the buffer at the end of line stations.

7.1 Finished product flow

Once the seat has passed the End of Line checks and functional test, the operator has to inspect it, looking for aesthetical defects. At the end of this inspection, the seat is packed and moved to the End of Line buffer. Generally, the car-makers are ordering kits of seats: a set of two seats, a driver and a passenger ones with the same features. For this reason, the seats to be moved to the warehouse have to be coupled. Once the kit arrives in the warehouse, they are packed and some administrative tasks are performed. The movement of seats between the end of line buffer and the warehouse is generally done with some big carts, where the warehouse operators place the seats and move them to the packing area. This flow is discontinuous and irregular and highly subjected to the shipping requests. The main drawback of this material flow is that most of the time, the seats remain on the ground and only when they are required to be shipped, they are collected and moved to the packing area. Since the seats are aesthetical components in the interior of the car, the main risk by placing them on the ground is to easily damage them. Furthermore, the dimensions of buffer at the end of the line is not negligible.

By implementing an AGV system in the production plant, one advantage is that once the kit is complete, it is immediately moved to the warehouse where is packed and stocked, ready for the shipping.

According to the typology of finished product to be transported, the choice is between two main types of AGV's: the piggyback one and the towing one. This is due to the fact that the kit of seats is loaded by the End of Line operator on a cart and then the cart has to be moved from the production line to the warehouse. Once defined the typology of cart to be used, it is possible to define the most suitable AGV. Two examples of carts that can be used can be found in the appendix. In order to be loaded with a kit of seats, they need a surface with the following dimensions: 120*60 cm.

For the following computations, the specifications of the MIR 100 will be considered, because this kind of AGV can be used both as a piggyback AGV and as a towing one, with mounting of a specific hook. Mir 100 specifications can be found in the appendix.

7.1.1 AGV fleet dimensioning

In order to properly dimension the AGV fleet, it is necessary to bear in mind the amount of material that the system has to support.

Production line	KIT/DAY	SEATS/DAY
M240	7	14
P16	7	14
M240 MONO	3	6
P16 MONO	4	8
P22	7	14
RENAULT	11	22
FERRARI	7	14
ASTON MARTIN	10	20
SEAT	23	46
ABARTH	25	50

Table 23 Finished product flow: from the end of line station to the warehouse

In the table above, the maximum line capacity in a shift is reported. The production lines highlighted with the same colour share the same end of line buffer, so the finished products have to be collected in the same place by the AGV.

Furthermore, in the figure below, we can observe how the production lines are located in the production facility. We can notice that main central aisle has a L-shape.

Figure 47 Plant layout: AGV path and picking points

In pink, the AGV path and the AGV picking points are drawn. The main distance between the various picking points and the warehouse can be summarized in the following table:

	KIT/DAY	SEATS/DAY	Distance from WH [m]
M240	7	14	43
P16	7	14	
M240 MONO	3	6	27
P16 MONO	4	8	
P22	7	14	
RENAULT	11	22	30
FERRARI	7	14	14
ASTON MARTIN	10	20	12
SEAT	23	46	33
ABARTH	25	50	54

Table 24 Distance between the picking point and the warehouse.

By recurring to the Fitzgerald theoretical formula, it is possible to have first idea about the number of AGV's necessary to support to the production flow.

$$C = \sum_{i=1}^{k} \frac{(N_i * t_i)}{n_i * h}$$

Where:

- C is the number of vehicles that are needed,
- N_i is the number of parts per day that have to be transported,
- t_i is the transport time, also considering the loading and unloading phase,
- n_i is the number of units to be transported in each vehicle,
- h is the number of hours in which the AGV's are working,
- i the index referring to different type of products to be transported, ranging from 1 to k: e.g. the product A is associated to i=1 while product B has i=2 and so on.

	KIT/DAY	SEATS/DAY	distance from WH [m]	travel time [min]	tot time [min]	tot time [hour]	#AGVs
M240	7	14	43	2.4	5.4	0.0898	0.07859
P16	7	14		0.0	3.0	0.0500	0.04375
M240 MONO	3	6	27	1.5	4.5	0.0750	0.02813
P16 MONO	4	8		0.0	3.0	0.0500	0.025
P22	7	14		0.0	3.0	0.0500	0.04375
RENAULT	11	22	30	1.7	4.7	0.0778	0.10694
FERRARI	7	14	14	0.8	3.8	0.0630	0.05509
ASTON MARTIN	10	20	12	0.7	3.7	0.0611	0.07639
SEAT	23	46	33	1.8	4.8	0.0806	0.2316
ABARTH	25	50	54	3.0	6.0	0.1000	0.3125

Table 25 AGV fleet dimensioning

In order to compute t_i , it is considered also the unload and loading time. As a reference speed is considered the one of the MIR100. This computation gives us the result of 1.07257. It means that 1.07257 AGV's are needed, in order to guarantee a continuous flow of finished product from the end of line station to the warehouse.

As said before the Fitzgerald formula is rather simple, for this reason, a more realistic computation is necessary, in order to a have a more precise dimensioning of the AGV fleet. For this goal a discrete-event simulation software is used: FlexSim.

7.2 AGV and buffer dimensioning through a discrete event simulation software

In order to analyse correctly the flow of the finished products from the end of line station to the warehouse it is necessary to model the facility production lines on the software environment.

One production line can be modelled using the following 3D objects:

- A flow item: it is the element that flows from one station, generally a fixed resource to another downstream station. In our simulation, the seat to be produced is the flow item,
- A source that creates the flow item. Each source represents the seats demand. For every element we can set various parameters. The most important is the interarrival time, allowing us to set the customer demand in the model.
- A processor is added to simulate the line processing time. As for the source, also here the process time is a parameter that can be set, in order to make the model closer to the reality.
- A queue is the element that allows to store flow item when they cannot be sent to the downstream station. In our case it is inserted in order to store flow items until they cannot be sent to the warehouse. This 3D element represents the buffer at the end of line. One of the objectives of this simulation is also to dimension those elements. An important aspect to notice here is the parameters regarding the "Output" section. The flow item can be sent to the following station, in our case the warehouse, only when the batch is complete, that's means two seats have to be produced and waiting in the buffer. Furthermore, the transport has to use a Task Executer item, in our case an AGV.

Once those elements are inserted into the model, they have to connected, using a port-connection. Therefore, only when each fixed resource, such as the source, the processor and the queue, are port-connected they can exchange flow items.

Secondly the AGV path has to be drawn. For the sake of this simulation, a single loop is drawn, maintaining the original dimensions of the facility, in order to correctly have a realistic understanding of the time employed by the vehicle to perform the loop. Each segment of the loop is represented using the 3D element called “Straight path” and they are joined together using the command “Join paths”. The following step to be followed is to position the control points along the AGV network. They are the basic building block of the AGV logic in the network.

A control point is a place where the AGV can:

- Pick up or drop off the flow item;
- Wait, before entering into a certain area. The control point acts as a stopping point;
- Decide what to do, for example it can stop there waiting for the assignment of tasks.

An important aspect to bear in mind during the designing of an AGV network is to prevent the collisions and deadlocks between multiple AGV’s along the path. AGV’s have a sophisticated look-ahead mechanism able to avoid crashes, by looking at the following control point on the path. Infact the AGV, automatically allocates itself to the following control point of the path before proceeding. In case the control point is occupied by another vehicle, it will wait until the point is not free. For every end of line buffer, a control point is positioned. In this case the control point acts as a pick-up location. A control point is added also near the warehouse, and in this case the control point acts as a drop off one.

The AGV’s is modelled using the “task executer” 3D object. The last element to be added to the model is the “Dispatcher”. This object is used in order to control a group of transporters or operators. Task sequences are generated by flow items and sent to the dispatcher that delegates them to the transporter or the operators that are connected to its output ports. The task sequence will be performed by the mobile resource that receives the request. In our case, the task sequence are the various requests of movement of the kits of seats from the end of line buffer to the warehouse, while the mobile resource is the task executer, and so the AGV.

For the sake of the simulation a vehicle initiated dispatching protocol is used, in particular a first called first served is adopted: the first workstation that generates a task is served.

The final result in the software environment is the following:

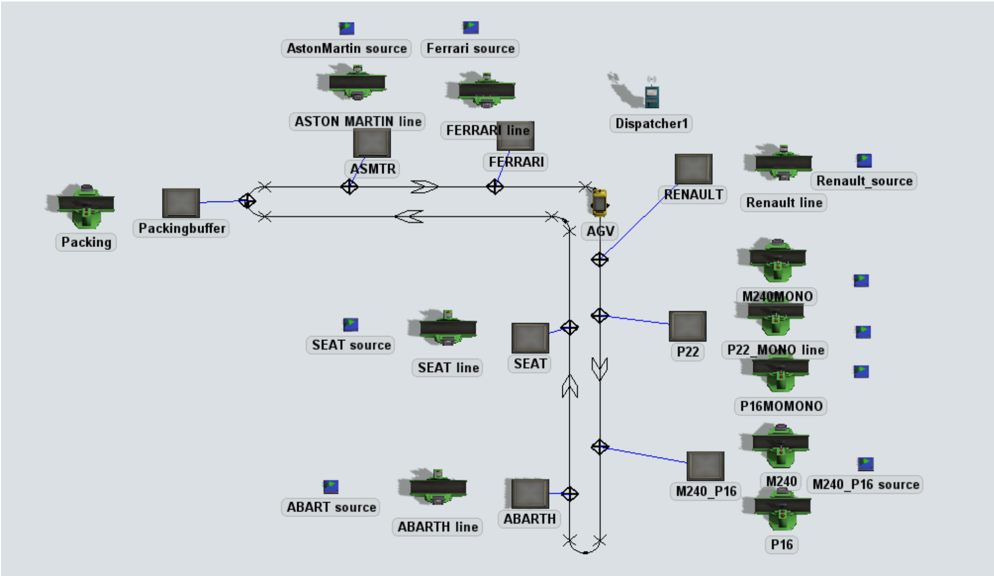


Figure 48 Production facility model on FlexSim

7.1.1 Obtained results from the software simulation

The Fitzgerald formula gave us the minimum number of vehicles to support the facility material flow. A first simulation is run using just one AGV. Two parameters have to be taken under control: the number of flow items in the queue, waiting for transportation and the stay time of each flow item in the queue.

Running the simulation with just one AGV serving all the lines, the following results are obtained. The number of seats in the buffer are then rounded up to have a more realistic insight on the buffer dimensions.

	KIT/DAY	SEATS/DAY	Buffer dimensions, 1 AGV [#seats]
M240	7	14	6.35→7
P16	7	14	
M240 MONO	3	6	6.36→7
P16 MONO	4	8	
P22	7	14	
RENAULT	11	22	5.02→6
FERRARI	7	14	3.44→4
ASTON MARTIN	10	20	4.7→5
SEAT	23	46	10.21→11
ABARTH	25	50	10.67→11

Table 26 Buffer dimensions at the end of line station with one AGV serving all the lines.

The data related to this computation are extracted by the simulation dashboards, that is recording the number of flow items in each queue on charts. As we can see from the charts below, there is a warm-up period, after which the amount of flow items remains constant.

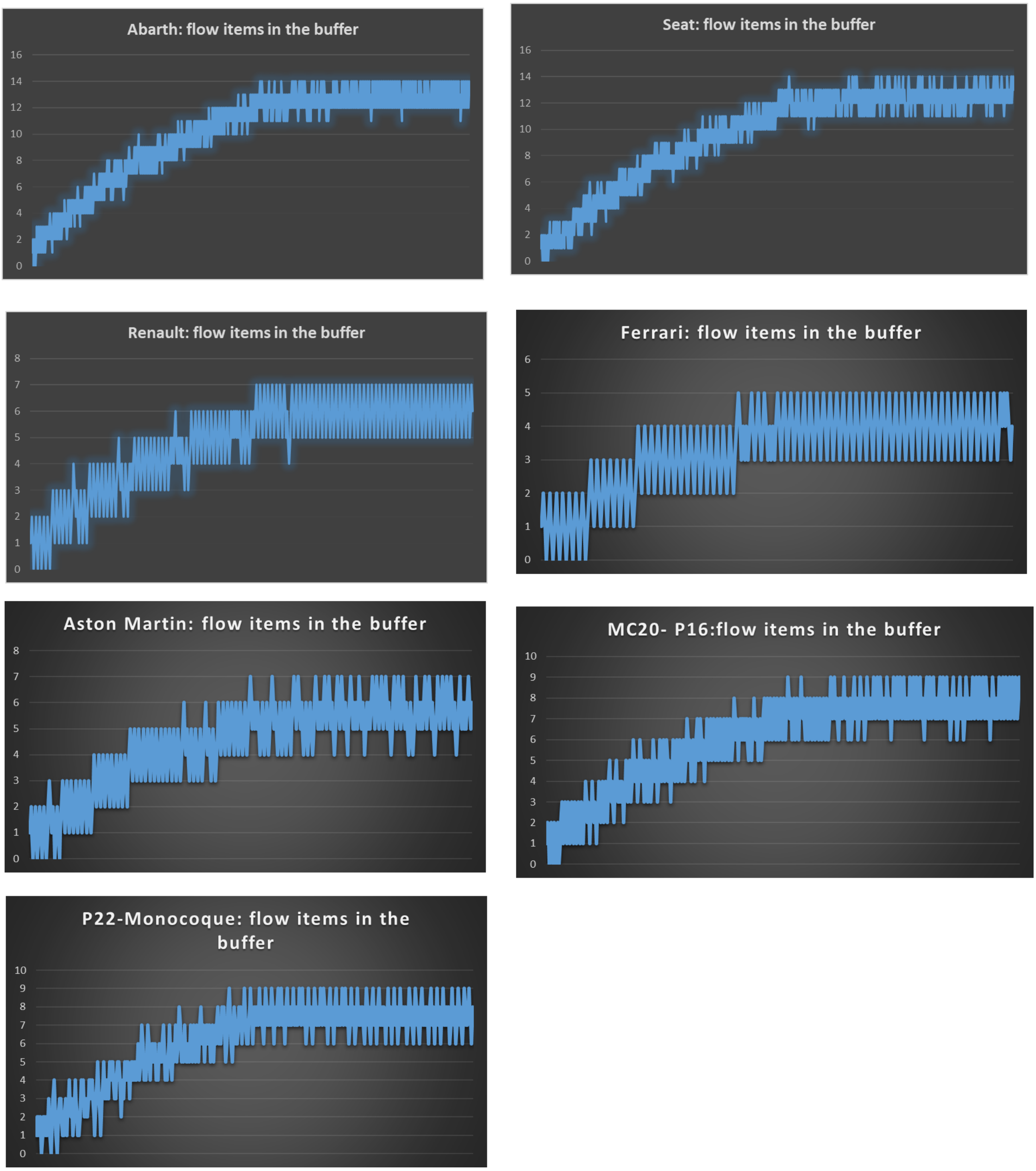


Figure 49 Flow items in queue in the buffer at the end of line workstation

Another important parameter that was tracked during the simulation is the stay-time of each flow item in the buffer, waiting for transportation to the warehouse.

	KIT/DAY	SEATS/DAY	Average stay-time with 1 AGV [min]
M240	7	14	133
P16	7	14	
M240 MONO	3	6	132
P16 MONO	4	8	
P22	7	14	
RENAULT	11	22	138
FERRARI	7	14	136
ASTON MARTIN	10	20	128
SEAT	23	46	123
ABARTH	25	50	128

Table 27 Flow item average stay time in the buffer at the end of line station

As done for the average number of seats in the buffer at the end of line station, the average stay time is computed considering the steady state conditions, without taking into account the warm-up period. In the figure below, there are the related charts.

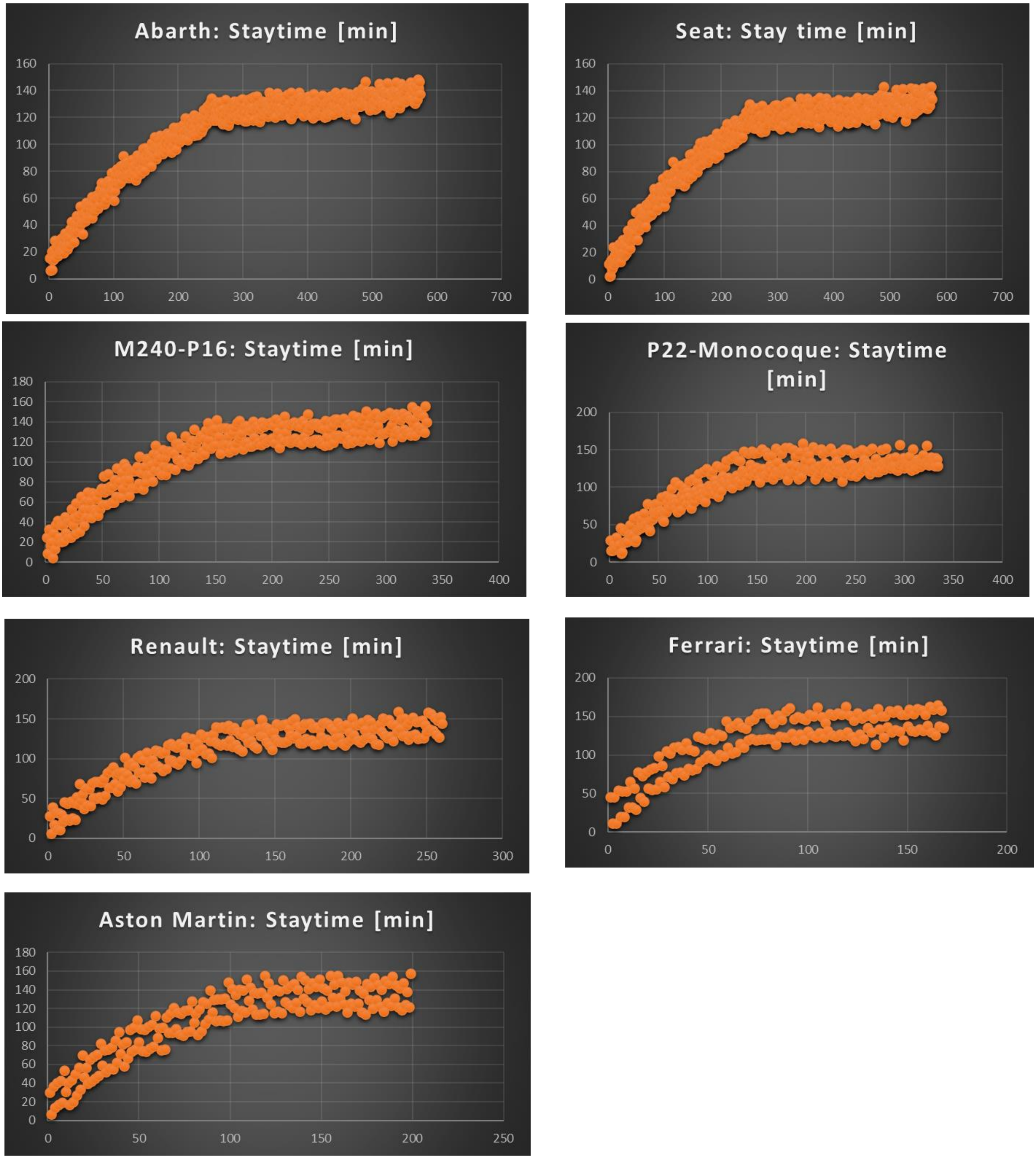


Figure 50 Flow item stay time at the end of line station, with one AGV serving the lines

By inserting one additional AGV in the loop, we obtained the following results:

	KIT/DAY	SEATS/DAY	Buffer dimension, 1 AGV [#seats]	Buffer dimension, 2 AGVs [#seats]	Reduction [%]
M240	7	14	6.35→7	2.49→3	61%
P16	7	14			
M240 MONO	3	6	6.36→7	2.48→3	61%
P16 MONO	4	8			
P22	7	14			
RENAULT	11	22	5.02→6	2.03→3	60%
FERRARI	7	14	3.44→4	1.49→2	57%
ASTON MARTIN	10	20	4.7→5	1.94→2	59%
SEAT	23	46	10.21→11	3.69→4	64%
ABARTH	25	50	10.67→11	4.14→5	61%

Table 28 Buffer dimensions at the end of line station with two AGV's serving the lines

We can notice a significant reduction both in terms of seats and of stay time in the buffer at the end of line station.

	KIT/DAY	SEATS/DAY	Average stay time with 1 AGV [min]	Average stay time with 2 AGV [min]	Reduction [%]
M240	7	14	133	21.69	84%
P16	7	14			
M240 MONO	3	6	132	21.886	83%
P16 MONO	4	8			
P22	7	14			
RENAULT	11	22	138	23.97	83%
FERRARI	7	14	136	30.10	78%
ASTON MARTIN	10	20	128	25.85	80%
SEAT	23	46	123	16	87%
ABARTH	25	50	128	21	84%

Table 29 Average stay time in the buffer with two AGV's serving the line

From the charts below we can observe that the warm-up effect, observed before is quite negligible.

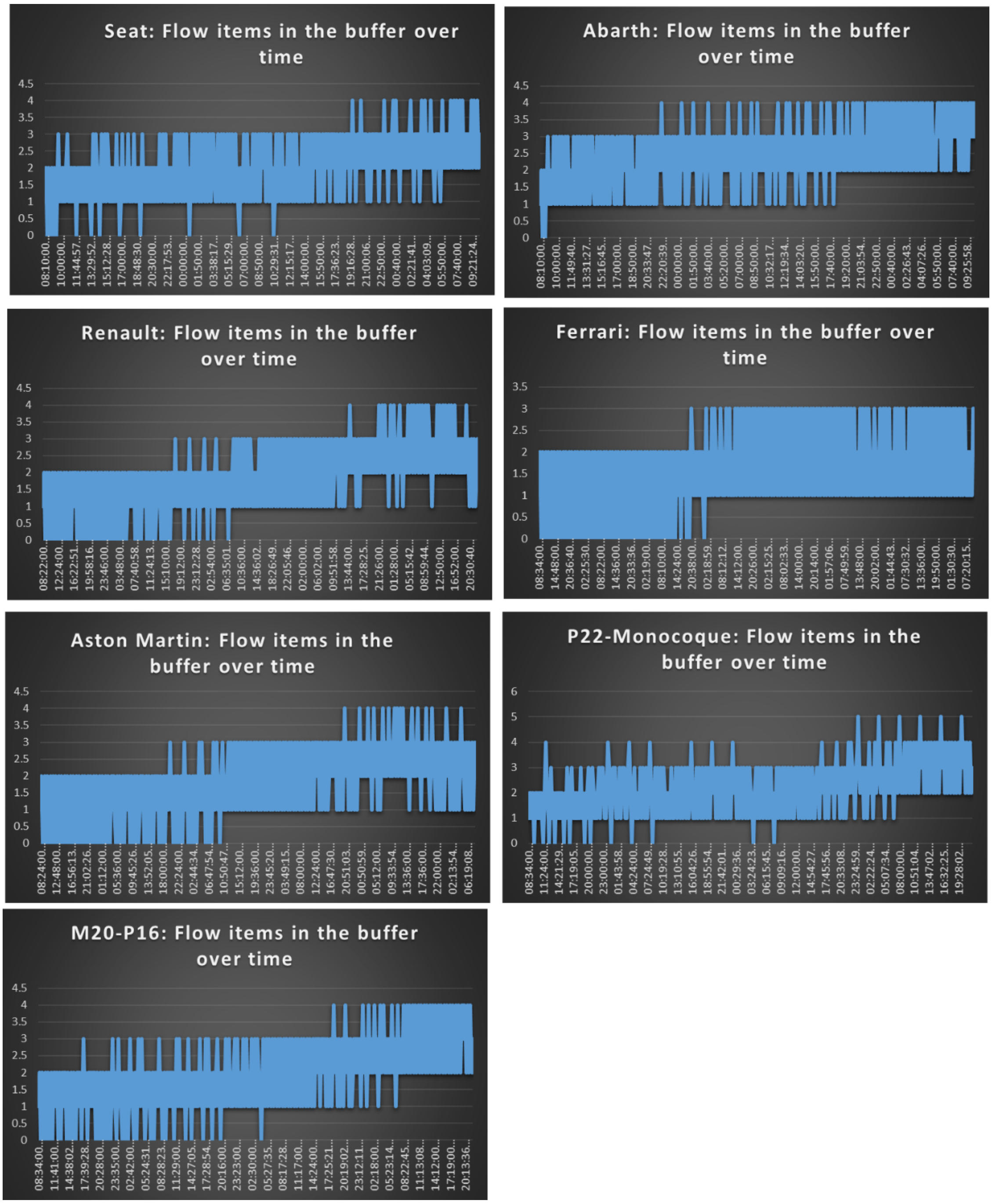


Table 30 Flow items in the buffers at the end of line stations with two AGV's serving the lines

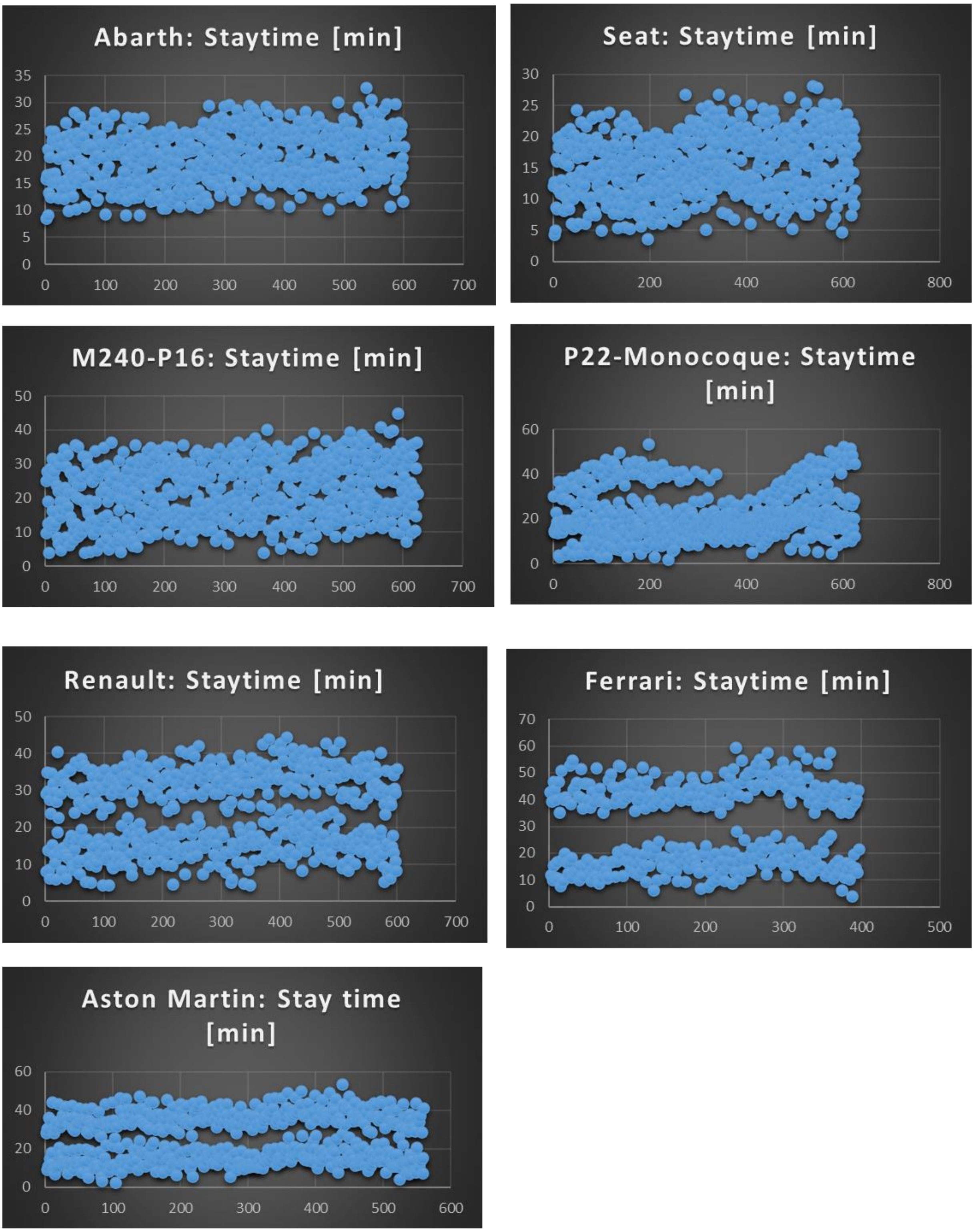


Figure 51 Stay time in the buffer at the end of line station with two AGV's serving the lines

By looking at the last three charts, connected to the Renault, Ferrari and Aston Martin lines, we can observe that the datas are spread over two main regions in the plot. For example, in the Aston Martin chart, half of the datas are along the value of 15 minutes and the other half is along the value of 35 min. This is due to the fact that the transportation request is sent to the AGV only when the kit of seats is complete. Therefore, the first seat of the kit that is produced waits more time in the buffer than the second one.

7.1.2 Benefits, limitations and future improvements

The introduction of the AGV fleet into the production facility has improved the efficiency, without a loss in flexibility.

The new transportation method has optimized the material flows in terms of performances, safety and ergonomics. It reduced the quantity of materials stocked along the line, decreasing the scrap rate during the material handling. Furthermore it reduced the ergonomics risk at which the warehouse operators are exposed, by lifting seats of more than 20/25 kg.

The chosen transportation method makes the material flows more efficient, without affecting the flexibility of the system, allowing to follow the market trends and customer requests: the increase of demand for certain product or the decrease for another one affects only the task sequence list the AGV fleet has to follow. Furthermore, it allows to implement in a practical way the FIFO rule.

One limitations of this study is the contemporary presence of two AGV's in the same plant aisle. Even thought the two AGV's are sophisticated enough to avoid crashes and collisions and the aisle is sufficiently large to be occupied by two AGV's, the potential risk has to be investigated carefully with the AGV provider. At this proposal, the speed of the AGV has to be reduced, taking into account the contemporary presence of both of them.

Another limitation of the study that has to investigated carefully before implementing the solution, is the Wi-Fi signal all over the plant. Without a full coverage over the plant the fleet is unable to work properly.

Lastly, before implementing a system of this type is common practice to perform cost/benefit analysis, comparing the actual Full time equivalents with the ones of the future scenario. For the scope of this thesis, it was not possible due to privacy agreement between the company and the cooperative that is currently managing the warehouse operators and the store house.

Although the previously mentioned limitations of the study, some considerations about the future improvements can be done. First of all, in the future months new business opportunities will be developed a couple of two lines will be industrialized in the future months. Consequently, the plant layout will be completely re-designed, in accordance with the manoeuvrability constraints of the AGV fleet. Secondly, it is highly recommended to develop a MES system completely integrated with the AGV software. The two systems should communicate one with the other one, exchanging information. The task sequence list that is governing the AGV transportation should be provided and compiled by the MES system.

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APPENDIX

Sabelt RICHIESTA MATERIALE DATA:

Codice	Descrizione	QTA RICHIESTA	QTA GESTITA	DA MAG	A MAG	DA UBICAZONE	A UBICAZIONE	DA CDI

Figure 53 Module for material requests from the warehouse

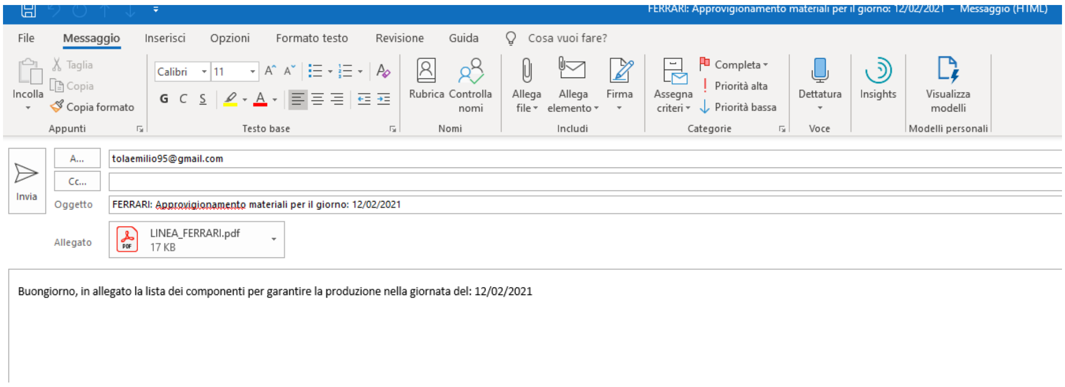

Figure 52 Automatically generated mail to the warehouse to communicate the componenets needed

	Lista per il primo rifornimento della linea Ferrari		12/02/2021
QUANTITY	CODE	DESCRIZIONE	BARCODE
5	AAF173122	GUSCIO SCHIENALE SX	
2	AAF173101	GUSCIO SCHIENALE DX	
2	AAF173102	GUSCIO CUSCINO PASS	
5	AAF173067	GUSCIO CUSCINO DRV 6W SX	
0	AAF173127	GUSCIO CUSCINO DRV 6W DX	
2	ACF173100	STRUTTURA 4W	
5	ACF173093	STRUTTURA 6W	
	PAD		
1	COMMESSA	340515	
1	COMMESSA	340529	
1	COMMESSA	340537	
1	COMMESSA	340601	
1	COMMESSA	340601	
1	COMMESSA	340576	
1	COMMESSA	340576	
	Lista per il secondo rifornimento della linea Ferrari		
PAD			

Figure 54 List of the components in attachment to the automatically generated mail

Sabelt — DICHIARAZIONE PRODUZIONE F173

CODIFICA	REV:
M.BP.SA-215	0
NUMERAZIONE	

POSTAZIONE	DALLE H	ALLE H	CODICE OPERATORE	GSX	GDX	MATRICOLA SCOCCA						NOTE
SETTIMANA							1	4W	6W	SX	DX	
							2	4W	6W	SX	DX	
LUNEDÍ							3	4W	6W	SX	DX	
MARTEDÍ							4	4W	6W	SX	DX	
MERCOLEDÍ							5	4W	6W	SX	DX	
GIOVEDÍ							6	4W	6W	SX	DX	
VENERDÍ							7	4W	6W	SX	DX	
SABATO							8	4W	6W	SX	DX	
							9	4W	6W	SX	DX	
							10	4W	6W	SX	DX	
							11	4W	6W	SX	DX	
							12	4W	6W	SX	DX	
							13	4W	6W	SX	DX	
							14	4W	6W	SX	DX	
							15	4W	6W	SX	DX	
							16	4W	6W	SX	DX	
							17	4W	6W	SX	DX	
							18	4W	6W	SX	DX	
							19	4W	6W	SX	DX	
							20	4W	6W	SX	DX	

DESCRIZIONE	TEMPO DI FERMATA	RALLENTAMENTI NON DOVUTI A QUALITA' NOTE:

Figure 55 "Dichiarazione di produzione" paper

Linea_Ferrari	martedì 5 gennaio 2021

DATI DA INSERIRE		
OPERATORI		
N° Operatori Presenti	5	OP F173
N° Addestramenti	2	5
N° Assenti per malattia e infortunio	0	OP MONO
N° Assenti altre causali (ferie,PAR)	0	0.0001
DATI GENERALI PRODUZIONE		
N° Pezzi a programma (Target)	NA	
N° Pezzi totali Prodotti In Qualità	5	
N° pezzi scarto	0	
DATI PRODUZIONE F173		TARGET
N° Sedili Ferrari F173	5	22
N° Sedili Ferrari Monoscocca	0	0
-	0	
N° Pezzi N Prod. In Qualità	5	
STRAORDINARI		
Ore di straordinario	0	
Operatori in straordinario	0	

CALCOLO PRODUTTIVITÀ OEE	
Disponibilità	1.00
Velocità	0.21
Qualità	1.00
OEE	**21%**
PRODUTTIVITÀ DIRETTA	**23%**
VALORE SCARTO	**€ 0.00**

CAUSE MANCATA PRODUTTIVITA'
RILAVORAZIONI

PROBLEMI DI QUALITÀ/SCARTI				
DESCRIZIONE	Tempo di fermata (min)	N° casi	Note	DIAGNOSI I LIV

RALLENTAMENTI NON DOVUTI A QUALITÀ				
DESCRIZIONE	Tempo di fermata (min)	N° casi	Note	DIAGNOSI I LIV
TOTALE	0	0		0

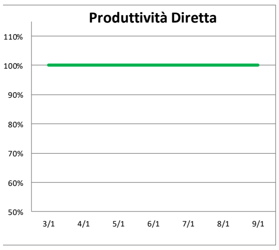

Figure 56 Daily line performance evaluation

Figure 57 MIR 100

Figure 58 MiR Hook 100 TM

Figure 59 Suitable cart for a piggyback AGV.

Figure 60 Suitable cart for AGV provided with a hook

Dimensions

Length	890 mm / 35 in
Width	580 mm / 22.8 in
Height	352 mm / 13.9 in
Weight (without load)	70 kg / 143 lbs
Ground clearance	50 mm / 2 in
Cover material	Co-extruded plastics containing PS (Polystyren) and a semi-conductive layer (due to ESD performance)
Wheel diameter (drive wheel)	125 mm / 4.9 in
Wheel diameter (caster wheel)	125 mm / 4.9 in

Figure 62 Mir 100 dimensions

Speed and performance

Maximum speed (with maximum payload on a flat surface)	Forwards: 1.5 m/s (5.4 km/h) / 4.9 ft/s (3.6 mph)Backwards: 0.3 m/s (1 km/h) / 1.0 ft/s (0.7 mph)
Minimum corridor width for a U-turn	520 mm / 20 in (around center of robot)
Positioning accuracy	+/- 50 mm / 2 in to position, +/- 10 mm / 0.4 in to docking marker
Traversable gap and sill tolerance	20 mm / 0.8 in
Minimum corridor width	1.0 m (default footprint)
Turning diameter around obstacle/wall	No load: 1.3 m, full load: 1.3 m (default footprint). No load: 1.2 m, full load: 1.1 m (minimized footprint)
Product design life	Five years or 20.000 hours, whichever comes first
Minimum distance between chargers	100 mm

Figure 61 Mir 100 speed and performance specifications

OPERAZIONI	inizio [s]	durata [s]	fine [s]
scollegare tubo a T dell'aria compressa	**0**	**10**	**10**
prendere chiave/brugola	10	3	13
svitare vite 1	13	20	33
posizionare vite sul tavolo	33	3	36
svitare vite 2	36	20	56
posizionare vite sul tavolo	56	3	59
svitare vite 3	59	20	79
posizionare vite sul tavolo	79	3	82
svitare vite 4	82	20	102
posizionare vite sul tavolo	102	3	105
rimuovere supporto cuscino, tirando verso l'alto	105	10	115
prelevare carrello	115	20	135
posizionare sul carrello il supporto cuscino	135	5	140
movimentare carrello fino allo scaffale	140	60	200
prendere il supporto cuscino appena rimosso	200	3	203
posizionarlo nello scaffale	203	3	206
prendere l'altro supporto cuscino dallo scaffale	206	3	209
posizionarlo sul carrello	209	3	212
movimentare carrello fino alla stazione di pre-sellatura	212	60	272
prelevare il supporto	272	3	275
posizionare il supporto in postazione	275	10	285
prendere chiave/brugola	285	3	288
avvitare vite 1	288	20	308
prendere la vite	308	3	311
avvitare vite 2	311	20	331
prendere la vite	331	3	334
avvitare vite 3	334	20	354
prendere la vite 4	354	3	357
avvitare vite 4	357	20	377
riporre chiave	377	3	380
collegare il tubo dell'aria compressa	380	10	**390**
riposizionare il carrello	390	20	**410**

Figure 63 Cushion pre-trimming changeover operations

OPERAZIONI	inizio [s]	durata [s]	fine [s]
bloccare il supporto del ceppo, in modo tale che non ruoti tramite il pedale a terra	0	3	3
prelevare il carrello e muoversi in postazione	3	10	13
avvicinarlo al ceppo da sostituire	13	5	18
prendere il tool di svitatura	18	3	21
svitare la vite	21	15	36
posizionare sulla postazione accanto la vite e la chiave	36	3	39
avvicinare il carrello fino a toccare il ceppo	39	15	54
assicurarsi che il carrello sia alla stessa altezza del ceppo e in caso contrario allineare i piani	54	3	57
tirare indietro il ceppo facendolo scorrere lungo le guide del carrello, fino a fine corsa	57	10	67
allontanare il carrello	67	3	70
prendere la chiave per le due viti del ragno	70	3	73
svitare la vite 1	73	15	88
posizionare la vite sulla postazione adiacente	88	3	91
svitare la vite 2	91	15	106
tirare il ragno indietro, facendolo scorrere	106	10	116
posizionare sul carrello il ragno, sopra il ceppo	116	3	119
movimentare il carrello fino allo scaffale	119	60	179
inserire il pin presente sul carrello nello scaffale	179	2	181
far scorrere il ceppo e il ragno sullo scaffale	181	5	186
spostare il carrello adiacente al ceppo e al ragno da prelevare	186	2	188
inserire il pin presente sul carrello nello scaffale	188	2	190
prelevare il ceppo e il ragno dallo scaffale facendolo scorrere lungo le guide del carrello	190	5	195
movimentare il carrello fino alla postazione	195	60	255
avvicinare il carrello al ceppo	255	5	260
posizionarlo in corrispondeza della sede del ceppo	260	3	263
prendere il ragno e inserirlo nella sua sede sulla pressa	263	3	266
accertarsi che il carrello sia alla stessa altezza del ceppo	266	3	269
spingere il ceppo lungo le guide del carrello fino a fine corsa	269	10	279
allontanare il carrello	279	3	282
prendere la chiave	282	3	285
prendere la vite 1 del ragno	285	3	288
avvitare la vite 1 del ragno	288	15	303
prendere la vite 2 del ragno	303	3	306
avvitare la vite 2 del ragno	306	15	321
prendere la vite del ceppo	321	3	324
avvitare la vite del ceppo	324	15	339
riposizionare il carrello	339	5	344

Figure 65 Trimming workstations changeover operations

OPERAZIONI: da P13/P14/P22 A M240/P16	inizio [s]	durata [s]	fine [s]
scollegare attacco aria	0	5	5
rimuovere perno di fissaggio	5	5	10
estrarre supporto schienale	10	5	15
portare supporto schienale nello scaffale	15	60	75
prelevare il nuovo supporto schienale	75	3	78
portare il secondo supporto schienale in postazione	78	60	138
prendere il nuovo supporto schienale	138	3	141
posizionare il supporto schienale	141	10	151
inserire il perno	151	5	156
avvitare piedino 1 fino a a battuta con tampone	156	5	161
avvitare piedino 2 fino a battuta con tampone	161	5	166

Figure 64 Aesthetical finishing workstation changeover operations

OPERAZIONI	inizio [s]	durata [s]	fine [s]
prendere tool	0	3	3
svitare vite 1	3	20	23
posizionare vite sul tavolo	23	3	26
svitare vite 2	26	20	46
posizionare vite sul tavolo	46	3	49
svitare vite 3	49	20	69
posizionare vite sul tavolo	69	3	72
svitare vite 4	72	20	92
posizionare vite sul tavolo	92	3	95
svitare vite 5	95	20	115
posizionare vite sul tavolo	115	3	118
svitare vite 6	118	20	138
posizionare vite sul tavolo	138	3	141
svitare vite 7	141	20	161
posizionare vite sul tavolo	161	3	164
svitare vite 8	164	20	184
posizionare vite sul tavolo	184	3	187
posizionare tool sul tavolo	187	3	190
scollegare attacco elettrico	190	5	195
scollegare tubo aria 1	195	5	200
scollegare tubo aria 2	200	5	205
scollegare tubo aria 3	205	5	210
scollegare tubo aria 4	210	5	215
estrarre piastra M240/P16	215	20	235
portare piastra fino allo scaffale	235	60	295
prendere piastra P13/P14/P22	295	30	325
portare piastra in postazione	325	60	385
posizionare la piastra	385	15	400
prendere vite 1	400	3	403
avvitare vite 1	403	20	423
prendere vite 2	423	3	426
avvitare vite 2	426	20	446
prendere vite 3	446	3	449
avvitare vite 3	449	20	469
prendere vite 4	469	3	472
avvitare vite 4	472	20	492
prendere vite 5	492	3	495
avvitare vite 5	495	20	515
prendere vite 6	515	3	518
avvitare vite 6	518	20	538
prendere vite 7	538	3	541
avvitare vite 7	541	20	561
prendere vite 8	561	3	564
avvitare vite 8	564	20	584
collegare tubo aria 1	584	10	594
collegare tubo aria 2	594	10	604
collegare interfaccia elettrica	604	20	624

Figure 66 Backrest pre-trimming changeover operations