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Method for the Production of Low Volume Vehicles and Application Criteria for the Technological Choices

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Preface

This document is the result of a project conducted during a period of internship in FCA Italy.

Preliminary and careful planning of the 7-month internship period has allowed me to acquire a good knowledge of the automotive production scenario.

I could divide the period of activity into three different phases:

- Learning phase, was characterized by visits to the plants and presentations of the activities carried out by the various members of the technological departments, ensuring an improvement of my knowledge and allowing my integration into the VLM department.
- Setting phase, dedicated to the draft of the guide document to be followed to start concretely the planned activities.
- Proactive phase, during which resources, belonging to all the manufacturing departments, have been involved, because only a continuous interfacing between the technological departments makes it possible to put in practice the defined method.

The basic know-how about the production processes adopted has proved to be fundamental for the development of the project.

Acknowledgements

I would like to express my immense gratitude and high esteem for my tutor Engr. Paolo Ollino, who guided me with great helpfulness and professionalism during my period of work in the company.
I would like to thank my supervisor Prof. Maurizio Schenone, for the important contribution provided in the development of this thesis document.
I am deeply grateful to all the members of the FCA Group and CRF that have been involved, they have put their experience and skills at my disposal.
My sincere thanks to my girlfriend and my friends for always being by my side, and I am sure they will continue to be my best support.
The most important thanks go to my family that has always supported me and that allowed me to complete my university career with serenity, I could never achieved this goal without their huge sacrifices.

Turin, October 2018

Damiano D'Asaro

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Acronyms

ABS	Anti-Blockier-System
AGV	Autonomous Guided Vehicle
AL	Aluminum
APAC	Asia-Pacific
BEP	Break Even Point
BIW	Body in White
BSR	Buzz, Squeak and Rattle
CAPEX	Capital Expenditure
CEO	Chief Executive Officer
CF	Carbon Fibers
CFCs	Chlorofluorocarbons
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRF	Centro Ricerche Fiat
DEMS	Dimension Engineering and Measurement Systems
DMC	Direct Material Cost
DPF	Diesel Particulate Filter
EEM	Early Equipment Management
EHS	Environment, Health and Safety
EMEA	Europe, Middle East and Africa
EPM	Early Product Management
EU	European Union
FCA	Fiat Chrysler Automobiles
FDS	Flow Drilling Screw
FEM	Finite Element Method
FLC	Forming Limit Curve
FSW	Friction Stir Welding
GC	Gran Cabrio

GOMA	Gruppo Organi Meccanici Anteriore
GOMP	Gruppo Organi Meccanici Posteriore
GT	Gran Turismo
H&S	Health and Safety
HCFCs	Hydrochlorofluorocarbons
HR	Human Resource
IT	Information Technology
JPH	Jobs per hour
LATAM	Latin America
ME	Manufacturing Engineering
MIG	Metal Inert Gas
MP&C	Manufacturing Planning and Control
MY	Model Year
NAFTA	North America Free Trade Agreement
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
OEM	Original Equipment Manufacturer
OP	Operation
PMI	Preventive Maintenance Information
PP	Polypropylene
PUR	Polyurethane
RIM	Reaction Injection Molding
RRIM	Reinforced Reaction Injection Molding
SMC	Sheet Molding Compound
SPC	Statistical Process Control
SPR	Self-Piercing Riveting
ST	Steel
TIG	Tungsten Inert Gas
VLM	Vehicle Line Manufacturing
VOC	Volatile Organic Compounds
WCM	World Class Manufacturing

1 Introduction

Fiat Chrysler Automobiles (abbreviated to FCA) is an Italian and American multinational corporation and is currently one of the eight largest automaker in the world, following the merger occurred in the October 2014. For this reason the FCA brand plays a leading role in the world of the industrial manufacturing, not only in the automotive sector.

FCA Group has always invested its efforts to produce mass or premium vehicles, but there is a growing interest in another kind of market segment, which regarding vehicles produced with lower volumes.

The purpose of this thesis work is to outline a method for the production of cars intended to a niche market. This type of cars is part of the automotive production segment called Low - volume.

The method described has the ultimate goal of optimizing the entire process carried out by the manufacturers, supporting their production of vehicles intended to limited numbers of customers.

This optimization consists in the minimization of the value of the Capex ("***Capital expenditure*** or ***capital expense*** (capex) is the money a company spends to buy, maintain, or improve its fixed assets, such as buildings, vehicles, equipment, or land.").

Low - volume must be synonymous with Low – investments, also enabling higher processing costs, this philosophy has been the main driver towards the realization of this project, and in fact this document can be used as guideline for the manufacturers wishing to undertake a Low - volume Production in an economically effective way.

The general aspects of the production world are considered below, just because the aim of the thesis is to draw guidelines for approaching low production rates; for many factors related to specific products and processes, it is necessary to adapt the assessments on a case-by-case basis.

It is very important for automotive companies to use a different production approach according to the volumes involved.

The case studies presented are the result of the application of the method and demonstrate its effectiveness: a systematic application to low volume productions would lead to a substantial reduction in investments, increasing the economic performance of the company.

The first part of the thesis briefly presents the world of manufacturing and the organizational structure of the FCA Company.

The third chapter is dedicated to the description of the typical production processes that are carried out in the plants and aimed at the construction of the cars, it also explains some distinguishing features for a mass production and a low volume production.

The fourth chapter describes the methodological flow to produce low volume cars efficiently, explaining the reasons that led to the project inception, the range of production volumes involved, listing all the areas of possible application and the specific points already identified for each area.

The fifth chapter concerns the technological solutions to be adopted to obtain benefits in the production of low volume vehicles; an overview of the polluting emissions that have a negative environmental impact is important because their reduction represents a target to be achieved by the OEMs and has a strong influence on the production approach; there is also a description of the use of the multi-material as a solution adopted especially for special cars, in fact it could be able to reduce emissions and increase performance, and consequently some hybrid joining technologies are presented.

The sixth chapter consists of some of the case studies in which the low volume method has been applied, supporting the technological choices made within the company.

With the seventh chapter the lessons learned arising from this project are explained.

2 Automotive Manufacturing

The method to follow when approaching the production of low volume vehicles, described in this document, is completely general, it takes into account all the single phases for the realization of the cars.

Although the production is the core of the project, it is essential that all the departments specialized about each phase are oriented towards the sole objective of reducing investments.

The organizational structure of FCA is large and complex, most of the activities are attributed to four main regions, which represent four geographical areas:

- NAFTA (United States, Canada and Mexico)
- LATAM (South and Central America, except Mexico)
- APAC (Asia and Pacific)
- EMEA (Europe, Russia, Middle East and Africa)

This project based on the low –volume production was conducted in the EMEA region, although it has not geographical constrains.

Manufacturing has the highest percentage of employees, also because most of them are workers.

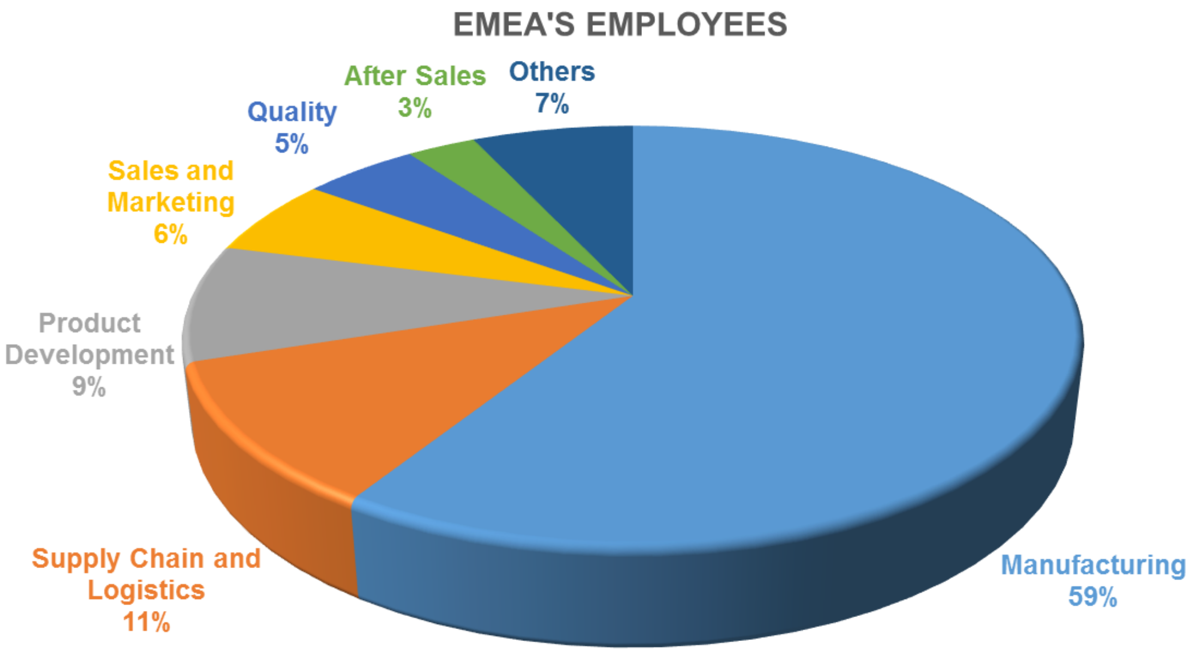


Figure 1 - Employee distribution in the EMEA region

As previously stated, this company deals with the production of mass and premium cars and the activities are carried out by the various brands, all belonging to the group.
The following scheme shows the group structure.

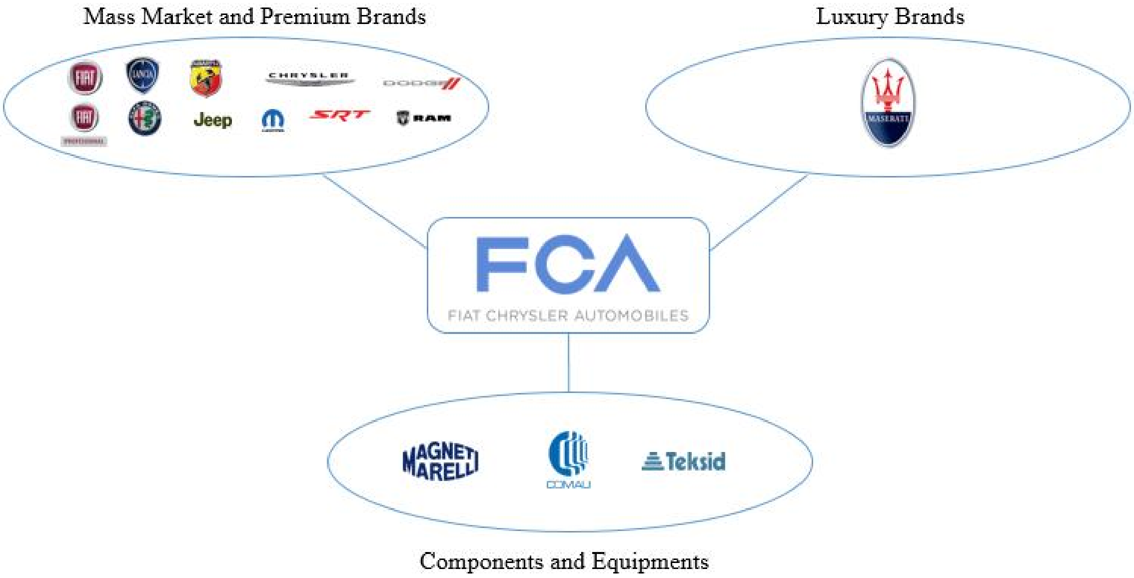


Figure 2 - FCA Group Structure

It is possible to see that 15 brands constitute this large company structure.
The Low volume approach, subject matter in this context, is strongly linked to the luxury brand Maserati and, in some cases, to models or special series of Premium brands such as Alfa Romeo with the model 4C.
The completeness of the company structure, on the one hand, makes it possible to choose carefully the optimal strategies for Low volume production thanks to the comparison with Mass Market production, on the other, forces the company to use two different types of productive approach.

2.1 Manufacturing Organization

Nowadays the cars are products made up of many components, complex and technologically more and more advanced. For this reason, behind the production there are different departments that cover specific roles.
The internal structure of a company is as more complex as more complex its product is.

Figure 3 - Manufacturing Organization in the EMEA region

The scheme shows the staff departments responsible for the choices that influence the production technologies, these departments support the various production plants present in the different regions.

- **Manufacturing Engineering (ME)** is concerned with the understanding and application of Engineering Procedures in Manufacturing Processes and Production Methods;
- **Manufacturing Planning & Control (MP&C)** deals with the planning of production and activate the work of suppliers;
- **Vehicle Line Manufacturing (VLM)** takes the optimal technological choices for the different vehicle segments;
- **Manufacturing Logistic System** optimizes the enslavement of materials to the plant and inside;
- **Environment, Health and Safety (EHS)** studies and applies all the key concepts to ensure safety at work and environment protection;
- **Finance** deals with financial activities linked to the different activities;

- **Human Resource (HR)** has the task of the human capital management and development;
- **World Class Manufacturing (WCM)** wants to control and reduce production costs by systematically following 11 pillars, through the application of multiple tools;

The Low volume project is born within the VLM department, but it requires the involvement of all the departments, as will be better explained below.

The VLM activities address the management of all the production aspects about the various models, which are divided by segments; the target market automatically creates the segment categories.

The table shows the vehicles produced that are the object of the VLM department activity in the EMEA region, throughout the processes flow leading to the realization of the product.

Basing on the target market, the different models are assigned to the segment they belong to, so the Brand of each model is not relevant for this classification.

This cataloging is necessary for the organization of the production in terms of technologies and production plants.

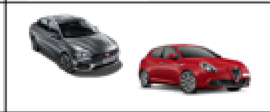
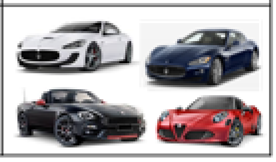
SEGMENT	MODELS	
A	Fiat Panda Fiat 500 Lancia Ypsilon	
C	Fiat Tipo Alfa Romeo Giulietta	
SUV	Jeep Renegade Fiat 500X Alfa Romeo Stelvio Maserati Levante	
L0	Fiat 500L Fiat Qubo Fiat Doblò	
LCV	Fiat Ducato Fiat Doblò Fiat Fiorino Fiat Talento Fiat Fullback	
D	Alfa Romeo Giulia	
E / F	Maserati Ghibli Maserati Quattroporte	
H	Maserati GT Maserati GC Abarth 124 Spider Alfa Romeo 4C	

Table 1 - Car classification by market segments

On the basis of what has been said, the reason why Alfa Romeo 4C and Abarth 124 Spider belong to the same segment of Maserati GC and GT is obvious; they are also the vehicles with the lowest production rates and for this reason they are very useful references for the purpose of this thesis work.

3 The phases of the Production Flow

The car is a very complex product and consists of a huge amount of subgroups that, pre-assembled through specific production processes, allow to obtain the vehicle with their subsequent assembly.

For this reason the production flow can be divided into different phases, consequently the engineering departments, the technological departments and the plants are skilled at:

- Designing the product;
- Designing the processes;
- Producing the expected quantities.

This section is useful to describe only the production processes, therefore the activities carried out in the plants.

The general macro-phases of production for the vehicle construction do not depend on the segment they belong to, production volumes or product requirements. Going into details of the technological choices of product, process and quality, the listed factors become the main decision-makers.

The production of cars can begin after a quite long period that includes a market survey, product and processes design, accurate feasibility studies with the help of advanced software and a period of industrialization to make the plant able to meet the estimated demand in terms of production volumes.

The manufacturing macro-phases are performed in the related shops of the plant and they are mainly four:

- Press Shop;
- Body Shop;
- Paint Shop;
- Assembly Shop.

In the first three steps the car body is completed, with the last passage the whole vehicle is assembled. Engine and transmission elements are made in other plants, they are connected to the body in the assembly shop through the "marriage".

The complexity of the product leads to the need to define the most appropriate level of vertical integration along the production chain. It follows that some processes or components can be realized internally or assigned to suppliers.
For these reasons, the decisions made in terms of "make" or "buy" are basic from an economic point of view.

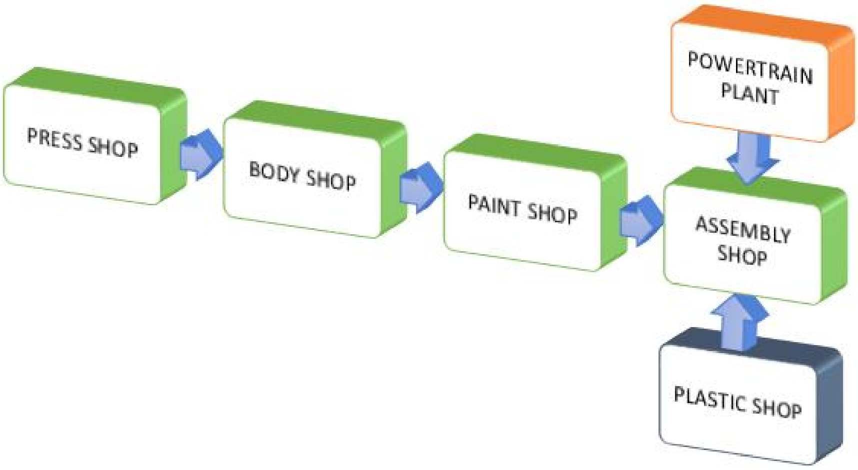


Figure 4 - Productive flow through the plant shops

3.1 Press Shop

In the press shop, all the metal parts characterized by large surface are processed, they will complete the car body through their union with the frame.
The stamping products are obtained starting from steel or aluminum sheet coils, depending on the choices made in the product design phase.
The blanks, of well-defined dimensions, are derived from the coils by means of sheet-cutting machines.
The processes design phases are integrated with virtual simulations to evaluate loads and dimensional requirements (run-off, bead, preload of the blank holders, etc.).
After being extrapolated from the coils, the sheets are brought close to the stamping line; it consists of a certain number of presses, on which the dies are assembled (die and punch), while, there are robots that manipulate the metal sheets between the presses to allow the plastic deformation gradually.
The line could be fully automatic, in that case the operator only takes care of maintenance during production stops.

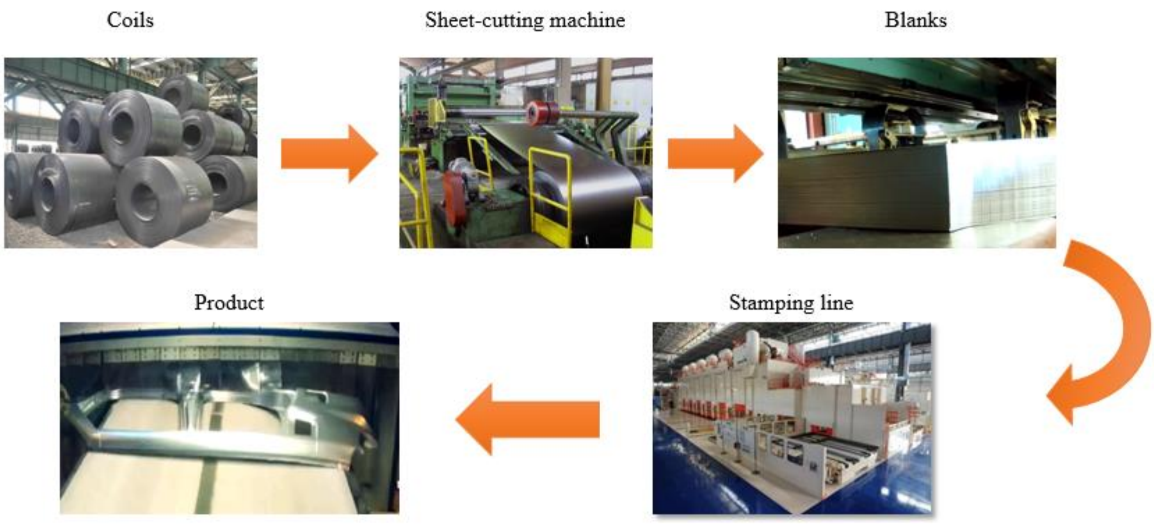


Figure 5 - Summarized scheme of the stamping process

In the press shop of the Mirafiori Plant in Turin, steel and aluminum sheets/ are stamped. The blanking is carried out to obtain the blanks in the case of steel, while the aluminum arrives already as blanks.
This is a strategic choice based on technological aspects, in fact cutting aluminum or steel involves the definition of very different process parameters due to the different characteristics of the two materials in terms of cutting forces.

3.1.1 Stamping Process

Metal sheet forming involves components with high surface/volume of material ratios. This process has several critical issues, so the design phase must be very accurate.
The starting material is first subject to the rolling process, through which the metal sheet acquires small thickness and considerable isotropy along the rolling direction.

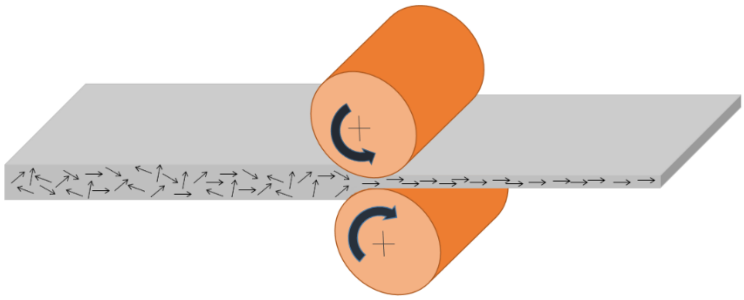


Figure 6 - Isotropy and thickness reduction in the Rolling process

The long metal sheet is wound to form a coil in order to make easier to move it towards the press shop.

In input to the sheet-cutting machine, the coil is unrolled and then straightened, the purpose of this step is to cancel the residual curvature effects in the material which previously constituted a coil.

With the stamping process it is possible to obtain products of various shapes thanks to the effect of plastic deformation, for this reason the deformations that the material must undergo are relevant, they must exceed the elastic limit characteristic of the material (yield strength) without however reaching the breaking limit (ultimate strength).

The strain - stress curve is the most common tool used to characterize the materials.

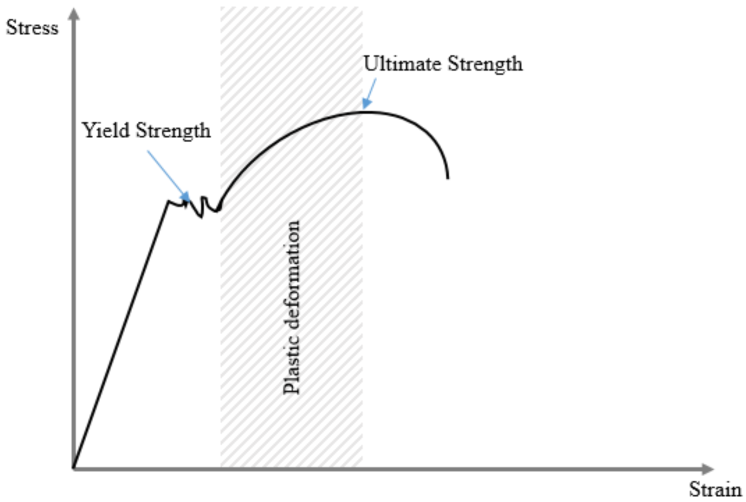


Figure 7 - Area of the materials plastic deformation

The hatched area shows the domain of the couples of values (stress - strain) allows the plastic deformation of the material, so it can maintain the shape obtained by deforming, except for an amount due to the springback.
Just the springback is a limit of the process that has not been completely overcome. Nowadays, the software, based on FEM and used for virtual simulations, are not able to provide reliable values of springback that will follow the real deformation.
The formability of the metal sheets is one of the most important parameter to be taken into account in the automotive manufacturing. Formability is a characteristic of the material and influences:

- Styling (vehicle shell shape);
- Geometry (fit and finish);
- Performance (wind noise, water leakage).

For these reasons a good stage of stamping process design is essential.
The process requires very detailed preliminary studies of feasibility that involve the use of diagrams, such as the forming limit curve (FLC), which allow to characterize the material relative to the product and to the process.
The FLC diagram is constructed by representing the minimum principal strain on the abscissa axis and the maximum principal strain on the ordinate axis. The two values are obtained experimentally following these three steps:

- Drawing circles on the component, in the most probable critical areas;
- Deforming the component until mechanical breakage;
- Measuring the percentage deformations of circles along the main axes.

The graph immediately allows to estimate the formability of the components using the maximum and minimum deformations as input data.

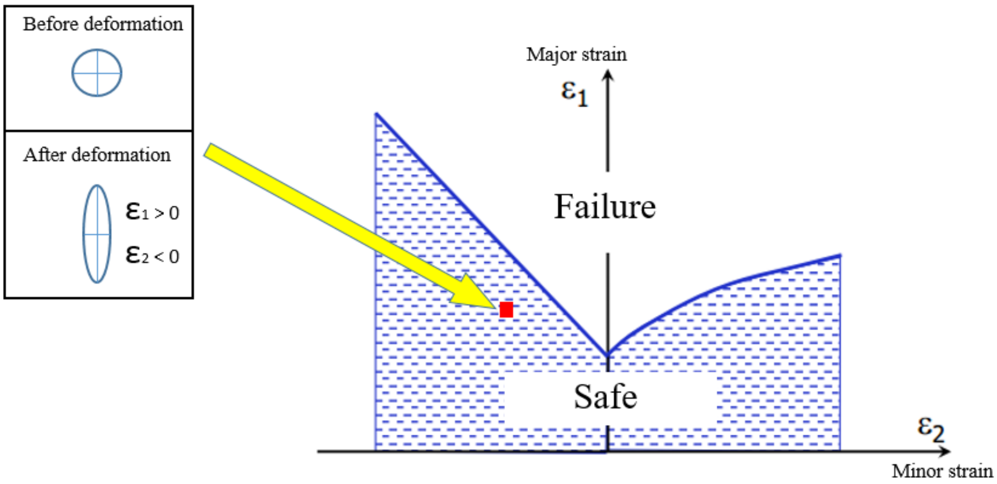


Figure 8 - Forming Limit Curve (FLC)

In the first analysis, a process is feasible when it causes deformations of the component that lead to points below the limit curve.

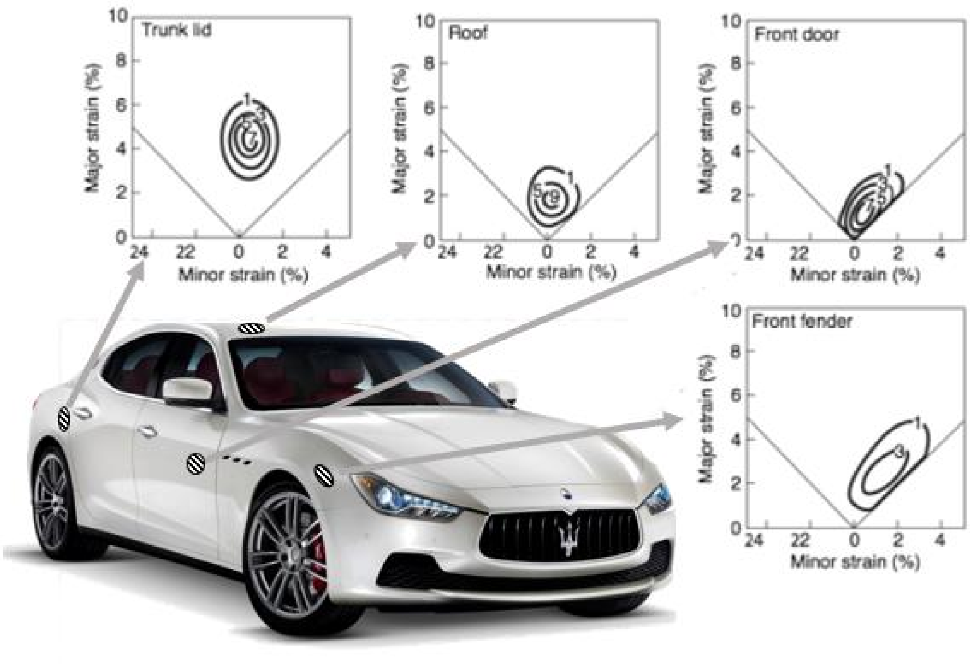


Figure 9 - Example of the formability test in automotive

As mentioned before, the tools used in the actual stamping process are two dies (punch and die) that are driven by presses, different accessories complete the machine and ensure the process is carried out effectively.

The presses can be mechanical or hydraulic, depending on the type of drive; the first are able to perform a greater number of strokes per minute than the hydraulic presses, which are instead able to handle higher resistance loads.
In the automotive production, the stamping dies are able to: locate the blank within its cavity, hold the blank in place while stamping through its binder and blank-holder, deform the blank until the design shape and release the formed panel by using rejection pins.

3.2 Body Shop

The mechanical assembly processes of various components that allow to create the car body, the bearing structure of the car, are carried out in the body shop.
The components to be assembled consist of both stamped parts and beams.
Subgroups of larger dimensions are gradually obtained from the groups of smaller components.
Three main parts can be identified in the body:

- Underbody;
- Body;
- Closures.

They are built individually by putting together the various subgroups, then they are connected to form the complete BiW that will be shipped to the paint shop.

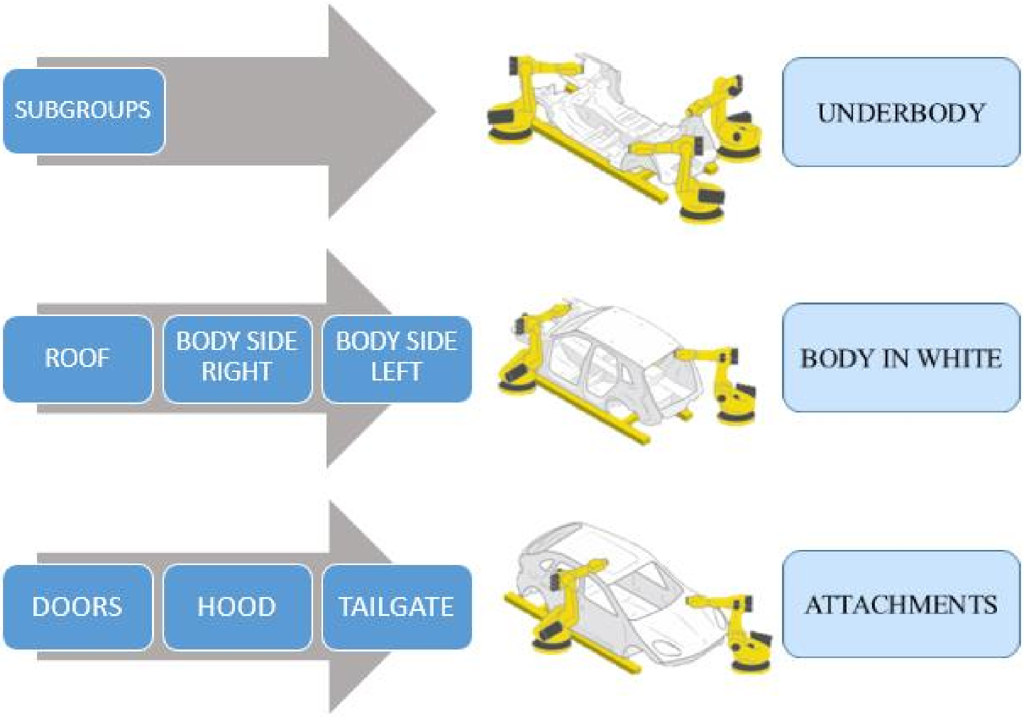


Figure 10 - Car Body subgroups

3.2.1 Body in White Process

Therefore the car body includes: a chassis consisting of front and rear frames connected by a central platform; an upperbody that is created directly on the underbody, on which inner and outer parts of the sides are joined, it is very linked to the style and performance of the specific model; the closures are assembled in the phase defined as "shoeing", to complete the body assembly.

The bottleneck can be represented by the construction of the upperbody on the underbody, starting from the welding of the sides. At this stage, several robots work in parallel in the station called “Robogate”.

Spot or continuous welding and riveting processes perform the mechanical connections, but other processes such as laser cutting and braze welding can also be used in the body shop.

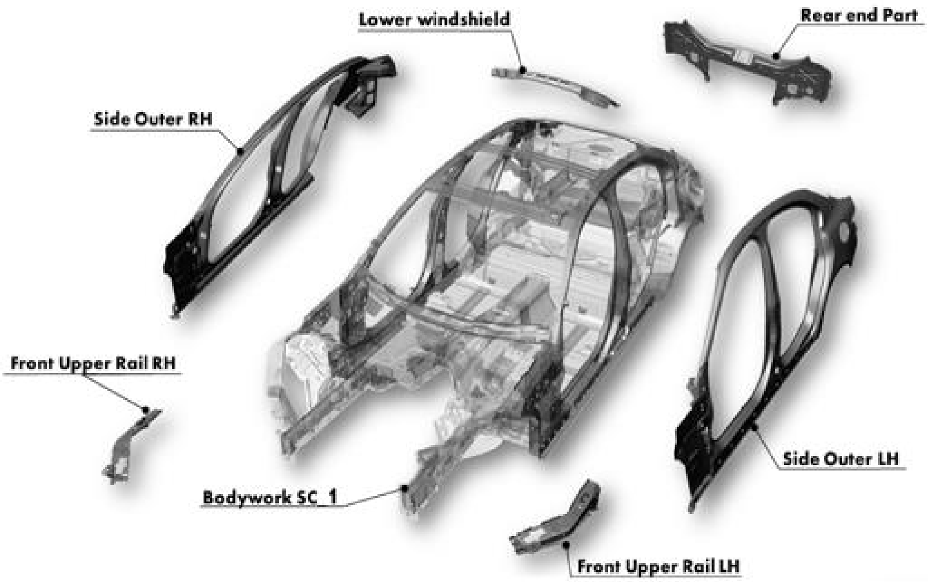


Figure 11 - Standard components of a typical BiW

The technologies used in the body shop to join the components to obtain the sub-groups can be multiple, the main ones are schematized below.

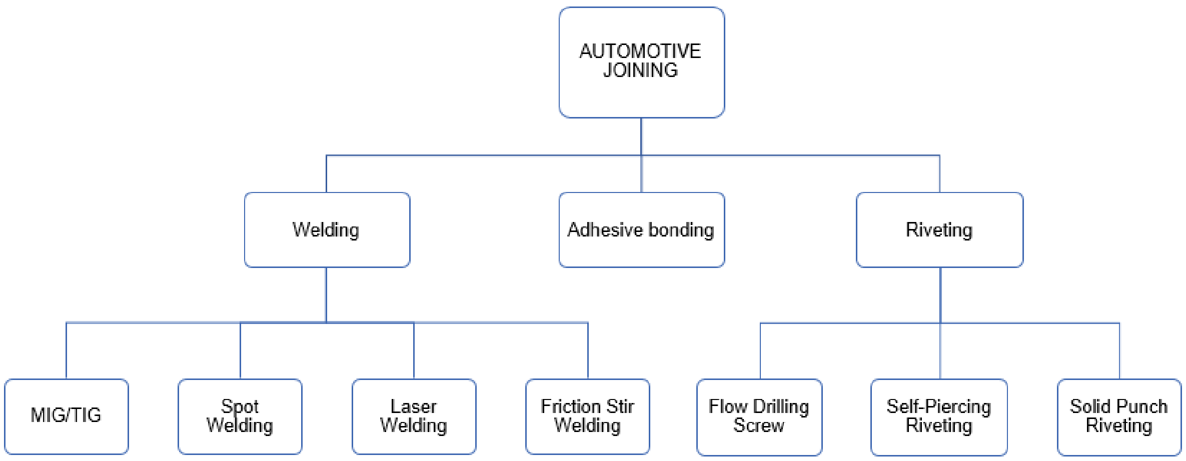


Figure 12 - The most common joining processes in automotive

The welding processes, the application of rivets and coating of glue can be performed automatically, semi-automatically or manually, therefore they present a wide margin of application of the "low volume approach", in terms of the possibility of reducing investments where it is possible.

It is clear that process constrains force a higher level of automation in some cases, especially as regards the more recent technologies, such as laser welding and FRW.

Welding is a mechanical joining process based on the fusion of the materials, different methods can be applied.

The welding processes schematized below are characterized by the methodology of achieving the fusion, in particular:

- MIG / TIG are electric arc welding, the creation of the welding seam is protected by inert gases (Argon or Helium) in both cases, in order to prevent corrosive phenomena that would cause a poor quality of the joint; the two processes are different because TIG uses a non-consumable tungsten electrode;
- Spot welding exploits the major resistance to the flow of electric current in the area of separation between the components to be joined; in fact, in that zone the conductivity is much lower than that there is into the material of which the two parts are constituted, this resistance converts the electric energy into heat, which leads to the local fusion of the materials. The car body contains hundreds of welding points obtained through this technology.
- Laser welding is a technology that allows joining the components through the use of an energy beam generated by a laser source. The beam involves high energy levels focused in the spot diameter capable of vaporizing the materials almost instantly; this process ensures to obtain continuous welding with very low cycle times.
- Friction Stir Welding (FSW) uses a shaped pin with a shoulder, in order to increase the contact surface and keep the molten material underneath to form the welding seam, this tool rotates to produce heat by exploiting friction effect and mixing the material of the two parts.

Among the joining technologies that do not provide for the fusion of material there is the application of adhesive; it presents deeply different characteristics from the other kinds of joints:

- No holes and other discontinuities in the components, with the consequent absence of stress concentrations;
- Pre-treatment necessary in order to increase the surface roughness in the joint area;
- Bonding is resistant to shear stress but not very resistant to normal actions.

Bonding is a very common joining technique in the automotive sector and particularly advantageous when the materials to be assembled are different, for example plastics and aluminum.
Some of the riveting technologies are included in the previous scheme, they will be explained in more detail in the chapter dedicated to low volume solutions in this document.

3.3 Paint Shop

The BiW completed can be shipped to the paint shop.
Nowadays the painting processes are very advanced and effective, although they have huge opportunities for improvement, for this reason they are undergoing continuous development.
Painting is a very important stage in the production process of the cars because it covers two fundamental roles that determine the final quality level of the product:

- Protect substrate materials such as steel, aluminum or plastic from corrosive actions due to external agents;
- Improve and characterize the aesthetic appearance of the car.

It is essential that the paint shop is designed to minimize the consumption of energy resources and water, polluting emissions and plant clean-up time.
These characteristics could make the painting a phase of the production flow with a high efficiency.

3.3.1 Painting Process

In this section the macro-phases carried out in the paint shop are described to provide an overview of the painting process generally used in the automotive industry.
The first steps are carried out to achieve the purpose of making the BiW resistant to corrosion, the subsequent phases attribute the final aesthetic characteristics to the product.
Before starting the painting, it is necessary that the car body undergoes a pre-treatment of cleaning and chemical coating for preparing BiW to the following stages.
The car body is moved by air transport hooks and chains, it proceeds along a path inside the plant; to start the painting process, it is immersed in tanks to undergo the phosphate baths, the electrodeposition of an epoxy or acrylic resin on all parts of the car body takes place thanks to

this "cataphoresis" process. The body rotates inside the tank, in this way the resin can reach even the less accessible areas.
The electro-statically deposited resin has a dual role, in fact it protects the parts from chemical and atmospheric agents and improves the adhesion of the subsequent layers of paint.
The bath in which the cataphoresis process takes place is called "phosphate bath", because the iron layer is converted into an iron phosphate or a zinc phosphate inorganic layer, through chemical reactions. The iron phosphate or the zinc phosphate makes the BiW surface corrosion-resistant.
After the phosphate baths it is necessary to bake and dry the layers on the BiW surface, the knowledge of the correct parameters in terms of temperature and humidity is vital to obtain a good final result.
After the baking and drying, there is the deposition of paints in different layers, the number can vary depending on the choices made by the departments of the painting technologies about the single model. During the spray painting, the environment is closely controlled in terms of temperature, relative humidity, cleanliness and paint flow rate; process control is very important to create layers with the desired thickness and final quality.
Good values for the painting conditions could be: air flow speed around 30-60 cm/s, air temperature around 22-24 °C and an air relative humidity around 40-60 %.
Between the various stations, ovens cook the resins allowing the consequent hardening, while cleaning the surface is useful to make each layer adhere to the others.

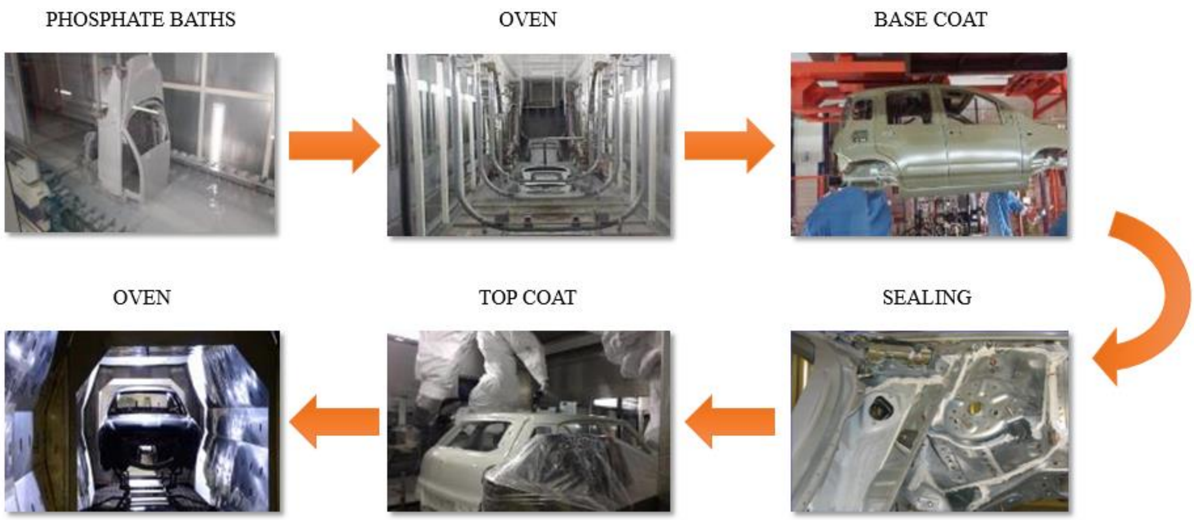


Figure 13 - Summarized scheme of the painting process

The sealing of the parts of the body to be insulated during the painting is essential for the final quality of the product, for this reason it must be carried out very accurately; generally the sealant is applied manually by activating and moving the sealant applicators.
The most important parts to be insulated are the welded joints, in fact they have the highest corrosion potential.
The general painting process of the car body has been schematized and briefly described above. As regards many components made of non-metallic materials, such as plastics and carbon fiber, painting is generally carried out on the single component that has not been assembled on the metallic body yet; this way of operating is especially due to the different effects that high temperatures have on materials.
All the parts that will form the car will put together in the assembly shop of the plant.
As already said, painting is still developing process, in fact some manufacturers are beginning to test and use low temperature processes to paint the BiW including plastic components.
The painting process, as well as the other production phases, presents different process issues that must be overcome in order to obtain a final product without defects, therefore sometimes manual reworks could be necessary even after fully automated stations.

3.4 Assembly Shop

All the subgroups that constitute the complete vehicle arrive in the assembly shop. The vehicle is the result of the assembly of thousands of components characterized by various dimensions.
The car body is the main part of the car and all the subassemblies are fitted on it, until the final product is realized; for this purpose the BiW runs across the main line that are the core of the assembly shop.
Usually the groups that are not part of the BiW (powertrain, cockpit module, doors, bumpers, etc.) are assembled off-line before being conveyed on board of the main line for its assembly on the car body. Therefore the assembly shop is generally made up of a main path, on which the car body moves, and off-line preassembly cells.
The assembly main line is covered by the car body following a variable altimetry and making some rotation around its longitudinal axis, in order to help workers and to make all the assembly processes complied with the ergonomic requirements.

Figure 14 - Jeep Renegade Assembly Shop in Pernambuco, Brazil

The design stages of the plant layout and the assembly sequences play a fundamental role for the results achieved by the company, as well as the logistics activities; the main purpose is to reach a high level of saturation of the lines. These are the factors that mainly affect production efficiency.

Many aspects of the assembly such as the layout of the plant, the level of automation, the training of the workers, the conveyor systems used (for example AGVs, Autonomous Guided Vehicles), should be strongly influenced by the production volumes of the specific model, as will be argued later in the document.

3.4.1 Assembly Process

To achieve a high production efficiency through the saturation of the available resources, each manufacturer invests in the design of the assembly sequence and the layout of the assembly shop. These two aspects are obviously linked to each other, because the arrangement of material resources strongly depends on the choice of the operations sequence to be performed.

Nowadays the virtual simulations are a daily support for efficiency and feasibility assessments, they are certainly the most important decision-making tools.

The assembly shop can be considered divided into different parts in which the assembly of the subgroups are performed, in particular it is possible to distinguish:

- **Trim**, dedicated to all the components to be installed inside the passenger compartment;
- **Chassis line**, for the pre-assembly of the powertrain, engine dress-up, marriage;
- **Final**, for the assembly of seats and doors;

- **End of line**, for the diagnostics of the electrical systems, toe test, wheels alignment, static and dynamic functional tests and other types of test, on the completed vehicle.

The choices about the assembly sequence can be various, one of the possible choices is briefly described below.

The car body comes from the paint shop and, first of all, the doors are removed for two reasons:

- They are shipped to their pre-assembly cells;
- The assembly of the components inside the body is made more comfortable.

In the trim, all the most hidden components are installed first, such as the wiring and harnesses, the shell insulation and radiator insulation, the air duct system, the pedal sub-assembly, etcetera, then the installations of the cockpit module, quarter glasses and windshield take place; in this case the assemblies of the cockpit module and the windshield are the most delicate phases performed in the trim stations.

The integration of the cockpit module in the car body is carried out by a worker with the help of a "partner", this is a manipulator that allows to cancel the effect of gravity.

Generally the assembly of the windshield is fully automatic, in fact an anthropomorphic robot, thanks to a visual system, can grab and move the component under an extruder nozzle, performing a perfect deposition of sealant along the entire edge.

Travelling a path with variable altimetry, the car body reaches the chassis line, where, the variable height of translation and some rotation around the longitudinal axis of the car facilitate the assembly of the pipes and other components under the BiW.

In the chassis line, the most important and delicate phase is the "decking", consisting of the "marriage" (matching between the car body and the powertrain pre-assembled) and the fastening.

The groups of mechanical parts are placed accurately on the “decking pallet”, which ensures to make a correct marriage.

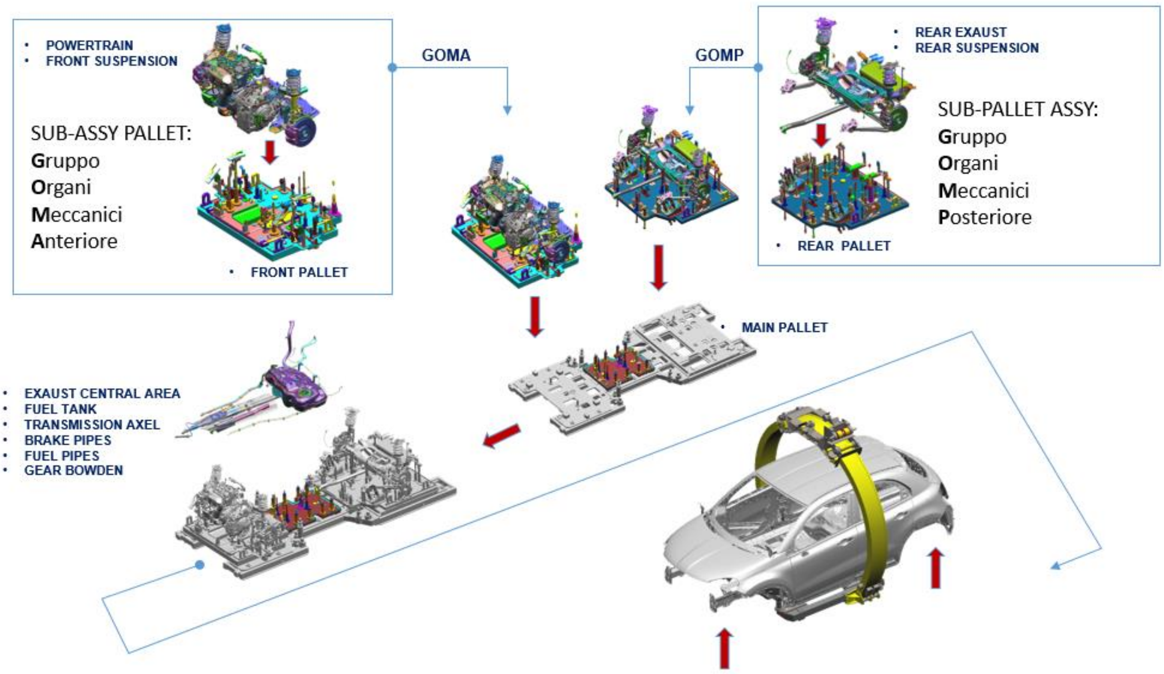


Figure 15 - Operations sequence of a Marriage process

The decking can be fully automatic, in case the fastening is made by robots, or more typically semi-automatic, in this case the workers perform the fastening through screwdrivers.

Later the bumpers can be mounted, after having been previously pre-assembled off-line in the dedicated cells. Nowadays the bumpers are components of the car that can be considered a huge subgroups and their assembly is complex. In fact in the new cars, the rear bumper always contains parking sensors, while the radar for driver assistance (adaptive cruise control, forward collision warning, etc.) can be installed in the front bumper.

The seats, the doors, initially removed and pre-assembled off-line, and finally the aerodynamic guards are installed in the line called "final".

In the "end of line" various kinds of diagnoses are carried out, such as electrical test, water test, BSR (Buzz, Squeak and Rattle), static (steering, ABS, etc.) and dynamic (torque, power, etc.) tests, toe test on the rollers, as well as obviously the aesthetic visual tests.

The cars completed cross the last station for the last checks; the "full body cover" could be applied to protect them and finally they are stored or shipped.

In all the shops, there are areas of validation between a station and the next one, where accurate checks are carried out to find and solve any defects created or not identified in the previous stations; this is vital because the entity of a defect increases with the progress of the production flow, in addition to the fact that some defects could be visible in a phase, becoming hidden in the subsequent ones.

“A production defect on a vehicle must never arrive at the customer” can be the main driver of the manufacturing activities.

3.5 Low - Volume Vs. Mass Production

The automotive industry can be divided into several segments, with different kinds of classifications.

A useful classification is based on the volumes of the cars production, in a simple case it is possible to consider three types of segments: Mass Production Vehicles, Premium Production Vehicles and Low - Volume Production Vehicles.

In the three cases the average production capacity is about:

- > 20 jobs per hour
- < 8 - 20 < jobs per hour
- < 7 jobs per hour

These values are absolutely approximate and used just to give reference quantities.

Low - Volume Production Vehicles includes all types of niche products of the Luxury brands.

This paragraph presents a comparison between Low Production and Mass Production.

These two segments of automotive sector are more distant than one might imagine, regarding the market of destination; for this reason the use of different production approaches for the different cases is essential.

The main task of this document is to explain a method for the production of vehicles which need an important focus in details in each part of the product.

The customer who buys this type of cars spent a lot of money to have a “unique piece” and for this reason the quality of product is most important request.

It is obvious that lot of companies are targeting low volume vehicles as a means to increase market share. What has been said makes it clear that, for automotive brands that have always been involved in Mass Production, the production of low volume models for the first time could represent an unsurpassable obstacle and they may have to give up the launch of the model itself.

In fact, according the economic assessment, carried out by the technologies departments examining the feasibility of the new model, the probability that the costs of investments and

production could not be recovered and then turned into revenues is high, due to the low number of cars produced and sold. This kind of vehicle must be designed as one of a small series of products to be launched in production and sold, already before the style approval phase.
It is clear that the training of engineering departments and workers must be the starting point to ensure that the company fits into this market.
To proceed with the launch of a low volume car, it is necessary that the design of the product and the processes aim at minimum investments in structures. The level of automation must be as low as possible, but always ensuring a vehicle with high quality, performance and reliability. Minimizing the automatic processes, entrusted to the robots and their programmers, involves advantages and disadvantages, from a low volume production point of view, the former are greater than the latter.
The cycle times in mass production are so low as requiring a high level of automation, this is not true for low volume productions; quality in the processes can be guaranteed by highly skilled workers who do not work under the pressure of the takt time. Reduced repeatability and a production slightly based on the subjectivity of the skilled workers are often considered by the customer as added values on the final product.

4 The Low-Volume Approach

Some evidences, both internal and external to the company activities, have led to the need to define specific guidelines for the low-volume productions, therefore to change the type of manufacturing approach deployed for this market segment.

1. Currently, there are several processes that are outsourced because they do not comply with the internal standards of the company; in some cases, whose details are not provided, the external suppliers use technologies that do not guarantee compliance with the same standards required.

   In many cases, low-capex processes cannot be exploited by the company because the standards are so restrictive that they force a “Buy” production.

   This example is not generally in line with the reduction in investments, because bringing a process from “Buy” to “Make” causes an increase in investments costs and a reduction in variable costs. But it shows that the correct detailed evaluations of the processes could lead to a significant final gain.
2. The case of Ex ITCA, a body shop in Grugliasco (TO), represents a further drive to the creation of the project; in this plant the models produced are: Maserati Gran Turismo and Maserati Gran Cabrio.

   ITCA was an external supplier for FCA and has kept the same technological approach despite the following acquisition by the group.

   The tools used are strongly low-capex, the automation is minimal, the skills of the workers are advanced, but products of maximum reliability and high quality have always been guaranteed through this production approach.

   The production setting described is not according, for many aspects, with the internal standards required by the company.

   Why is it not possible to adapt standards to processes that guarantee optimal performance in the case of low-volume?
3. The visits to the plants of other OEMs, which deal with special series and niche cars, have shown that production volumes are very influential about the technological choices. Many suppliers have already implemented, in some specific cases, the method that is described in this document, but in this case it will be useful for all future projects of the FCA group.

4.1 Criteria for the method application

The first step of the activity was to outline the perimeter in which the method could be applied effectively.

The domain of volumes, that makes it possible to distinguish a high-volume from a low-volume model, cannot be defined strictly, in fact there is an overlap zone.

In this intermediate area, the analysis of the technologies of interest allows to define the belonging of the model to the specific segment. For example, the current production volumes of the Maserati Levante can be placed in the overlap area.

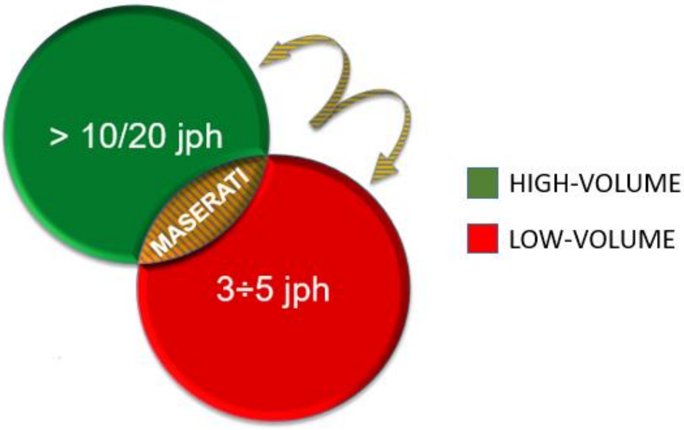


Figure 16 – Production rates

As mentioned before, the reduction of Capex in the low-volume production is the primary purpose. The aim can only be achieved by analyzing critically the design, production and quality standard from the point of view of low-volume production, by using as a tool of assessment the comparison between the current technological choices and technologies adopted in the past, when the skills of the workers were more important than the automation.

A proposal of intervention should be based on detailed assessments in terms of quality, investment costs and technical feasibility, therefore they are the core of the method.

The application of the method basically consists in the analysis of the technologies used for the mass and premium vehicles, and in the evaluation of their goodness also in the case of low volume production.

In other words, is it actually convenient to produce by imposing current design, production and quality control standards (mass or premium vehicles) even when producing a low-volume car?

As already stated, thanks to the analysis of some parameters it is possible to answer this question.

The application of the method allows to make the economically correct decisions, i.e. it is possible to choose the most convenient technology among those available to produce a component; in the same way, with the same assessment procedure, it is possible to produce components by using low-cost tools or raw materials more suitable for low-volumes, always guaranteeing the quality of the product to the customer.

The assessment of production costs, both fixed and variable, is certainly the most effective tool to be used when making technological choices, but these alone are not absolutely sufficient.

Various parameters and constraints must be satisfied in the product and process design, for this reason the method must take into account all the needs that each department requires.

In other words, it is not possible to make design decisions only by considering the production rates foreseen for a specific vehicle.

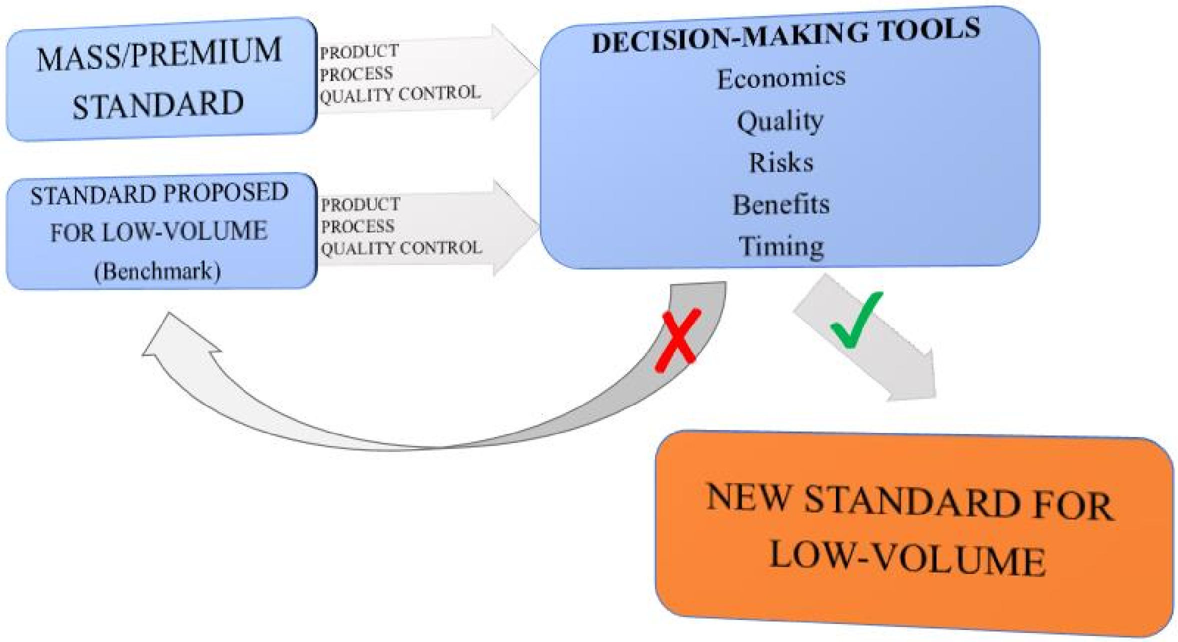


Figure 17 –Analysis method

The figure shows schematically the procedure to follow to approach a low-volume production. Benchmark activity is essential for finding technical solutions that are profitable for the low-volume production. The activity of the competitors can be used both as an inspiration in the choices of product / process design, both as an excuse to the low volume proposal, therefore the benchmark could belong also to the field of the comparison tools between the standards currently imposed and those proposed with a low capex perspective.

In a multinational company like FCA, consisting of a very complex organization, to propose new standards or "simply" to change the existing ones is not an immediate action.

The following figure shows a possible flow of the process to modify a standard.

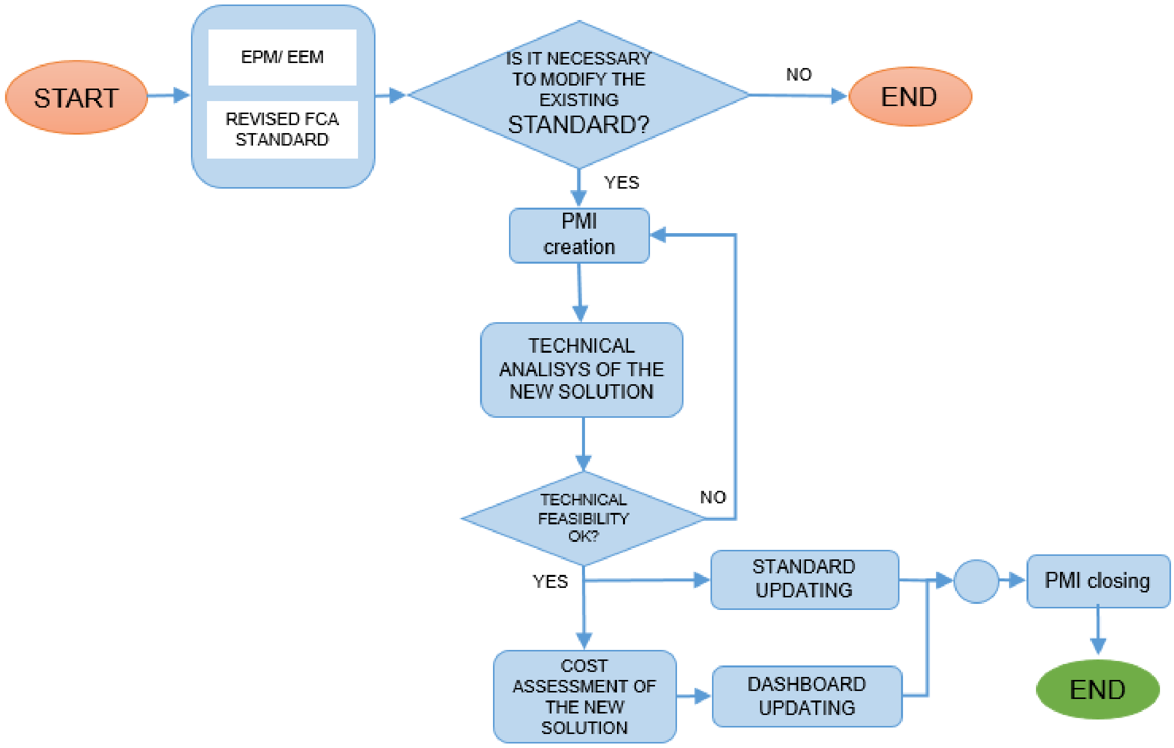


Figure 18 - Method for the modification of a standard

By basing on evidence from external or internal benchmark, starting from a new low volume proposal, it is necessary to create an EPM (Early Product Management), in the case of product standards, or an EEM (Early Equipment Management), in the case of process standards which influences the structures and machines used in production, this is fundamental because FCA places the tasks of the WCM (World Class Manufacturing) industrial philosophy at the base of production; if it is necessary to modify an existing standard, a PMI (Preventive Maintenance Information) will be opened; when the technical feasibility is also verified, after a cost assessment, it is possible to update the standard and the company dashboard, concluding with the closure of the PMI.

It is clear that the low volume method must be applied transversally, all the company areas must be involved. Each area is strongly bound to the others, the method can be applied effectively only if everyone puts it into practice.

This concept can be explained by an example: if tolerances, established in design of the product, are obtainable only by means of robots, it is clear that the manufacturing department cannot try to reduce investments by considering the possibility to entrust the process to skilled workers, because maybe the cycle times would have allowed it, and savings could have been obtained for limited production volumes.

All the areas of possible method application are identified for each phase of the production flow, these are the areas that influence the decisions regarding all the technologies.

STAMPING
BODY IN WHITE
PAINTING
ASSEMBLY
END OF LINE
QUALITY PROCESS / DEMS
PLASTICS
LOGISTICS
WCM, ERGONOMIA E H&S
TECHNOLOGICAL DEPARTMENTS TRAINING
WORKERS TRAINING

Table 2 - Areas of possible method application

The various specialized departments are responsible for the respective areas, they are able to analyze into details the activities of each area of intervention identified. In this way, it is possible to define the points of interest within each area, i.e. all the aspects that, covered by the evaluation criteria, could lead to a reduction in investment costs, with a consequent low-volume production economically effective for the company.

4.2 Items of interest

This paragraph presents a list of some items that have been identified, and which may lead to the opportunity of investments reduction, achievable through the application of the method described above. They will be described quickly, it is not necessary to go into the details because these items are the results of the specific company choices.
It is not possible to establish in advance if the reduction of the Capex is achievable for each specific case, in fact the items identified for each area are defined "items of interest", because they can be carefully analyzed.
First of all, the items common to all the areas were clustered.

- *Definition of the integration level*: also analyzing the pre-assembly of subgroups that are usually outsourced. The level of integration affects the distribution of the costs between investments and variable costs, so they represent an excellent analysis factor in the capex reduction perspective.
- *Feasibility constraints related to product style and design*: they are restrictions forced by the product development departments. It is essential that, already from the first stages of the activity, product design and manufacturing departments cooperate, in order to design a production flow suitable for low volume, choosing the most appropriate technologies for this type of production.
- *Quality process*: the tools must comply with low volume standards so they must guarantee low investments but, at the same time, they must satisfy all the process requirements; the analysis should allow to select the right quality levels to be imposed to the processes.
- *Possible new technologies available*: this aspect opposes the investment reduction, that is the purpose of the activity, but is perfectly in line with a requirement of the maximum flexibility applied for all the low volume productions; in fact, new technologies should be analyzed and taken into account if they guarantee maximum flexibility, in this case, they may require higher initial investments but they may be applicable in the future to achieve the best plant saturation, in order to recover the investment costs.
- *Definition of the automation level*: a crucial aspect to be analyzed; the level of automation required must be as low as possible in a low volume point of view, the lower

limit should be defined by other factors: required design standards, required flexibility level, capability, ergonomics and safety standards.

Some of the items of interest identified for each intervention area are briefly described below.

4.2.1 Press Shop

- *Materials requested*: the materials of which the equipment is made have a greater potential for intervention, especially the dies rather than the various accessories. For example, the aluminum dies guarantee a reduced number of jobs in their useful life, they could be advantageous compared to the steel dies in a low volume perspective, although steel dies have a higher capacity.
- *Number of the process steps*: the number of steps necessary in the stamping process could be reduced through a reasonable design of the product, reducing consequently the cost of investments in presses and dies, as well as the variable costs of transformation.
- *Laser cutting*: a laser cutting machine obviously ensures a greater flexibility compared to the installation of blanking equipment, re-evaluating the required product quality levels may present opportunities to use this technology. The cycle times for laser cutting are higher than blanking process, but this parameter does not represent a real problem in the low volume productions.
- *Secondary operations*: the low production rates would allow the possibility to carry out some operations after the end of the main processes, in order to recover the dimensional tolerances necessary for the subsequent joining processes performed in the BiW Shop, also taking into account the quality requirements provided for the complete vehicle; in this way the previous main processes could be characterized by lower initial investments,.

4.2.2 Body Shop

- *Joining technologies*: the design choices about the product strongly influence the process technologies to be used; sports or luxury cars have some constraints (multi-material junctions) that can represent opportunities (the use of unconventional technologies) in terms of innovation, for this reason to evaluate this aspect in terms of low volume could be very interesting.

- *Bonding technologies*: look at the possibility to use adhesives in some processes carried out in BiW shop, with consequent possible reduction in investments.
- *Machining*: it is essential to carefully analyze the mechanical processes that could be performed in the body shop, the opportunities of manual labor and low investment equipment, obviously taking into consideration the very high cycle times.
- *Secondary operations*: the same remarks that are mentioned in the case of the stamping area, but for obvious reasons, the assembly process constraints must be considered in the control of the dimensional tolerances.
- *Conveyor systems*: a detailed analysis of the body shop layout and the cycle times, provided for the processes, is crucial to make the right decisions in terms of the conveyor systems to be used into the body shop, for moving the components between the various stations or pre-assembly cells (AGV or manually guided truck).
- *Closures pre-assembly cells*: workstations optimization through the use of multi-figure cells, for example: the investments for the closures hemming process could be greatly reduced by using a single robot in the center of a multi-figure structure, on which all components are placed, rather than using stations where six robots are installed. The cycle times required in the case of 3-4 jph productions would certainly allow this setting.

4.2.3 Paint shop

- *Possible presence of composite materials on the car body*: the use of a lean painting process, able to manage metal bodies with the presence of composite materials, would be very useful; nowadays, the composite materials are applied for the weight reduction of the low volume cars, with consequent reduction in emissions and improving performance.
- *Manual sealing*: look at the possibility to entrust the sealant application to skilled workers, who have long time available and can guarantee a high quality of the process. Some working postures non-compliant to the ergonomic standards may be necessary for the application of the sealant, especially in the case of super sports cars; for this reason the requirements should be assessed by comparing the time in which the worker takes certain positions with the total cycle time.

- *Single-color volumes requested*: they are very low because they obviously depend on the total production volumes of the models, for this reason a centralized piping system may not be profitable.
- *Management of special series with color-matching problems*: color-matching is recurring when particular bright colors are required; if BiW and plastic (for example the bumpers) are painted separately, furthermore processes for the body painting "make" and plastics painting "buy" could be planned, the components could have slightly different tones. Introducing a "low temperature technology", that would allow to paint the body complete with plastic components or other materials, would solve the problem.

4.2.4 Assembly Shop

- *Upgrading of the assembly line*: A plant layout that includes assembly cells separate from the main line could be profitable, considering the very high times required for the assembly operations; skilled workers can perform several activities (even the assembly of entire complex sub-groups), by exploiting their time available in these technological cells. This type of setting is projected towards the industrial philosophy called "group technology", furthermore the workers training is crucial.
- *Types of equipment*: provide the use of equipment with a technological level appropriate to the cycle times, always in compliance with the safety and ergonomics standards required and evaluated from the low volume point of view.
- *Fastening technologies*: choose the type of screwdriver suitable for the class of mechanical fastening to be performed (they are classified according to their role in terms of safety); also the classification should be critically analyzed to assess which really the highest fastening class are. Depending on these aspects, evaluate when it is possible to entrust the validation of the fastening to the workers themselves or instead impose high traceability through IT systems. It could be effective to entrust the validation control to a worker other than the person who made the fastening and vice versa, by exploiting the reliability of a "cross-checking".
- *Bonding technologies*: economic benefits could derive from the use of bonding technologies applied to moldings, gaskets, stickers, and so on.

- *Traceability*: as mentioned for the case of the fastening technologies, the traceability constraints of the various components could be upgraded from a low volume point of view; the possibilities of human error are lower in the case of the low volume production, thanks to the high cycle times.

4.2.5 End of line

- *Control systems integration for new content*: flexibility and preparation for new implementations can be decisive factors of advantage, these two characteristics are essential because connectivity and driver assistance systems, at various levels, are strongly developing. The final diagnostic tests are multiple, the possibilities of control systems integration in a smaller number of stations could reduce the investments. For example, choose to carry out the BSR test on the rollers used for the Toe test could be a solution, as well as the adjustment of the emission tests in compliance with the new regulation concerning the control systems. This type of integrations would greatly increase cycle time, for this reason they are more suitable for the low volume productions.
- *Necessary controls*: definition of the control types really necessary by considering all the validation stations along the main line towards the "end of line" and by optimizing the controls arrangement with possible integrations, as stated in the previous point.
- *Types of equipment*: an in-depth analysis of the equipment could provide important instructions to choose the best facilities for low volumes, even in the case of the end of line.

4.2.6 Quality Process / DEMS

- *SPC and control equipment*: SPC (Statistical Process Control) were defined by Joseph Moses Juran as "the application of statistical techniques to understand and analyze the variability of a process"; the main tools are the database derived from the plant activity and the control charts; even the instruments used for data acquisition play an important role in terms of capex, for this reason this is an item of possible optimization for low volumes;

- *Laboratory and metrological room*: an accurate analysis as regards the diagnostic equipment used in the control areas could be effective (for example meisterbock, master cubing tools, gauges, etcetera) in order to propose the use of possible alternative techniques that involve lower investments for a low volume perspective;

4.2.7 Plastics

- *Materials*: the choice of the material to be used to obtain a specific product also influences the process technologies. Therefore, more expensive materials can lead to a reduction in investment costs in structures and machines, through a detailed analysis based on production volumes it may be more convenient to choose a material with higher variable costs (DMC, Direct Material Cost). These assessments must obviously take into account the specific technical characteristics, the opportunity of "make" feasibility, the consequent painting processes and the compliance of the cycle with the current plants.
- *Secondary operations*: some intermediate processes between stamping and painting, and post-painting processes, such as for example glued or joined parts on the component, should be appropriate, always following the low capex logic.
- *Use of carbon fiber components*: define the product and process characteristics could be necessary to optimize the techniques used for the application of any carbon fiber parts on the plastic components.

4.2.8 Logistics

- *Management of the complexity related to the models*: the factors related to logistics activities are fundamental to achieve high production efficiency; in the case of low volume models the complexity of the product is certainly high, there are needs in terms of management of several part numbers, areas of kitting, pre - assembly of some subgroups to be conveyed towards the main line, optimal conveyor systems, and ending with the choice of containers to be used.

4.2.9 WCM Standards

- *WCM requirements*: the application criteria concerning the pillars, on which this industrial philosophy is based, should be influenced by the production volumes, therefore they should take into account the type of vehicle.
- *Workplace organization*: redefine the activities that a worker can perform in terms of complexity and distinction, by considering the high cycle times and the skills of the workers themselves, arrange consequently the work stations.
- *Human resources training plan*: returning to the previous point, the workers must be trained to carry out activities with particular attention and skills but, at the same time, they have more time available. The workers will be more responsible for their job, therefore preventive training will be vital.

4.2.10 Ergonomics, Health & Safety

- *Ergonomic requirements*: the aspects related to ergonomics at the work stations should consider the optimal technologies used for low-volume production. As described in the example at the point concerning the manual sealing of the painting area.
- *Analysis of the work stations*: a preliminary study of all the determining factors such as: high cycle times that often exceeding 20 minutes, use of tools for manual activities (for example the sealant applicators), postures that can be accepted if compared to cycle times or if the workers are supported by special tools.

4.2.11 Technological departments training

This area has been included in the program because all members of the technological departments must be trained and oriented towards the low volume approach. Technological training is preliminary to the application of the method and the launch of low volume cars production.

As already mentioned, each technological department must not create restrictions that prevent other departments from applying the low volume method. Production volumes must be a discriminating factor for the technological choices.

Therefore an appropriate technological training must be provided and implemented for each area previously identified

4.2.12 Workers training

The activity of the workers becomes one of the most important factors in the production of special cars, because, especially a minimum level of automation leads to a significant reduction in investments. The quality of the job carried out by the workers can increase through different measures and a specific production organization.

Different activities are entrusted to the single worker, even very complex operations, therefore their skills are essential. The training of the workers is the base from which to make low volume production possible.

Greater responsibilities and a greater number of activities to be managed, even entire processes or preparations of complete sub-groups, create a feeling of satisfaction and professional achievement in the workers, thanks to which the they increase their productivity, also in terms of quality.

For these reasons, the training of the workers plays a leading role in this productive approach concerning the low volume vehicles.

5 Solutions for the Low Volume Production

As already mentioned above, the automotive industry is subject to multiple pressures deriving from various factors as well as different nature. One of the main ones is certainly required by the legislative bodies that impose strong restrictions on the quantity of polluting emissions. The Regulation (EU) No. 333/2014 of the European Parliament and the Council of 11 March establishes the target to be achieved in the years following this date: by 2021, in fact, the emissions of carbon dioxide must be lowered by 130 g/km, which was the target to be achieved in 2015, at 95 g/km, with a drop of 27% over 6 years.
Although the threshold of emissions imposed is different depending on the type of vehicle, in fact it is related to the weight of the car, the legislative decisions are certainly very influential with all aspects of the car production, from the design to the final quality control, but obviously they are indispensable and essential for the protection of the environment that hosts us.

5.1 Emissions control

The climate changes are the clearest aspects that give an immediate idea of the enormous damage man has been able to make towards the environment.
This factor, historically too undervalued, begins to be part of everyday life; unfortunately it is now customary to speak about the greenhouse effect, the hole in the ozone, pollution, acid rain and so on. Nowadays there are more and more frequent meetings between different delegations of the governments, in which the points of discussion include the protection of the environment and the legislative actions that must be implemented in this regard.
From this perspective, the manufacturers would like to be a "solution to the problem" and no longer a "cause of the problem".
The automotive sector has a very high potential influence on changes in the environment, it can be exploited positively, by implementing the correct design and production strategies.
The goal is to arrive at a final condition, in a future as close as possible, where all means of transport are environmentally friendly.
The emissions of pollutants obviously do not come only from motor vehicles, but from many other users that exploit the combustion of hydrocarbons to achieve their purposes.

The following diagram has been obtained through the estimates made by the World Resources Institute.

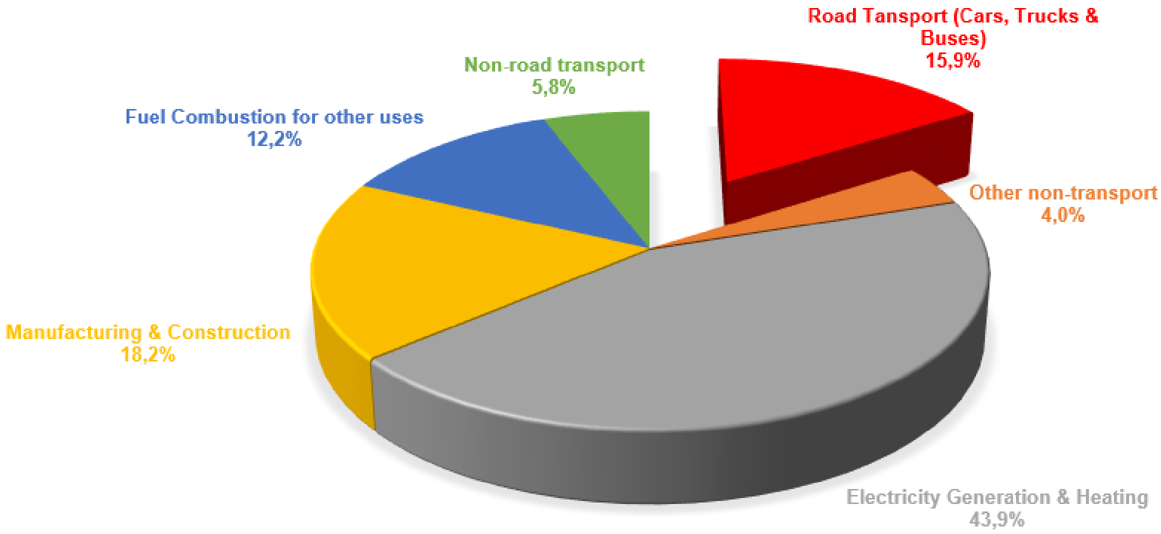


Figure 19 - Breakdowns of the causes of greenhouse gas emissions

Greenhouse gas emissions attributable purely to transport means around 16%, therefore the cars are not the main cause of CO_2 emissions.

The results of these surveys show that, although the automotive sector wants to propose solutions to the problem of environmental pollution, these solutions alone are not sufficient to effectively improve the general conditions in which we live.

Surely, both the lifestyles of each individual both the technologies and the materials used by the industry must switch towards the Eco-sustainability.

In October 2007, car manufacturers CEOs from around the world gathered to discuss climate changes, noting that the change approach must be general and involve not only car manufacturers but also governments, energy industries and all users.

It is inevitable that the changes required to the industrials then will be converted into costs, these changes include several cost factors, for example:

- Know-how acquisition to have the necessary skills to implement the strategies;
- Use of new materials that could have a higher variable cost;
- Use of new technologies and structures, or implementation of existing ones, for the transformation of materials.

These are just some of a wide range of aspects related to the automotive industry that are influenced by the new eco-sustainable trend.

5.2 Categories of polluting emissions

The carbon dioxide is considered the main cause of climate change, pollution and greenhouse effect; in reality, the range of harmful substances is much wider than imaginable, and the types of pollutants can be divided into a quite large number of subgroups.
For obvious reasons, only the main causes of air pollution are mentioned, although unfortunately they are not the only existing forms. This paragraph will try to list and describe different types of pollutants in a very simplified and schematic way.
It is known that some polluting gases are released into the environment following a combustion of hydrocarbons, burned to obtain energy convertible in another form of energy (mechanical, electrical, etc.). Any substance that, emitted into the environment, alters the chemical composition of the earth's atmosphere is considered an atmospheric pollutant.
To change the conditions of the air we breathe has the unavoidable consequence, unfortunately, of causing irreversible damage to the health of man and all living beings that inhabit the planet. Obviously, on the planet there are areas with a higher concentration of pollutants, therefore at higher risk for people who live there, and areas with lower risk.
Agencies in many regions are responsible for monitoring the amount of emissions and providing feedback to government bodies, therefore that they act promptly with actions to reduce emissions.
Let focus the attention on certain types of atmospheric pollutants:

- CARBON DIOXIDE (CO_2): it is made up of a carbon atom (symbol: C) linked to two oxygen atoms (symbol: O). It is a substance of fundamental importance in the vital processes of plants and animals. In particular, it is involved in plant photosynthesis and is produced during the respiration of animals. It is also produced in chemical combustion processes.

  It is considered the main greenhouse gas produced by human activities in the Earth's atmosphere (its overproduction causes an increase in the greenhouse effect, contributing to global warming by 70%), although there are other potentially more dangerous greenhouse gases (such as methane or nitrogen trifluoride), but they are present in the atmosphere in lower concentrations than carbon dioxide.

Carbon dioxide emission into the environment is inevitable when burning carbon-containing fuels, it is the case of all those deriving from petroleum. Alternative fuels are the ones with the lowest carbon content.

The presence of carbon dioxide in the atmosphere is a natural factor, it is not harmful, but the substantial increase of its concentration is the main cause of global warming.

- CARBON MONOXIDE (CO): it is a particularly insidious poisonous gas as it is odourless and tasteless. Its molecule consists of an oxygen atom and a carbon atom bound by a triple bond (consisting of two covalent bonds and a dative bond).

  Carbon monoxide is produced by combustion reactions in air defect, i.e. when the oxygen present in the air is not sufficient to convert all the carbon into carbon dioxide, for example in forest and wood fires, where the main product of the combustion remains however carbon dioxide. Other natural sources are volcanoes, while most are generated by photochemical reactions that occur in the troposphere. It is also released during combustion in closed rooms and old liquid gas stoves, which are responsible for the high frequency of carbon monoxide poisoning.

  The problem for human health is that CO easily reaches the pulmonary alveoli and therefore the blood, where it competes with oxygen for binding with haemoglobin.

  The carboxyhaemoglobin thus formed is about 300 times more stable than oxyhaemoglobin and therefore significantly reduces the ability of the blood to bring oxygen to the tissues.

  The health effects are essentially due to the damage caused by hypoxia in the nervous, cardiovascular and muscular systems.

  The most sensitive groups are individuals with heart and lung disease, anaemia and pregnant women.

- NITROGEN OXIDES (NO_X): the generic composition of nitrogen oxides is indicated with NO_X, it represents those compounds originating from the bonds between oxygen and nitrogen. The two most important and widespread oxides of this type, in terms of atmospheric pollution, are nitric oxide (NO) and nitrogen dioxide (NO_2), the latter characterized by an acrid and pungent smell.

Nitrogen and oxygen are naturally present in the atmosphere and come together to form these two oxides, following chemical reactions occurring at high temperatures such as combustion or explosions. Prolonged exposure to the presence of these oxides, in particular to NO_2, causes damage to human health, such as irritation of the mucous membranes and problems with the respiratory tract. As regards the effects that nitrogen oxides have on the environment, according to research studies, these are the main cause of photochemical pollution and acid rain.

- VOLATILE ORGANIC COMPOUNDS (VOC): The class of volatile organic compounds includes several chemical compounds formed by molecules endowed with different functional groups, having different physical and chemical behaviours, but characterized by a certain volatility, characteristic for example of common organic solvents such as paint thinner and gasoline.
  These compounds include hydrocarbons (containing, as unique elements, carbon and hydrogen) and compounds containing oxygen, chlorine or other elements in addition to carbon and hydrogen, such as aldehydes, ethers, alcohols, esters, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).
  The Italian legislation defines volatile organic compounds those organic compounds which, at a temperature of 293.15 K (20 °C), have a vapor pressure of 0.01 kPa or higher. The harmful effect on human health is substantially linked to respiratory difficulties. The effect on the environment is mainly the contribution to photochemical smog in certain climatic conditions.
- PARTICULATE MATTER (PM): this category contains all those substances suspended in the air (fibres, carbonaceous particles, metals, silica, liquid or solid pollutants).
  It is present in the Earth's atmosphere due to natural and anthropogenic causes or in industrial workplaces.
  It is a very current topic of debate, in fact, fine dusts and PM10 level in urban areas are everyday topics. It is not by chance that it is constantly monitored by the competent bodies.
  The particulate comprises a large variety of particles of different chemical compositions and sizes, in particular the PM10 identifies the fraction of fine particles with a diameter of less than or equal to 10 μm. The smallest particles are also the most dangerous, because they easily reach the pulmonary alveoli.

Because of the serious effects that the particulate has on the health of living beings, in particular of the people, since the level of PM10 is higher in large cities, it was essential to impose a maximum threshold at the level of PM10.

Legislative Decree 155/2010 established the daily limit value for human health protection for PM10 in 50 μg/m^3, not to be exceeded for more than 35 days per year.

The mandatory installation of the particulate filter (DPF, Diesel Particulate Filter) on diesel-powered vehicles produced in recent years, Euro 4 / 5 / 6 cars, is an example of how the legislative decrees influence the automotive industry; in fact this device has the purpose of reducing the level of PM10 in the air.

5.3 The use of the multi-material

The goal of reducing CO_2 emissions is therefore common to all car manufacturers.
Different decisions can be made according to the strategic choices, in fact there are several solutions that can help OEMs to achieve this product target.
It should be said that any solution that can be implemented has advantages and disadvantages of different nature.
The market for electric or hybrid cars is very current and attractive.
At first glance it might seem that electric propulsion is the solution to environmental impact problems, but in this sector there are still several question marks:

- The battery packs are very bulky, heavy and not very reliable;
- The times of charges are still too long;
- The energy density inside the accumulators is low (low autonomy);
- Pollution is delocalized but not completely eliminated, we could find a scenario in which energy production would pollute more, with a negative netting of the reduced emissions.

In terms of negative environmental effects, the disposal procedures of the huge lithium ion batteries, at the end of their useful life, are not negligible.
In addition, to switch to the production of electric and hybrid vehicles, for many car manufacturers would mean risking not being able to fill the gap already existing towards the leaders in the sector, in terms of sales.
Other strategies that could be taken into account are the adoption of engines powered by biofuels or vehicles with propulsion systems that exploit hydrogen. These solutions are not yet

very feasible in the automotive production sector, due to current cost, safety and reliability limits, but there are interesting studies in this regard and prototype vehicles realizations.
An interesting strategic choice, currently traveled by many manufacturers is the weight reduction of the cars. Lighter cars bring to a significant reduction in emissions and increase in performance.
The choice of the right materials is the most powerful means for lighten vehicles.
The design of the chassis and the body of the vehicle play a fundamental role, in fact about 60% of the total weight of the car come from these two groups.
Therefore, the most important factors are: the optimization of the components geometry, the choices about the materials and the production technologies.
The use of lower density materials instead of the most common used materials, or extruded components rather than assemblies of stamped sheets, leads to obtain the desired result; the final mechanical characteristics of the components are the greatest constraints.
A global optimization of the parts is fundamental, through an accurate preliminary analysis of the role that each individual component plays in the whole vehicle.
Reliability, safety and performance of all components must be always ensured.
It must be said that lighter and innovative materials with significant mechanical characteristics, at the same time, generally have a higher cost. The immediate consequence is that innovative, resistant and low-density materials have already found, or they are finding, widespread application in the productions of luxury vehicles and supercars, which are products whose cost is very high. These ideas have arisen in sectors far from the world of mass production cars. Lighten the components and maintaining high structural characteristics are the tasks of the aerospace industry, while improving performance is, undoubtedly, the main goal of the racing cars manufactures.
Starting from these two sectors, this approach is increasingly spreading towards the production of niche vehicles and, in the future, it will probably involve also the mass productions.
The body and the frame can be made up of sub-groups of different materials. A right mix of materials such as aluminum, steel, magnesium and plastics reinforced with carbon fiber, can increase:

- Product complexity;
- Complexity of the technological processes.
- Total costs of production.

Weight reduction of the frame-body assembly and increased torsional rigidity can be achieved, in opposition to the previous disadvantages.

5.4 Alfa Romeo 4C

The model 4C of the Alfa Romeo brand is briefly presented because it represents a type of low-volume production that could come under the perimeter of interest of the method, with a maximum target of about one jph, imposed in the production planning phase.

Figure 20 – Alfa Romeo 4C

This car is an important example of the unconventional materials use for the weight reduction and the performance improvement. This supercar has a very low weight / power ratio (4 kg/CV). The 4C chassis is a monocoque in carbon fiber, its weight is just 73 kg, with aluminum front and rear crash boxes, while the outer body is made of the special SMC compound, a low-density material that combines lightness (it is 20% lighter than steel) with a stability comparable to that of steel and superior to that of aluminum.
The total weight of the car is 934 kg.

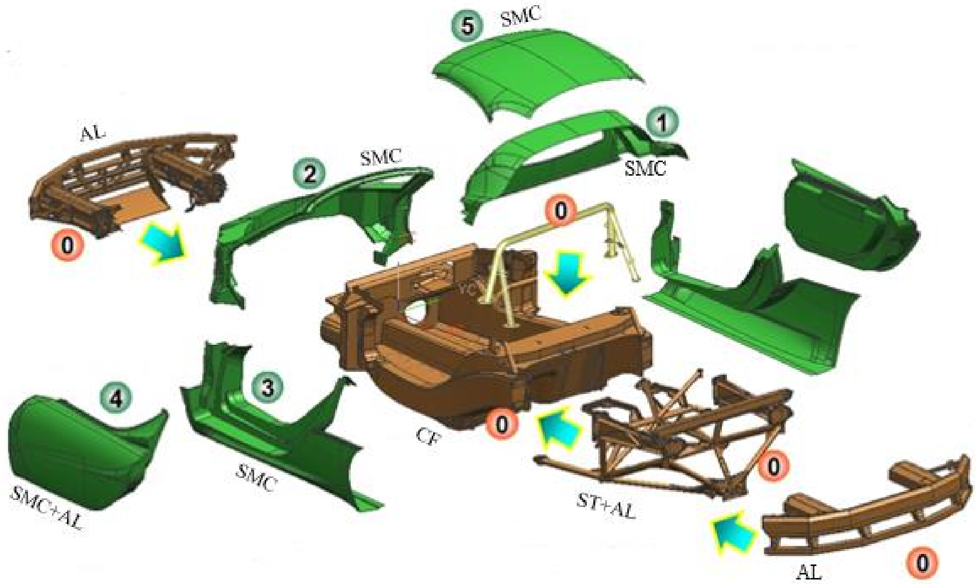


Figure 21 – Assembly sequence and different materials of the Alfa Romeo 4C chassis

This car is the best example of how the use of a right mix of materials can lead to the weight reduction, therefore emissions, and the performance improvement; it is clear that the selected materials must be applied in the right place, in order to guarantee always the safety of the passengers.

A product with this level of complexity forces the research and experimentation laboratories to make a greater preventive effort. It is necessary to find reliable technological solutions that allow to produce this vehicle by joining materials with very different mechanical, physical and chemical characteristics to create a single body.

5.5 Mechanical hybrid joints

A design and production approach that orients the product towards the use of multi-material should obviously take into consideration a detailed study of the technologies to be used.

In some cases the product and process technologies can be adapted with more or less extensive adjustments, in other cases they must come from studies conducted by research laboratories and innovation and development departments.

As regards the production of a single-material car body, the use of special fixed (non-removable) joining technologies between the parts is not required. In the case of two components consisting of the same type of material, for example steel, the welding between the parts can be carried out using methods that are highly widespread and well-established. By contrast, if a subgroup is designed with two different materials such as steel and aluminum, their assembly process is not trivial.

Steel and aluminum have notoriously different mechanical, chemical and physical characteristics, for example their melting points are very far and consequently the welding between the parts becomes an unsurpassable obstacle. Nowadays, welding processes able to ensure a weld bead with sufficiently reliable strength characteristics have yet not been developed; in various laboratories throughout the world studies are being carried out for overcoming this huge constraint.

The problems that emerged with the previous example are unfortunately valid in all cases of multi-material assembly.

While welding for this type of product remains a utopia, on the other hand, some joining methods based on riveting are very widespread.

Riveting is the technique used in place of welding, in fact it is a fixed joining technologies that guarantee high mechanical resistance of the final assembly.

Nowadays the use of several types of rivets, applied with specific process technologies is consolidated, although there are still many problems that must be overcome, therefore it is a portion of the production world undergoing strong evolution and innovation.

The rivets are now strongly used for joining the components of the cars, also belonging to the Mass Production segment, not only in the production of the top of the line vehicles.

Their use is born in the aerospace industry due to the characteristics that a rivet has: high reliability, lightness, reduced dimensions and advantageous geometry from an aerodynamic point of view.

There are many factors to be evaluated to select the suitable rivet to perform a joint, they are essential to overcome product constraints related to the quality of the joining, and process constraints in terms of parameters and tools used.

The following are some evaluation features of the rivet that OEMs consider before selecting a joining technology:

- Accessibility;
- Multi-material applicability;
- Joint strength;
- Automated / manual process

- Technology status;
- Piece cost;
- Facility cost / requirements
- Operation required before assembly;
- Cycle time to spot;
- Nail presence;
- Possible combination with adhesive;
- Max number of layers;
- Minimum thickness;
- Maximum thickness;
- Aesthetical aspect;
- Possible gap between layers;
- Required soundproofed station;
- Power supply system;
- On-line checking;
- Off-line inspection.

On the basis of the evaluation of all these aspects it is possible to make the correct choice on the technology to be used.

The greatest part of the features listed above are binding on the applicability of the riveting technology to product considered. For example, accessibility, i.e. the type of access to the material surfaces is determined by the geometry of the component, in the case of joining technologies such as resistance spot welding, clinching and almost all rivets a two-sides access is required, in other words, for many components they are not workable.

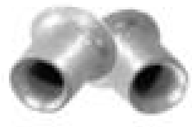
Another opportune consideration concerns the cycle time, this evaluation is very important for high-volume vehicles, remembering that the number of joints in a BiW is really high, instead in the case of low volume vehicles this constraint loses its significance, especially for the productive rates covered in this project.

A similar reasoning can be made about the costs of the joining, these are distributed on different volumes and therefore they influence quite the difference in total cost between a high and a low volume car.

In this session, some riveting technologies are described, each one has some unique characteristics and needs specific equipment.

5.5.1 Self-Piercing Riveting

The mechanical joining technology called Self-Piercing Riveting is the most used in the production of vehicles with regard to FCA.



The geometry of the rivet used is an annular shape that allows the rivet to penetrate and deform into the material.
The equipment that ensures the application of these rivets consists of a rivet gun (or tongs) able to apply a pre-compression on the sheets and a high pressure on the rivet though a hydraulic cylinder, to ensure its correct insertion.
The rivet gun requires a two-side access, for this reason the applicability of this technology is strongly linked to the product geometry.
The sheets to be joined are overlapped (1) and subsequently kept in contact thanks to the action of the rivet gun (2); in the following phase, the cylinder travels towards the overlap area (3) and, by applying a high pressure on the rivet, forces it to penetrate into the materials, while the rivet gun itself opposes on the other side with a fitted die, causing the deformation of the annular crown of the rivet, creating a flange inside the second sheet penetrated and ensuring the mechanical resistance of the joint (4); the cylinder goes backwards when its work has been completed (5); the tongs are opened, ending the application of the rivet (6).
All the stages of the SPR process are schematized in the figure.

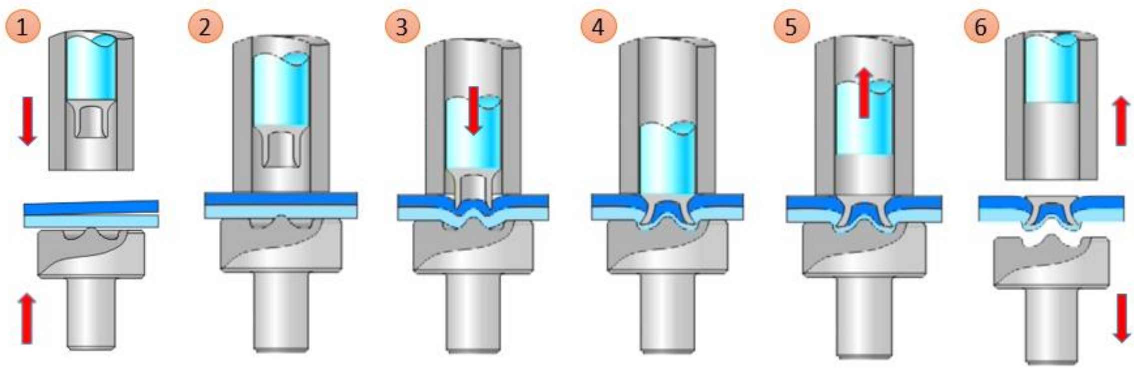


Figure 22 – SPR process steps

This joining technology has many advantages among which:

- No preliminary operations (for example predrilled or punched holes);
- A process that does not pollute;
- It is also applicable to sheets with protective coating;
- Possibile automatic process;
- Good resistance to cyclic fatigue loads;
- It guarantees tightness.

Feasibility and quality of this type of joint depend on the materials of the parts to be joined and also on their arrangement with respect to the rivet gun, in fact some materials can be assembled with SPR only with certain arrangements.

For example, aluminum or steel with magnesium can be jointed as long as magnesium is the material of the upper sheet (on the punch side).

These rivets are used for steel, aluminum and their combinations by replacing the welding processes. The total thickness that can be joined vary depending on the materials, for example about 6-7 mm for steel and 10-12 mm for aluminum.

The main limits related this technology are:

- The last sheet (in which the deformation of the rivet generated by the die occurs) must consist of a material with a percentage elongation at least 12%, a thickness at least equal to 1/3 of the total thickness and it must not be brittle;
- Two-side access to be able coaxially performing the reaction force;
- There is always a deformation capability on die side.

The first point highlights the limit of SPR in terms of materials that can be joined and this is the major constraint of this technology. Instead the second point represents the specific field of applicability on the only components with quite simple geometries that guarantee the rivet gun access on both sides.

5.5.2 Solid Punch Riveting

Solid Punch Riveting is a technology very similar to the Self-Piercing Riveting, but in this case the process is more expensive. They differ in a few aspects:

- Different type of rivet used, in this case it is a solid rivet with the shaped side surface, in order to increase the resistance of the joint against the loads direct along the axis of the rivet;
- The sheets are completely pierced by the rivet, which replaces the material previously present in that area;
- No need for a shaped die because the rivet should not be deformed, in fact the die side material flows into an annular groove.

The main advantages achievable with this joining technology are:

- High strength materials without deformation capability on punch side are possible;
- More than 3 sheet metal layers can be joined;
- Nearly flat in the area of the joining on both sides.

Also the sequence of the process steps is very similar to the previous one, the following figure outlines it.

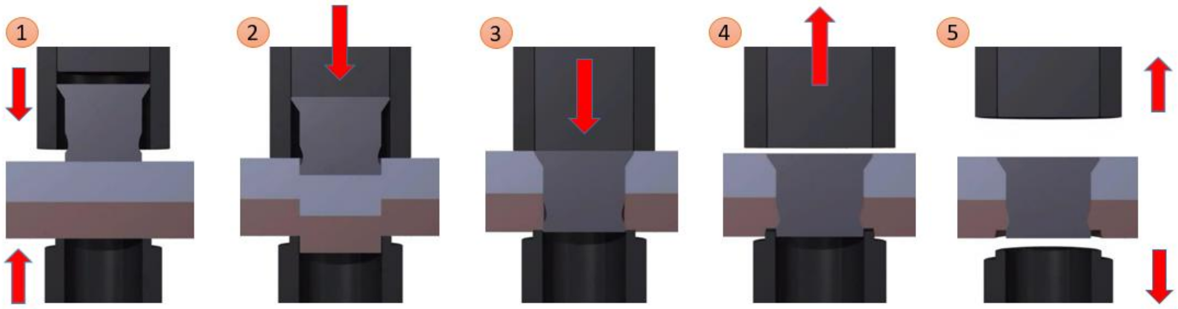


Figure 23 – Solid Punch Riveting process steps

The blank-holder approaches the area to be joined (1); the punch performs the drilling by applying a high pressure on the head of the rivet (2), in this way the rivet is inserted into the two or more different material sheets (3); at this point the punch goes backwards (4) and the die and the blank-holder can leave the parts now joined (5).

If on one hand this technology presents a huge potential in joining materials with different mechanical characteristics, on the other the conventional design of the tools is unsatisfying for these joining tasks. The required dimensioning of the die for every single joining task, high forces and occasional global deformation of the sheets are disadvantages of the conventional tool design.

5.5.3 Flow Drilling Screw

Flow Drilling is an innovative process that has an interesting application potential, but not widespread in the production field, because it is still a developing technology.

This joining technique can be considered a mix between riveting and welding processes, because it consists in the application of the rivet with subsequent welding between the rivet and the last penetrated sheet.
The heat generation is obtained thanks to the friction effect, it allows the rivet to weld to the farthest metal sheet and guarantee the mechanical resistance of the joint.

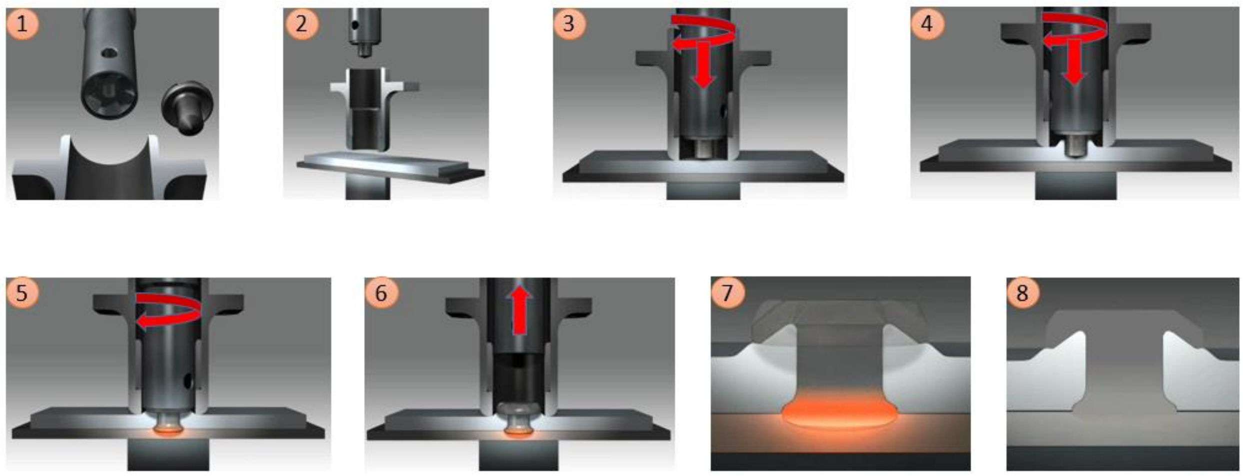


Figure 24 – FDS process steps

In this case, the punch is similar to a screwdriver, at first it moves the rivet, that is like a screw, towards the components to be joined (1), (2), (3); by applying a pressure it allows the penetration of the rivet into the materials and heat is generated by friction thanks to the rotation, this amount of heat brings the temperature to reach the melting point of rivet and second sheet

(4),(5); the punch ends the rotation and detaches itself from the rivet (6); the joining process concludes with the solidification of the parts and the cooling phases (7), (8).
The opportunity to perform this joining with one-side access mode, makes this technology very interesting and topic of current laboratory studies.
There are still several limits to overcome, in particular with regard to the materials and thickness of the sheets that can be joined through this technique with a significant reliability.

5.6 Qualification of hybrid joints assembled with mechanical systems

As previously stated, the activity carried out by research laboratories in the field of joining processes is crucial, especially as regard the innovative technologies.
CRF (Centro Ricerche Fiat) represents a very important support for FCA group in terms of experimentation activities and innovation.
A collaboration has been undertaken with the CRF researchers during the internship period, the purpose of the work was the development of a new standard, useful for the company, used for the hybrid joints characterization.
To qualify a hybrid joint, i.e. a mechanical connection between different material components, five types of tests are considered necessary, through which a complete characterization of joints is obtained.
The five tests for the qualification of the joints are:

- Shear test;
- Cross-tension test;
- Fatigue test;
- Macrographic examination;
- Corrosion test.

All instructions to correctly perform the five tests are now included in a single standard document.
It is obvious that all the tests are performed on the specimens, in fact each test leads to specific results about the joint tested.
In the section concerning the shear test there is the definition of the geometric characteristics of the single and double joint specimens, which must be submitted to the tensile shear test; the

single joint specimen must be tested without adhesive application between the joined sheets, instead adhesive is applied for double joint specimen.

Test equipment and procedures are described, as well as all the items that must be contained in the final report; these are aspects common to all the tests, therefore they constitute the structure of each section of the standard.

Regarding the cross-tension test, an x-shaped specimen has been defined. Only single-joint specimens are tested in this case.

The fatigue test concerns single or double joints, the specimens used are the same as those used for the shear test, but they undergo cyclic loads to determine their fatigue resistance.

Macrographic examination is used to define the quality and the acceptability of the mechanical joints and to determine the presence of internal faults. This test consists of 4 phases: Sampling, Mounting, Grinding and Polishing, in this way it is possible to analyze effectively the cutting-surface.

To carry out the corrosion test, the joined specimens are submitted to "quick aging" cycles , with humid stages and drying stages, by means of spray saline solutions; furthermore all the environmental parameters of the chambers must be monitored during the process.

All tests are destructive.

Therefore, this new standard presents the same section structure for each type of test to be carried out, in particular:

- Purpose of the test;
- Condition of the part prior to processing;
- Test procedure;
- Process control;
- Test equipment;
- Test report.

The details of the standard cannot be reported, just its sections have been briefly described, in order to preserve confidentiality.

The following targets have been achieved thanks to this new standard: standardize the joints qualification process, opportunity of using only a guidelines document for all types of tests, in order to guarantee comparability and repeatability of tests and results, even when the joining technologies change.

6 Case Studies

The methodological approach described in this thesis allows to apply standardized assessment criteria during all product / process design stages, obtaining profitable results in terms of investments reduction, to reach the final goal of producing cars destined to a niche market.
The method has already been tested in the assessment of some factors related to both the process and the product.
The comparison between a solution currently adopted and a low volume solution proposed, which could allow to reduce the initial fixed costs, is the core of the method application. The most important purpose of the evaluations made for the study cases, that will be presented below, is to outline lesson learned that will be the main guideline for the next low volume productions.
The management and the deployment of a database, that includes all the data resulting from the systematic application of the low-volume evaluation criteria, is vital; this database will make many company activities, that lead to the creation of new low volume models or special series, lean and successful. In this paragraph two study cases are presented: hood pre-assembly cells and bumper material choice, they respectively belong to the BiW and Plastics areas.
The technological choices have implications both on the product and on the process, this aspect emerges from the parameters that must be taken into account in the evaluations of the comparison tools in both cases.

6.1 Hood pre-assembly cells: Maserati Levante Vs Maserati GT/ GC

The criteria described by the low volume method were applied to the case of the hood pre-assembly cells, within the area of intervention of the BiW.
The standard technological solution considered is the preparation of the hood of the model Maserati Levante, which activities are performed in the Mirafiori body shop, in Turin. In this case, the technological choices made during the product and process design phase have been aimed towards production capacities exceeding 10 jobs per hour.
A low volume solution is placed thanks to the internal benchmark activity on the other side of the scale, in fact, as mentioned several times, the benchmark is a fundamental support; this low

volume solution is represented by the pre-assembly cells of the Maserati Gran Turismo and Maserati Gran Cabrio hood, of the Plant 193 (Ex ITCA), in Grugliasco (TO). The production rates in this case are about 3 jobs per hour, so much lower than in the previous case, this kind of production certainly belongs to the domain of our interest and can be analyzed as a low volume reference solution.

A first analysis of the product and of the processes must always be carried out in the application of the method, in order to select all the features that make the two or more solutions comparable and discard all the other aspects.

The hoods of the Maserati Levante and the Maserati GT / GC are perfectly comparable in terms of product, in fact both inner and outer hood are made entirely in aluminum. In both cases the process provides for the preparation of the inner hood with reinforcements and the subsequent assembly with the outer hood.

The hemming process is performed by roller hemming machine in the case of the Maserati Levante, while a low capex equipment is used for GT and GC.

In the body shop of Mirafiori, in the same cells of preparation are assembled both the hood and the tailgate of the Levante, for this reason, only the costs in investments for the preparation of the hood were considered, in order to make the comparison reliable.

It is clear that the production approach in the two cases is very different. At the Mirafiori plant the level of automation is high, in fact there are 9 robots for the preparation of the hood and tailgate, the cycle times are low, the process control systems are advanced, the portion of the plant occupied by the fully automatic cells is relevant, the human craftsmanship is reduced and does not require a very high level of technical training.

The Plant 193, already mentioned in the fourth chapter, presents characteristics that are totally opposite to the previous ones, because it has a small-scale industrial imprint: the level of automation is minimal, the space taken by this preparation cells is really reduced, the level of training, skills and technical experience of the workers are very high, the process controls are often entrusted to the workers. In addition, these skilled operators perform various activities in their time available, for example a single worker manages the whole process of the hood preparation in the present case.

All these factors are strongly influenced by the cycle times required, therefore by the production volumes of the specific model, and are heavily reflected in the costs of investments in structure.

The following figure gives an idea of the size and level of automation of the hood / tailgate assembly cells in the Mirafiori body shop.

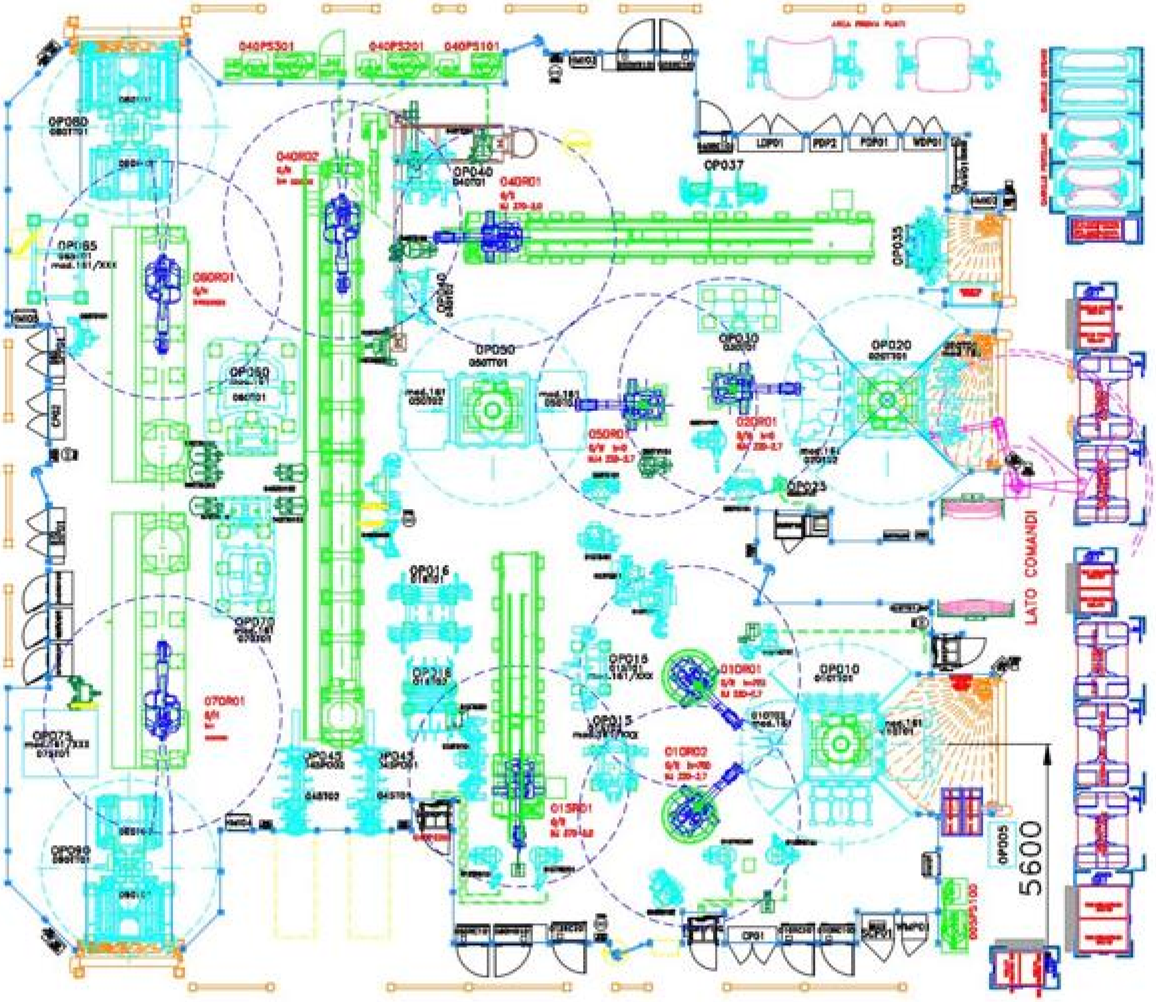


Figure 25 – Hood/ tailgate pre-assembly cells layout, Mirafiori Plant

The layout of the cells is represented in this 2D view, here is possible to see both the nine robots that manipulate the components and perform all the operations necessary for the assembly of the hood and the tailgate, and the conveyor systems used to move the subgroups.

In the plant 193 in Grugliasco the layout of the cells dedicated to the hood preparation has small size and a minimum level of automation, as shown in the following figure.

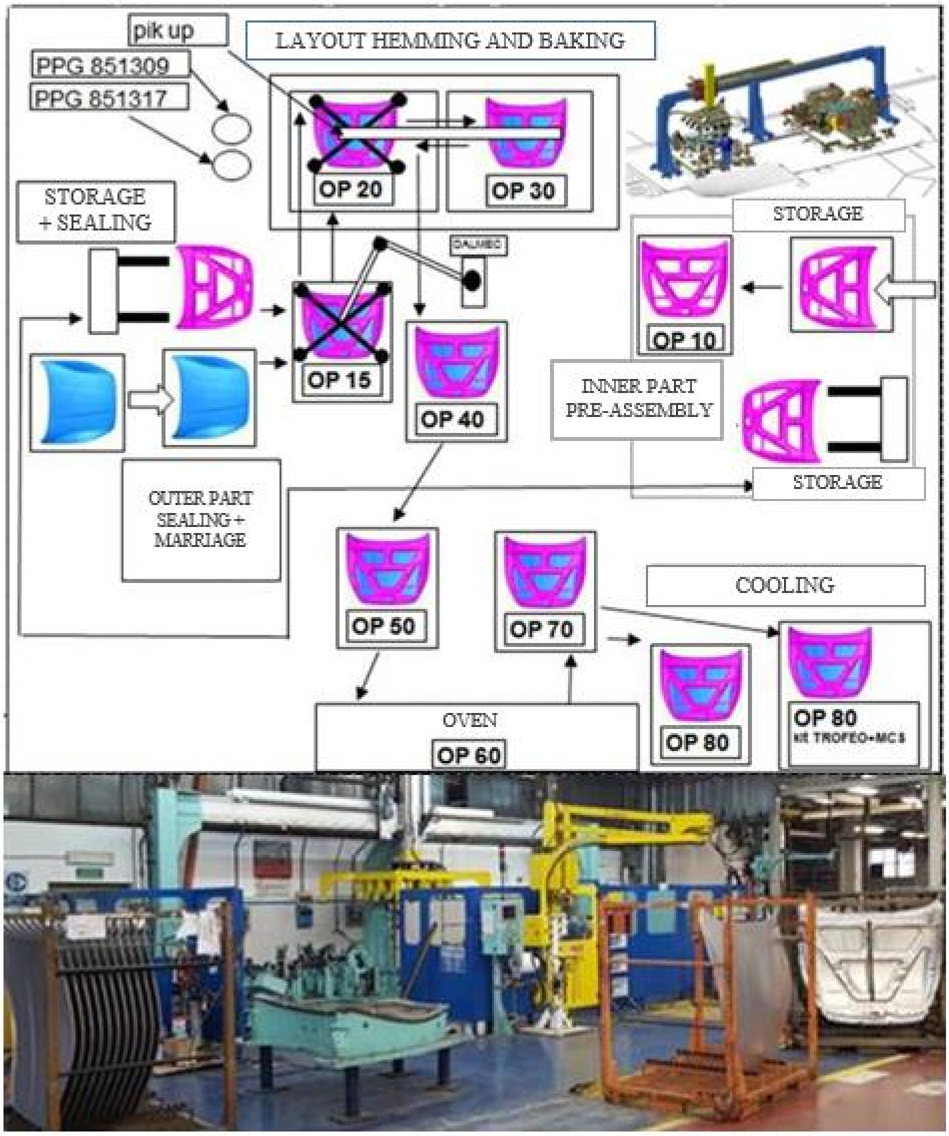


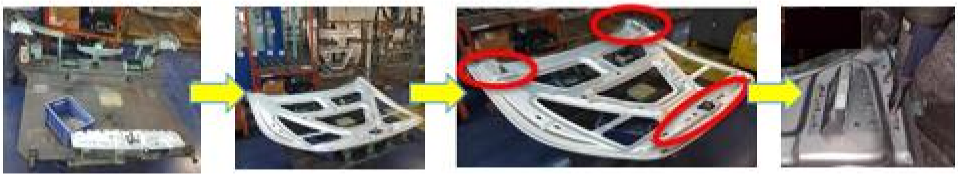
Figure 26 - Hood pre-assembly cells layout, Ex ITCA Plant

Recalling that a so simplified production setting is suitable only for very low capacity required and possible only thanks to the advanced skills of the workers who perform the operations.

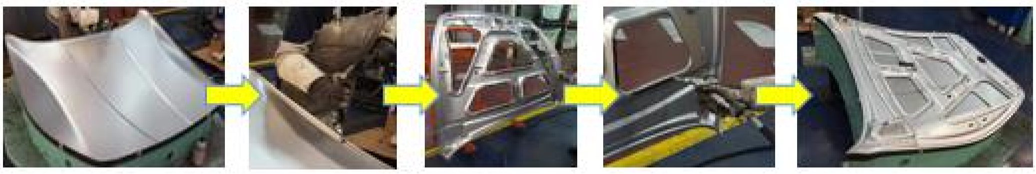
All activities are performed manually, including the manipulation of the components between the various stations; only the OP.20 is performed automatically by a low capex hemming machine, but even in this case the parts to be assembled are placed inside the structure by the same operator that manages the whole preparation cycle, obviously with the help of a mechanical "partner" to make easier the handling of these rather bulky subgroups.

The macro phases of the hood preparation cycle do not depend on the plant considered or the level of automation; the sequence of the operations can be summarized in:

- Inner hood preparation with reinforcements and riveting process;



- Structural sealant extrusion and "marriage" between inner and outer parts;



- Hemming.

The process ends with the hardening of the structural sealant obtained by exposing the hood to high temperatures, but far from the critical temperatures characteristic of steel or aluminum.
The activities can be performed and managed by the operator or by automatic systems, depending on the level of automation required, for example the extrusion of the sealant or the riveting process performed on the inner hood are manual operations with regard to the GT and GC models (as shown in the figures that are related to the Ex ITCA plant), instead they are fully automatic for the hood of the Maserati Levante.
As already mentioned, the type of equipment and the management of the operations with this approach do not comply with certain standards currently required by the company; in fact, the Plant 193 has maintained the same technologies used prior to its acquisition by the FCA group. Nevertheless, the results in terms of product and process quality have always been, and continue to be, optimal.

The purpose is to make certain processes in compliance with the standards required, by implementing the standards according to the production volumes, also by revaluing and modifying the technologies if it is necessary, but always with a view of capex reduction.
As stated above, the cycle times required for the two plants activities are very different, because of the different production capacities, in fact it emerges that the preparation of the hood involves:

- About 7 minutes, in the case of the Maserati Levante;
- About 20 minutes, in the cases of the Maserati GC and GC.

The obvious differences between the two plants in the type of production approach are inevitably reflected in costs.
The production characterized by a lower level of automation is more disadvantageous than the production performed in the fully automatic cells in terms of variable costs (euro / car), but entails considerable advantages with regard to the initial fixed costs.
Therefore, economic assessments were carried out in the two cases, by considering the total production volumes as the main parameter, with the aim to estimate the period of time required to achieve the break-even point of the total costs.

MIRAFIORI PLANT	TOTAL INVESTMENT	1895 k€	STRUCTURE •808 k€ PRODUCT •1087 k€
	VARIABLE	3.34 € / car	HOURLY LABOUR COSTS •27.50 € / h CYCLE TIME •7 min
Ex ITCA	TOTAL INVESTMENT	900 k€	STRUCTURE •72 k€ PRODUCT •828 k€
	VARIABLE	8.60 € / car	HOURLY LABOUR COSTS •27.50 € / h CYCLE TIME •19 min

Table 3 – Investment and variable costs for the hood preparation, Mirafiori and Ex ITCA Plants

As already mentioned, the costs attributable to the preparation of the tailgate have been excluded in the investment costs of the Mirafiori plant. Total investments are divided into structure (structures and equipment that could also be used for other future productions) and product (costs related to the specific product currently in production).

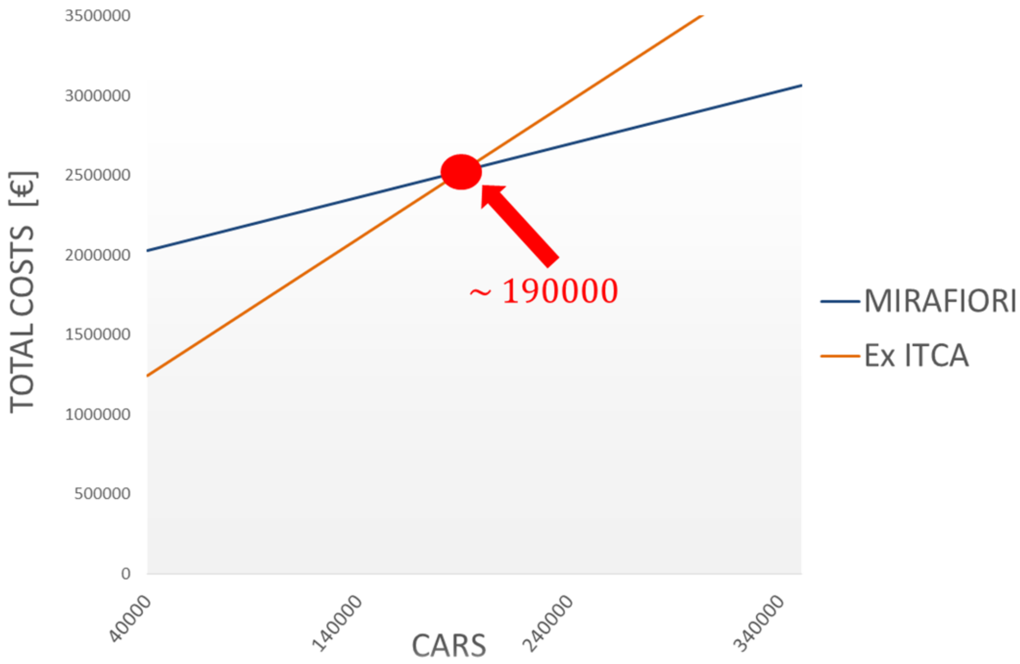


Figure 27 – Total costs trends

With this analysis is possible to evaluate the impact of the automation level on the hood preparation activities.

From an immediate comparison based on the costs of investments and the variable costs, that take into account the cost of labor, it emerges that the recovery of the initial difference of costs, due to investments, is obtained for a production volume of about 190.000 cars, i.e. a production 4 - 5 times a total production considered as low volume in this thesis.

An analysis of the risks that these proposed solutions involve for the product and the process is unavoidable; as regards the activities that are carried out in this study case analyzed the risks to be considered are:

- Manually sealant extrusion does not guarantee the same accuracy of a robot with a vision and control system of the flow rate, therefore it may be necessary to carry out subsequent cleaning operations;
- Capability might not be ensured;

- Handling and conveyor systems could damage the parts.

In this specific case, the historical and current data show the high level of quality and reliability that has been achieved in terms of both product and process.
This type of preparation cell also bring several advantages:

- Investment costs reduction (main purpose of the low volume method);
- Size reduction inside the body shop;
- Reduced maintenance interventions;
- Easy set-up of the equipment;
- Easy retooling for any new models.

The Ex ITCA plant should be the main reference for approaching new low volume productions, obtaining benefits in economic terms, therefore to start the production activities.

6.1.1 Hood: innovation

During this thesis work, reference has been made to the importance of research studies that aim to develop new process and product solutions.
CRF, in collaboration with the FCA plants, has conducted studies about solutions for the hood; this product has some aspects that could be optimized and some interesting solutions have been developed in terms of weight reduction, in particular a hood with optimized geometry and aluminum sheets thickness less than those typically used.
To achieve this product target, the following steps are followed:

- Geometry optimization through reduction of the amount of material, where it was possible;
- Use of the best mix of materials;
- Thickness reductions.

The following table summarizes the product parameters resulting from this study case.

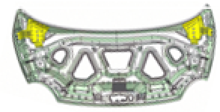
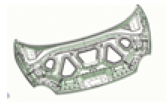
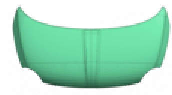
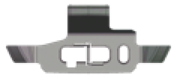
PART	MATERIAL	THICKNESS	
Inner Hood	Al 5182	0,55 mm	
External Hood	Al 6016	0,8 mm	
Hinge Reinforcement	FeE 340	1,2 mm	
Latch Reinforcement	FeE 340	1,2 mm	

Table 4 – Main characteristics of the innovative hood

Important results in terms of weight reduction have been obtained with these solutions, in fact the total weight of this hood is 3.9 kg, against the 4.5 kg of the hood in Al 520 (-14%) and the 8.1 kg of the hood in steel 320 (- 52%).
The phase of virtual simulations of the processes was crucial to obtain these excellent results, in order to estimate the formability of the material when the thickness changes, as well as the prototyping phase that was developed thanks to the support of the activity carried out in the Ex ITCA plant.
It is clear that it was also necessary to conduct tests about the joints to be applied, in this case SPR, in order to evaluate the qualities of this technology in the application to these materials.
In this regard, the standard that was made during this thesis work and briefly described in the fourth chapter, will be a fundamental support in the development of the next projects.

6.2 Bumpers: Polypropylene Vs Polyurethane

The study case presented in this section is the result of the application of the low volume method to choose the material to be used for the bumpers obtained by injection molding process, therefore it belongs to the intervention area of the plastics.
The aim is to create a guideline to streamline the choice of the most suitable material in the case of the special series productions.

A collaboration with the departments of plastic molding and painting technologies has been undertaken to achieve this purpose.

The comparison elements were the Polypropylene (PP) and the Polyurethane (PUR), processed with RIM (Reaction Injection Molding) technology, because the company choices always fell on these two materials.

The use of PP involves investment costs in structures and equipment generally higher than those relating to PUR, which instead has higher variable costs, in terms of DMC (Direct Material Cost). For these reasons the PUR has always been chosen for the production of bumpers for the special series, while the PP for the highest production volumes.

The analysis that has been carried out allows to define in detail the range of volumes within which the PUR is more convenient than the PP; furthermore, other parameters considered are the "make" or "buy" feasibility of the molding and painting processes.

The perimeter considered for the analysis consists of the following activities:

- Molding of all typical plastic components;
- Assembly of the bumpers (bonding and / or welding processes);
- Painting.

All the assemblies after painting has been excluded because they are too specific for each product and make the proposed solutions impossible to compare.

The fixed and variable production costs considered refer to two different series of the same model:

- Maserati Levante MY 19 Sport - PUR;
- Maserati Levante basic version - PP.

The car is produced in the Mirafiori plant, it must be considered that the painting plant for the PP components has already been adjusted for the PUR, therefore the initial equipment adjustment costs have not been taken into account.

The production scenarios that have been considered and compared are:

- PUR molding buy + painting buy;
- PUR molding buy + painting make;
- PP molding make high volume + painting make;
- PP molding make low volume + painting make.

The production cycle of the bumper in PP has been proposed also in a low volume point of view; in fact, different process solutions have been proposed compared to the typical technologies adopted for the PP in terms of equipment, manual operations, materials used for the molds, etc., which allow a significant reduction in investments with a slight increase in variable costs.

For example, the molds typically used for PP molding are made of steel and allow long life cycles, about 100.000 pieces, with cost of about € 550.000, but a solution could be to use aluminum molds that guarantee shorter life cycles, around 40.000 pieces, perfectly suitable to low volume productions, but whose cost is lower, around € 400.000.

This type of management, applied to all accessories and equipment, led to the production cycle called "PP molding Low Volume".

The following table does not provide the details about all evaluations, only the resulting total values used to derive cost trends in the various cases are included.

PROCESS	INVESTMENT [€]	DMC [€]
PP molding make / buy High Volume	4.654.650	85
PP molding make / buy Low Volume	3.126.150	115
PUR molding buy	1.250.423	443
PP painting make	240.000	51
PP painting buy	100.000	70
PUR painting make	240.000	81
PUR painting buy	100.000	110

Table 5 – Investment costs and DMC for the molding and painting process solutions

The costs related to the entire molding and painting processes of the bumper are obtained by combining the various solutions that can be implemented. In this way, the cost trends of the four scenarios listed above have been plotted.

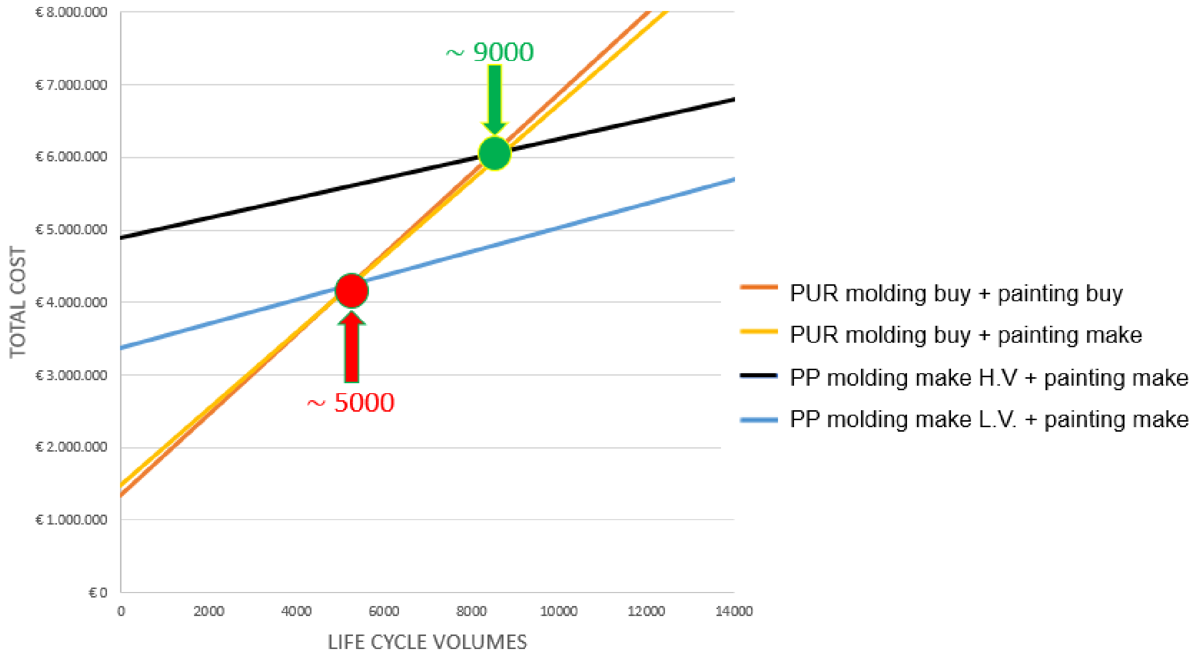


Figure 28 – Total costs trends for the different solutions

The graph shows that the Break Even Point between the solution "PP molding make High Volume" and the solutions that consider the use of the PUR is reached with about 9.000 cars produced.

In this case it would always be convenient to use the PUR for low volume productions. But, if the PP is processed with low-volume setting, through the cycle called "PP molding make Low Volume", the bep is reduced to 5.000 cars, this value represents very low production volumes and therefore the choice to use the PUR could be questioned.

In addition to the economic aspect, the differences in terms of product and process must also be taken into consideration as results that depend on the use of PUR rather than PP.

The advantages of PUR compared to PP are:

- Less expensive equipment;
- The undercuts can be managed with manual sliders.

The disadvantages of PUR compared to PP are:

- No mold flow;
- Poor chance to intercept the aesthetic defects and dimensional problems with the current simulation methods;
- A long lead time for curing (about 10 days) after molding, before the painting process;
- Surfaces abrasion process required before all the painting phases;

- Long and complex manual operations to trim the flash, by using cutters;
- Greater weight;
- Thermosetting resin therefore difficult to recycle;
- Less repeatable dimensions;
- Less match between process parameters and dimensional / aesthetic results (very complex process tuning);
- Poor chance of acting on the molding process, since there is only one direct injection;
- Very long molding cycle (about 10 – 11 minutes per piece);
- Greater final product cost.

The results of the economic analysis and the several disadvantages of the PUR compared to the PP lead to a revaluation of the production technologies, applied in the production of the PP bumpers, because the use of this material could be convenient even in the case of low volume models and special series.

6.2.1 Bumpers: innovation

Currently the research work in the field of materials is huge; research laboratories and suppliers are oriented towards the applications of innovative materials in the automotive industry.
The main purpose is always the lightening of the components produced and the improvement of the characteristics related to the choice of materials, such as mechanical resistance, process parameters, final quality of the product, lower production costs, and so on.
Regarding the plastic materials used for the production of the bumpers, interesting studies are developing towards the use of a lightened PUR.
The technology used for the molding of PUR is the RIM (Reaction Injection Molding). This process consists in the injection of two parts of polyurethane resin (polyol and isocyanate) into a low pressure mold, and this is interesting for low volume productions because low cost tools are used. The two forms of resin are combined at high pressure in a mixing head to obtain the PUR that is injected into the mold cavity.
A technology very similar to the previous one is the RRIM, in this case there is the opportunity to mold the PUR reinforced with glass or carbon fibers to obtain an improvement of the material characteristics.

Thanks to the use of reinforcing fibers, it is possible to obtain components with lower density and high mechanical characteristics; in this way a significant weight reduction of the components is ensured. This result is very important because the PUR, generally, has the disadvantage of a greater weight of the components compared to the PP, as mentioned in the previous paragraph.

7 Conclusion

The production of low volume models and special series certainly requires a way to approach the design of products and processes very different from that applied for mass production.
Several automotive companies get important economic benefits from the luxury / niche / super-sport market.
This thesis work shows that low volume productions are possible only with a setting of production activities that guarantees low investments costs, therefore the reduction of capex must necessarily be the main drive in the application criteria for the technological choices.
It is essential that the product, process and quality control standards are oriented towards the investments reduction, even enabling an increase in variable processing costs, as these could be allowed by low volumes.
It is necessary to make the required standards and the low capex technologies compliant with each other; all technological departments should carry out their activities in line with the method for the optimization of low volume productions to achieve this purpose.
The flow and the application criteria of the method described in this thesis could be the guidelines to follow when making the technological choices, this document could be an important support for the departments of the FCA group.
The technological choices, even for low capex productions, must always guarantee a high level of product quality; this aspect does not contrast with the opportunity to use processes, equipment, structures and tools that involve reduced investments and allow the launch of production.
What has been said is supported by the case studies that were presented in the previous chapter:

- From the first application of the method, it emerged that a low cost setting of the equipment and tools is able to ensure a product with high quality and reliability characteristics, if it is supported by the advanced skills of the workers, who can take advantage from a very long time available to carry out their activities;
- From the second case study presented, it is clear that an in-depth analysis based on production volumes can positively influence product and, consequently, process choices. It was possible to evaluate the total production volume range of certain models for which the choice of the right material leads to the reduction of the total costs. The

results of this specific method application can be exploited for the next models to be produced.

The project called "low volume" has the purpose to spread, among all the departments of the company, a standard method to approach the production of cars destined for a niche market. Only the involvement of all the areas will lead the company to an effective benefit, by exploiting the effectiveness of the technological processes suitable for low volume productions.

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