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Use of Lean Manufacturing by applying a kit preparation process in Formula 1 composites production

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Table of Contents

1. Introduction 4
1.1 A definition of Lean manufacturing 4
1.2 The history of Lean Manufacturing: the Toyota production System 5
1.3 The Toyota Production System revolution 6
1.3.1 The 7 wastes of Toyota Production System 7
1.3.2 The TPS house: an organic description of the Toyota Production System 9
1.3.3 TPS house's pillars: the tools sustaining the system 10
1.3.4 Foundations of the TPS house: the base of the system 12
1.3.5 The cultural side of TPS: the Toyota way 15
1.4 From TPS to the Lean Manufacturing 19
2. Literature review: an evaluation of the field of interest 24
2.1 Lean manufacturing in Formula 1 environment 24
2.2 Lean manufacturing in High-Mix-Low-Volume production 25
3. Company presentation 34
3.1 Product portfolio – GT cars 34
3.2 Manufacturing facilities 36
3.3 Formula 1 participation 37
4. Kit preparation project 39
4.1 Composites division in Ferrari GeS 39
4.2 Context and problems detected in the composites plant 40
4.3 Analysis of the AS IS process 46
4.3.1 Clean Room 1: information flows 47
4.3.2 Clean Room 1: material flows 53
4.3.3 Body shop: information flows 62
4.3.4 Body shop: material flows 67
4.4 Design of the TO BE process 80
4.4.1 Clean room 1: information flows 80
4.4.2 Clean room 1: material flows 84
4.4.3 Body shop: information flows 94
4.4.4 Body shop: material flows 96
4.5 Practical implementation 101
4.5.1 Planned introduction steps 101
4.5.2 Physical process design 104

4.5.3 Analysis of the logics for grouping materials in kits 104
5. Conclusions 111
5.1 Expected results and benefits for the company 111
5.2 Limitation of the thesis project 113
5.2.1 Time availability 113
5.2.2 Debug of the developed software tool 113
5.3 Next steps for the company 115
6. Bibliography 117

1. Introduction

The following thesis provides the analysis and design of a kit preparation process as a strategy to reduce wastes associated with operators' movement in the context of Formula 1 composites parts' production. As part of a Lean manufacturing implementation strategy, the designed kitting process is aimed at presenting to the point of use materials needed for manufacturing in pre-assembled kits, so as to avoid time wasted in searching for materials and reduce the risk of out-of-stocks discovered just-in-time for production. The kit preparation process is made possible by a redesign of the current information flows aimed at the development of a software tool able to generate a dashboard giving the status and position of any searched item required for manufacturing. Given the inherent extreme variability of a Formula 1 production plant, the designed traceability software tool aims at supporting both the picking operations and the daily planning of the shops involved in the project.

As an introduction to the development of the thesis, a description of the Lean manufacturing concept is given, analysing its origin and development path from the original system to the modern Lean methodologies. Afterwards, in the chapter 2 the literature review will be introduced, analysing the wider sector of Engineer-to-Order manufacturing systems and the research gap in which the topic of this thesis will be developed. Chapter 3, then, will introduce Ferrari, the company in which the project has been developed, and its core business.

The analysis and design of the kit preparation process is presented in Chapter 4, in which the context and issues found in Clean Room 1 and Body shop, i.e. the two shops involved in the improvement plan, are introduced. Starting from a description of the AS IS situation, a TO BE scenario featuring the kit preparation process and the newly designed software tool will be presented. Chapter 4 ends with the planning and description of the practical implementation steps required, with the additional design of a suitable logic to group materials in the kits.

Finally, Chapter 5 will introduce the conclusions of the project, with the expected benefits for the company, the issues found during the development and implementation phase, and the next steps to pursue the Lean ideal in the context of Ferrari's Formula 1 production plants.

1.1 A definition of Lean manufacturing

"Lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer and internal variability." [1]
Conceptualized by Toyota with its Toyota Production System (TPS), Lean manufacturing is not only a set of acknowledged technical tools to be used in manufacturing and operational management for waste minimization, but it is, most of all, a cultural mindset aimed at operations excellence and continuous improvement. This characteristic of being two-sided, technical and social, is the real core of the Lean manufacturing concept and it is on the one end what it makes so powerful, but on the other side it is also what it makes its implementation so hard and time consuming. Indeed, if setting up a series of techniques for streamlining operations and reducing the surface problems in the manufacturing shops is

relatively easy, changing the whole company cultural mindset from the highest hierarchy to the production shop operators require a strong and sustained effort that not all the companies are able to keep up.

1.2 The history of Lean Manufacturing: the Toyota production System

Lean manufacturing concept is inextricably linked to the history of Toyota and its TPS, from which not only the technical Lean tools have been originated, but in particular the cultural and social background on which the entire Lean method relies.

Born at the end of the 19th century as a wooden loom manufacturing company, Toyota's journey in automotive sector began with the foundation of "Toyota Motor Corporation" in 1933 by Toyoda Sakichi, under the direction of his son Kiichiro Toyoda: he had travelled to Europe and United States to investigate automobile production, coming into contact with Fordism and its way of managing manufacturing and operations. Toyota's first production car, the Modell AA sedan, was placed on the market in 1936. The company shown a constant growth until the WWII broke out, during which Toyota was dedicated to truck production for military purposes and suffered from bombings and disruptions in operations due to the ongoing state of war. After the war, Japan experienced extreme economic difficulties: serial passenger cars production started again in 1947 but, due to the inflation and the consequent loss of purchase power by the consumers, the cash flow situation for Toyota was so extreme that the company was on the brink of bankruptcy by the end of 1949. The crisis was solved by a hard cost-cutting policy, obtained through wages reduction and more than 1600 layoffs. This set of measures was successful in avoiding bankruptcy but led to a two-months strike, to solve which president Kiichiro Toyoda was forced to resignation. After Kiichiro, Taizo Ishida was appointed as president of Toyota. Care businessman having served in Toyoda Automatic Loom company as chief executive, his role in the Toyota history is the one of having massively invested in equipment rather than people, because he was determined never to be forced to lay off thousands of workers as happened just few years before. His investments resulted fundamental for the expansion of Toyota and its lead over the major Japanese competitor of that time, Nissan, paving the way for the future expansion of the company.

Ishida was followed as chief executive and president of Toyota Motor Manufacturing by Eijy Toyoda. He was the youngest cousin of Kiichiro Toyoda and he has been the main responsible for bringing Toyota Corporation to profitability and worldwide prominence as an example of operational, cultural and manufacturing excellence: it was under his tenure, indeed, that Toyota Production System and the underlying corporate culture later became famous as "Toyota way" were developed. Since it was born Toyota produced low quality vehicles with a poor technological level, way behind the products manufactured by American car manufacturers of the time. Moreover, the market and the consequent capacity of the plants were very different in the two cases: as an example, consider that a typical Ford's assembly shop in the thirties was able to produce around 9000 cars per month, while in the same period Toyota has an installed capacity of only 900. This was not only a consequence of the larger US market but also of the Fordism and mass production concepts used in US to produce vehicles.

Toyota knew well before WWII that it would have need to open its production to foreign West markets and to adapt concepts belonging to Fordism and mass production to compete on the world market with American and European car manufacturers. After the WWII the company, under Toyoda's leadership, began a careful study of American automobile manufacturers. Toyota executives visited regularly the production facilities of companies, including Ford, to observe their way of managing vehicles manufacturing and operations, implementing some concepts in their own production facilities and leading to an immediate increase in efficiency. What Toyoda and the executives saw in American's production plants, though, was for some points disappointing: manufacturing technology did not change much since thirties' and the Fordism showed all its main drawbacks with large inefficiencies, huge amount of inventory due to the large production batches, extremely irregular material flows and a sustained overproduction.

Some of the issues saw during the visits of the American plants would have later become the 7 wastes formalized by Toyota and addressed by the Toyota Production System. The man who crafted the TPS was Taiichi Ohno, at the time Toyota Motor Company's plant manager. He visited American production plants alongside Toyoda and he was officially instructed by him of keeping up with US productivity in three years, while eliminating at the same time many of the inefficiencies saw during their experiences. Ohno's task was not easy: Ford's system was designed to produce large quantities of a limited number of model variants for feeding well-developed home and foreign markets, with a strong network of suppliers and thus being able to benefit from economies of scale. Toyota, on the contrary, was dedicated to produce low volumes of mixed models on the same assembly line for feeding a small domestic market, without the possibility of benefitting from economies of scale and without a structured and developed network of suppliers.

Toyoda's assignment to Ohno was clear: Fordism must be adapted to Toyota's peculiar situation, achieving a mass production with, at the same time, high quality, low costs, reduced lead time and extreme flexibility. During his thirty years spent at Toyota, Ohno developed and implemented the TPS, that will be analysed in more detail in the following section, paving the way for Toyota success and by making up a set of techniques and a management method that are, nowadays, of common use in thousands of companies all over the world.

1.3 The Toyota Production System revolution

Ohno's innovative vision started by assuming a different perspective in analysing the current state process: he looked at any activity performed from the customer's point of view, being it internal or external. By wondering what a customer expects from a process he introduced the concept of value, that became the real core of the innovation represented by TPS. Value is defined as the output that a customer expects from a process: by looking at any process from a customer's point of view we can define which activity is value-adding and which is not. Target of the TPS, and of the later Lean manufacturing concept, is to reduce at the minimum possible level the number of non value-adding activities in a process.

1.3.1 The 7 wastes of Toyota Production System

Strictly connected to the notion of value is the waste one: Ohno defined 7 wastes (Muda) proper of any operational or manufacturing process that are non-value adding and, as such, must be acknowledged, analysed and addressed for their elimination. [2][3]

Figure 1- The original 7 wastes of Lean [www.kanbanize.com]

1. Overproduction. It occurs any time products are manufactured that have not been ordered by a customer. According to Ohno this is the greatest waste, being the root cause of any other loss in the process: overproduction leads necessarily to an excess of inventory in the process, as well as to an excess in workforce, machinery and all the costs related to these issues, just to mention the problems immediately visible when an overproduction problem arises. Producing more than ordered from a customer, indeed, causes a broad series of wastes not immediately visible in the manufacturing process but connected at the root with this situation. Ohno's view was revolutionary at the time because it was the contrary of what the reigning Fordism concept assumed: producing more is convenient as long as machinery and workers are kept running, saturating installed capacity and building up stocks of products ready to be sold. TPS, on the contrary, is a fierce competitor of overproduction and batch production, acknowledging that it leads to problems and wastes that, even though with a lower saturation of machinery and workers that may seem counter-intuitive, may be solved with a set of tools that ultimately allows to get an efficiency even higher than the one of the never-stopping Ford's equipment.

2. Waiting. This waste involves workers waiting for material from the previous manufacturing steps or waiting for an equipment to finish its cycle. From a machinery point of view, instead, waiting waste is happening any time we have an idle equipment due to lack of material, bottlenecks in the previous steps and any other reason possibly happening in the shop floor.
   Waiting time, in general, is often caused by unevenness in the production stations and the consequent presence of bottlenecks, causing both workers and machinery to wait

for the completion of the previous step and often resulting in excess inventory and overproduction to counteract the loss in productivity.

3. Transport. Whenever materials, tools, people, WIP inventory and equipment are moved more than the strictly necessary, a transport waste occurs. It is often the case that items are stored in warehouses or in areas from which they must be picked up and taken to the point of use in the production plant: being all the transportation a non value-adding activity it is important to carefully design the internal logistics as it is a major source of wastes, particularly of the transport one.
   Moreover, excessive transportation leads to fatigue for the operators involved, damages and defects of goods and longer lead times. It is for this reason that TPS requires to avoid at all costs double and triple handling, typical situation in the batch-and-queue production model as formalized by the Ford approach.

4. Over-processing. This peculiar waste occurs any time a useless operation is performed on a product and it is double faced: it not only involves processing more than needed a certain product, but also reworking an item any time a quality issue arises. Over-processing is the key waste to be targeted when implementing the Lean principle of perfect first-time quality, that must be achieved not only to satisfy customer requirements but also to avoid wastes and in particular the over-processing one, strictly related to reworking as described before. TPS' view about over-processing waste is customer-centred: in order to avoid this waste is fundamental to understand customer's view and requirements and to produce exactly what customer asks. In this perspective, over-processing happens also when producing components with a quality or quantity higher than requested, or when using equipment with precision and capacity larger than those required by the customer's expectations.

5. Inventory. This waste is related to building an excessive stock of material, being it raw materials, WIP items or finished goods: unnecessary inventory can be built up at any stage of the production process and must be avoided as it is a common yet major waste. Even though inventory is defined in the common sense as an asset, indeed, TPS recognized that excessive stock actually leads to longer lead times, higher warehousing and transportation costs, product damages and, most of all, can hide quality and flow problems. Excess inventory, indeed, prevents from detecting production-related problems such as quality issues, bottlenecks, delays in manufacturing and deliveries from suppliers: by building up stock, it is more difficult and requires more time to detect those problems and act with countermeasures, thus leading to even further wastes as defined in this section.

6. Motion. A motion waste occurs anytime a worker is forced to perform unnecessary movements to complete a manufacturing task. Taking inspiration from Taylor's studies about time and motion studies, later adopted also by Ford, Ohno went further when describing the motion waste: instead of carefully studying and selecting the "one

best way” to perform a manufacturing task and splitting it in dozens of simple actions, TPS simply prescribes to eliminate the unnecessary movements by providing the worker with an easy reach of every material needed for performing his/her operation. Based on this simple principle, any walking, searching for an time, bending and reaching must be avoided. Walking to get tools or materials, in particular, must be carefully avoided with a proper design of the workstation and of the materials flow in order not only to avoid unnecessary non value-adding movements for the workers, but also to ensure an ergonomic position and enhance health and safety levels.

7. Defects. Whenever a product with a insufficient quality level is produced, a defect waste occurs. This situation typically lead to other wastes, such as reworking (thus over-processing) and scrapping: any situation different than the “perfect first-time quality” is defined by TPS as leading to a non value-adding activity, resulting in a waste. Ohno identified those non value-adding activities also in the excessive number of quality checks performed. The ideal target of the TPS, indeed, is that of completely eliminating the waste by designing processes able to manufacture products with the required quality right at the first time, thus (ideally) avoiding quality checks and any defect waste meaning additional costs and no value for the customers. In a real-life manufacturing process, where the ideal situation of a defects-free production cannot be achieved, TPS focuses instead on the quality delivered to customer. It prescribes to design processes that, besides being ideally error-free, are effective in detecting defects and stopping them from going downstream the production flow: quality issues must be immediately detected and their root causes corrected, without reaching the customers or being moved to the next manufacturing step thus propagating the defect waste.

The above-mentioned wastes are crucial to understand what the real step forward introduced by the TPS was. Unlike the leading Ford’s movement, TPS is not focused on the “quantitative” side of the manufacturing process, rather on the “qualitative” side: the process must be carefully designed and the quantity of production must be, if necessary, sacrificed for the sake of quality and efficiency. A brilliant example of this concept is the “andon” introduction. Ohno expected the assembly line employees to pull the andon rope whenever a quality or process problem was detected during regular operations in the shop: the result was the immediate stop of the line and the gathering of selected trained workers to solve the issue. Moreover, work had to be stopped until a solution for the problem was found. This situation was not even conceivable in Ford’s plants where the most important thing, on the contrary, was to never stop the assembly lines.

1.3.2 The TPS house: an organic description of the Toyota Production System

All of the TPS innovations as a socio-technical system were finally condensed in a simple yet powerful graphical representation known as “TPS house”. After several years from its development Fujio Cho, Ohno’s successor, tried to represent the core principles of the TPS as a house: in such a way he represented in a simple way the structures building the TPS with its leading technical and cultural principles [3].

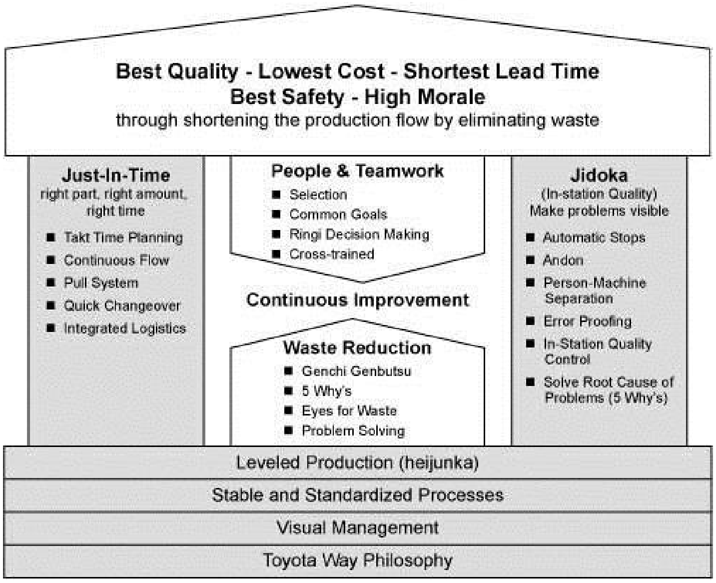


Figure 2- The house of TPS [3]

Starting from the roof we can find the targets of the TPS: best quality, lowest costs, lowest lead times, best safety and high personnel morale and involvement. These are the high-level strategic targets pursued by TPS, achieved by deploying the technical tools of the Toyota way with the aim of targeting and eliminating the 7 wastes in the production plant.

1.3.3 TPS house's pillars: the tools sustaining the system

The roof is sustained by two pillars: Just-in-Time (JIT) and Jidoka. JIT aims at reducing inventory at the minimum possible level in order to prevent the related problems that may arise during production. JIT is considered as a pillar of TPS for many reasons. First of all it targets the inventory, which is one of the key wastes conceptualized by Ohno, able to hide all other wastes behind excessive stock levels until the problems are exposed at a moment in which it is too late for them to be solved without large losses and inefficiencies. Moreover, JIT covers a broad range of operations, not being focused just on manufacturing: JIT is basically about delivering the right item in the right quantity at the right location and at the right time. In such a definition we can easily read how JIT covers every aspects related to material movements. From suppliers' deliveries to internal logistics, warehousing, point of use feeding and finished products deliveries to customers: every material movement must be fine tuned to be compliant with the JIT pillar to avoid waste and streamline operations.

The other pillar is represented by Jidoka, a dual-faced principle: on the one end it is about never letting a defect pass through a step in the process to the next one, on the other end it refers to the "autonomation", which is the "automation with a human touch". This is the formalization of the principle described previously, for which the automatic production process of the modern plant must always have a human touch, i.e. it must be always supervised by a operator in charge of stopping it whenever a quality issue or abnormality is detected: the essence of jidoka is that quality is prevailing on running continuously machinery, if the machines are manufacturing defective products it is a duty of the operator stopping immediately production and solve the root cause of the problem.

Jidoka is the pillar about quality in the Lean concept and the TPS house details also the main technical tools to employ to apply the Jidoka principle. We have then the automatic stops of machineries and the andon, both for stopping the production whenever a quality issue arises and is detected respectively by the machine itself or by the operator: the key difference between the two concepts is that automatic stops is related to a machine automatically detecting a defect during production, so it is about technical problems to the products, while the andon principle is related to any type of problem/abnormality of the process as experienced by the operators in their own judgement. Thus, problems determining an andon stop can be not only strictly related to the quality of the manufactured products but, more importantly, they can be related to flows of materials, management of production and inefficiencies in the process. Andon tool is about empowering operators over machines, hard automatization and production processes to give them the possibility of performing a continuous improvement and refinement of the processes and their quality.

At the centre of the TPS house we can find the continuous improvement: this is the strategic target of the TPS, i.e. never stopping the improvement by empowering employees in finding ever more innovative ways to reduce wastes. As represented in the picture, continuous improvement is made possible by two basic requirements, i.e. the teamwork of dedicated employees and the uninterrupted effort to reduce wastes. When it comes to people, as will be better described later when analysing the Toyota way, TPS requires to select the best and most dedicated employees able to embody the Lean philosophy in their everyday corporate life: an individual in the TPS exists only as a member of a cross-functional team devoted to ease and build quality in products and processes. The great respect and care for people is perfectly represented in the TPS' "Ringi" decision making process: it consists in a standardized bottom-up approach used by Toyota to address any change in the internal processes for an improvement or the solution to a detected problem. Ringi is usually articulated in four steps:

1. Proposal. Can be issued by anyone in the company, according to the type and scope of the addressed solution. A proposal is an official document with a standardized format in which a problem, or a waste detected in a process, is described and the related solution is provided by the writer of the proposal itself.
2. Circulation. The proposal is circulated through all the departments potentially involved by the change proposed and it can be discussed, commented and modified, in accordance and full cooperation with the promoter of the idea.
3. Approval. Only once all the departments involved have received, thoroughly analysed and agreed on the change proposal, it can be officially sealed as accepted by the upper level management, which usually simply confirms the agreement already reached.

4. Record. After the approval, the decision is recorded and can be quickly implemented thanks to the agreement of all the stakeholders involved in the proposed improvement plan.

Ringi system is a brilliant example of the high level of consideration that TPS has towards employees and their active participation in the continuous improvement of the company.

The final target of any continuous improvement plan, as said, must be the reduction and elimination of wastes in corporate processes. To this end the most important tools of TPS' problem solving and waste analysis methodologies have been reported in the centre of the house of TPS: employees are expected to go-and-see personally where a problem or waste in the process is detected (Genchi Genbutsu) to have a clearer understanding of the situation and to share information with operators and people involved in that stage of the process. After having understood the issue, the whole team must ask itself 5 times why a certain problem is being experienced (5 Whys), in order to figure out the root causes of the waste detected and to solve them in a definitive and stable way.

1.3.4 Foundations of the TPS house: the base of the system

Finally, the TPS house is built on solid foundations, represented by four concepts. First is the "heijunka", i.e. the levelled production, both in terms of quantity and mix: it is important to carefully balance the production mainly to avoid fluctuations leading to excessive inventory, unbalanced load with bottlenecks and reduce at the minimum level the amount of WIP in the process, empowering the desired JIT production and delivery.

The levelled production is not only about volume itself but also about mix. One of the most counter-intuitive principle of TPS is related to this fact, because it prescribes the necessity of producing with the smallest possible batches, in order to maintain a balanced production in terms of models mix. It is important not to over-produce large stocks of products of one type at the expense of others, resulting in large inventories and general unbalance of the system extremely detrimental for the flow and operations. Once again TPS went over the most widespread ideas of the time in which it was developed about producing with large batches to reduce at the minimum level the changeover times, prescribing instead to change set-up of machineries the largest possible amount of times, though by developing techniques such as the SMED (single-minute-exchange-dies) not to impact on the available production time while at the same time keeping low the production batches and minimise the inventories.

The ideal target of heijunka is the one-piece flow, i.e. a material flow through processes for which a unit is produced for each unit started. A "piece" in one-piece flow principles it's not necessarily a single item manufactured, being instead a unit of order as required by the customer: the key point under the heijunka principle is that it must be produced just what asked by the customer, in the quantity required and at the time it requires it. One-piece flow is connected to a series of positive achievements when implemented:

- Better quality. By processing one piece at a time it is easier and more effective performing the quality check of products and processes by the operators. Every worker can check every item produced during his/her manufacturing phase and, also in case of missed detection of a defect in a stage of production, it will be detected in the next phases taking immediately place downstream, being the inventories ideally completely eliminated from the process.

- Larger productivity. A one-piece flow means reducing the lead time to a minimum value by performing the manufacturing operations one after the other in a continuous flow. The principle allows to define and perform just the real value-added steps required by the production process, eliminating or reducing to a minimum all the wastes recognized by Ohno and connected to the traditional batch-and-queue production model. The production process must follow the takt time, which is a measure of the time available to produce one unit of finished product to satisfy customer's demand: it is an important measure in Lean manufacturing and the production process must be set so that lead time is lower than or equal to takt time. The proper production planning according to the one-piece flow allows to produce according to takt time which is considered as a fixed constraint, thus leading to a large overall productivity according to customer's demand without overproduction.

- Larger flexibility. A proper balance in production volume and mix allows for larger flexibility of production processes thanks mainly to the reduced lead time linked to the heijunka principle. With a reduced lead time, indeed, we can perform a manufacturing process in just a fraction of the time required with a non-one-piece flow model, thus empowering flexibility and more time available to set up machines for the production of a different product mix in order to react to any variation of the customer's demand.

- More free space in the production plant. One-piece flow is connected to the reduction, or even elimination, of inventory between manufacturing steps and to the JIT production without building large stocks of finished products to absorb manufacturing and demand fluctuations: as a consequence, all the space required by those materials is freed up in the plant. Floor space occupied by raw materials, WIP and finished products is usually a large amount in a typical batch-and-queue system, so that benefit achievable by TPS' one-piece flow concept is of particular relevance in this case.

- Lower costs for inventory. Of course the one-piece flow, leading to an ideal elimination of all the inventory in the process, is connected to a drastic reduction or elimination of the warehousing costs and of the tied-up capital in the materials stocked and not yet delivered to customers. One-piece flow, indeed, is intimately connected to the concept of pull production: any item must be made-to-order (MTO), i.e. produced just when an order has been issued for it by a customer. A pull production system is perfectly realized by a one-piece flow model, in which the items are produced just after a customer's order, and moreover the upstream manufacturing steps start to produce just after a signal has been delivered by the downstream ones, in order to phase manufacturing times and reduce or avoid inventory between steps.

Heijunka itself is based, in the TPS house, on the foundation of stable and standardized processes. Moving from Taylor's studies about standardization of work, TPS went further in applying the concept, saying that any process must be based on standards and best practices elevated to standards level able to guide people, while at the same time leaving enough flexibility to continually improve standards themselves.

Standardization of a process is described by Ohno as the base for process improvement: it is impossible to improve a process before having standardized it. TPS' standardization is composed by three core concepts:

- Takt time. Takt time, as described before, is the main constraint and has to be defined for any product manufactured. It is of paramount importance sticking to this time by designing a process able to be compliant with it, which becomes a standard to be respected in the process.

- Manufacturing sequence. The sequence of manufacturing steps to be performed for producing a product is set by its geometry and characteristics. TPS tries not only to standardize production processes but, going into a deeper level, standardizes the sequence of operations that any worker must perform to complete his/her tasks. The key point in this fact is that standards must be carefully developed in cooperation with operators themselves. There is not a "one best way" to perform a process as said by Taylor and Ford, but there are ways better than others to complete tasks in a time coherent with the prescribed takt time and quality level: purpose of engineers is designing such tasks together with the operators daily involved in performing those, so that the best practices can be elevated to standards and continuously improved by operators, which is a key point in the standardization process. In other words, standards must be specific and fixed enough to drive operators in their tasks so to reach the target cycle time and quality level, but on the other hand standards themselves and management's attitude must be flexible enough to allow for a constant revision of those standards to improve them step by step.

- Inventory level. Being excessive inventory reduction one of the core target of TPS, the minimum amount of inventory material needed by operators to perform their tasks is specified in standards, and no exception should be made when it comes to inventory and materials management inside the production plant, being them a major waste able to cover all the problems affecting the processes.

Standardized work in TPS' view empowers the operators, allowing them to effectively perform their job by building quality in the process with defined guidelines allowing them to control they job, without being a coercive set of rules fixed once and for all. This is the core difference between Toyota way and Fordism: in the former the worker is not a machine engineered to follow orders and instruction designed for the maximum efficiency as in the latter, being instead an analyst, an expert of the products and the processes able to perform tasks and solve problems of any kind related to his/her tasks, even the ones beyond the scope of the standards daily followed.

Going further in analysing the foundations of the TPS house we find the visual management. By this definition we identify any tool used to check in real time the status of the production process and any possible problem that may be present in it. Visual management is the cluster under which a broad variety of reports, KPIs and graphical representations fall, and it is about managing the information flow of the process together with the material flow of the process itself: visual management is about showing JIT the right information to the right user in order to allow a fast and correct execution of manufacturing and operative tasks. The scope of visual management as used in the TPS is broader than a collection of data and KPIs representing the current status of a process and any possible deviation from the set standard, it collects rather all the possible information that can be produced and retrieved in a visual way: according to this principle any process, piece of equipment running, inventory batch or task performed by an operator must have a visual management tool to give information at a glance about the standard expected situation and the current status, with a focus on possible deviations from the standard itself.

The final target of TPS' visual management is providing real-time information for checking and enhancing the production flow. With visual management, for example, it is easy to detect if an excessive quantity of inventory is being produced, or if the takt time for any product is being respected by the current production or not. As it can be seen in the TPS house, visual management is the foundation of a stable and standardized process: having reliable, constantly updated information about the state of the flow and of the processes is a basic condition for ensuring the standardization of the processes themselves is respected and their stability is ensured at any time, with no deviations from the designed standards.

1.3.5 The cultural side of TPS: the Toyota way

Last foundation is the so called "Toyota way"[2][3], the cultural side of the TPS, i.e. the collection of the founding principles on which the entire TPS is built. A key point of TPS and the Lean manufacturing concept, indeed, is that besides the tools making up the technical part of the system, the successful realization of the method requires as a basic condition the development of an internal "Lean culture" able to receive, sustain and continuously develop the system itself. Building a corporate culture orientated towards innovation and Lean principles is the first step to perform the Lean transformation and the basic foundation to ensure the benefits brought by this method are retained, sustained and even increased in the future. It is for this reason that the Toyota way is placed as the foundation of the whole TPS house, because it is the hardest part to implement and sustain, from which any other principles is generated. The Toyota way is constituted by fourteen Lean management principles collected in four sections, summarising the culture on which any Lean corporation should be built [3]:

Section I: Long-Term Philosophy

1. Base the management decisions on long term philosophy, even at the expense of short term financial goals.

The long-term survival and prosperity of the company is the most important target to pursue for the management. Benefits in efficiency brought by TPS are not achieved without great expenses: the initial effort for implementing its concepts and the sustained energy required to maintain the system are high and resources-consuming. Since some tools and concepts provided by TPS such as JIT and small production batches are, just apparently, counterintuitive with respect to immediate financial goals, the management must be strongly committed and determined in sustaining and investing in them for the long-term benefit of the company.

Section II: The right process will produce the right results

2. Create continuous process flow to bring problems to the surface

The process flow must be place in the centre of the corporate culture. From the flow indeed, meaning flow of materials as well as flow of information and ideas, all the benefits linked to the Lean concept are generated. Based on this fact, production processes must be designed and run so that each step adds value to the product with a continuous flow, able to disclose wastes and problems and to allow for their immediate resolution.

3. Use pull systems to avoid overproduction

As described before, pull system is the context in which the JIT tool is deployed. Principle 3 underline the importance of basing production on the pull principle: the company needs to produce just what the customers want, when they want it and in the required quantity. Customers pull the production, i.e. starting from their orders the manufacturing starts and the materials are taken to each step in the quantity and at the time needed, according to the JIT principle. Using a pull system allows to reduce inventory to the minimum possible level and all the connected wastes, making a company flexible and efficient in producing exactly what customers need even in case of swift change in the demand both in terms of volume or mix.

4. Level out the workload.

This is the theoretical equivalent of the heijunka foundation. In order to achieve the greatest efficiency it is of paramount importance not only targeting manufacturing wastes, but also eliminating as much as possible any unevenness in the process: it may be in excessive burden of people and equipment, or in continuous swift variations in production schedule. The tool used to eliminate this variability and the related waste is the heijunka, prescribing to maintain a balanced continuous work flow along all the value chain and the production process.

5. Build a culture of stopping to fix problems, to get quality right the first time

This principle is the formalization of the Jidoka pillar: quality is the value proposition of a Lean company and it must be built and delivered to customer without any waste, i.e. as soon as the product has been manufactured, with no need for rework and rebuild. A corporate culture oriented to the Jidoka principle implementation needs to be open to stopping an activity to solve quality issues by analysing its root causes, resulting then in a process improvement and larger efficiency in the long-term period.

6. Standardized tasks and processes are the foundation for continuous improvement and employee empowerment

This principle expresses the importance of using standard and repeatable methods to effectively design and manage stable processes and prevent variability that can result in wastes. Standardization is the basic requirements of continuous flow and pull systems and it must be achieved by acquiring the best practices developed by industrial engineers in full cooperation with the operators, thoroughly analysing the tasks, and finally raising them to the status of internal standards. An important point is not wasting operators' creativity: standards are never definitive and they must be flexible so to leave space for modifications by the operators, who are the main stakeholders in the continuous improvement process.

7. Use visual control so no problems are hidden

Continuous flow and pull production must be sustained by a simple and complete set of visual management tools able to show at a glance to the operators if they are in or out of the prescribed standard for the assigned task.

8. Use only reliable, thoroughly tested technology that serves your people and processes

Whenever a new technology to be implemented in the production process is addressed, it is important to carefully evaluate and test it in order to verify its suitability in sustaining the flow, that must always be the first concern. New technologies are in general difficult to standardize and to manage, it is for this reason that established, well-known technologies must be preferred to the new ones, according also to the products and customer needs. An important point expressed by this principle is that technology and automation must not be used to replace operators, rather to help them in their work and to sustain the flow. Toyota believes, indeed, that an efficient technology used to sustain an efficient process helps in enhancing even further the efficiency, while in the opposite case the result will just be an increase in inefficiency. It is for this reason, as expressed by principle 8, that a new technology must be implemented only after having thoroughly optimized the current internal processes at the maximum possible level with the current technology, i.e. it should be not used as a solution in itself for the problems. When a tested new technology has proven to be reliable and efficient, it must be adapted to sustain the flow in the production process and the operators involved in it, in order to help them work better and in full accordance with the Toyota way's principles.

Section III – Add value to the organization by developing your people

9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.

Leaders at Toyota must be internally developed and formed. They must be people with a broad view of the on-going processes with a strategic view and at the same time a strong knowledge of the present situation. The key point expressed by this principle is that leaders must be models able to embody the founding philosophy of the organization, teaching it to the others by behaving in accordance with it.

10. Develop exceptional people and teams who follow your company's philosophy

The natural prosecution of the principle 9, referred to the leaders of Toyota, is the principle 10, referred instead to all people and teams of the company. Leaders embodying the Toyota way must transfer the company's founding philosophy to people and teams that will behave themselves in accordance with it. People must be continuously trained and formed so that the corporate culture is consolidated and developed, inspiring and leading the teams' daily work. The Toyota way must be agreed and practiced by all the corporate levels with no exceptions, creating people and teams acting together towards a shared goal.

11. Respect your extended network of partners and suppliers by challenging them and helping them improve

A founding principle of the Toyota way is the respect for suppliers and partners: they play a key role in the success of the organization and they must be treated accordingly. Developing a strong, reliable and fixed network of suppliers is fundamental, as well as maintaining it to pursue a shared objective: partners must be treated as an extension of the corporation itself, by being fair in the commercial relations, sharing technology and know-how for a mutual gain. Many key tools of the TPS, such as the JIT, require a complete integration of the internal production processes with the external suppliers ones, for this reason it is vital to develop and sustain the flow together with all the external partners involved, in order to achieve and share the benefits linked to the Lean principles with the whole network.

Section IV - Continuously solving root problems drives organizational learning

12. Go and see for yourself to thoroughly understand the situation

Anytime a problem is experiences, the involved people are expected to go and see directly where the problem was detected, to have a clearer understanding of the issue: just by checking first-hand the situation it can be analysed to its root causes and improved. According to this principle, any problem and any corporate level must use a go-and-see way of approaching and analysing issues. Only once the situation has been clarified the analysis for its resolution could be performed, by going up to the root causes: the 5 Whys tool is part of the TPS problem solving methodologies and it consists in asking yourself five times why a certain problem has happened, to go from the particular situation to the root cause and solve it in a definitive way.

13. Make decisions slowly by consensus, thoroughly considering all options, then implement decisions rapidly

Once problems have been acknowledged through a go-and-see method and their root causes have been identified, a solution must be developed and implemented. Principle 13 requires to evaluate and propose different alternative solutions to a problem, by analysing the impact of these alternatives with all the stakeholders involved in the process. The ideas and contribution of every team member must be taken into consideration and used to develop shared possible solutions, then they must be discussed, agreed and finally implemented. This problem solving process, known as "nemawashi", may be time consuming and longer than a regular one in which a solution is analysed and proposed by a dedicated team of people without involving every possible stakeholder, relying much more on the analysis phase rather than on the implementation one: by spending time in analysing multiple shared possibilities, indeed, once a decision has been taken the solution identified can be implemented in a much faster way. Sharing the solution development process with all the involved stakeholders create consensus and allows to analyse the process from different point of views in order to prevent possible implementation problems that may delay the solution of the issues experienced.

14. Become a learning organization through relentless reflection and continuous improvement

The last principle of the Toyota way is maybe its most important one, stating that the target of an organization must be that of never stop improving. Any organization or process, indeed, may be improved time after time in a theoretically never ending process: there is no fixed standard or solution, everything should be continuously improved through a constant reflection about the activities performed and the current situation. The organization must be dynamic, applying the continuous improvement (known as "kaizen") techniques to recognise, analyse and solve any sort of inefficiency found in the processes, introducing new standards and increasing efficiency. The best practices, moreover, should be shared at a company level and made standards after having thoroughly investigated them, so that the know-how of the company is continuously increased and spread through all departments to really make the company a learning organization endlessly improving itself.

1.4 From TPS to the Lean Manufacturing

Toyota production system and the Toyota way represent unquestionably the theoretical and technical framework of the Lean manufacturing system. However, through the years the Lean concept developed and changed, moving from the original TPS to something slightly different. The term "Lean", indeed, was coined in 1988 by John Krafcik, a researcher at MIT, in his article "Triumph of the Lean production system"[4], published while he was collecting data for the book "The machine that changed the world", written by James Womack, Daniel

Jones and Daniel Ross[5]. This book is based on a five-year study on the automotive production and its forecasted future, being regarded as the key book in Lean manufacturing topic after Ohno's own published volumes. The authors reflect on the history of Lean concept contrasting it with the Ford's mass production system by highlighting how they represent two opposite methods in which companies can create value. The analysis about Lean systems presented in the book is complete and is focused on the managerial point of view: to date it is still one of the most complete ever made, arguing that the Lean model will eventually replace mass production systems thanks to the broad range of benefits and efficiencies it takes.

The publication of "The machine that changed the world" set a milestone in the Lean movement, because it made an accurate description of the TPS accessible to every reader and made the word "Lean" diffused in the popular lexicon. Lean manufacturing, then, became a diffused topic for researcher and companies interested in applying its principles: from TPS to Womack's book up to the current days, Lean is still an evolving concept [1].

Shah and Ward in their paper "Defining and developing measures of Lean production"[1] recognised that, through years, a conceptual confusion about Lean has arisen, mixing the original contribution given by the TPS with the more recent introduction up to a point in which a shared and clear definition of Lean manufacturing is not available anymore. Through their research work, they empirically identified the set of tools making up the modern concept of Lean production and ten underlying components which identify what is Lean in the current manufacturing environment [1][2].

1. Supplier feedback. Providing regular feedbacks to one's network of suppliers and external partners is a Lean practice among the most important ones. In full accordance with principle 11 of the Toyota way, a Lean company must be in constant connection with its suppliers' network to give and receive feedback about the mutual performances.

2. JIT delivery by suppliers. The JIT pillar of the house of TPS is still one of the most used Lean tools, giving great advantages but requiring a strong cooperation with suppliers and partners. Every Lean company must strive to adopt JIT delivery not only for its production to the customers but, just as important, for the incoming flows of goods from suppliers. This solution is achieved with a huge effort but allows to get the largest benefits for a Lean company with a consistent wastes' reduction.

3. Supplier development. Key point for implementing the previous points 1 and 2 is developing a company's suppliers: it is of paramount importance building a net of trusted partners joined by long-term agreements for a mutual gain. Companies, nowadays, are operating in an environment made up of hard fights with competitors, such that usually the criterion to select a supplier is just the lowest cost offered for a product or a service to be purchased. A Lean company must go beyond this strategy and build a trusted network of selected suppliers to develop them in a long-term strategy. Suppliers are crucial for a company's efficiency and competitiveness, it is for

this reason that Lean corporations prefer to develop suppliers together with their own company by sharing technologies, best practices, tools and know-how in order to make suppliers able to sustain the flow and the efficiency levels required by a company who wants to be really Lean: it would be impossible to fully implement the Lean concepts by focusing only on the internal processes in the current market, where companies are linked by complex commercial relations that make impossible to survive on their own alone.

4. Customer involvement. This point is descending from a core concept of the original TPS, i.e. the notion of customer. In the complex modern market the customer assumed an even larger importance, being every company's activity targeted to the specific customer's needs and demand. A Lean company must produce what customers ask in the quantity they want and in the moment they need, in order to get the maximum efficiency and avoid at all costs the worst of the wastes, i.e. overproduction. Moreover, the focus on customers must be not only on the external side, but also on the internal one: internal customers' needs and requirements are the only things that should drive manufacturing, basic requirement for the full implementation of a pull production system as described in the following point.

5. Pull production. Lean companies must fully implement a pull production system, i.e. a system in which production in the previous steps is pulled by the downstream phases. This point means that Lean companies are producing just what asked by customers in the quantity they demand, delivering products JIT not only to the final users but also to the internal ones: JIT is the key pillar to avoid overproduction, excess inventory and thus wastes, and must be implemented with a full and effective Kanban system in the manufacturing environment. Kanban, in the modern Lean companies, is seen as a fundamental and famous tool to implement JIT production in an easy and effective way. It is a tool fully embodying the concept of JIT delivery, featuring simple cards associated to boxes of items. Whenever a box is emptied the related card is collected and fixed to a board: this is the signal for refilling the workstation with a new fully loaded box and to put back in place the associated Kanban card. Modern Lean companies now uses electronic Kanban cards instead of the traditional ones but the underlying concept is the same. With a very simple tool a JIT delivery of material to the point of use is implemented, thus eliminating inventory and wastes in the phase.

6. Continuous flow. The notion underlying all the Lean manufacturing system is that of continuous flow. Lean companies strive to implement and ease the continuous flow, and in doing this they largely use the technical tools of TPS, still perfectly suitable to address modern complexity: from cellular manufacturing to heijunka, every tool of TPS is addressed to create and promote the ideal of a continuous one-piece flow of pure value-adding activities, and this is still the target of any modern Lean company.

7. Set up time reduction. Since the situation of continuous one-piece flow with no wastes is ideal, in real processes need non-value adding activities must be thoroughly investigated and eliminated. Through tools such as the value stream mapping, modern Lean companies find and address all the manufacturing steps which are not adding value to the final product, and as such they must be reduced to a minimum. An unavoidable non-value adding activity is the set up time of machineries: straight from TPS' SMED (Single Minute Exchange of Die) concept, Lean companies must develop techniques to reduce to the lowest possible value the changeover time of machines, in order not to interrupt the flow or accumulating inventory to react to this downtime, which is exactly what happens in a batch and queue production system as opposed to a Lean one.

8. Total productive/preventive maintenance. TPM is a comprehensive system for addressing equipment maintenance with the target of maximizing its performances and uptime. Lean companies implement TPM programs to strive for no breakdowns, maximum performances of machineries, no defects on the manufactured products and maximum safety for the operators, with no equipment-related accidents. The system was developed by Toyota in the sixties and it is, with the ever increasing presence of machineries in the production plants, a fundamental method to promote and allow for the continuous flow. An important point of the modern concept of TPM, directly inherited from the TPS, is that it focus on preventive maintenance empowering operators in maintaining their equipment at the best of its possibilities: within a system like this the separation between production and maintenance departments is not as marked as it is in a non-Lean environment, because it is a daily task and responsibility of workers care for their equipment and report any issue experienced with the machinery, so that it can be immediately addressed.

9. Statistical process control. SPC is employed as a method to check the products manufactured and ensue no defective product is passed to the downstream process, not to make wastes go beyond the phases in which they were generated. SPC allows to determine whether a production process is into the statistically acceptable expected variability or there is some influencing factor producing defects: SPC must be thoroughly implemented by Lean companies, and every time a defect beyond natural variability is detected the process must be stopped by operators and the root causes must be investigated with techniques such as the aforementioned 5 whys until their stable resolution.

10. Employee involvement. The final point characterising any modern Lean company, again in a perfect analogy with the Toyota way, is that a great focus on employees involvement must be put. Any process, indeed, must be managed by dedicated, well-trained and cross-functional employees understanding and playing an active part in the Lean corporate culture, which is the basis for the effective tools implementation:

without a shared knowledge and acceptance of Lean values, indeed, any implementation would be just temporary and not as effective as it could be, which is a waste in itself.

From the previous description it is clear that Lean manufacturing, in full accordance with its underlying nature, is a changing system and philosophy: current Lean companies, and Toyota itself, are modern corporations that have adapted TPS' original tools to the current environment in which they have to compete. They still adopt the original TPS' technical tools and management methodologies relating to the aforementioned ten Lean concepts, though adapted to the modern needs and evolved into something different: Lean as described by TPS has given birth to a series of similar yet different methodologies for the broader operations management and waste reduction, such as World Class Manufacturing and Six Sigma just to mention some. Those methodologies heavily rely on TPS and Lean concepts, although with some peculiar differences that make them different systems than the TPS itself.

In conclusion, a key point always highlighted when analysing modern Lean companies, being them more or less similar to the original TPS, is that there is a high risk of mistakenly confusing the Lean method with its tools[1][3]. Many modern Lean corporations, indeed, tends to focus more on the technical tools provided by Lean for waste management, such as JIT or Kanban for example, rather than on the deeper founding concepts of a Lean system: they may be able to get an acceptable increase of efficiency in the short term, being though unable to firmly hold the change and to further improve the processes in the long term. This is an outcome very common in many companies having not understood that the technical tools provided by Lean methodology simply cannot survive on their own, requiring instead a strong support and a solid shared Lean culture among all the employees of the company. As described by the house of TPS, indeed, the tools are just a part of the whole structure and the Lean system is a method in which every part is deeply connected to the other and to the founding culture: whenever a single component is missing, the whole building simply cannot stand up.

2. Literature review: an evaluation of the field of interest

As a basis to the development of this thesis a literature review has been performed, in order to identify the state of the research about the topics dealt with in the paper and the possible research gap needing to be addressed in greater detail.

2.1 Lean manufacturing in Formula 1 environment

The available literature about Lean manufacturing application in the Formula 1 production environment is practically non-existent. It has been impossible, indeed, to find any research paper addressing the application of this production management system to the very specific context of Formula 1 teams' production shops. Online resources for literature research, namely Google Scholar and the online Politecnico's catalogue, were consulted to find related material, giving no evidences of previous studies in the field. Consulting the internal staff and managers of composites plant, moreover, did not result in any literature available on the topic to their knowledge. The reasons could be many:

- Production volumes. Even though production volumes in Formula 1 are large, compared with the fact that only two race cars are taking part to the Championship each season, they remain very low compared to any mass manufacturer. Since Lean has been originated in the automotive mass-production context, not all its tools and techniques may be applied to a low-volume producer, and many of them require a strong adaptation to fit the unique challenges found in manufacturing a low quantity of products with very large variability [7][9]. This challenging task, in particular, will be addressed in more detail in the following of the literature review.

- Targets. Lean concepts originated as a comprehensive set of tools and methodologies to identify and eliminate wastes, as described in the previous introduction. It is with this target that the concept has been developed throughout the years, evolving in the more general idea of adding value to any activity performed in order to maximize the efficiency of any given system [5]. Even though this general target is valid also for a Formula 1 production environment, it must be pointed out that in this latter the focus is more in eliminating wastes in order to optimize the invested resources and ensure a faster production, resulting ultimately in a faster development of the products. The core business of any Formula 1 team, indeed, is the design and engineering of innovative solutions and products to race and win against competitors. Manufacturing in a fast way the designed prototypes and parts, then, is a key part of the development: the faster the production, indeed, the faster the development rate that can be sustained by the engineering department and the greater the possibility of gaining a technological and performance competitive advantages against competitors. For the mentioned reason, Lean application in a Formula 1 production environment is targeted at reducing wastes in order to speed up the development process, rather than to save money in the production phase as usually happens in a more standard application, as largely described in the available literature about Lean [3][5].

- Limited number of case studies. Given the very small number of teams participating to the Formula 1 Championship (as an example, only 10 teams are enrolled for the 2019 season), the list of possible case studies to perform a research about manufacturing systems in such a motorsport context is extremely limited. Unlike Lean application to standard manufacturers, which can be found all over the world in a large number, addressing the task of applying Lean to a Formula 1 production context requires to approach this very limited set of teams, which can pose major difficulties and drastically reduce the possibility of relying on a sufficiently large set of case studies necessary to generalize the obtained results.

- Confidentiality. Formula 1 is a highly-competitive environment in which major investments are made each year by all the teams participating in the Championship. Production plants features and their characteristics, such as installed capacity, available personnel and infrastructures, may give important clues to competitors about the level of investment sustained in production and development of new parts and components, so that in general information about production environments are kept confidential.

2.2 Lean manufacturing in High-Mix-Low-Volume production

Lean concept originated in a High-Volume-Low-Mix (HVLM) automotive production context, thus becoming the most widespread system to manage manufacturing plants characterized by a fixed product mix with high output. In such a context the key requirement of standardization of products and processes allowed Lean tools to be effectively applied and refined, enabling researchers and practitioners to develop an extensive body of literature about Lean application in HVLM environments.

In the modern production context, though, Lean principles and tools have been successfully applied also in High-Mix-Low-Volume companies. It is generally agreed that the application of Lean in such contexts is extremely challenging, given the inherent variability of products and processes: the lack of standardization requires Lean tools and principles to be heavily adapted to the HMLV context and, moreover, to the specific need of every company they must be applied to.

HMLV companies may be distinguished in Make-to-Order (MTO) and Engineered-to-Order (ETO), according to their characteristics and their customer order decoupling point (CODP) [7]. This latter is defined as “the point in the material flow where the product is linked to a specific customer” [8]: the more upstream the CODP, the more the production is driven by customer’s order and the more the company operations are farther from a mass-production behaviour.

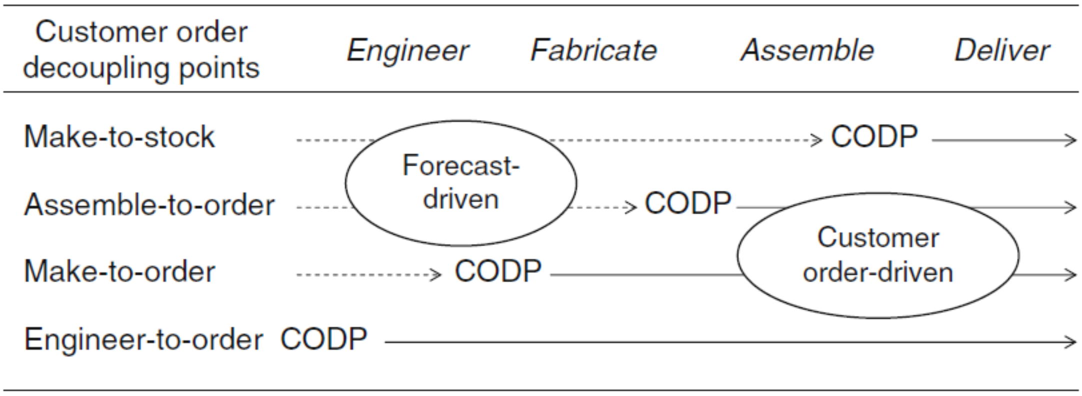


Figure 3- Classification of companies according to their customer order decoupling point [8]

MTO manufacturing process is defined as a process in which the production does not start until a customer's order has been received. ETO, in a similar fashion, is defined as a process in which a product is engineered, developed and manufactured only after a specific customer's order has been received. An inherent peculiarity of those two systems is that they are suitable to be applied in a high variability context, in which or the demand or the product specification, or a combination of the two, is extremely inconstant [7]. While a good amount of literature exists about Lean tools application to MTO companies [9], it is not the same for ETO production: to date, literature and case study availability on application of Lean tools to ETO manufacturing are still lacking.

The Scuderia Ferrari F1 team, subject of this thesis, may be regarded as an example of a peculiar Engineered-to-Order company: the core business of the team is the design of new components following from the requirement and development strategy pursued by the management and the specific performance and track requests. The design of every component is followed by a limited production for prototyping or track use. Since this thesis deals with the description of a kitting process introduction performed in the composites plant of Ferrari Formula 1 production department, it is worthwhile to mention that in such a context the great majority of products are one-of-a-kind items, manufactured in an extremely limited number (often not more than 3-4 per season) with dedicated processes, tooling and production cycles. For this reason, according to the aforementioned classification, the research field of this thesis may be regarded as the Lean tool application in an ETO manufacturing system.

The available literature about Lean applications in ETO companies is focused both on the development process and the manufacturing phase, with a peculiar emphasis on the former. Given that the core business of a ETO company is the engineering phase of a product, indeed, researches in this field are mainly dedicated to the rationalization of product development and planning phases. A much lower attention is put in the available literature on the manufacturing side of Lean application to ETO environment, given the extreme variability of cases and situation peculiar of this manufacturing system making it difficult to analyse from a broader perspective as a coherent research topic. [7] identifies some key qualitative Lean principles suitable to be applied to ETO manufacturing companies, covering core activities such as product development and production. From a manufacturing point of view, they found flexibility, continuous process flow, demand pull, transparency, technology and continuous improvement to be the key Lean tools possible to be adapted and applied to a HMLV environment:

- Flexibility. ETO operations require a high degree of flexibility to cope with the always changing product configuration and characteristics. Flexibility is required not only in the product development phase but also in the production facilities and processes, that must allow to reconfigure tools, routings and manufacturing cycles in order to adapt to the different products to be manufactured [11][19].

- Continuous process flow. Continuous flow is a direct application of the one-piece-flow concept as expressed by the Lean ideal, particularly suitable to be implemented in an ETO environment given the low production volume. A continuous process flow in such a context is enabled by flexibility in manufacturing, as described in the previous point. Production batches are not used in an ETO manufacturing company, so that a near-to-ideal situation in terms of continuous flow may be achieved: as already described in the previous introduction about Lean, the smaller the production batch, the smaller the wastes and the shorter the lead time [2][3].

- Demand pull. Strictly connected to the continuous process flow is the demand pull principle, for which the production should be managed with a pull strategy rather than a push one. Pull production is particularly suitable to be implemented in a ETO company, being it a customer order-driven environment by definition: a well-designed ETO manufacturing system allows to produce exactly what is needed when it is needed, allowing to potentially eliminate stocks of materials at any end of the production cycle. This possibility is much more evident than for an equivalent Make-to-stock manufacturing system, given that in an ETO context usually a very low stock is kept of a large variety of products due to its inherent variability. For this reason, demand pull in ETO environments enables Just-in-Time production. This concept may be effectively implemented not only towards the final customer, but also in the production cycle steps: thanks again to the fact that production batches are very small or not used due to the low volumes, a JIT delivery to the next step can be achieved, avoiding any inventory between phases [5].

- Transparency. In order to allow for an effective continuous flow and JIT production to take place a key Lean concept is using visual management to share information among all the involved stakeholders. In a ETO manufacturing system information management in a visual and immediate way is even more important than in a traditional MTO system: given the complex flows of materials, production processes and inherent variability, it is of paramount importance to access the related information from a system-wide perspective in order to control and support the continuous flow through the subsequent process steps [14][18].

- Technology. ETO manufacturing is exposed to a great variety of product and processes, being them a function of the customer's orders. Technology supporting not only the product development, but especially the production process, is a key concept to be implemented in order to sustain the Lean implementation, the transparency of the network and the continuous flow of materials and information [3].

- Continuous improvement. The final Lean concept applicable to ETO companies is the continuous improvement: it is a key tool to be applied in any Lean implementation, being even more important in a highly variable context such as the ETO manufacturing, in which no standard situation is defined and every new product and process requires to adapt the existing infrastructure to keep pursuing the Lean ideal [3][6].

Those Lean principles could be used as a basis for identifying and eliminating wastes in any ETO manufacturing system [10]: they represent the founding concepts on which any Lean implementation, tailor-made for each ETO company, should be built and developed.

Keeping those concepts into consideration, the literature available on Lean tools application to HMLV environments is focused on case studies, clearly stating how the inherent variability of such a manufacturing system entails a comparable variability in the Lean tools adaptation from the technical point of view [11].

An example covered in literature is the application of value stream mapping in a ETO context, a tool used to map the value added activities and wastes related to a product flow through its manufacturing cycle. [12] suggests an innovative approach structured in eleven steps to adapt the standard Lean VSM tool to a ETO system, in which product mix is very high and material flows are extremely interwoven: a multi-branch VSM is proposed, suitable for a generic HMLV environment, with the innovative consideration of the CODP position as a peculiarity suitable for ETO companies. The solution proposed is addressed to solve typical problems found when realizing a VSM in a ETO company's job shop, as described by [13]: the methodology, originally developed for automated, low variability manufacturing cycles, must indeed integrate highly variable cycle times, setup times for machinery, product routings and inventory hold between phases.

Another tool suitable to be adapted to ETO manufacturing is Kanban, used to control the amount of WIP in the shop floor and implement the pull flow. It may be adapted from the original Toyota's Kanban system in terms of a tool known as Kanban board. [14] shows it as a valuable production control tool to visually manage daily manufacturing activities and control the amount of WIP released in the system, thus enabling a continuous flow of jobs and activities. Kanban boards collect information about the tasks to be performed and fully implement the pull concept: as reported in the following picture, activities and jobs are pulled by operators from a "Backlog", so that a the amount of WIP released in the production floor is constrained a-priori. Differently than the Toyota's Kanban system which is managing the material flows, Kanban in an ETO context in literature is addressed more at managing information flows supporting the production itself [11].

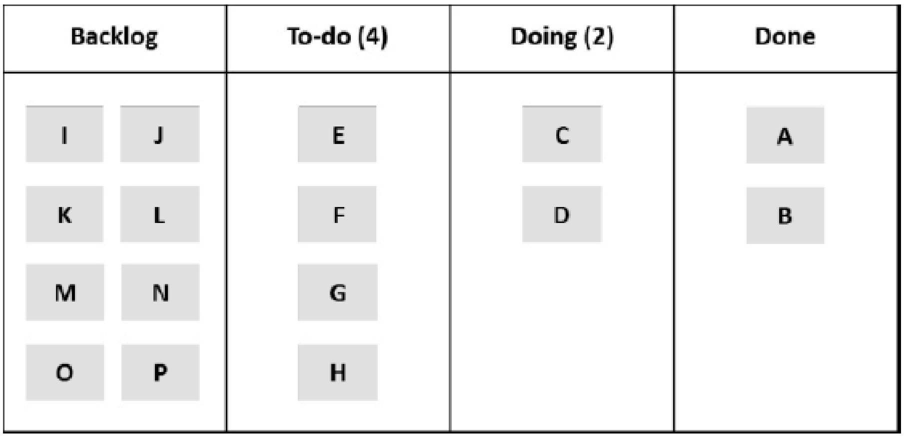


Figure 4- An example of a Kanban board [14]

Kanban boards used to manage production control represents an effective way of applying this Lean tool to ETO manufacturing, allowing to potentially reach lead times reduction in the magnitude of 50% [14] by simply focusing on the information visual management, the pull production and continuous flow implementation.

Pull system itself is described in [11] as a valuable tool to be implemented in ETO manufacturing, requiring though some adaptations according to the product family considered and its turnover. In the case study presented, a typical Lean supermarket is proposed for high-turnover products (high-runners), while a FIFO pull system is suggested for medium and low-runners. The author suggests his findings as a general pull adaptation for an effective reduction of inventory and wastes in ETO manufacturing.

Overall, a scarce literature on practical Lean tools application to ETO manufacturing processes exists, being mainly based on case studies difficult to generalize in an organic set of tools to be picked and used as they are, given the differences existing between ETO companies.

2.3 Kitting process in High-Mix-Low-Volume production

Kitting process is defined as the process of preparing a "specific collection of components and/or subassemblies (i.e. a kit) that together support one or more operations for a given product or shop order" [15]. The authors provide a framework to classify kitting operations according to the characteristics of the process itself: ETO manufacturing is associated with stationary kits and with a variable kit mix, i.e. with kits serving a single workstation (thus a single process) and constituted by a variable mix of products according to the daily scheduled production. Such a kit usually requires to be prepared in advance and stored prior to the manufacturing phase, thus entailing a not negligible kitting lead time and operators' effort.

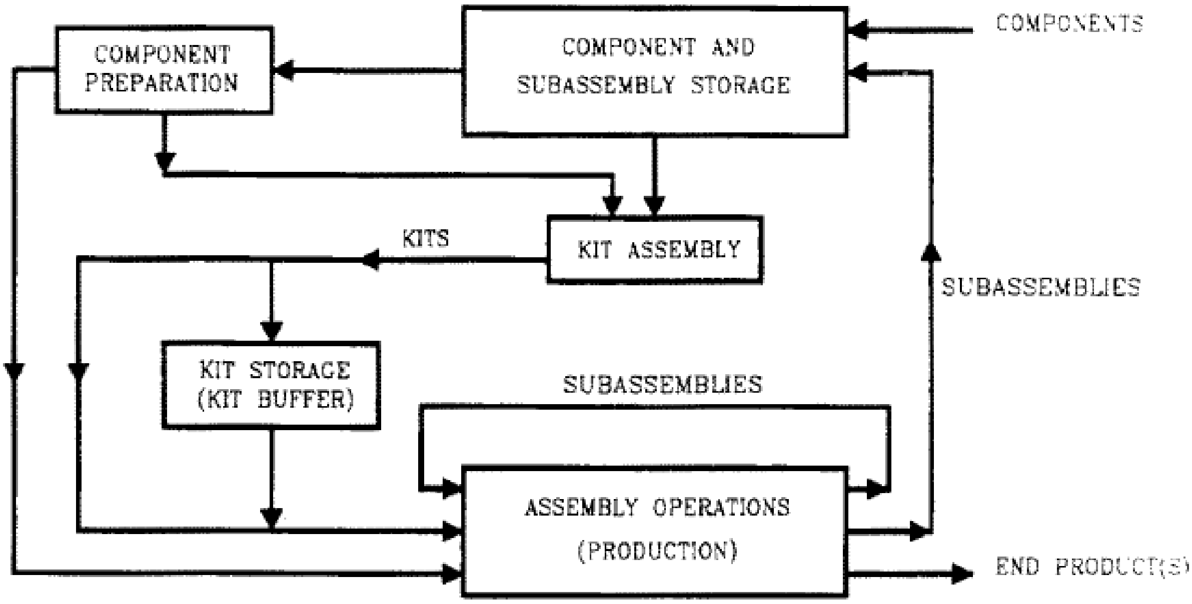


Figure 5- Flowchart of a standard kitting process [15]

Kitting, as compared with line stocking, is associated with a series of advantages, of which will be reported those applicable to a ETO manufacturing context [15]:

- Handling flexibility. Routing of kits containers alone streamlines handling operation, as compared with routing individually each component container needing to be delivered to the different workstations in the shop floor. In a ETO context handling and delivering single items' containers one at a time to workstations would be massively impacting on the internal logistics operation, whereas kitting allows to collapse the items handling and delivery to point of use in a smaller number of operations.
- Manufacturing productivity. Workstation productivity may be highly increased by feeding each with the complete amount of material required for performing the assigned manufacturing phase. Allowing floor staff to dedicate its effort to the production phase alone is highly beneficial for productivity, by removing the time wasted in searching and picking the material needed: kitting, indeed, is associated with the capability of potentially eliminating the time spent searching and picking parts from stores [16].
- Small batch operations. Kitting allows for small batch and one-piece-flow operations giving its high flexibility and the ease of performing product changeover. A kit may be created by potentially including any kind of item, thus changing product mix and specification is obtained by simply creating a dedicated new kit. This flexibility in performing product changeover by changing kit structure is particularly valuable in ETO manufacturing operations, in which the high variability of production calls for high flexibility.

Kitting process, though, comes also with some disadvantages potentially highly impacting in ETO operations:

- Kit preparation. Assembling kits is usually a manual operation, especially in high-variability contexts such as ETO manufacturing systems, in which a variety of different items need to be handled and it is not possible to define a standard material handling system. The kit preparation phase, moreover, may be regarded as a low to non value-added activity [17], given that it requires a double handling of components from storage to kit preparation area, and from this area to the shop floor.

- Space requirements. Kitting process requires a dedicated area to be implemented and where to perform the kit assembly and storage, particularly in those cases in which kits are prepared in advance and need to be stored, waiting for the delivery to the point of use. In high variability contexts such as ETO companies, kitting in advance may be a strict requirement given the impossibility of providing a JIT kit preparation, due to the product variability and the related picking and kitting lead time change[15]: this consideration entails a subsequent need of floor space both in terms of kit preparation and of kit storage areas.

- Parts shortages. Kits are particularly vulnerable to missing components. Whenever a part required to be put in a kit is missing at the moment of the kit assembly operation, the kit itself will need to be put on hold and completed at a later stage, leading to a double-handling operation and a comparable waste. This situation may be a common one in ETO systems, in which the large variety of non-standardized items and their low volumes may create difficulties in the procurement process. Overall the need of kitting in advance, peculiar of high-variability environments, together with the higher possibility of parts shortages, potentially leads to a reduced efficiency and wastes in kit preparation process.

Given those considerations, kitting is often presented in literature as a common and effective way to manage material presentation to the point of use in ETO manufacturing contexts. In their case studies [11], [10], [19],[17] point out that ETO manufacturing systems have to face complex material flows and handling due to many reasons:

- Material mix and volume. The standard situation in ETO context is that of a broad variety of materials in a low volume per type. This implies a complex material handling during manufacturing operations and, often, wastes for operators spending time in retrieving physical items or information related to which specific item needs to be picked to perform the assigned production step.

- Manual operation. In a ETO context manual operations are much more common than in other manufacturing systems, given the inherent variability of products requiring a comparable variability of processes and manufacturing operations. Retrieving manually the materials needed for production is time-consuming and it usually represents a major source of waste in a non value-added activity directly impacting on the time available for manufacturing, being performed by the shop floor staff [16].

- Information management. Dealing with a large number of different products in small volumes is a complex task also from the information point of view: registering and managing the location and documentation of all the items in their supply chain, making the information transparent to the network and to the operators, requires a considerable effort and IT softwares suitable to sustain it [18].

Authors suggests kitting as a material presentation strategy to deal with those issues, validating it through several case studies showing how this solution is currently implemented by many ETO companies. [17], in particular, gives an organic description of the available methods to feed material necessary for manufacturing to the production line, identifying kitting as the most beneficial solution for situations in which a high mix of parts must be presented at the point of use. In case of manual processing of highly-variable parts sharing very low product communalities, kit preparation starting from materials stored in a central stockroom is identified as the right trade-off between time spent in gathering materials and robustness in delivering the right product, at the right location, at the right time. The author argues that kitting process should not be preferred by Lean practitioners as it implies an additional non value-added activity of kit preparation prior to the manufacturing phase. It is for this reason that in HVLM environments, the point-of-use strategy is used and the materials are delivered JIT and JIS to the manufacturing phase they apply. As complexity and mix of products to be delivered increases, though, point-of-use material presentation is more difficult and its benefits decrease: [11], [10], [19], [17], [16] recognize that the target in ETO manufacturing environment is that of reducing material manual handling and non value-added activities of manufacturing operators, accepting to deal with complexity and maximize productivity of shop floor staff by shifting the non value-added material sorting phase to a moment prior to the manufacturing step in which the material is needed.

2.4 Identification of the research gap and contribution of the thesis

This thesis is aimed at giving a contribution in covering the research gap represented by application of Lean manufacturing in Formula 1 production facilities. Given the actual non-existence of a line of research in this field, the thesis aims at describing a case study to foster more research in Formula 1 production environment and, in particular, in Lean manufacturing use as a valuable tool to reduce wastes and the time to market of the products manufactured.

From a more general point of view, the analysis and solution developed can be regarded as a case study to deepen the knowledge on the possibility of applying Lean manufacturing concepts in ETO production characterised by an extremely high degree of variability. In particular, the thesis deals with the application of kitting in HMLV manufacturing environments as a valuable Lean tool to manage internal material flows to the point of use, focusing on two areas of interest:

- Information management. The case study presented may be useful to cover the further research gap about the integration of available IT systems to provide a transparent information flow sustaining the kitting process and material procurement. Even though information availability is acknowledged to be a key requirement in ETO manufacturing contexts, researches about the actual implementation of information systems in those environments is scarce in literature: the thesis offers a framework for the integration of MES (Manufacturing Execution System), ERP (Enterprise Resource Planning) and WMS (Warehouse Management System) softwares into a unique tool supporting the kit preparation process.

- Kitting process design. The presented analysis is aimed at giving insights about advantages, disadvantages and issues found in designing the kitting process for a highly variable ETO manufacturing context. The case study can offer some ideas about how to integrate highly variable material flows with a kit preparation process, giving cues about how to deal with the most recurrent issues as found in the management of such variable material flows and integrating them within a stable and robust kitting process.

3. Company presentation

Ferrari N.V. is a luxury sports car manufacturer and Formula One world championship participant through its racing team Scuderia Ferrari. Based in Maranello (Italy), it was founded in 1939 by Enzo Ferrari and in 2019 has been awarded as the world's strongest brand, reporting in 2018 a net revenue of 3,420 mln € with more than 9200 vehicles delivered [20].

3.1 Product portfolio – GT cars

Ferrari's current product portfolio is divided into 4 pillars (Sport range, Gran Turismo range, Special series and Icona) and includes ten models: three sports cars (488 GTB, 488 Spider and 812 Superfast), three GT cars (GTC4Lusso, GTC4LussoT and Portofino), two special series cars (488 Pista and 488 Pista Spider) and two Icona models (Monza SP1 and Monza SP2). In addition to these products, Ferrari manufactures also a number of limited edition series ("Fuori serie" product line) and one-off cars.

Figure 6- Overview of the product families offered by Ferrari [20]

Starting from the road cars mentioned above, Ferrari produces also track-oriented special versions for several motorsport championships: namely the 488 Challenge, the FXX K Evo and 488 GTE and GT3, taking parts each in the corresponding leagues. In the following picture, a full overview of the models currently offered by the company.

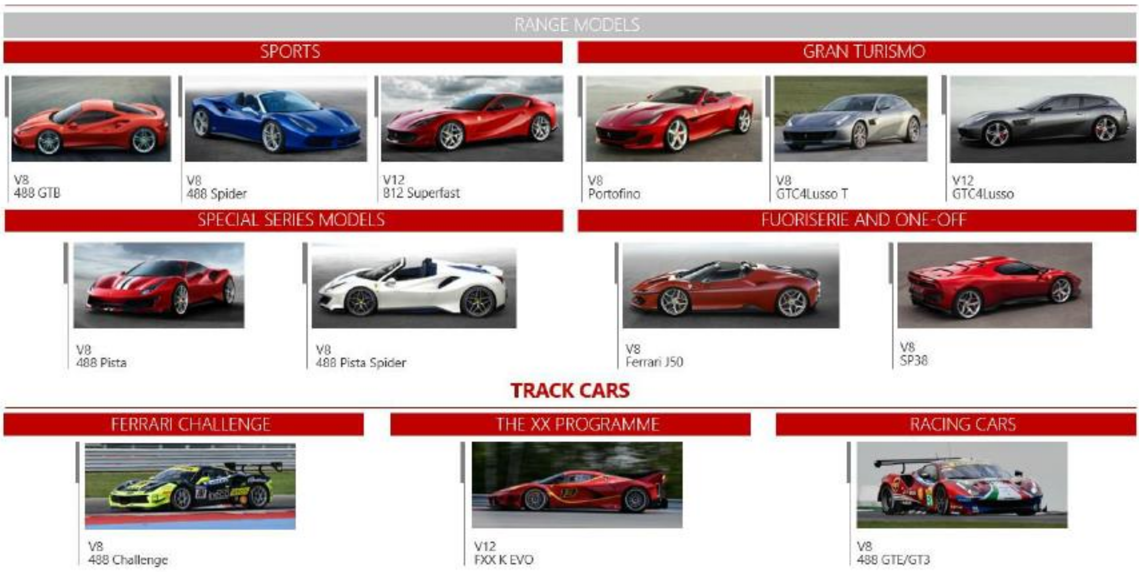


Figure 7- Overview of the current products' portfolio offered by Ferrari [20]

Figure 8- The Monza SP1 and SP2, first two models of the Icona segment [www.ferrari.com]

Figure 9- The F8 Tributo, set to replace the 488 GTB in 2020 [www.ferrari.com]

Ferrari sells its products in over 60 markets worldwide exporting 95% of its output, which is mainly represented by Sports series cars, are shown in the following picture.

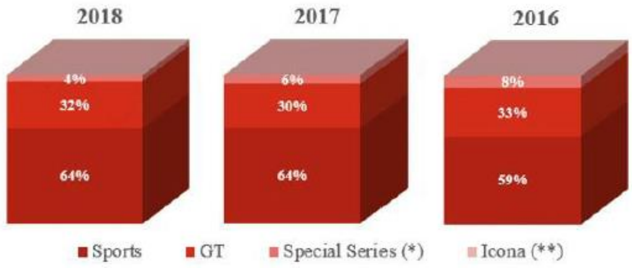


Figure 10- Contribution of the products' segments to the total sales [20]

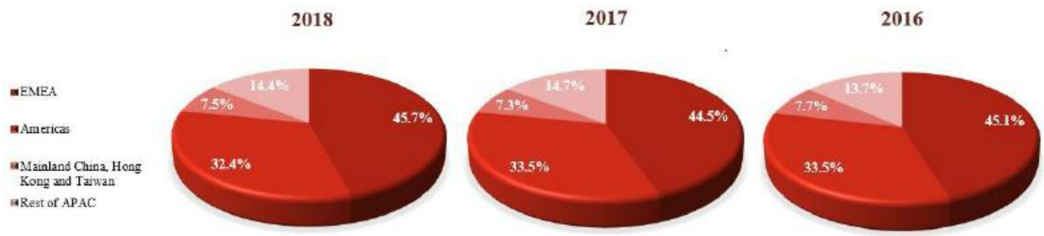


Figure 11- Contribution of the regional markets to the total sales [20]

The company aims to offer a unique customer experience and iconic product design and features. For this reason all the models feature are offered with highly customizable interiors and exteriors, and further customization possibility is given to customers in three levels, ranging from an increasingly wider catalogue of accessories and trims to the possibility of designing a one-of-a-kind car with exterior and interior completely set by the customer. Exclusivity, luxury and performances are the core value propositions of Ferrari, which is a major player in the luxury market, reporting good market shares as described in the following picture.

Figure 12- Shares in the global market [20]

3.2 Manufacturing facilities

Production takes place in two plants located in Modena and Maranello (Italy). Modena plant produces all the cars' aluminium bodyworks, which are then shipped to Maranello plant for all the remaining manufacturing phases. The facilities include a foundry for the aluminium alloy engines' components casting, a machining shop, an engine assembly shop, as well as a painting facility, car assembly lines and benches for testing.

Ferrari also produces V8 and V6 engines for Maserati company since 2003. Production takes place in the Maranello plant facilities and is performed according to the same manufacturing process used for Ferrari's own engines. Maserati's V8 are directly derived from Ferrari's engines and are intended for equipping the highest performing models of Maserati: they produce V8 turbo engines for the Quattroporte, the Ghibli and the Levante models, as well as V8 naturally aspirated engines for the Granturismo and Grancabrio cars. V6 engines, instead, are dedicated to the Quattroporte, Ghibli and Levante Maserati models. Given the much higher production volumes (around 28000 V6 engines have been delivered to Maserati in 2018) and the four different versions to be produced (from 330 to hp to 450 hp), those engines are produced in a dedicated, highly automated facility in Maranello plant. There, engines are assembled starting from components mainly procured from external suppliers.

Ferrari, for its production and management operations, employs overall 3850 people, of which around 2050 blue collars and 1700 white collars, with the residual number being represented by executives.

3.3 Formula 1 participation

Ferrari name is worldwide famous for and inextricably linked to its participation in the Formula 1 world championship through the Scuderia Ferrari, this latter being the only team having participated to each season since the launch of the championship in 1950. For this reason, Scuderia Ferrari is the oldest team of Formula 1 and the most successful, having reported 235 Gran Prix wins, as well as 15 Driver's championships and 16 Constructor's championships.

Formula 1 cars are completely engineered, developed and built in Maranello, in dedicated facilities located in the same compound hosting the production plants for road cars. Every year a set of two racing cars is built: while the chassis are designed to be used throughout the whole season, the vast majority of components are produced and adjusted to match the characteristics of the different circuits. This is particularly true for all those parts having aerodynamics function, for which a continuous development is strictly necessary to perfectly fit the different circuits' peculiarities.

Ferrari production plants for the single-seaters' parts manufacturing is constituted by two facilities:

- Meccanica GeS, in which all the mechanical and metallic parts for the vehicle's systems are manufactured
- Compositi GeS, in which all the composite parts of the vehicle's are produced. More information about the characteristics of this facility will be given in the following Kit preparation project introduction, being it the area in which the Lean project of this thesis has been introduced.

The engineering, testing, quality and vehicle assembly departments, instead, are placed in a dedicated building near the main compound. Overall, the Scuderia Ferrari employs some 700 people to design, manufacture and test the single seaters and their components, resulting in a considerable amount of manhours as reported in the following picture (related to the 2016 season vehicle but comparable to the current one).

Technical details

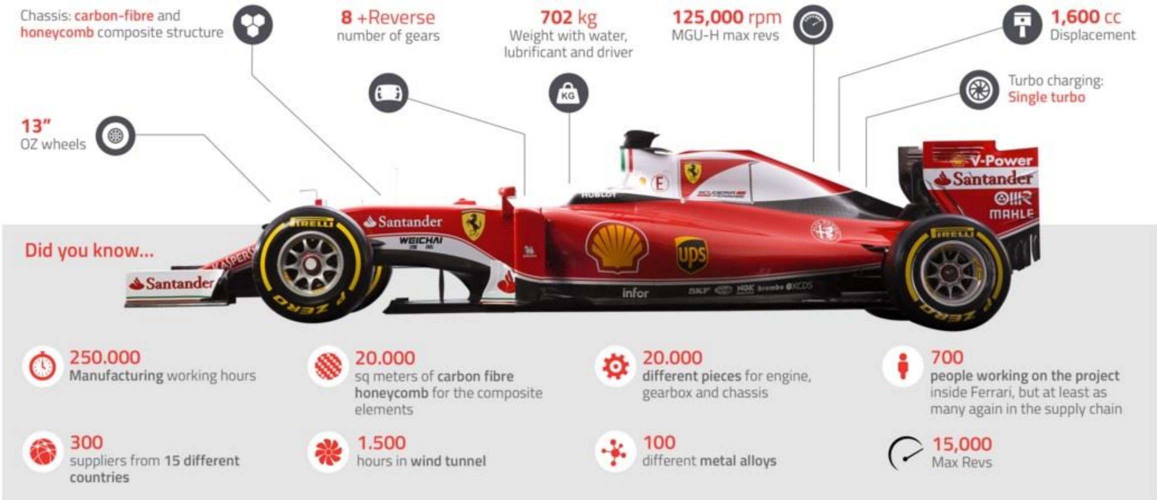


Figure 13- Data overview of the 2016 season's single seater [www.autoblog.it]

Ferrari has historically related its marketing expenditures and brand identity to the Formula 1 racing, given its unique history and heritage in the competition. Moreover, the R&D performed in designing and engineering the single seaters has been successfully transferred to the production of commercial cars, which benefited from the Formula 1 expertise in performances and technology: it is the case, for example, of aerodynamics improvement and energy recovery systems, which have been adapted to a road use straight from the track use as developed for the Formula 1 vehicles.

4. Kit preparation project

This thesis deals with the description of a kitting process introduction performed in the composites plant of Ferrari Formula 1 production department. In this chapter the description of the background of the kit implementation activity and the steps performed for its development are addressed, in order to describe the current situation and the newly designed information and material flows for the areas involved in the kit logistic improvement plan.

4.1 Composites division in Ferrari GeS

The composites department is a plant in the Ferrari GT compound dedicated specifically to the production of CFRP (Carbon fiber reinforced polymer) products and assemblies for the F1 cars where most of the manufacturing steps are made internally, ranging from the receiving raw materials to the bonding and painting of assemblies. These are subsequently delivered to external or internal customers, the latter being represented by the various other departments involved in testing or car assembly. Due to the complexity of the components manufactured, there are not many standardised production cycles as concepts are driven by the continuous design evolutions, therefore the composites department manufactures a large variety of built-to-order products not only for the race weekends but also for experiments, prototypes and mock-ups of the various car systems.

The composites facility features:

- a logistic area for inbound and outbound materials;
- two “Clean rooms” (CR1 and CR2) dedicated to the moulding and vacuum bagging of the CFRP parts;
- autoclaves for curing the vacuum bagged carbon fibre parts, associated to the clean rooms;
- a mould extraction and preparation room, in which cured parts are extracted from the moulds, cleaned and the moulds are then prepared and waxed again for a new manufacturing cycle;
- workshops each dedicated to the bonding, assembling and machining of the parts extracted from the moulds and bonded in assemblies. There are dedicated job shops for: front and rear wings (FW and RW respectively), body and chassis, suspension and gearbox fairings;
- machine shop used to machine patterns, rohacells, moulds and cured parts;
- Inspection area where dimensional and generic quality checks are performed;
- automated vertical stores for storing moulds, patterns, laminates, inserts and any kind of material needed for the manufacturing activity;
- additive manufacturing area with stereolithographic machines for inserts production;
- cutting room for raw carbon fibre sheet cutting into plies;
- Offices for management personnel and industrialization activities.

In the composites facility there are roughly 150 shop floor staff and 25 office staff, and the annual average output is of roughly 10000 laminates overall. There is a production peak in the pre-GP season months from December to March, when the cars for the upcoming season must be produced, homologated and assembled.

4.2 Context and problems detected in the composites plant

The kit introduction project was born out of a need to resolve a common problem found in both the clean rooms and fitting shops: shop floor personnel use many different sources of information to simply understand what items are required to manufacture a component and subsequently lose time searching for the various parts. This mode of operation led to a series of problems and wastes in non-value added activities, as well as problems related to the traceability of the products stored and the reliability of the data retrieved from the internal warehouse management system (Gestione Giacenze 2.0, described later in the thesis in the AS IS and TO BE information flows sections).

The kit preparation project described in this thesis has been developed for the clean room 1 and body shop floors, which are the most affected by this issues due to their high capacity and number of products manufactured per year. In the following points the main issues of their AS IS situation relating to the storage and internal logistical flow of material will be reported.

- *Wastes for shop floor movement*. As previously introduced, shop floor staff are used to walking from their workstations to the stores in order to get the materials they require, resulting in considerable time wasted especially during peak production periods. The typical workflow for collecting items includes the following steps:
    1. Reading of the required parts identification codes from the Bill of Materials shown on the drawing of the item to be manufactured;
    2. Manual typing of the parts ID in a PDA (personal digital assistant), which retrieves the information of the position of the items in the different warehouses by extracting the data from the WMS;
    3. Walk to the vertical store as indicated by the PDA output. Note that different materials may be stored in different vertical stores serving the same job shop;
    4. Select the tray as indicated by the PDA and wait for its retrieval by the automated vertical lift system, which delivers the required tray to the picking bay, where it can be accessed by the operator;
    5. Pick the material required, scanning first the QR code on its label and selecting the retrieval operation on the PDA, communicating it to the WMS;
    6. Repeat the steps 2-5 for every item required;
    7. Walk back to the workstation with the picked material;

  Please note that these general steps are performed in a slightly different way in the two analysed areas of CR1 and body shop, as will be described in detail in the following dedicated chapters of the thesis. These differences affect the analysis performed and the kit solution proposed, which must be a common solution to resolve the same basic problem whilst taking into consideration differences in terms of sources of information and type of materials involved.

- *Logistic complexity and data reliability problems*. Since shop floor staff are in charge of picking the materials required for the items assigned in the daily plan, every member has access to each warehouse. This holds true in clean room 1, while it is not the situation in the body shop: in this latter, indeed, selected operators have been dedicated to internal logistics to limit the complexity of material collection and delivery to the point of use. This has streamlined the operations reducing the possibility of errors associated to having too many people allowed to access the various stores. Nonetheless, especially in peak production periods in which the time pressure is high, logistic complexity and inefficiencies were reported.

  Given that in CR1 alone around 50 people are employed, it has been verified in several past cases that the operational instructions for picking operation were not fully respected: there were some cases of picking of materials without QR code scanning, so that the operation was not properly registered on the WMS. This problem, due also to the high time pressure put on the floor staff and operations to meet the track department requests, was verified especially with some low-economic value commercial codes such as bolts, nuts and bushings but also with some high-value inserts and materials, thus creating a misalignment between the stock of material as expressed by the WMS and the actual one.

- *Out of stock materials exposed JIT*. Another main problem caused by the current warehouse management method is related to the out of stock risk, particularly impacting in an F1 manufacturing environment. The constant changes in specifications, product design and time constraints due to the tight sequence of GPs force the planning department to constantly update and change manufacturing plans. It is often the case that an item like an insert, required to manufacture a product, has not yet been produced or checked by the upstream departments, or it is still in the manufacturing/delivery phase by a supplier, which usually produces JIT built-to-order items. As a result of this situation there is a stockout of that particular item, so that the scheduled part to be manufactured must be postponed later in the day or in the next days for production. This not only represents a problem for planning and manufacturing scheduling but sometimes, especially in high output periods, it is exposed just in the same instant in which the operator goes to the warehouse to pick the material, discovering that it is missing. Usually, in this rather common case, the out of stock problem is managed by the floor managers, together with the product family responsible in the body shop environment and the purchasing department. The situation is usually addressed in an "offline" way, i.e. by means of phone calls and emails, mainly because the information about the location of a searched item is spread through at least 3 different software, that must be checked one by one manually for each part number. It is often preferred to ask directly the involved actors rather than

retrieving the location from the available software not only for the sake of simplicity, but also for accessing traceability information that may not be available on those platforms, as will be described in the following point.
Given this situation, whenever an out of stock occurs the time lost in understanding where the missing part is and when it could be available for manufacturing is usually considerable: the solution to this problem was one of the key drivers for the development and implementation of the kit preparation project.

- *Traceability of the part numbers*. In the context of composites production facility, complete traceability for all the products used in the clean rooms and body shop is not guaranteed. While all the items that will be assembled in systems and subsystems ending up in the final configuration of the cars for a GP are completely traced in an unambiguous way with labels, the WIP parts and many other items required to manufacture the end products are not completely traced or their traceability is managed on different software platforms, as will be described below. Please note that the software introduced in the following points are mentioned just to give an overview of the different available platforms and the product traceability guaranteed by each, more detailed information about their features and their actual use in the composites environment will be given in the information flows analysis section of this thesis.
  The Clean Room 1 case will be first introduced:
  1. *Ply kits*. The first step in the manufacturing process of any item in clean rooms is the cutting into shape of the composite raw material, which is a pre-preg carbon fibre fabric rolled in cylindrical shape. A roll of the specific required material is rolled out and cut into plies suitable for the following moulding by an automatic machine. The activity takes place in the cutting room, then the plies are bagged with an identifying label and stored into a freezer in the cutting room itself or in the clean room, depending on the space availability.

     These ply kits are traced by means of the drawing identification number and they also have a barcode printed on the label, in order to dialogue with the MES C3 through barcode scanning. The information about the location of the kits and their association to the part to be manufactured is just stored in the MES software, i.e. it is not managed by the WMS (GG2). All of the ply kits used both in clean rooms 1 and 2 are internally cut and bagged, so that in this case a distinction between MAKE and BUY products does not apply.

  2. *Moulds*. CFRP and metallic moulds may be both MAKE or BUY products according to the available internal capacity. In both the cases, again as for the ply kits, the information about their location is stored just in the MES software, where the association with the part number to be manufactured is performed by manually typing the data into the MES itself. Composite moulds, in particular, are usually manufactured internally in Clean Room 1 itself, then cured in autoclave, extracted and prepared for the following lay-up process in the moulds extraction and

preparation room and stored in this latter room or in a vertical store. It is often the case that moulds are extracted from autoclave and prepared for lay-up process just in time, so that they are not stored in a warehouse, being instead kept in a specific rack in the mould's preparation room. Being stored outside a vertical store, it is not possible to input their warehouse location in the MES software as for the other moulds: floor staff are aware that if a specific location is not given for the mould of the part number to be manufactured it means that the mould must be searched in the rack in the extraction and preparation room. Overall, it must be noted that the logistic flow of the moulds is not unique but has at least two sources, i.e. vertical stores and moulds extraction and preparation room, and of these two only one is fully traced, i.e. the vertical stores, in this latter case being the data typed manually into the MES software and not managed with the WMS software as for any other material stored in a vertical store.

3. *Inserts*. Any other material used for manufacturing a part number in clean rooms is defined as insert: in that context we are mainly speaking about metallic parts co-laminated with the carbon fibre plies, smaller laminates ending up in an assembled laminated product, commercial codes such as bushings, fillers for hollow geometries manufacturing or patterns for the lay-up of specific geometries. It is clear how under the name insert a broad variety of material is considered, usually made-to-order by the upstream departments or purchased from suppliers for the manufacturing of a specific part number: inserts are only stored in the vertical stores and their location is registered in the WMS software by scanning the QR code reported on their label or by manually typing on the PDA the number of drawing associated to the item, which is often used in the composite plant as the identifier for a specific part. Inserts, thus, are fully traced on the WMS software GG2 and every time an operator picks or put an item from/in a vertical store he/she must report the action to the WMS software by using a PDA. On the other hand, by using the same software GG2 it's possible to retrieve information about the availability and location of any insert.

   Cases were reported of operators failing to report the picking operation of items to the WMS software, especially in peak production periods, in order to save time. Moreover, especially with small commercial codes like bushings which are usually picked in large quantity, cases were reported of wrong picking quantity indication to the WMS software, thus creating a misalignment in the long term between the theoretical available quantity as given by GG2 and the actual one.

   All the inserts except laminates, moreover, are subjected to an internal quality check by the quality control department, located in another building: after the check they are returned to composites plant by a milk run delivery taking place at scheduled times. More details will be given below, in terms of traceability of material though it must be pointed out that GG2 is able to trace also the quality control in terms of done/not done yet and the milk run movements: it is possible, then, to completely trace whether an insert has undergone quality checks and has been loaded on a milk run shuttle or not. The same information about quality check performed or not can be retrieved by the tool CCQ LIGHT in the MES software C3, in this case though lacking any information about milk run movements.

In the following the body shop environment will be briefly described, having some communalities and differences compared with the Clean Room 1 environment. The semi-finished products in a body shop environment are represented by laminates, that will be bonded together by using bonding jigs and inserts in order to create finished assemblies.

1. *Laminates*. Laminates may be MAKE or BUY materials and depending on the case a different traceability is ensured. MAKE laminates have been produced in clean rooms and extracted in the moulds' extraction room, from which they are usually picked and stored in a vertical store in the body shop itself. Internally made laminates are labelled with the drawing identification code and the serial number of the part, with in addition a QR code reporting that information in order to speed-up the picking/putting away process from/in a vertical store by using a PDA. Depending on the availability of the laminates from the upstream processes, if the part is to be used just in time, it is possible to find them in specific racks in the upstream job shops instead of in the vertical stores in the body shop: in peak production periods, for example, it is often the case that a laminate is extracted in moulds extraction room and placed there on a rack labelled with its product family name just in time for bonding in the body shop. In those cases the operators of body shop, not finding the part in the vertical stores after having searched with the PDA on GG2, are used to go directly to the extraction room to pick the required laminate. This is a particular yet common case because the part is not traced in the WMS, not being stored in a warehouse: in the AS IS situation the problem is solved by physically checking the availability of the product in the moulds extraction rooms or by asking the extraction room supervisors.

   Another particular case that has to be taken into account and represents a lack of traceability is the case in which a BUY laminate has been received to the receiving area of the composites plant from which it is routed to the body shop directly: in this case the laminates are used just in time for manufacturing and they are not stored in the warehouses, being instead temporarily stored in a rack in body shop itself. This is again a particular yet common case of lack of traceability, because the parts are not stored in a warehouse and thus they are not registered on the WMS software GG2: the receipt of the goods is registered on the ERP LN, from which the MES C3 and the order status software LEGO collects the information to notify that the ordered BUY laminate has been received, but as soon as the material is taken from the receiving area to the body shop rack the traceability is lost because this latter movement with the new material location is not traced in any software.

2. *Bonding jigs*. As for laminates, bonding jigs may be MAKE or BUY products according to available internal capacity. Both MAKE and BUY products must undergo an internal quality check in the composites plant: what sometimes happens is that the jigs are manufactured/received and quality checked just in time for the following bonding phase, so that they are not placed in a vertical store and thus traced with GG2 but they are kept in a quality department rack waiting for picking by the body shop operators.

   In this case there is a lack of traceability because the information about the location of the jigs is not registered on the WMS software. The operators deal with this issue by physically checking the presence of jigs in the quality check area or by phone calling the responsible, thus in an "offline" way.

3. *Inserts*. Any material ending up in the final bonded assembly produced in body shop and different from a laminate may be defined as an insert: they are usually MAKE items such as rohacell fillers or carbon stockblocks, or BUY items such as metallic inserts, being them bolts, nuts, bushings or built-to-order structural parts. According to their sourcing strategy, those parts undergo different processes until their use for manufacturing and so do their traceability.
   MAKE items are usually completely traceable through their whole production process. Being internally made, they are labelled with the identifying QR code as printed from their associated production order created on the MES software C3: after the production they are taken directly to the vertical stores of the body shop and placed on trays according to the family of the assembly they end up in. Every time an item is placed in a vertical store the movement is registered on GG2 by scanning the associated QR code. Interviewing the operators of the body shop associated to those material flows it has been highlighted that such MAKE inserts do not, usually, represent a problem in terms of traceability.
   A more complex situation is that related to the BUY inserts, mostly metallic parts purchased from external suppliers. For those items it has been verified to be particularly critical the traceability in case they are provided JIT for manufacturing in body shop from the goods receiving area, as found for laminates: the traceability of inserts, indeed, is ensured as long as they are received at the composites plant's receiving area. The moment they are picked and taken to the body shop for immediate use in the bonding phase, their movement is not traced on any software, thus inducing a lack of traceability.

Particularly in peak production periods the goods receiving area and the body shop are filled with a great amount of material that, often, must be used JIT for manufacturing: it is in this context that the lack of traceability just described has proven to be potentially extremely impacting on the search of an item, given that its internal movement is not traced and the information about its new location can just be retrieved by asking the logistic operators involved in its handling.

Another case of reduced traceability which was reported during the analysis and peculiar to the BUY inserts is that related to those items having small dimensions. Following an internal guideline, small dimension inserts are delivered by suppliers in plastic bags labelled with the associated drawing identification code and progressive number. Those bags are stored in the vertical stores and registered on GG2 as if they were physical parts. Following from this fact the traceability of the insert is linked to that of the plastic bag in which it is contained: the moment in which an item is picked from the bag the action is registered on GG2, but if for any reason the item is not used immediately and is lost trace of it in the work area, it is very hard to rebuild its traceability in terms of related identification code, being it an insert without a drawing code printed on.

As pointed out in the previous overview about traceability in the current clean room and body shop environments, most of the steps are traced but still several cases are experienced in which not enough information are provided by the available software about the traceability of a searched item. Those missing traceability steps have been taken into account in the design of the kit preparation process considering them, where possible, as potential situations to be solved with a new logistic process. When not possible, instead, they have been considered as constraints and exceptions with which the kit preparation process will have to deal, thus incorporating them in the standard designed workflow leading to a kit creation.

4.3 Analysis of the AS IS process

The first step in developing the kit preparation process introduction was performing an analysis of the AS IS situation with the aim of understanding the flows of materials, the flows of information, the software used, the stakeholders of the different processes and the criticalities of the current situation beside those already introduced in the previous section. The target of the analysis was first of all to come up with a flowchart of the logistics and information flows of the AS IS situation in clean room 1 and body shop, then the information collected in these flowcharts were used as a basis for the design of the kit preparation process, ending up in two “TO BE situation” flowcharts related to clean room 1 and body shop. These latter, then, served as a basis for the creation of a specification for software development and integration, necessary for the full implementation of kitting and to solve many of the issues found in the current processes. Finally, the actual implementation of kitting took place, again using as a frame of reference the to be flowcharts developed during the preliminary analysis.

The analysis that led to the flowcharts has been conducted by interviewing the stakeholders of the production and logistics processes related to clean room 1 and body shop. The following roles have been interviewed:

- Head of Lean
- Software development responsible
- Responsible of clean room 1
- Floor managers of clean room 1
- Operators responsible for autoclaves loading/unloading and operations
- Floor manager of moulds extraction and preparation shop
- Operators of clean room 1 and body shop, particularly those responsible for warehousing activities
- Responsible of body shop
- Floor managers of body shop
- Product family responsibles

The interviews were carried out during a one-month timespan and through several refinement steps, it was a cooperative work constantly updated and shared with all the previously introduced stakeholders. The interviews were focused on the description of the process in which every stakeholder was involved, the type of information used, the sources of these information, the destination of the information, the software used, the criticalities found in the process and the ideas for their solution.

The flowcharts resulting from those interviews are reported in the annex and will be described in details in the following.

4.3.1 Clean Room 1: information flows

As a starting point for the description of the flowcharts the information flows are presented and analysed. This follows from the fact that the flowcharts have been realized with a kit preparation introduction point of view, i.e. with a focus on the operators' activity: rather than focusing on the mapping of material and logistics flows alone we decided to start with what kind of information an operator needs, from which software/document he/she takes that information and what action is performed once that information has been collected. Finally, we analysed what information is generated following that specific action performed and in which document/software it is registered and stored. This introduction is fundamental to clarify the logic underlying the mapping performed, which is targeted to highlight the criticalities of the current processes, the ideas for their resolution and the types and sources of information already available that can be used to design an effective kit preparation process.

The core of the information flows of clean room 1 is represented by the MES software Cost Control Composite (C3), an in-house developed suite for management and costing of manufacturing activities in composites plant. C3 allows to create a production order (OdP, i.e. "Ordine di Produzione") to start the manufacturing activity of any part: by creating an OdP a new entity is generated in C3, in which all the information related to the production of that specific item are registered and can be retrieved at any time just by typing the drawing code. The main information collected in an OdP entity are:

- Drawing identification code and serial number of the part in production
- Internal shop destination of the finished part
- Value-based bill of material (Distinta C3) for the part in production: this BOM (Bill Of Materials) does not contain all the necessary parts to manufacture an item but only the most valuable ones. Commercial codes, for example, are usually excluded.
  In this section of the MES software is possible, in particular, to associate children orders to the related parent ones' to maintain a full traceability of the association between each part and the component/assembly in which it ends up after the manufacturing cycle. It is, for example, the case of inserts used in the lamination of an item: they are associated to the parent-OdP in the Distinta C3, in order to register on the MES software that the specific insert is now associated to that laminate and thus its traceability is associated to the one of the parent item.
- Manufacturing cycle
- Tracing of the manufacturing steps according to the categories completed/WIP/to be started and related cycle time, as manually typed in by the operators when closing a phase. This information is collected in a subsection of the OdP called C3 tracer, whose role in the kit preparation process design will be described in the following information flows analysis sections.

In such a way C3 allows to keep trace of every production order and, moreover, on the same platform it is possible to keep trace of the status of every BUY item in terms of received/not received yet at composites plant and, in this latter case, the system collects information from the ERP LN giving as a result an expected delivery date. Overall C3 is the core software used in the composites plant to manage daily work and manufacturing: as can be seen in the flowchart all the information flows are connected to C3 in a direct or indirect way.

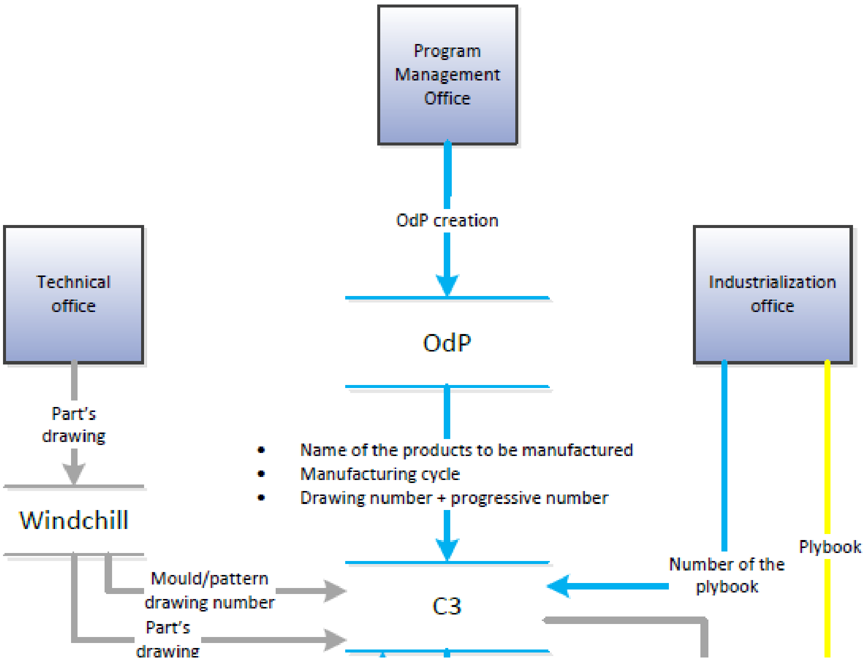


Figure 14- Focus on the OdP information content

By using C3 every evening after the daily shift a "Programma di lavoro" is generated: this is a document in which every clean room 1 operator is associated to a variable number of items to be manufactured the working day after. The parts number to be produced in a specific day are selected from a list according to the planning department output, establishing an expected delivery date for any finished product and, from that, a lamination date. The association between parts number and operators is performed by the floor managers of clean room 1, in a way such that the full shift duration for every operator is saturated and the production targets are met, according also to the experience of the operators and the complexity of the parts associated to each. The daily plan contains the following information:

- Name of the operator
- Drawing identification number and progressive number of the product to be manufactured
- Description of the product to be manufactured
- Manufacturing step scheduled for completion in the day
- Number of the Plybook (i.e. of the part's technological drawing)
- Location of the carbon plies kit (box in the clean room 1 freezer)
- Drawing identification number of the mould/pattern assembly related to the product to be manufactured
- Location of the mould/pattern (vertical store and tray)

The daily plan configured in such a way is printed and put on a board in order to be visible to the operators at the beginning of the shift the day after. The information flows to the operators

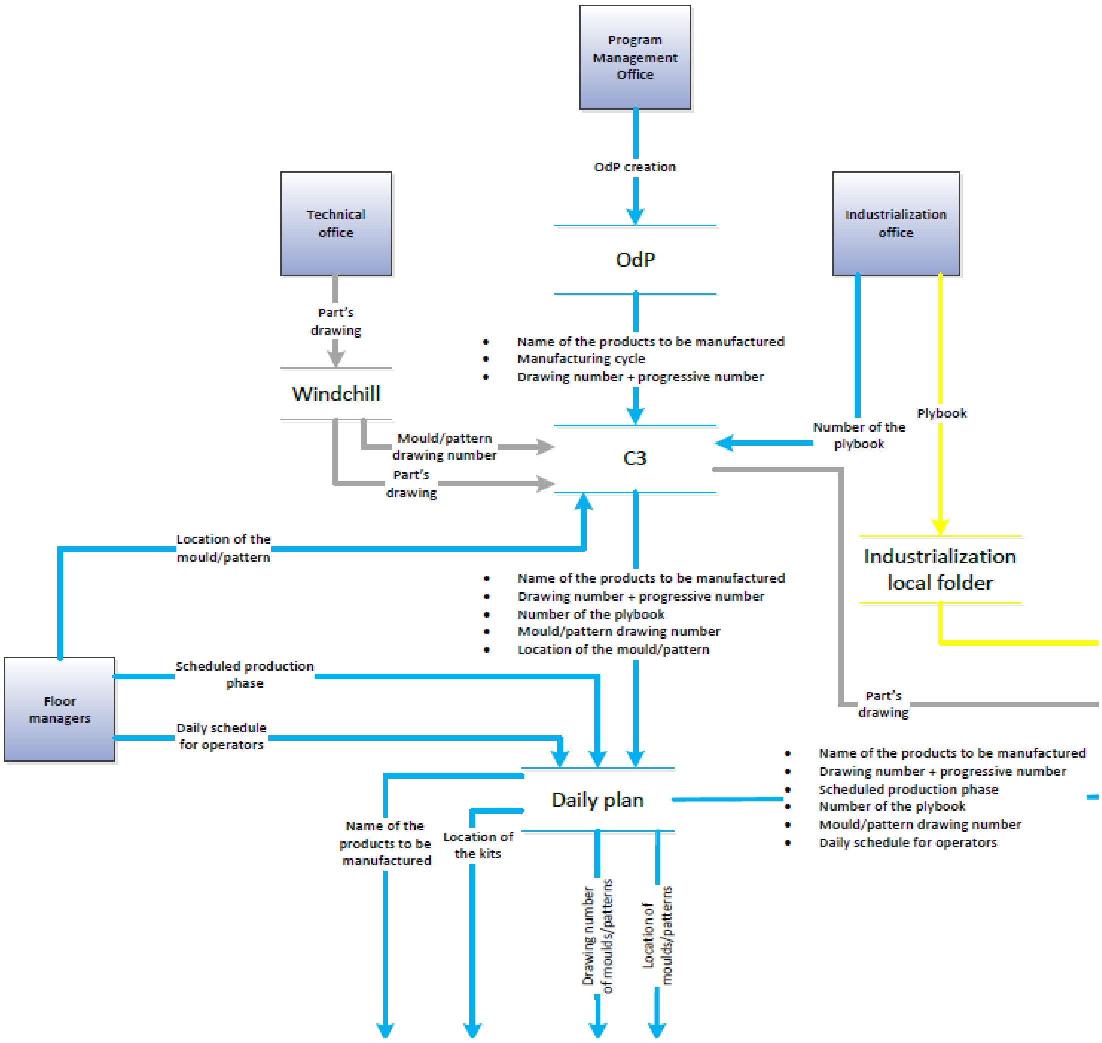


Figure 15- Overview of the information flows converging into the Daily plan

basically stems from this printed daily plan, because all the floor staff collect most of the information about the materials needed for production right from this document, although in different moments as will be detailed below.

Once the daily plan has been fixed on C3 and exported in an Excel format, the floor managers in charge of planning extracts the complete list of moulds/patterns and of ply kits to be picked by operators for the day after. This is a simplified picking list containing basic information as extracted from the "Programma di lavoro":

- Drawing code of the mould/pattern assemblies
- Location of the moulds/patterns (vertical stores and trays)
- Number of the carbon plies' kits
- Location of the kits (boxes in the clean room 1 freezer)

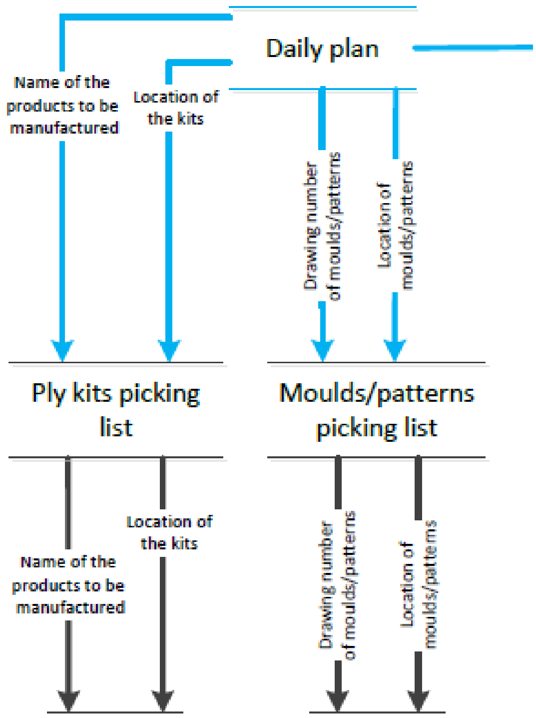


Figure 16- Focus on the currently available picking lists

The use of this document by the floor staff will be described in the next section dedicated to the material flows analysis.

The information about the parts scheduled for manufacturing in the daily plan is also delivered to the utility called "Clean Room Desktop" (CR Desktop), a software that collects information related to the items associated to each operator. CR Desktop is installed in the PCs present in every workstation: by logging in with its credentials, each operator can access information useful for its daily work, in particular:

- Parts assigned for manufacturing (information from "Programma di lavoro" realized in C3)
- PDF plybooks of the assigned parts (collected from a local folder in which the original drawings from the designers are noted and added with information specifically related to manufacturing issues).
- 3D geometry of the parts to be manufactured (collected from Windchill, see below for further details)

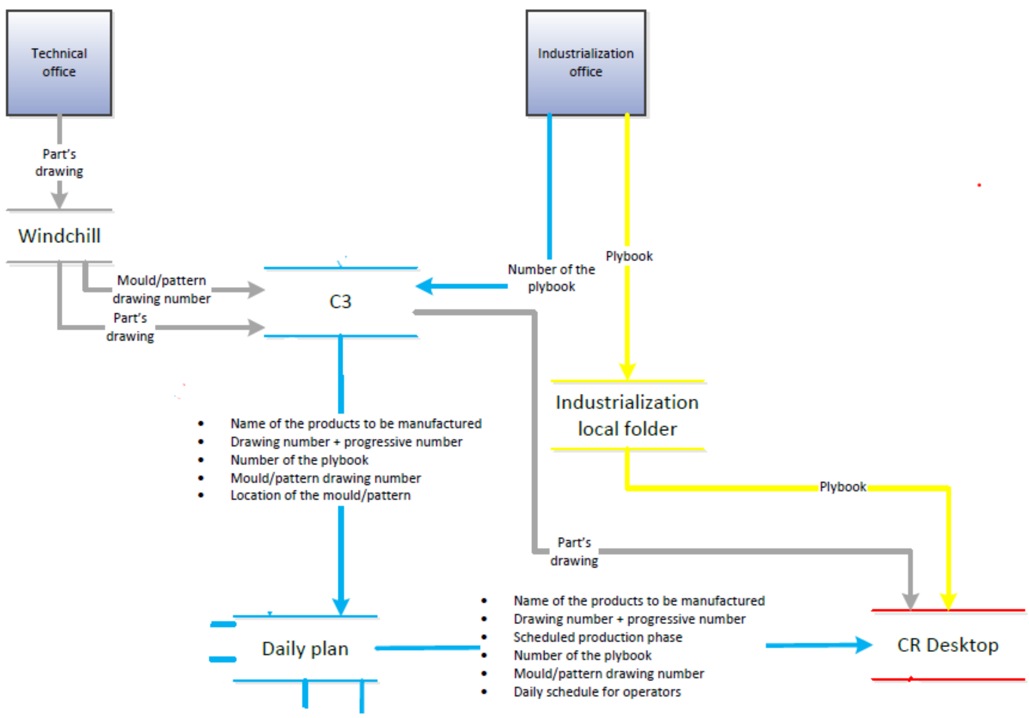


Figure 17- Overview of the information converging into Clean Room desktop

Windchill is a PLM software internally used, among other features, for storing and managing modifications and variants of technical drawings and CAD geometries of all the parts making up the cars. CR Desktop, as well as C3 itself, has a direct link with Windchill from which the operator can access the 2D and 3D CAD drawings as emitted by the technical office.

The technological drawings mentioned above, instead, are created from the drawings emitted by the technical office and accessed via Windchill, then modified by the internal industrialization office of the composites plant. Those drawings are then stored in a local shared folder that can be accessed by the operator via CR Desktop.

Another important storage of data used in clean room 1 environment is the aforementioned WMS software Gestione giacenze 2.0. Every time an item deposited in a vertical store is picked from it or put in it, the operators are trained to register the action on GG2 by using a PDA. Besides going into the description of the features of GG2, already described above, in terms of flows of information it is meaningful to mention that the information about the quantity available and the location in a vertical store of an item with the related tray can be accessed also from C3 via a direct link. Starting from an OdP or an element of the "Distinta C3" it is possible to access immediately to the related page on GG2 and the information provided by the WMS.

With the same link it is also possible to verify whether a BUY code has been ordered and it is expected to be delivered to the company by a supplier. In the AS IS situation this tool, however, is rarely used because it requires to open one by one the items entities in order to verify their availability and location: it is impossible to extract a list of all the materials required with their relative location in a fast way, so that it is a step generally avoided. The way in which an item stored in a vertical store is located features the use of the PDAs, connected again to the WMS GG2: the operators manually type in one by one the code of the items needed and they get as an output store, tray and available quantity of the required part, provided that it is available in stock and that it has been correctly registered when previously put in storage.

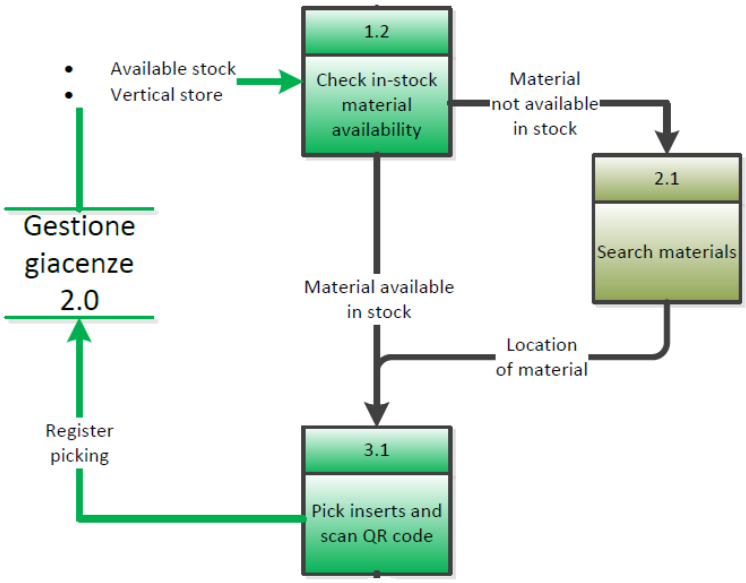


Figure 18- Focus on the information flows of the WMS Gestione Giacenze2.0

4.3.2 Clean Room 1: material flows

Once a brief overview of the main information sources and collectors have been introduced, in the following section the material flow analysis will be developed, focusing again on the operators' activity: it will be introduced the input information they use, the material they pick or the action they perform and, finally, the output information they produce.

As reported in the flowchart the materials used in clean room 1 have been identified and collected in three main clusters: pre-preg ply kits, moulds/patterns and inserts, whose flows were analysed separately.

- Pre-preg ply kits

The carbon fabric plies are cut into shape in the cutting room, then bagged and stored in the cutting room itself or clean room freezer, according to space availability: the standard situation is the one in which the bagged ply kits are stored directly in the freezer of clean room 1 in separate boxes. As soon as the daily plan is ready the floor manager extracts the list of necessary kits for the day after, as described in the previous section. This picking list is then delivered to the autoclave operator who, usually during downtimes from his/her late shift, reads the number of kit to be picked together with its box location in the freezer of clean room 1 and perform the picking operation. The kits, once extracted from the freezer, are then placed on a moving table in the clean room in one or more boxes, ready to be picked by the manufacturing floor staff the working day after. An important point to remark is that currently there isn't any option for registering the picking of the ply kits from the freezer: once they are extracted the traceability is lost because the only information available on a software is related to the original location in the freezer for the kits. It means that the picking of the kits is not traced, and any movement upstream or downstream the freezer of clean room 1 of the kits is not managed as a regular material by the WMS, giving as a result a lack of traceability that sometimes -though rarely- has ended up in loss of kits.

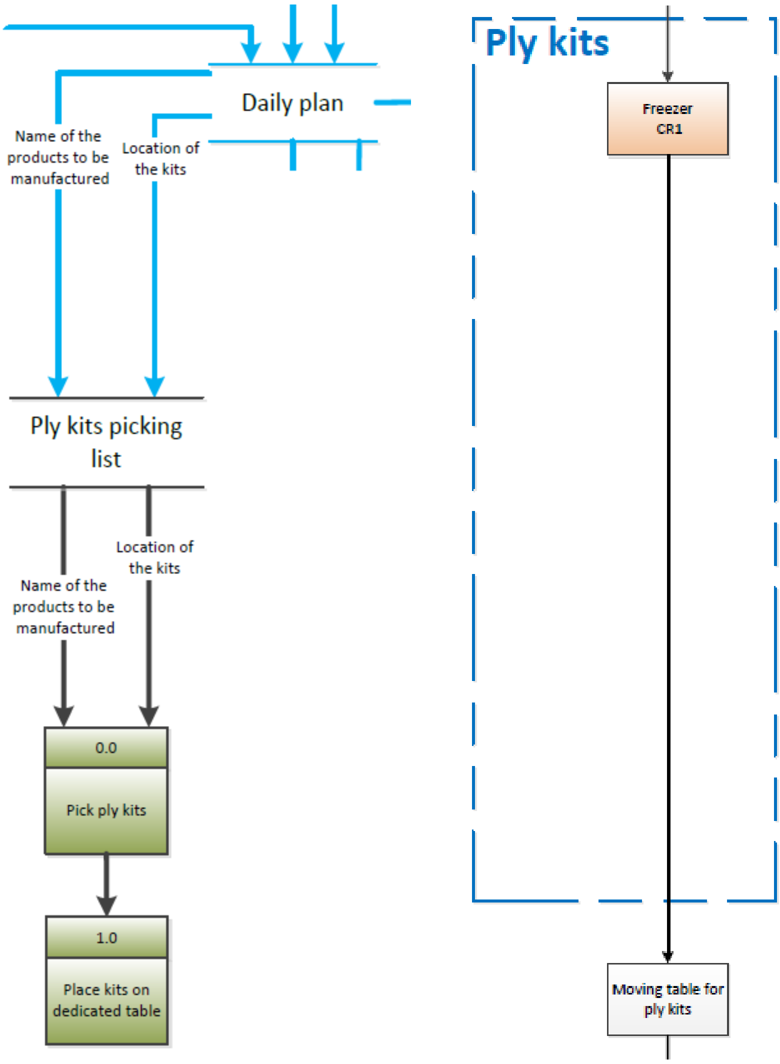


Figure 19- Focus on the flows associated to ply kits

- Moulds/patterns

Similarly to the carbon ply kits, the moulds/patterns are picked by the autoclave operator in his/her downtimes, again obtaining the information about the items to be picked and their location from the rough picking list extracted by the floor manager of clean room 1 from the daily plan. Moulds and patterns are then placed on a dedicated rack in clean room, ready to be picked by the operators the working day after at the beginning of the shift. It is worth noticing that the information about the location of moulds and patterns, as said in the previous sections, is stored in the MES software C3, and not in GG2 as for the regular items: this information is manually introduced in C3 once the moulds/patterns have been manufactured and stored in a warehouse, but in the frequent case of moulds/patterns available just in time for the subsequent lamination the location is missing, because the items are directly picked from the upstream shops and routed to clean room. This fact introduces a lack of information and traceability for some products in a certain stage of their life cycle: autoclave and clean room operators are trained to look for the missing moulds/patterns by directly asking or visiting the upstream departments involved in their manufacturing cycle, but this information is not stored in any software/database.

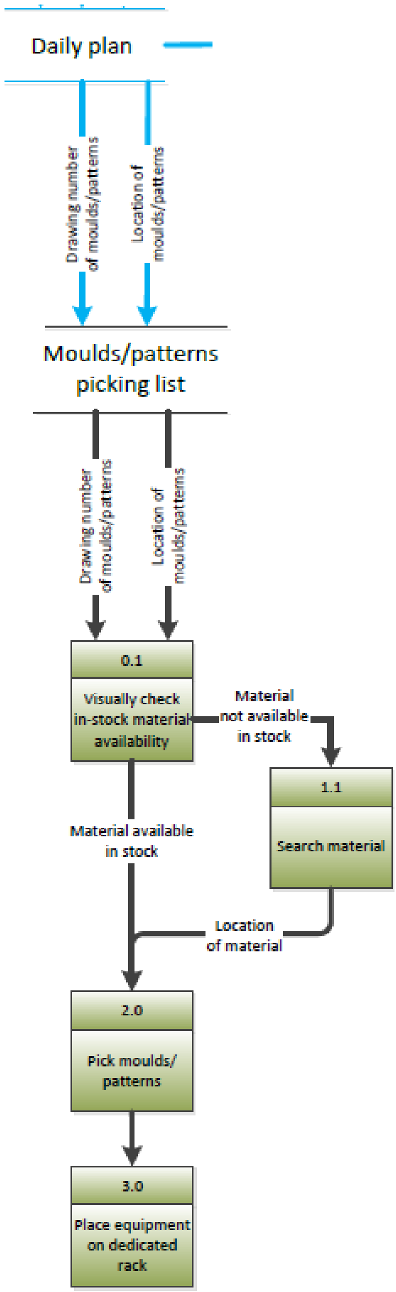


Figure 20- Overview of the flows and processes associated to the equipment picking

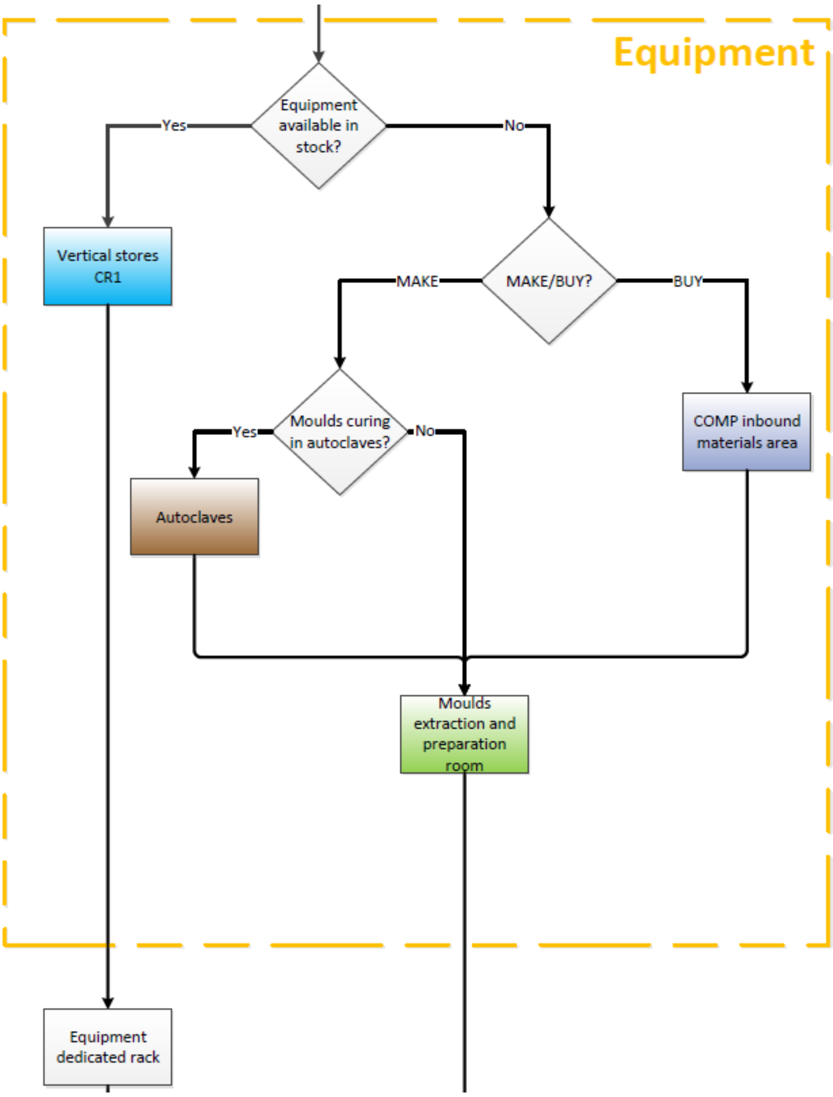


Figure 21- Material flows associated with the equipment

- Inserts picking and floor staff’s activity

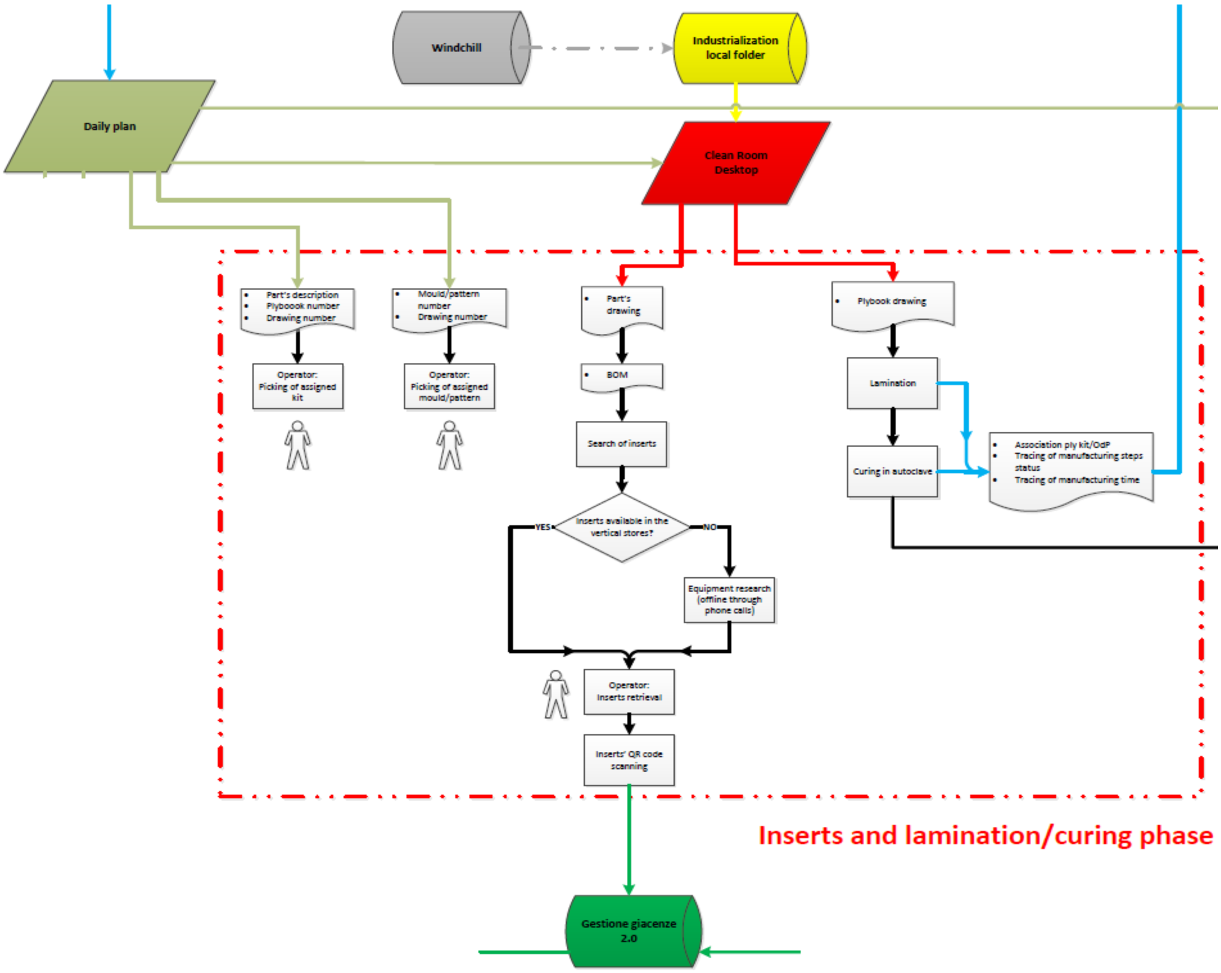


Figure 22- Overview of the processes associated with inserts picking and manufacturing phase

Once the ply kits and moulds/patterns are placed in their dedicated location in clean room by the autoclave operators, those items are picked up by floor staff at the beginning of the shift the following working day, as soon as they get in clean room. The input information they use to understand which ply kits and moulds/patterns to pick is retrieved from the daily plan, displayed nearby the kits’ table and moulds’/patterns’ rack. By reading the drawing code or description of the item associated to his/her name in the daily plan, the operator is able to find the assigned ply kit among the ones picked from the freezer. Same holds for the moulds/patterns: the input information used, i.e. mould/pattern drawing code or part drawing code, is retrieved from the daily plan and used to select the assigned moulds/patterns. In peak production periods, in which a large amount of material has been picked and prepared for the operators to ease their retrieval of the items necessary for manufacturing, finding the assigned ply kits and moulds/patterns may require some time: indeed collecting all the materials in the same place forces the operators in searching the assigned items among the many others, thus slowing down the operation.

Once the operator has picked the materials he/she is able to choose any available workstation in clean room, logging in the CR Desktop software, where the assigned daily plan is displayed together with the previously described information about the products to be manufactured. From CR Desktop the PDF technological drawing of the part is opened and the complete BOM is obtained: the codes associated to the inserts to be picked are noted and the operators walk to the vertical stores area to find the required items.

Operators search the location of the inserts by using a PDA with the WMS software GG2 installed, by manually typing the codes associated to the required items, one by one. As an output they get the information about the warehouse and the tray in which they can find the inserts. They are then picked, registering the performed activity on GG2 by scanning the associated QR codes. Apart from the standard situation in which the material is already present in the vertical stores serving clean room 1, it sometimes happens that inserts are missing: the out of stock is usually exposed just in the instant in which the operator types the code of the required insert in the PDA, obtaining as a result a zero stock.

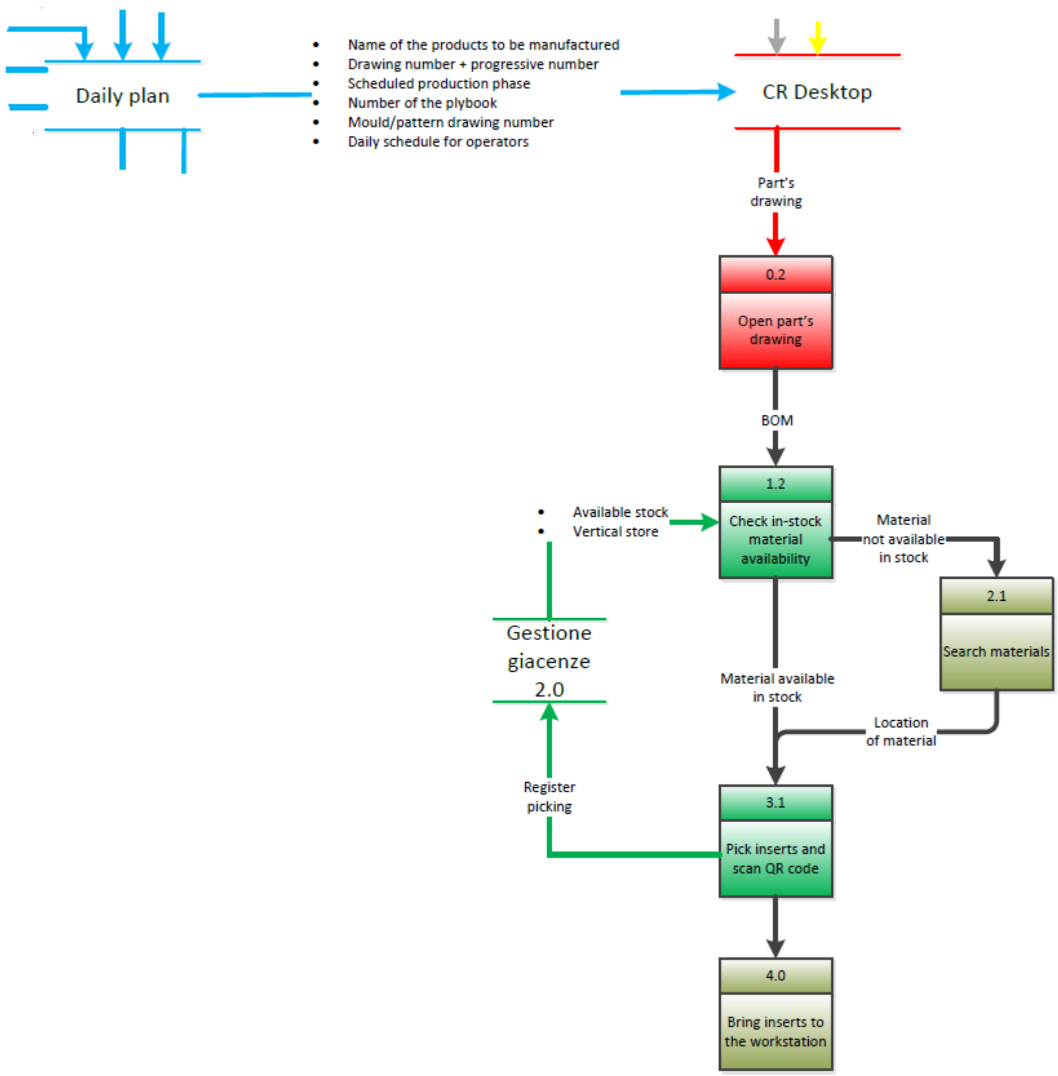


Figure 23- Focus of the information and processes associated with inserts picking

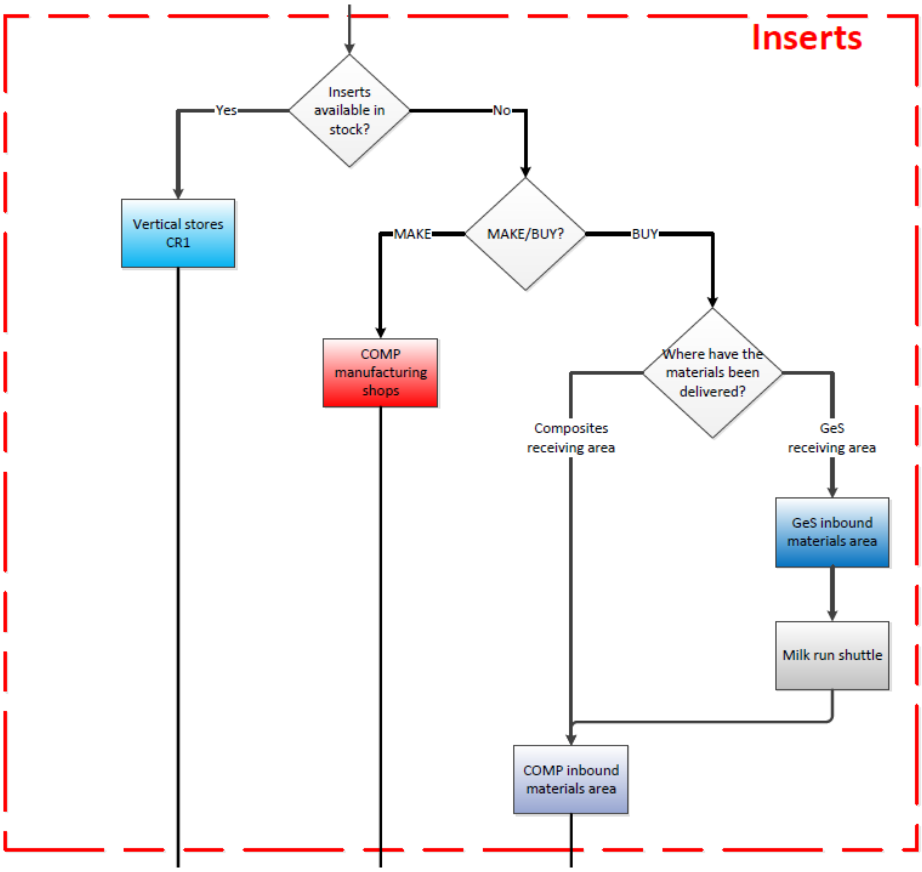


Figure 24- Overview of the material flows associated with the inserts

Cases like this, in the current situation, are managed mainly by the floor managers who respond to the out of stock by querying the available software (C3, GG2, LEGO) to verify whether the item is MAKE or BUY and its possible location or, more often, by phone calling the responsible of the departments that may be involved with the missing insert. Finding a missing insert may take up to several hours, especially in the case of BUY inserts not yet received by suppliers: the floor managers have to spend time to trace the missing items and the operator has to wait for the completion of the manufacturing of the assigned part, so that overall cases like this are reported as the most critical situations to be dealt with and possibly to be solved with a kit preparation process, as will be described later on in the TO BE situation analysis.

Once all the necessary materials have been collected the manufacturing operations are performed and the vacuum-packed part is stored in clean room until it is collected and cured in autoclaves. After the curing cycle, the parts are extracted from the moulds/patterns in the extraction room and, from there, routed to the departments involved in the following manufacturing steps. From an information flow point of view, operators associate first the materials used for manufacturing to the parent-OdP in the “Distinta C3” section of the OdP itself, registering that from now on the carbon plies kit and the inserts used belong to the specific laminate assigned for production.

Every step in the manufacturing cycle, then, is registered on C3 tracer: starting from the different lamination phases performed in clean room 1 to the curing phase in autoclaves and the extraction from the moulds/patterns, all the phases are registered as done/WIP/not done yet and the lead time of every operation is manually typed by the employees, in order to keep trace of the manufacturing steps performed.

Figure 25- Focus on the material flows associated with the manufacturing phase

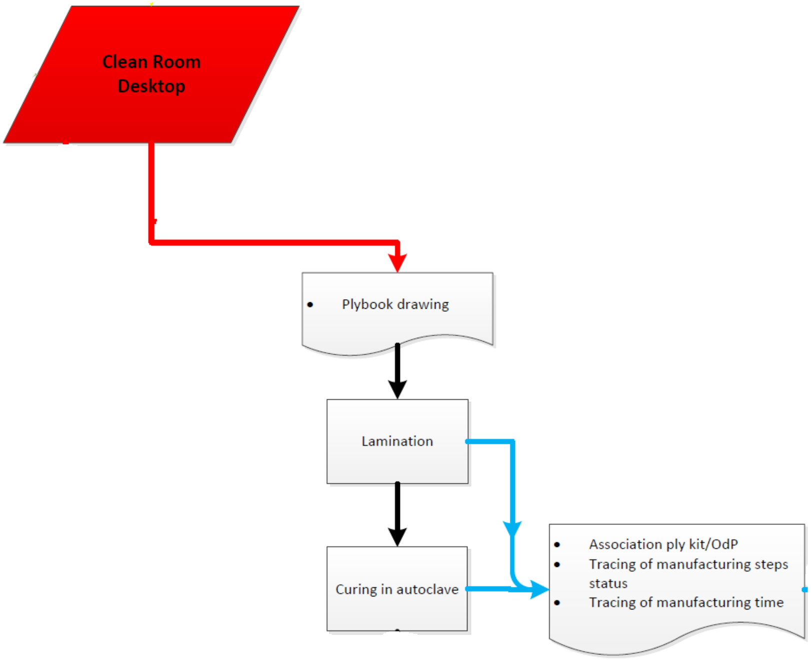


Figure 26- Focus on the information flows associated with the manufacturing phase

- Post-lamination material flows

As a conclusion for the analysis of materials flow related to clean room 1 a brief description of the post-lamination flow will be given, even though it takes place outside clean room 1. After the extraction of the cured parts in moulds extraction and preparation room, the moulds/patterns are usually prepared again for another manufacturing cycle and then, according to the daily plan, they can follow two paths.

If the mould/pattern has to be used again in the same day, the item is positioned in the rack of moulds extraction room, ready to be picked up again by an operator of clean room 1 and used for a new manufacturing cycle. On the contrary, if the mould/pattern has not to be used in the same day, it is stored back in the vertical stores, by previously scanning the associated QR code in order to register the action on GG2. It is worthwhile to mention that the first case represents a limited traceability because the movement from moulds extraction and preparation room to clean room for a new manufacturing cycle is not registered on any software: it follows from the daily plan and, as such, the information about the movement can be indirectly retrieved by reading that a laminate as been scheduled to be produced more than one time per day, but the information is not directly stated in any software. In the AS IS process usually floor managers or operators themselves manage to retrieve this information, if needed, by directly asking to the moulds extraction and preparation room manager.

Same process holds for the cured laminates, after the extraction from moulds/patterns they are routed according to two flows. If they need to be used immediately by the downstream departments, according to their respective daily plans, they are placed on a dedicated rack in the moulds extraction room associated to the name of a product family responsible: according to the type of item currently manufactured, the operators pick the required material from the rack in moulds extraction room, finding it by means of the association product family of the manufactured item-product family responsible, and employing it immediately for production. It is worth to mention that the downstream department usually served by laminates produced in clean room 1 is the body shop: given the mutual relationship, this is why the kit preparation process introduction has been developed as a first step for clean room 1 and body shop, among the other composites plant departments.

On the other hand, if the laminates extracted don't need to be used immediately for production, they are stored in the vertical stores by previously scanning their QR codes for registering the action and thus ensuring their full traceability on GG2.

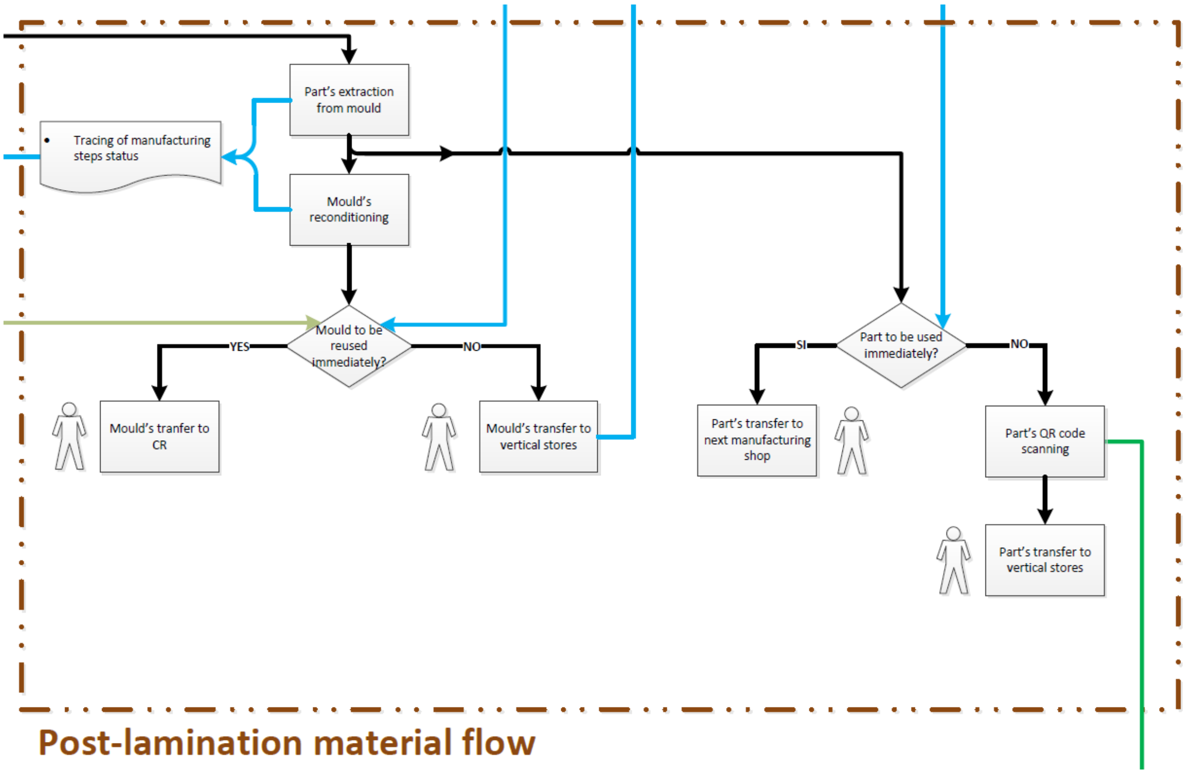


Figure 27- Overview of the information and processes associated with post-lamination phase

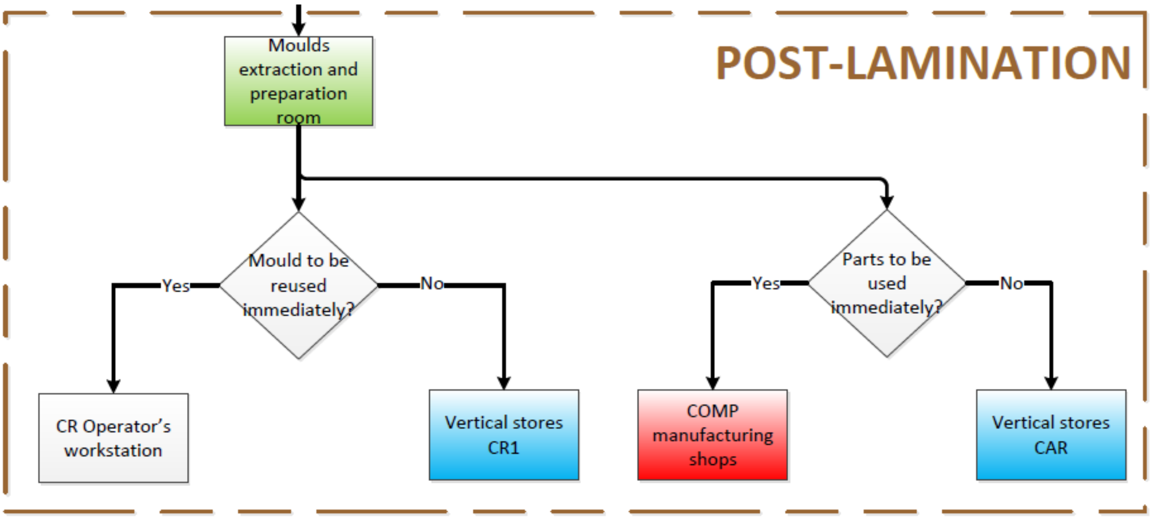


Figure 28- Overview of the material flows associated with post-lamination phase

4.3.3 Body shop: information flows

In the same way as made for clean room 1, a detailed analysis of the body shop's AS IS situation has been made as a first step for designing the kit preparation process. Both the analysis of information and material flows of clean room 1 and body shop have been conducted in parallel, given the final target of developing a unique tool suitable for both the production processes and environment. As it can be seen in the flowcharts reported in the annex, the analysis of body shop has been conducted with a deeper level of detail because of the peculiarities and difficulties proper of that environment. Many findings, though, have proven to be useful also in the investigation of clean room 1: besides the mutual differences in terms of process and issues experienced, then, it was possible to design a unique kit preparation solution able to fit both the environments.

The information flows of the body shop is very similar to the one of clean room 1, being based on the same software as sources and collectors of the information used in the daily manufacturing activities.

The MES C3 is again the core software used for generating and collecting information in the body shop as it was in clean room: an OdP must be created for the production of every part, in order to register the time spent in the manufacturing process and to ensure the traceability of the production steps. In the body shop environment, differently than for clean room, an OdP is created by the program management office or by the product family responsibles to keep trace of the manufacturing in the MES software, although not for the daily scheduling of the shop floor's activity.

Given the complexity and the variability of the production performed in the body shop, indeed, the daily program for the operators starts with a weekly schedule made by the product family responsibles about the items to be manufactured in a specific working week. This document is represented by an Excel file that, for a generic bonded assembly to be manufactured, contains the following amount of information:

- High-level description of the product to be manufactured in a specific day
- Name of the phase in the planned manufacturing cycle to be performed in a specific day, for production processes lasting more than one day
- Priority level associated to the scheduled manufacturing operation
- Name of the family product responsible associated to his/her respective item scheduled for production

This Excel planning is shared with the body shop floor managers, who use it as a basis for scheduling the daily activity of operators: according to the list of available floor staff for each day, floor managers associate every operator with a manufacturing step to be performed or with an assembly to be produced. The association is made directly on the original Excel spreadsheet as sent by the product family responsible.

The just described daily plan, being managed with an Excel format, allows for great flexibility in its modification and in the amount of information and level of detail to be written inside. As a drawback, it is entirely managed in an "offline" form, i.e. in a shared local folder, thus outside the traceability guaranteed by the use of C3 software: a fundamental step for the kit preparation process introduction, as will be described later in the TO BE information flow, is the making of the daily plan by using the dedicated tool of C3, as already done in the clean room environment.

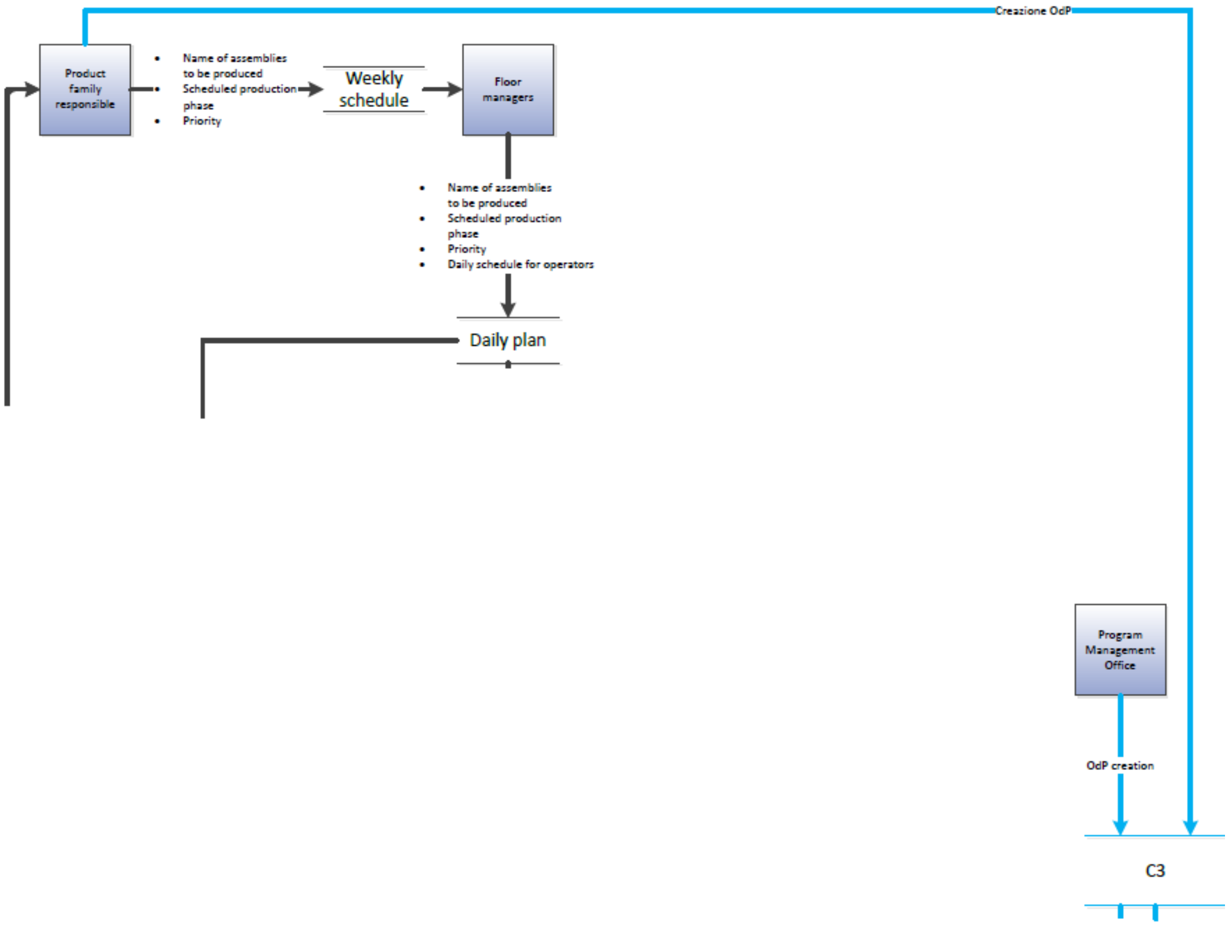


Figure 29- Focus on the information flows converging into the daily plan

Going further in the description of the information sources and flows of the body shop we find the different sections of the OdP entity created for every manufactured product in the MES software C3, which has the same structure of the OdP generated in clean room environment being them the same object in the software.

C3 Tracer, then, can be accessed to trace the position of an internally made item in the different steps of the manufacturing cycle.

CCQ light is an entirely different subsection of the C3 software and may be used, instead, to check whether an item is undergoing quality control in the central quality department (QC GeS): this is mainly the case of inserts purchased from external suppliers and CCQ light is a valuable instrument to check if the quality control has been already performed or not, being the checks an important bottleneck in the material supply process to the composites plant. It is worthwhile to note that any internal quality control performed in the composites plant itself is traced, instead, on the C3 Tracer section of the OdP entity, thus creating a double source of information for items that undergo quality checks: it may be a source of confusion but, usually, it is not a problem since standard checks are prescribed for different product families, so that inserts and selected laminates (for which the quality control is optionally required) are checked by the central quality department while the bonding jigs are internally checked at the composites plant (QC Composites).

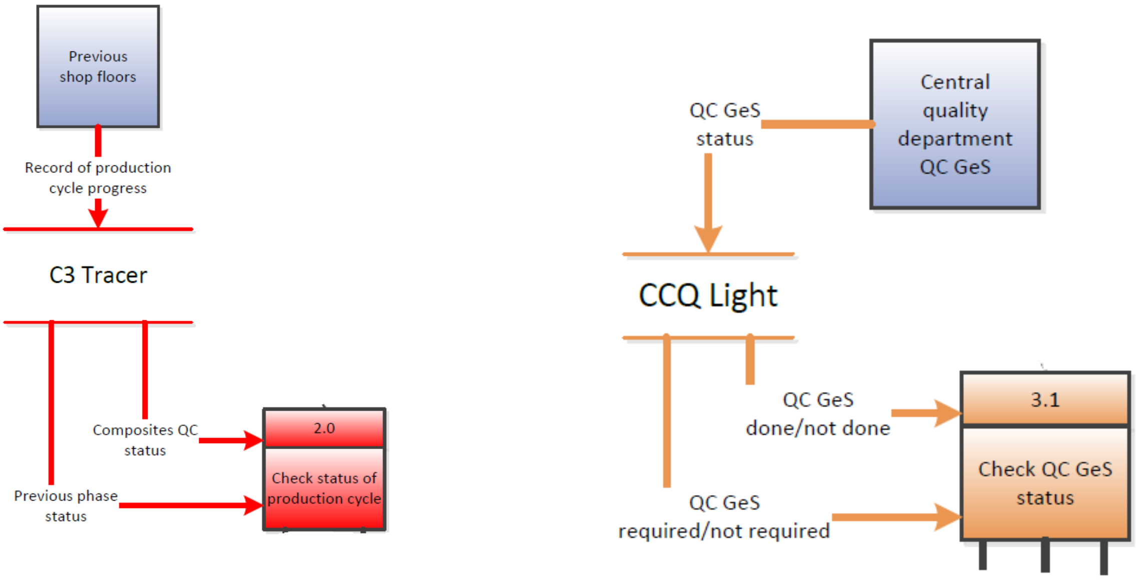


Figure 30- Focus on the information flows associated with the quality checks

Furthermore, all the BUY items are traced in the supply chain with the ERP software LN. In the composites plant environment, LN is used as a source of information for accessing the location of every item coming from a supplier with regard to its delivery status: if an item has been received at any incoming goods receiving area of Ferrari, the information is available and can be retrieved by the user from LN. A different case is that of receiving of the materials at the composites plant receiving area: since the composites plant's incoming goods department is not run 24/7, in those time spans in which it is not operative, the goods are delivered to the central receiving area in a different building of the company. Here the goods are received, registered on LN and stocked. Then, they will be delivered to composites plant with a milk run shuttle the following days according to capacity of the trucks and manufacturing requirements: the details of this shipping will be described later in the material flow analysis section, with regard to the related information flow it is meaningful to say that the receiving of the goods at the composites plant can be retrieved by the associated OdA (Ordine di Acquisto) status from C3 orders management section. Any item ordered by the composites plant and purchased from a supplier, indeed, is associated to an OdA reporting basic information about the materials procured:

- Drawing identification number
- Progressive number
- Quantity
- Price
- Date of the purchasing order
- Scheduled date of delivery from supplier
- Delivery status of the item

The last bullet point is expressing the receiving status at the location of the composites plant alone: i.e. whenever a purchased item is received from a supplier its delivery is registered on LN, but only when the good itself has been received at the composites plant's receiving area the associated OdA's status is turned to "Closed and accepted" to register on C3 that the material is available for manufacturing. It is this latter information that has proven to be useful for the floor managers and the product family responsibles to check the delivery status of a BUY item and its availability specifically at the composites plant, whereas the receiving of the material in the central incoming goods receiving area is verified on LN.

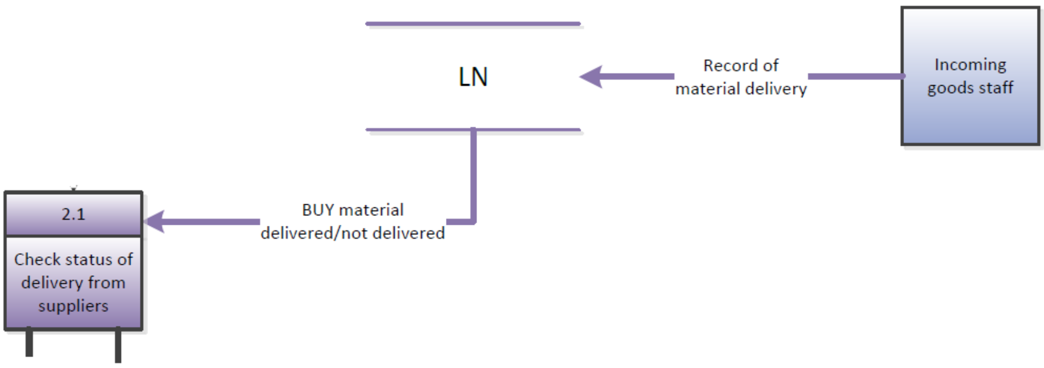


Figure 31- Focus on the information flows associated with the ERP LN

The OdP section "Distinta C3", furthermore, is used in body shop environment to link in a unique and unambiguous way items ending up in a bonded assembly: the section of the assembly production order is accessed and the OdP of the single laminates and inserts making up the assembly itself are manually associated to the former OdP. This operation registers on C3 that those single parts have been used to create a bonded assembly, and from now on their traceability is merged into the one of the related assembly, whom they belong. From an information point of view, the association is performed between the OdP or OdA of any item used and the OdP of the bonded assembly they end up in. The complete traceability across the manufacturing cycle given by this association performed on C3 is of paramount importance particularly for items ending up in races and track events, for which a 100% traceability is required.

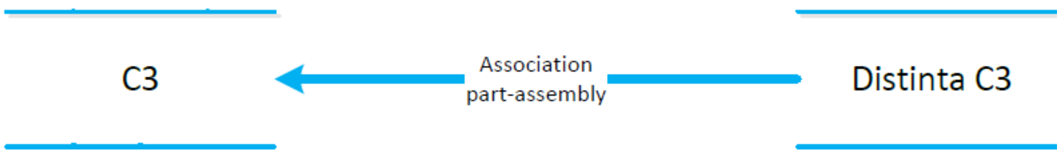


Figure 32- Focus on the information flows associated with traceability requirements for track-use assemblies

Going further in the analysis of the information flow, all the items stocked in the vertical stores are traced on the WMS software GG2 in the same way as done in Clean room 1 environment with regard to the type of the information available and the way of retrieving it: GG2 is mainly accessed with PDAs on the one hand to check the in-stock availability of the searched material in the required quantity and, on the other hand, to register any in/out movement of items from the warehouses in order to ensure their full traceability.

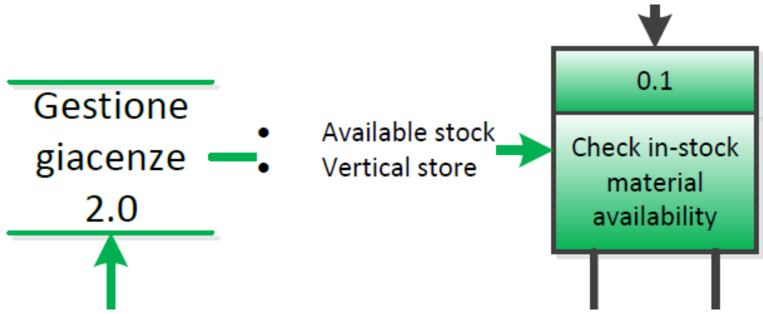


Figure 33- Focus on the information flows associated with the WMS Gestione Giacenze 2.0

Overall the information infrastructure of the body shop is the same as that of Clean room 1, being it common to all the composites plant in terms of software used and type of information available. What makes a meaningful difference between the two environment, though, is the use of that information to support the respective daily activities. Clean room, indeed, is much more focused on the manufacturing side of the information, using the available software to support the daily planning, register the time spent in the different manufacturing steps and trace materials picked from or placed in the warehouses. Those same activities are performed in body shop environment by using the same softwares and their subsections used in clean room (with the important exception of the planning, performed with Excel spreadsheets in body shop) but, in this case, the focus is put on the information about the traceability of the many items converging in body shop for the final assembly, being them internally made or purchased from suppliers. This fact is highlighted in the different level of detail and scope of the body shop flowchart compared to the clean room's one, where a particular focus has been put on rebuilding which information flow is used in the current situation to trace any item through its supply chain. The challenging task of the performed analysis has been that of designing a single tool able to fit the slightly yet important differences and requirements of the two manufacturing environments considered: as will be described in the TO BE sections of the thesis, the target was accomplished in terms of tool development, while the difficulties associated with the practical implementation of kit preparation process proved to be very different in the two considered cases.

4.3.4 Body shop: material flows

Once the Excel spreadsheet of the daily schedule for the body shop is available, according to plans and priorities a dedicated operator is in charge of materials picking from the vertical stores. The information about which items are needed is retrieved by reading the bill of materials from the printed drawings of the assemblies assigned for production that day, which are available in the shop floor: it is task of the product family responsibles to provide those drawings, downloading them from the PLM Windchill, and to keep them updated to the latest available version from the technical office. The location of the searched item, as previously described, is obtained by manually typing the associated drawing identification code on the PDAs connected to the WMS software GG2 or by operator's experience.

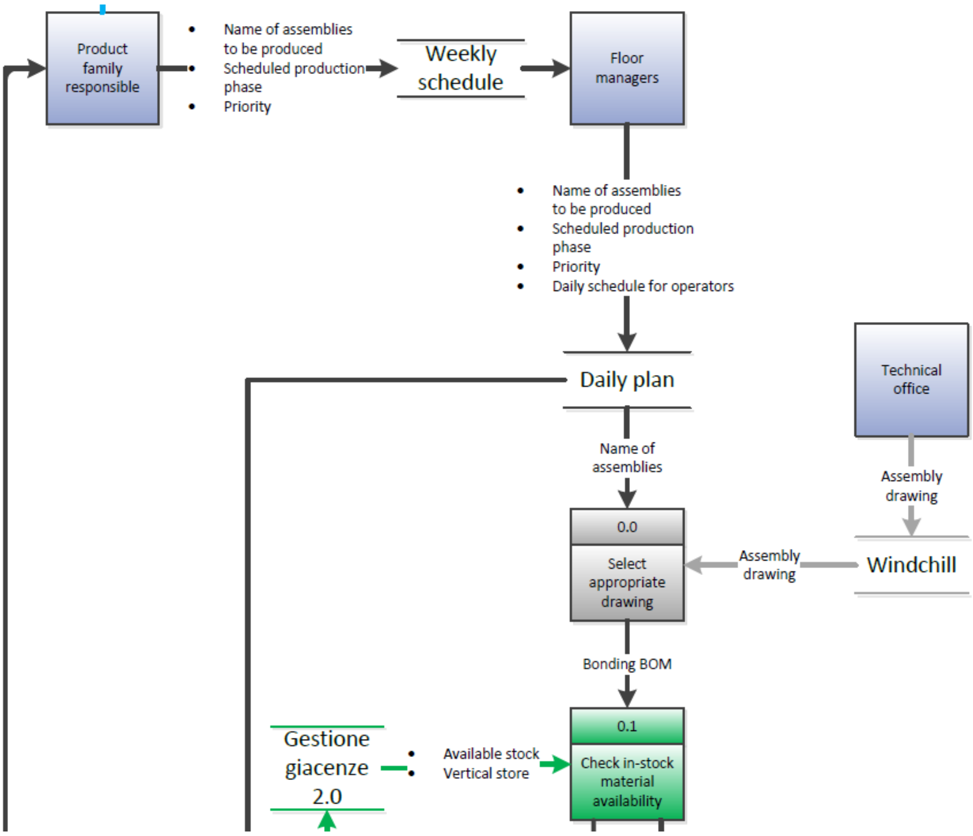


Figure 34- Overview of the information and processes associated with the search of materials

In the case in which all the searched materials are available in the required quantity in the body shop vertical stores, the dedicated operator simply picks them and hand them to the manufacturing floor staff directly at their workstations. The traceability of the item picked up from the warehouse is ensured by scanning the part's QR code with the PDA and registering the movement on GG2: note that this action is a standard procedure for any part and it is usually performed, but cases were reported of operators failing to register on GG2 the picking of material due to time constraints. In cases like this, in the worst case in which the item is forgotten to be registered even time after the picking has been performed, its traceability is ensured with the association by the manufacturing operator between the picked item and the bonded assembly in which it is used, performed in the previously described "Distinta C3" section of the associated OdP. Of course, missing to register the picking of any part from the vertical stores creates a misalignment between the actual stock available and the theoretical one: in the AS IS situation, though, such event has been reported has rarely happening and just in peak production periods. Moreover, usually the error in scanning operation is related to commercial codes of low economic value picked in large quantities such as bolts and nuts, so that it is generally a problem not deeply affecting operations in the body shop.

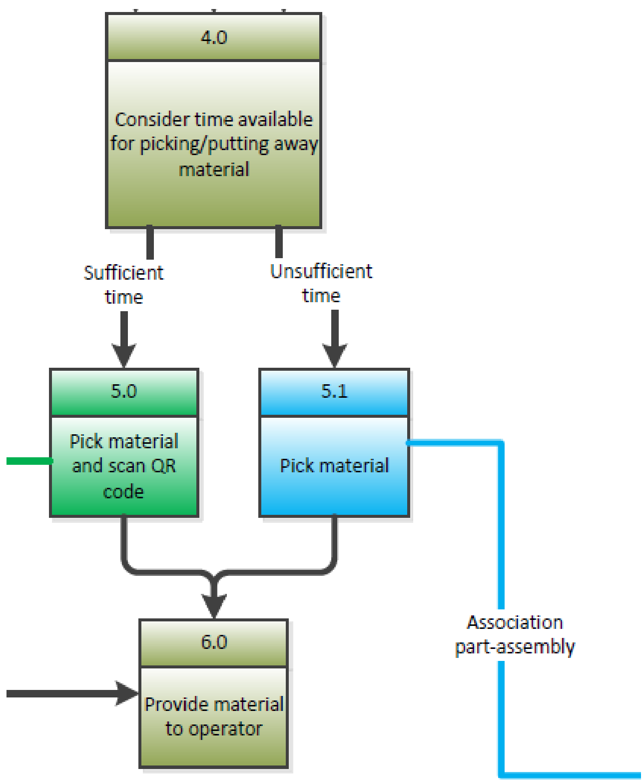


Figure 35- Focus on the information flows associated with the picking of materials

The worst case scenario in body shop environment is represented by the lack of in-stock availability of a searched item: it is not an unlikely case in this shop floor, given the high number of parts involved in its material flows coming both from upstream departments or external suppliers. According to the type of searched part, a distinction in terms of material and information flow can be done, as will be presented in the following analysis.

- Laminates

Simple laminates are the basis semi-finished products used in body shop to produce the bonded assemblies. Laminates may be MAKE or BUY items: the body shop is heavily relying on suppliers for its operation, with around 10000 items per year purchased, as opposed to the 16000 sourced from clean room 1. Given this fact, whenever a searched laminate is not available in stock in a vertical store the first software used to locate it across the supply chain is C3. By typing the associated drawing identification code is immediately possible to retrieve the item's OdP or OdA, giving as a result the information about the MAKE or BUY sourcing strategy of the part itself.

If the laminates are MAKE items, they must be located in the upstream departments responsible for their manufacturing. This task is performed by accessing the C3 Tracer section of the item's associated OdP and checking the last marked manufacturing steps: the information, provided that the previous production phases have been properly closed and registered, is used to understand whether an item is available for the current manufacturing step or not. In case of a positive answer the material can be picked from the upstream department, usually being it the moulds extraction and preparation room, and used for production in the body shop. If the parts are not yet available from the preceding manufacturing phase, instead, the performing of the operation is requested and set to high priority mostly in an “offline” way, i.e. by means of phone calls or direct speaking. Two cases may happen as an outcome of this situation. First, the upstream department is able to deliver the part in time for its subsequent bonding in the body shop: in this case the start of production in shop floor is delayed to later in the day, or started and progressed just up to the point in which the needed item must be used. Second, the release of the part by the upstream department is not possible in the current day: in such a case, the production of the bonded assembly in the body shop must be rescheduled to another day, according to the mutual available capacity of body shop and upstream department involved in the production of the missing items.

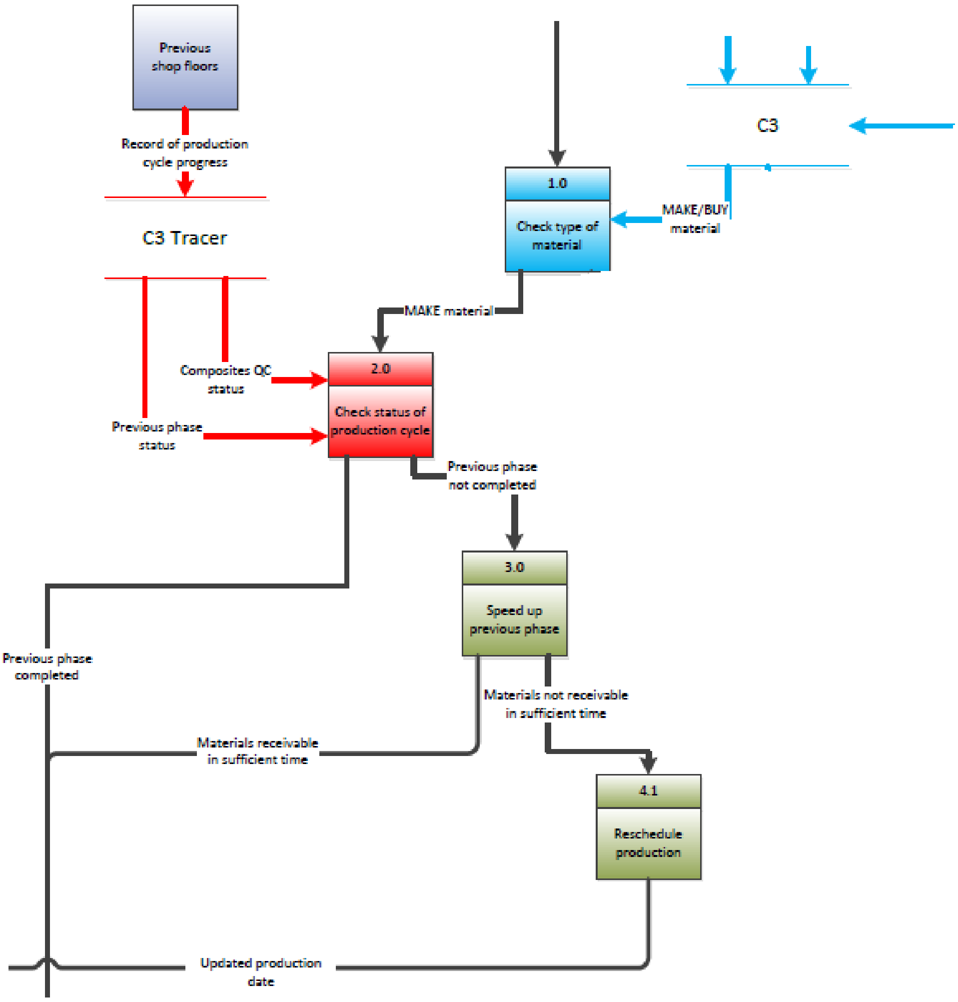


Figure 36- Overview of information and processes associated with the searching of MAKE items

It is worthwhile noticing that in cases like these, in which a searched product is not available in a vertical store and may be sourced from another department just in time for manufacturing in the body shop, a traceability issue arise: the direct passage from the upstream department to the operator’s workstation in the body shop, indeed, is not traced in any software and certainly not on the WMS software GG2. It would be useless, indeed, to register JIT received parts as stored in a warehouse and immediately picked from it for production. In a case like this, the part can be traced just by its later association with the related bonded assembly performed on the Distinta C3 section of the assembly's OdP: this traceability issue is linked to the very nature of body shop operations and will be addressed in the designed TO BE situation, described later in the thesis.

If the laminates are purchased from an external supplier, instead, the information and possible material flows, and thus the locating of the item in the supply chain, are much more complicated.

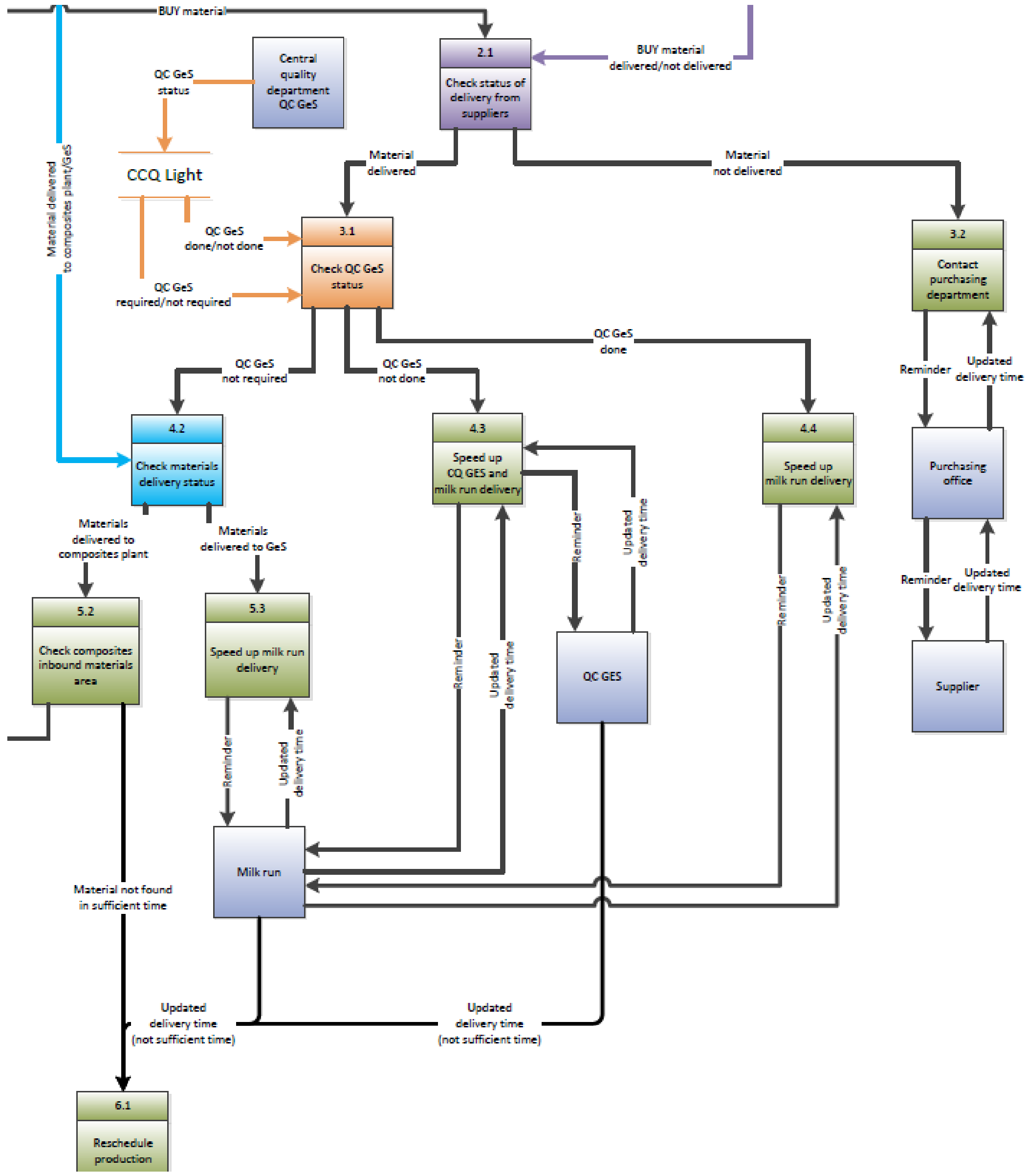


Figure 37- Overview of information and processes associated with the searching of BUY items

After having assessed that the item is "BUY" by checking C3 software, product families responsibles are used to retrieve from the ERP LN the information about whether the product has been received in one of Ferrari's receiving areas or not. If the delivery has not taken place yet, even though it was scheduled for that day or the previous ones, the standard procedure is to contact the purchasing office by phone calls or emails and let the buyers keep in touch with the suppliers, asking information about the production and delivery status. As a result of these calls, if the laminates can be delivered by the suppliers within a period consistent with the time requested for the bonding phase, the start of production is delayed to later in that same day. On the contrary, if the laminates cannot be delivered within the requested period, the production of the bonded assembly must be rescheduled to another day.

Given the nature of the built-to-order products manufactured in the composites plant environment, the late delivery of items from suppliers is rather a common case, since the purchasing order is delayed to the latest possible moment and so is the manufacturing as a consequence. This fact empowers a JIT delivery and sourcing of materials by the local supplier network, coming though with the drawback of an increased risk of delay in the delivery itself.

If the BUY item, on the contrary, is marked as already received on the LN software, further information must be retrieved to locate it. All the purchased materials, as described before, are delivered whether to the composites plant's receiving area or to the central warehouse's receiving area, and from there they are routed to the respective destinations. The receiving of materials in one of those two areas is a consequence of two main factors:

- *Composite plant's opening hours*. All parts ordered by composites department are delivered directly to its receiving area during the regular working day. Outside the business hours, tough, meaning late in the evening or at weekend, all the deliveries are routed to the central receiving area located in a different building: they will be temporarily stored there and sent by means of milk run shuttle to the composites plant the first working day available after the receiving. Please note that this receiving area is shared with other departments: the delivery of materials to the composites plant with the milk run may take some time as they can easily queue and wait for a certain amount of time before being taken over.
- *Quality checks*. Purchased items that, according to their type, are subjected to standard internal quality checks are received directly at the central receiving area, located in the same building of the quality department that will take over the materials' checks. Items undergoing quality controls will be stored temporarily in a dedicated store, then quality checked and, finally, delivered to the respective destination by means of milk run shuttles. This part of the material flow is particularly critical, especially in peak production period: the centralized quality department is responsible for quality checks of the great majority of materials used, so that it is usually a bottleneck in the sourcing phase of a part and may stretch the lead time of an item from its order to its reception in the production shop floor.

Based on these two cases, product family responsible aim as a first step to discriminate if a BUY item has been received at the composite plant's or at the central receiving area. They check first of all the software CCQ Light, managing the traceability of required quality controls in the central quality department: from the software, it is possible to verify whether quality audit has been requested for the selected laminate and whether it has already been performed or not. In case of positive answer, i.e. in presence of a laminate which have been checked by the quality department, it means that the item is waiting on a shelf dedicated to the already checked materials in the quality department itself, waiting for the delivery by means of milk run shuttles. In those cases, the milk run delivery to composites plant is urged by phone calls and, when applicable, a dedicated delivery is arranged to make the laminate available for production as soon as possible.

Whenever the quality check has been requested but not performed yet, instead, the AS IS procedure is that the product family responsible urge both the quality check and the milk run delivery to composite plants, setting them to high priority. Again, it is a procedure arranged mostly by phone calls, given the lack of a structured tool to manage such instances.

Once the materials have been loaded on a milk run shuttle, their effective delivery to the composites plant is checked by product family responsible by consulting the OdA status on C3 software: when a milk run delivery is received at the composites receiving area, indeed, the OdA associated to the purchased item is turned into “Received” to register on the software that the sourcing phase of that part number is closed, having it being received at its final destination, i.e. the composites plant. If the item has been received, given the urgency of the case, it is usually taken directly to the body shop for manufacturing. Cases were reported, though, of parts loaded on a milk run shuttle that were not received at the composites receiving area: when such a situation occurs it means that the parts were missed in the milk run trucks given the large amount of material that is possibly delivered in one milk run mission, so that the vans shuttle must be checked manually and a new delivery must be arranged. Other reported cases of items missed to be delivered to the body shop even though their delivery to the composite plant’s receiving area has been tracked on C3 are related to the loss of items in the receiving area itself: particularly in peak production periods, indeed, a lot of material is accumulated on the receiving area’s shelves, thus causing a loss of traceability of the received items subsequent to their OdA closing on C3. The result of this situation is that the receiving area must be checked manually to look for the missing part, stemming from the fact that there is not an internal WMS solution to manage the storage of material in the composites plant’s receiving area, being it just a transient solution prior to the loading of parts in their assigned vertical stores.

In the end of such an inquiry, performed by the product family responsible, the searched laminate may be found in time for bonding and thus taken immediately to the body shop, or too late for performing the manufacturing phase: in this case the whole bonding operation involving the missing laminate is rescheduled for another working day.

A simpler case is that in which the quality control by the central quality department is not required for the searched laminate. After having verified by accessing the CCQ Light software that the quality control has not being requested, it is checked the associated OdA status on C3 to assess whether the laminate has been received at composite’s receiving area or not. In case of a positive answer, it means that the material is most likely stored in the shelves of the receiving area, waiting to be taken to the respective vertical stores: the laminate, in this case, must be manually searched and taken to the body shop for manufacturing. On the contrary, if the status of the item as retrieved by C3 is not set as "Received", it means most likely that the material has been received in the central receiving area and it is temporarily stored there, waiting for the milk run shuttle. In such a case, the presence of the searched item is assessed and the milk run delivery is urged by phone calling the receiving area. Please note that every time a product is loaded in milk run for delivery, it is still possible to fall back in the previously described cases of items' traceability loss in the milk run shuttles or in the composite plant's receiving area, thus possibly requiring further manual searches.

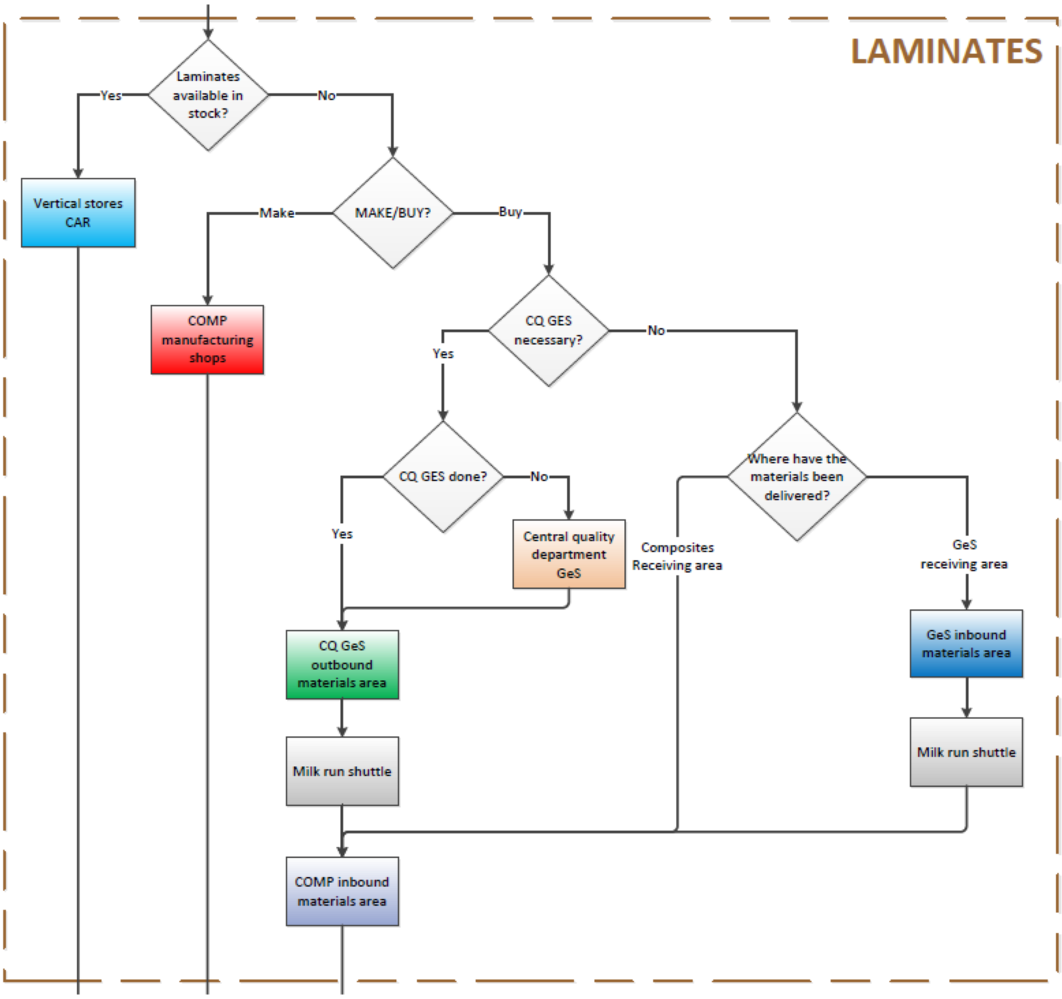


Figure 38- Overview of materials flows associated with laminates in the body shop

- Bonding jigs

Jigs and equipment are fundamental tools for the manufacturing of complex bonded assemblies as performed in the body shop. As for laminates, they can be internally made or purchased by external suppliers according to the available capacity. According to the weekly and daily schedules described in the information flow analysis, the assigned equipment is searched by typing its drawing identification code in the PDAs connected to the WMS GG2 and retrieving its location in a vertical store: as described for laminates, if the material is available in its assigned warehouse it can be immediately picked by the logistic operator and handed to the manufacturing staff, by registering its movement on GG2 or on the "Distinta C3" section of the assembly's OdP in case of time constraints for the operation.

In case the searched equipment is not available in a vertical store, instead, it is again task of the associated product family responsible to search and locate it across the supply chain. The steps followed, the software used and the information sources of this search are exactly the same already described when analysing the laminates flow in the previous section, that can be referred together with the flowchart annexed for the full description of the process. The only meaningful difference is related to the path followed by internally made piece of equipment: for those items, indeed, an internal quality check at the composite plant's quality department is required. This implies that a new potential bottleneck is added to the flow of the jigs, since the equipment can be available from the previous manufacturing steps but still queuing in the quality department, waiting to be checked and released for the subsequent use in body shop.

The information about whether the internal quality check has already been performed or not is retrieved from the C3 Tracer section of the OdP associated to the searched jig. In case the check has not been performed yet, it is urged mainly in an offline way by phone calls: usually, setting the check to high priority allows to release the item from the quality department in a time span coherent with the needs of the body shop, so that in general a rescheduling of the production is not needed.

Please note that the same internal quality check performed at the composites plant is required equally for all the jigs and equipment purchased from external suppliers. Given the nature of those items and the quantity involved throughout the year, much lower than that of BUY laminates or inserts, they are generally received directly at the composites plant's receiving area and from there routed to the internal quality department. Their traceability in this latter steps is ensured first by their reception status accessible on the ERP LN, which allows to understand whether the equipment has been received from suppliers or not, and then from the status "Received" of the associated OdA on C3 software, notifying that the item has been correctly received at the composites plant.

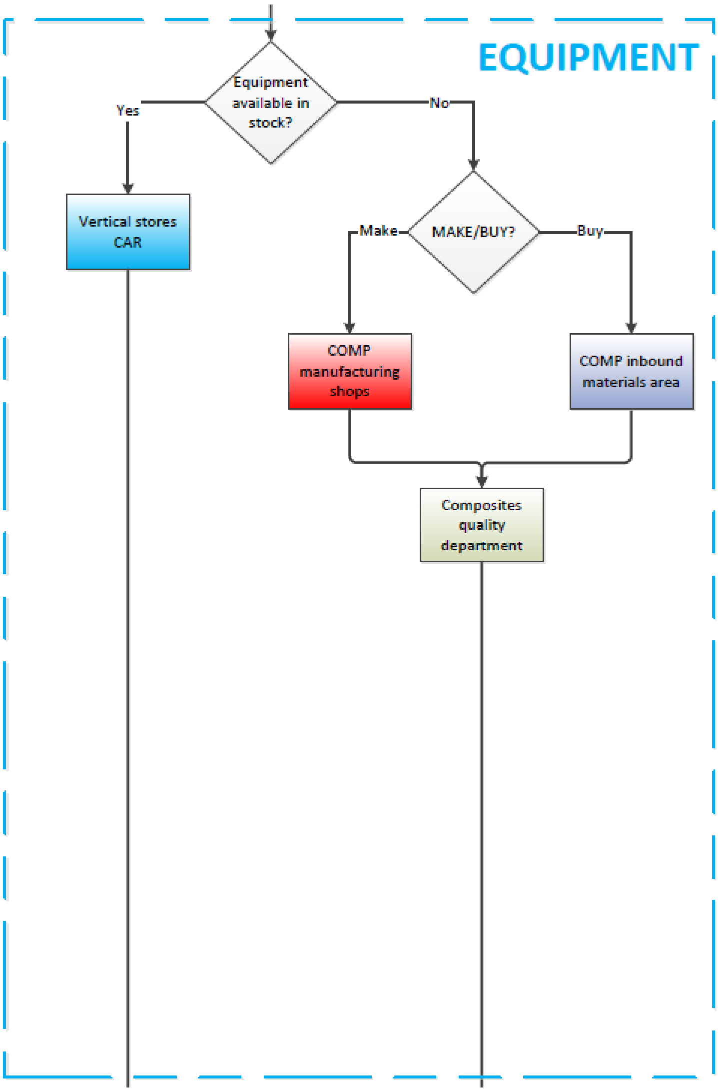


Figure 39- Overview of materials flows associated with equipment in the body shop

- Inserts

In the analysis performed we identify as insert a wide variety of items used in body shop environment ending up in the final bonded assemblies manufactured there, as opposed to laminates and tooling. The main families of inserts identified in this shop floor are rohacells, stockblocks and metallic inserts: they are respectively fillers for hollow shapes, solid and uniform carbon plates and various inserts in metallic materials such as bolts, nuts, bushings but also structural parts bonded with the laminates themselves.

Material and information flows for inserts are comparable to those previously introduced for laminates. Again, when the drawing identification code of an insert is typed into the PDA its position and availability in stock is retrieved from the WMS software GG2: if the item is available in a vertical store in the required quantity, the logistic operator simply picks it up, registers the movement on GG2 by scanning the QR code associated to the part itself, and then hands it to the operator at his workstation. As described before the QR code scanning operation, despite being fast (around 10-15 seconds), is performed just when no time constraints are present in the operations: the situation in which the picking is not registered on

GG2 is unlikely, but cases were reported especially in peak production periods. In this situation, the traceability of the insert is ensured again by its association with the bonded assembly's OdP in the "Distinta C3" section.

In the worst-case scenario instead, in which the search of an insert on GG2 gives as a result a zero-stock level, the information flow for locating the missing item within the supply chain and its possible material flows is shaped in the exact same way as described for laminates and tooling.

After having checked on C3 about the MAKE/BUY sourcing strategy used for the searched item, the availability of the insert from the previous steps of the manufacturing cycle, in case of MAKE parts, is assessed via the C3 Tracer section of the associated OdP. If the inserts are not yet available their production is urged and, if this is the case, the bonding in body shop is rescheduled to another day in the working week by the product family responsible in accordance with the shop floor managers. MAKE inserts are represented mainly by rohacells and stockblocks, for which a quality check is necessarily required by the internal composites' quality department: the time required for this check must be added to the one possibly required to end the production of the insert by the upstream manufacturing departments. Moreover, as described in the previous section about internal quality checks performed on tooling, this may represent a bottleneck in the production cycle of the insert, being possible for an insert to spend time waiting to be controlled and released.

BUY inserts, instead, are usually commercial codes such as bolts, nuts and bushings or built-to-order structural metallic parts: all those items must be quality-checked by the central quality control department before being available for manufacturing in the body shop. For the analysis of information and material flows of this latter class of inserts it is possible to refer to the corresponding class of BUY laminates: as reported in the AS IS flowchart, the path followed to search a missing item is the same in the two cases and there is a complete coincidence of software used and traceability possibility.

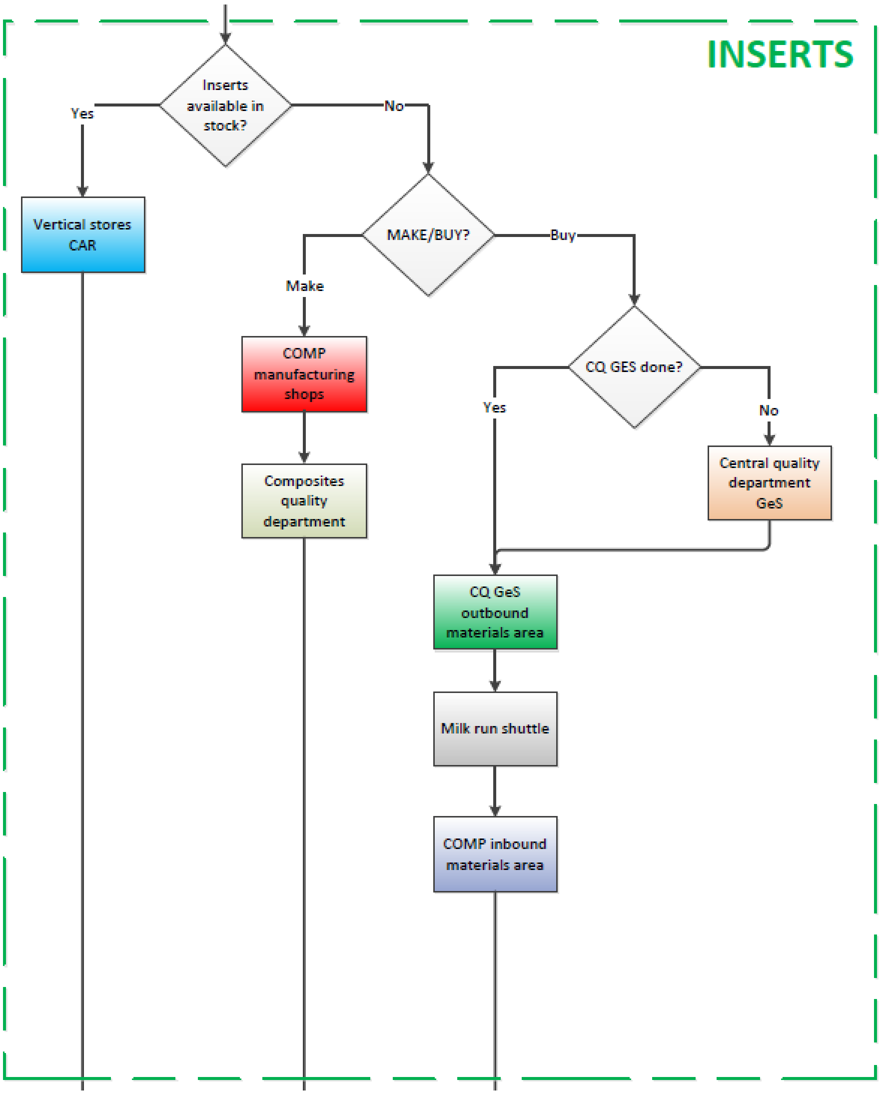


Figure 40- Overview of materials flows associated with inserts in the body shop

- Operator's activity and post-bonding flows

Once all the materials and items required for manufacturing have been retrieved and are available in the body shop, they are delivered by the logistic operator to the assigned floor staff directly at their workstations. The production phases taking place in the body shop are traced on the C3 Tracer section of the manufactured assembly's OdP, registering the manhours spent for every step performed on the product and the progress of production by opening and closing the phases of the theoretical cycle reported in the C3 Tracer section itself. After the bonding phase and the manufacturing steps performed in the body shop are completed, the assembly may follow different paths.

If the item requires downstream manufacturing step it is taken directly to the relevant department. Note that the information about the destination of a bonded assembly is not clearly stated in the AS IS situation: the entire manufacturing cycle planned for the item is registered on the C3 Tracer section of the associated OdP, but once the bonding is complete it is not explicitly stated whether the assembly must be immediately taken to a downstream department or not. Usually this situation is managed by the product family responsibles together with the involved departments' floor managers, who are in charge of following the flows of the items across the whole manufacturing cycle and to ensure they are produced according to the deadlines set in the planning phase.

On the contrary, if the assembly is not required for immediate manufacturing by some department downstream body shop but it still needs some steps to be performed on it, it is stored in one of the vertical stored of body shop, by previously scanning its QR code to register the movement on GG2.

The last possible case is that of an assembly that does not require any additional step downstream the body shop manufacturing phase, then being ready for delivery to the customer that usually is the internal department in charge of assembling the racing car. In such a situation the product is prepared for delivery and temporarily stored in the body shop waiting for the taking-over by the internal logistic employee: in the moment in which the assembly is loaded on the milk run shuttle to the assembly department, the status of its associated OdP is turned to "Delivered" on C3 and its production cycle is officially closed.

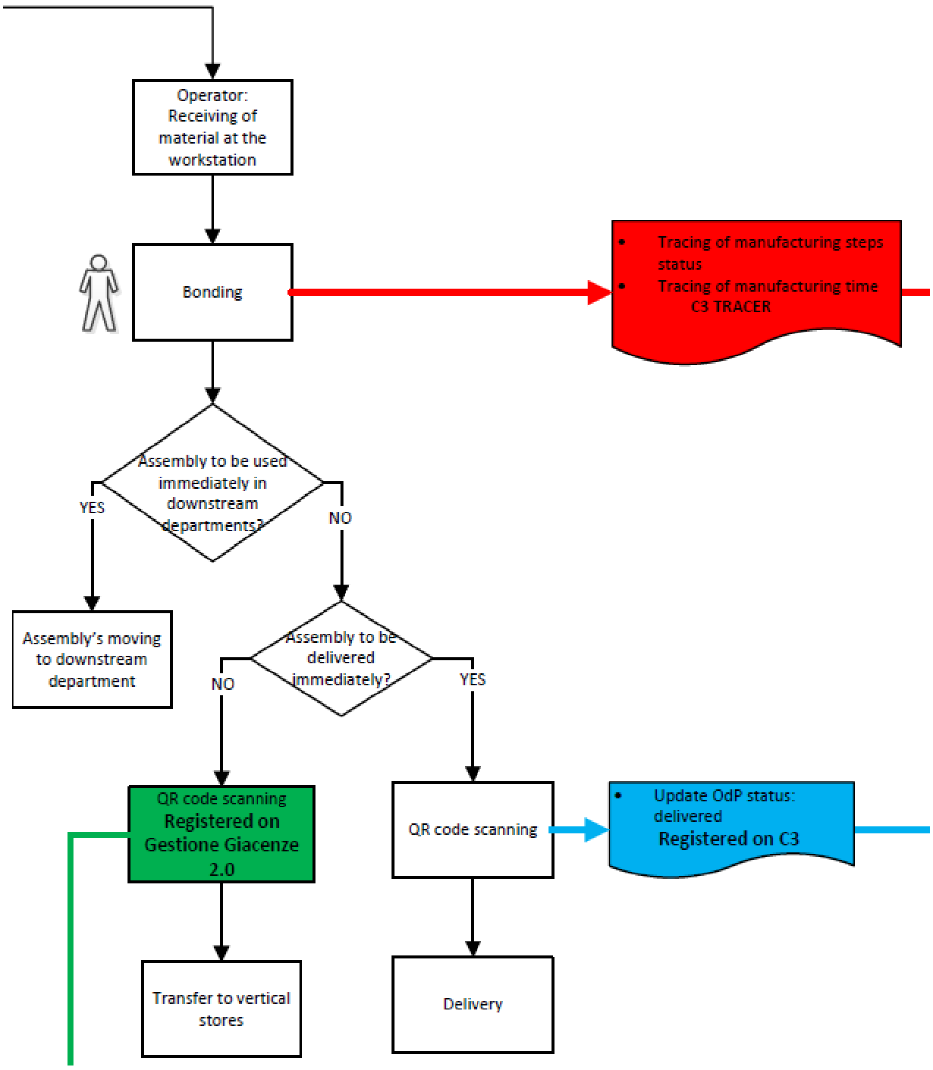


Figure 41- Overview of the information and processes associated with the post-bonding phase

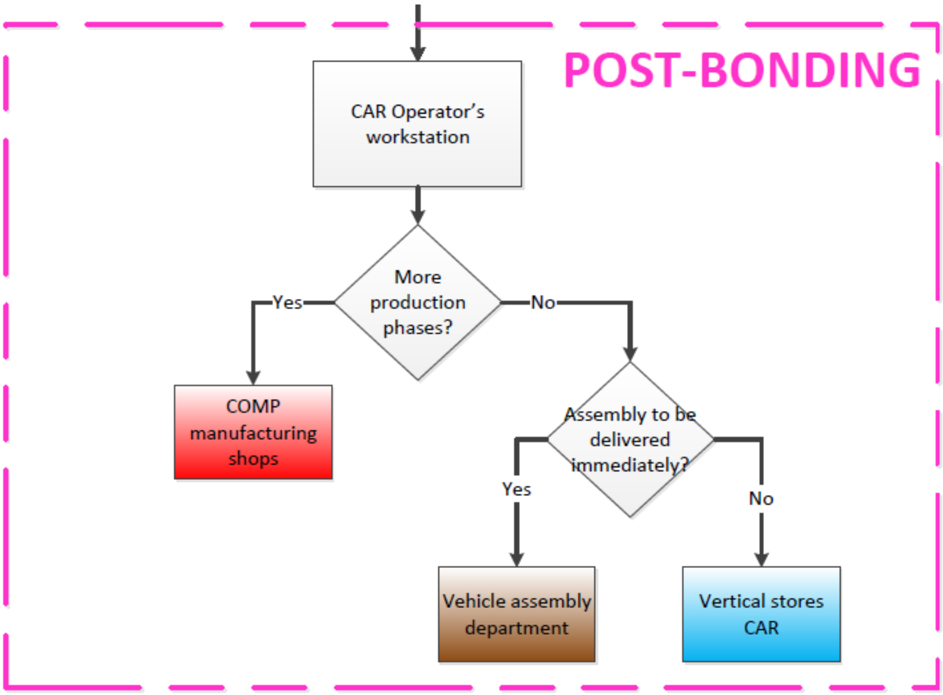


Figure 42- Overview of the materials flows associated with the post-bonding phase

4.4 Design of the TO BE process

The analysis of the AS IS situations for clean room1 and body shop has proven to be extremely useful to understand characteristics and criticalities of the interwoven materials and information flows as a starting point for the definition of kit preparation process required features. Following the AS IS analysis, TO BE flowcharts have been developed representing the material and information flows of the redesigned clean room 1 and body shop featuring the newly introduced kit preparation process. The flowchart is aimed not only at defining how the kit preparation will have to be done in the ideal future state, but also at defining which information from which software will have to be integrated and at acknowledging and standardizing some recurrent "exceptions" of the AS IS situation, as will be better described in the related TO BE section.

4.4.1 Clean room 1: information flows

As a first and fundamental major change for clean room 1 environment, compared to the current situation, in the TO BE scenario the kits will be prepared by a limited number of selected operators (1-2 depending on the amount of work to be done) as soon as the daily program is available, i.e. in the standard situation the evening before any working day. This solution allows in first place to anticipate possible out of stocks detection or any problem related to material availability or delivery by upstream departments/suppliers, so that they can be faced immediately with a certain time margin instead of detecting the problem at the beginning of the shift the day after. Moreover, with the new process it is possible to reduce the number of people accessing the warehouses, thus limiting the possibility of mistakes in the warehousing and tracing operations while at the same time introducing a clearly defined logistics responsible in charge of managing all the internal information and material flows.

Following from the AS IS analysis about the information flows it has been highlighted that the core software used for clean room activities, and in particular for those activities related to internal logistics, are C3 and GG2. In the to be information flows, therefore, C3 and GG2 will remain the core sources and collectors of information, though with some important data to be sourced and integrated from other software in order to create an information background able to effectively sustain the physical kit preparation process.

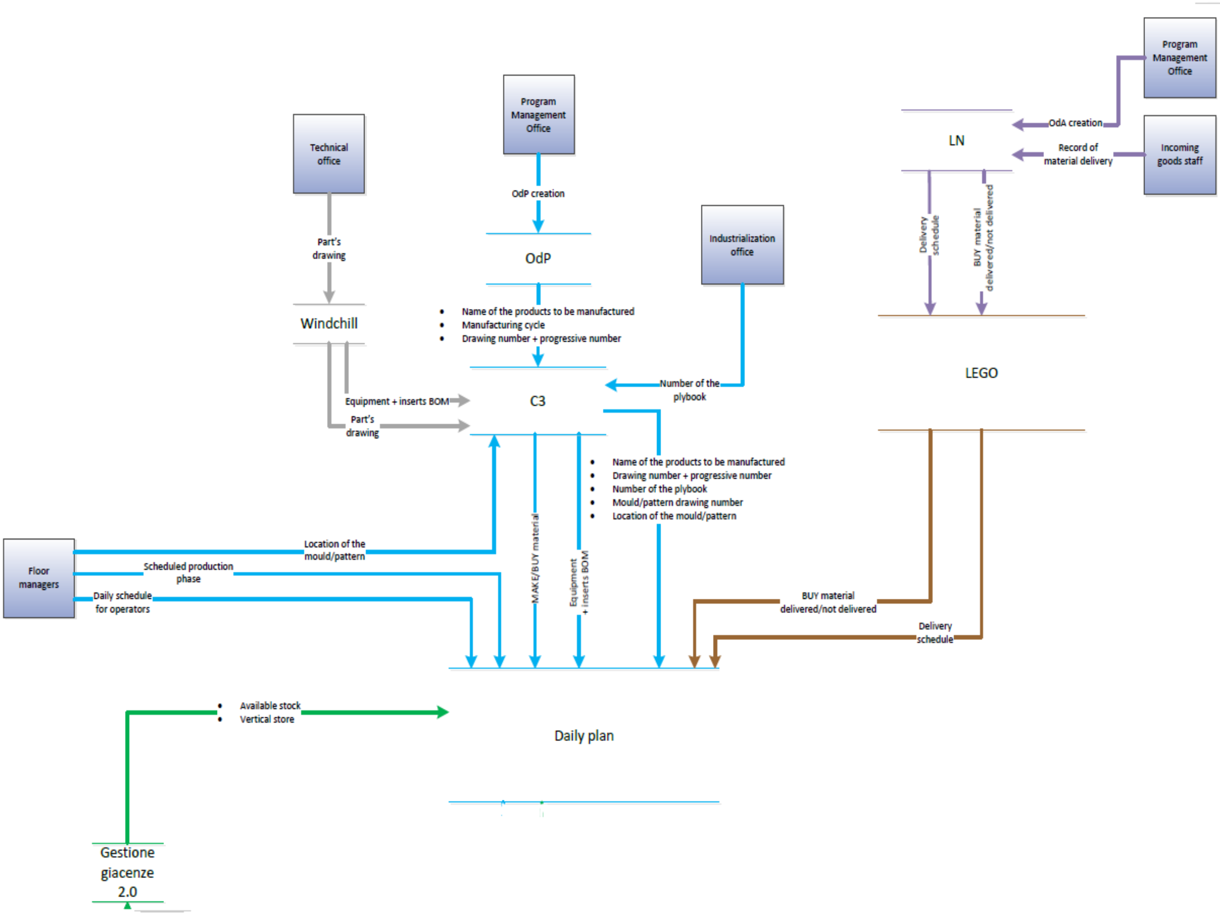


Figure 43- Overview of the information flows converging in the TO BE daily plan for CR1

In the TO BE situation starting from C3 the daily plan "Programma di lavoro" is generated by the clean room floor managers, with the same information already present in the AS IS plan but also with some fundamental additional features and a new digital format. The "Programma di lavoro", formerly an Excel file with a limited amount of information, is now a digital tool with the opportunity to get more information on the materials needed by directly accessing it from C3. The designed tool, indeed, is a dashboard intended to provide the picker with the necessary information about all the items required for the daily scheduled production in clean room 1, with the following targets:

- Provide the complete BOMs of all the parts scheduled for manufacturing in a specified working day, collecting all kind of materials previously described such as carbon ply kits, moulds/patterns and inserts in a unique list with the related identification drawing codes.

Moreover, not only all the necessary daily items of clean room 1 must be merged in one list, but the connection between each item and the related part to be manufactured ("Codice padre"), to whom each belongs, must be clearly specified and shown.

- Provide the status of the availability of each item in stock in the vertical stores through a green/red light signal: the green light is given just when the required item is present in one warehouse, while a red light is given in all the other cases. The information about the presence or absence of an element in a warehouse is retrieved from the WMS software GG2 and, consequently, the green/red light is given as an output directly in the new "Programma di lavoro" tool. Note that the integration between C3 and GG2 is already existing in the AS IS situation, the only missing part in terms of information for this point 2 is the status output for the materials.
- Provide the location in terms of vertical store and tray in which every item to be picked is stored. The exact location of an item is immediately given as an output in the new "Programma di lavoro" just in case of green light, meaning that the required quantity of the searched item is available in stock and can be picked immediately.
- Provide the information about the most probable location of an item in the supply chain in case of red light. Whenever a red light is given as an output for the availability status of the searched item, meaning that there is no sufficient available stock registered on the WMS GG2, the new designed tool features a link redirecting to a dashboard page collecting all the available information able to give the best estimate of the position of the required item in the supply chain. In this dashboard page the following information and software are merged:

  - C3 "Ordini" section: the core entity needing to be integrated in the dashboard page is the OdP/OdA associated to the searched item right from its opening section. The OdP/OdA object in the current C3 software is provided with a set of standard status useful to give a hint about the possible location of the searched item (active, closed and accepted, closed and scrapped, delivered, among the most common). Including this very basic information in the dashboard page is intended first of all to give an insight about the classification of the item as MAKE/BUY. Then, the status information is useful to be checked especially for BUY parts: any OdA, indeed, is closed and its status set to "Closed and accepted" just in the moment in which the associated part is received at the composites plant's receiving area, regardless of the fact that it is being received from an external supplier or from the milk run shuttle. Overall this information proves to be useful to understand whether a BUY item has been received at the composites plant or not, irrespective of its source in the supply chain.

  - C3 Tracer: from this section of the searched item's OdP on C3 it is possible to read the last performed and registered manufacturing operation. In this way the user can physically look for the required item in the department responsible for the last performed operation or, for example, understanding if the last step before the planned manufacturing phase is still WIP or not even started yet. In general, this tool gives information about the location of a searched item in any upstream department or composites internal quality control areas, proving to be useful to trace all the MAKE components manufactured in the composites plant.

- CCQ Light: this subsection of C3 is useful, as previously introduced, to trace the status of the quality control performed in the main quality department area (QC GeS). It is a fundamental tool to be included in the dashboard, allowing to trace particularly all the MAKE and BUY items –specifically the inserts- for which a quality control performed by this department is required. Note that from the point of view of our logistic purposes this tool, though, is able to give only the information about the status of the quality control in terms of done/not done yet: it may be effectively used, thus, to trace those items already quality controlled waiting for a milk run shuttle to the composites plant. By accessing CCQ Light alone, instead, it is not possible to assess whether an item has already been received at the quality department and it is waiting to be controlled.

- Gestione Giacenze 2.0: the WMS software GG2 is another main part of the dashboard page, useful to trace different cases for materials even when they are not stocked in a vertical store in the composites plant. It is worthwile to note, indeed, that the check about the availability in stock of an item, the key feature offered by GG2, is not included in the dashboard page, given the fact that this one is intended as a link just to trace parts not available in a warehouse: if an item is already present in stock, the newly designed Programma di lavoro will show its location immediately in its main page retrieving it from GG2 itself, but the link to the warehouse tracing feature of the software will not be included in the dashboard. This latter featured offered by GG2 will be included, instead, to trace the presence of the searched item in all those warehouses different than the assigned one. For BUY items received at the central goods receiving area and waiting for milk run delivery to the composites plant, indeed, a specific location is reserved in the receiving area and as such is traced on GG2. Another tracing possibility ensured by GG2, moreover, is that of materials waiting to be quality controlled at the central quality department: equally to what just described, for those items a specific location in the central warehouse is dedicated, and as such is traced on GG2.

  A final feature offered by GG2 and included in the dashboard is that of the milk run tracking possibility: the software is able to register whether an item has been loaded on a milk run shuttle or not, being then useful to clarify those cases in which a part may have been “lost” in the shuttle during the delivery of items from the main central receiving area or the quality control area to the composites plant. By cross-checking the data about the milk run loading and the missed unloading, indeed, it is easy to assess that the item is still in the shuttle.

- LEGO: it is a collector of information from other softwares to trace the status of any OdP/OdA created as well as the material availability associated to each. LEGO is intended mostly to collect the OdAs from C3 and associate them the ERP software LN information: the result is a simplified dashboard in which for any identification code with a related OdA the status about the delivery of material is given. As such, LEGO is a valuable tool to be included in the designed dashboard, useful specifically to trace the reception of BUY items in the central goods' receiving area before the milk run or quality control checks are even performed.

The tool, as described, is intended basically to be a virtual picking list of all the material needed to perform the daily scheduled production and to be a collector of already available information covering the traceability issues in case the material searched is not present in a warehouse. These two core targets are aimed at providing the material to the operators in the fastest and most efficient possible way.

The newly designed Programma di lavoro will continue to be prepared by the clean room floor manager as in the current situation and must be ideally ready the night before a working day, so to prepare kits before the first shift in the morning. It is important to point out that the new software tool has been designed not only to perform the picking operation of material from the vertical stores but also to support floor managers and planners in their job: indeed it has been conceived as a dashboard able to highlight with the green/red light logic the availability status of the material, so that it is easy to anticipate out of stock problems at the planning phase and, if necessary, change the schedule if it is known a priori that a required item will not be available in time for lamination.

The core information flow of the TO BE situation, beside the new daily plan, remains the same as in the current organization in terms of software used and information stored/retrieved. A modification necessary in terms of traceability for the effective implementation of kit preparation process and the new daily plan dashboard is that moulds/patterns and carbon ply kits, now traced on C3, must be traced as any other material on the WMS GG2: this is a basic requirement to streamline floor staff operations and to standardize information flows for all the material, simplifying at the same time the software integration and development necessary to introduce the new kit preparation process by recollecting all the information about stock availability of material from GG2 alone.

4.4.2 Clean room 1: material flows

Given an overview of the new information flow designed for the introduction of the kit preparation process, the material flows and operator's activity of the TO BE situation will be now described. The to be flowchart has been developed with the underlying logic of mapping on the one hand the standard situation in terms of kit preparation process, i.e. the situation in which all the searched items are stored in the warehouses (green light situation) and can be picked immediately, and on the other hand the most common red light situations, i.e. the ones in which a required item is not found available in stock, defining how to perform kit preparation in those situations and how to deal with the search of the items.

The analysis performed is not intended to cover the entirety of the cases that may possibly happen in the traceability and availability of all the materials used in clean room 1 that, given the peculiarity and variability of the process and of the products manufactured, would be impossible to map in a complete way. The target, instead, has been to map just the most common cases, as reported from the interviewed people, defining and standardizing how to deal with those exceptions to the standard situation in terms of kit preparation.

- Pre-preg ply kits

In the TO BE situation carbon ply kits, as said, are traced on the WMS GG2 and their availability in stock in the freezer of clean room 1 is checked from the newly designed daily plan. The production process and operator's activity are unchanged compared to the AS IS situation until the picking of the item from the freezer of clean room must take place: if a green light is displayed on the daily plan dashboard the picker can read the location of the searched carbon plies bag, pick the material by previously scanning its QR code in order to register the picking on the WMS, and put the item in a single box associated to the operator that will perform the manufacturing of the part.

A red light situation has not been analysed for the carbon ply kits because it has been reported during the interviews that the event of a loss is quite unlikely for this type of material: all kits are internally manufactured and the cutting operation does not represent a bottleneck, so that in the great majority of cases the ply kits are available in stock in the freezer of clean room without any further problem for performing the kit preparation operation.

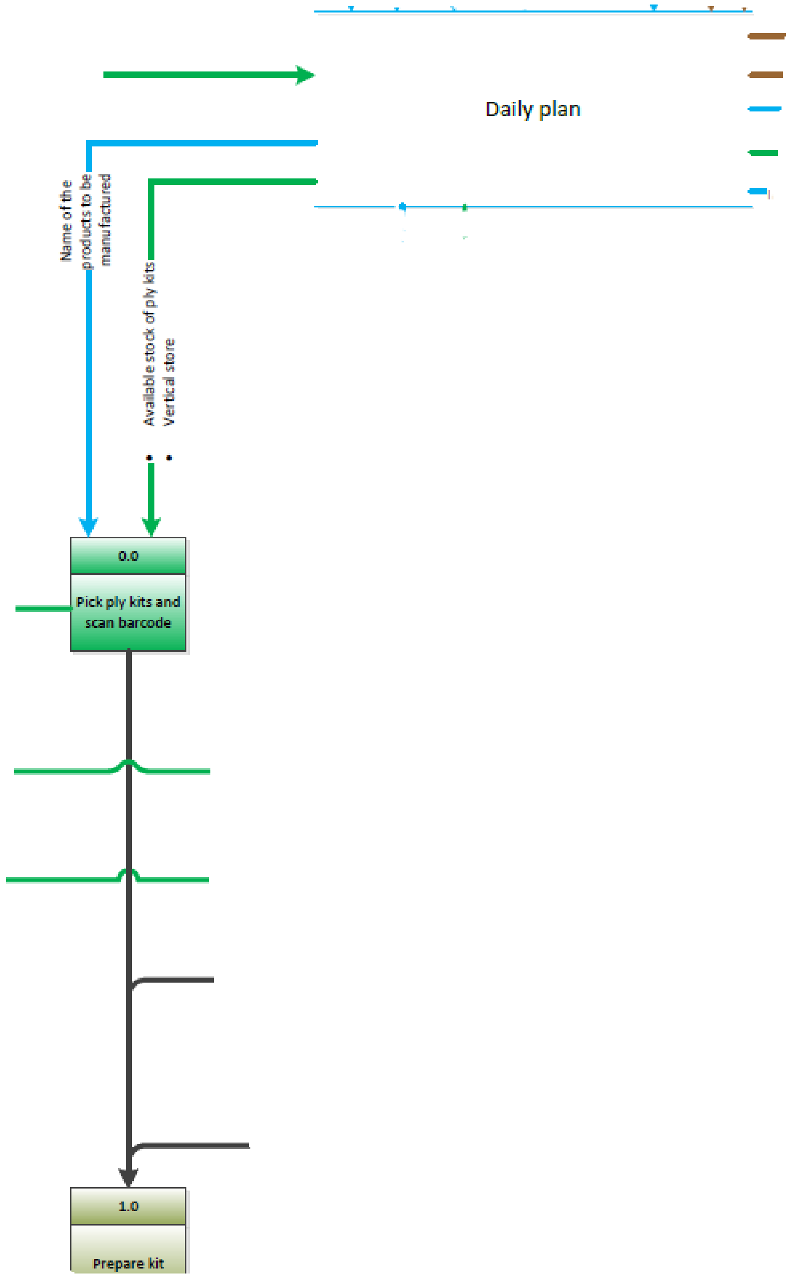


Figure 44- Focus on the information and processes associated with the TO BE flows for ply kits

- Moulds/patterns

As for carbon ply kits, moulds and patterns to be picked are read on the picking list represented by the newly designed daily program. In the TO BE situation, in a green light scenario, the moulds/patterns are already available in a vertical store, so that they can be picked up, their QR code scanned to register the picking, and they can be placed in the kit box associated to the specific operator according to the daily plan together with the carbon ply kits already picked.

In case of a red-light situation, though, another logic for kit preparation must be followed: it is very usual, indeed, that at the moment of kit preparation for the day after the great majority of moulds are not yet available from the upstream manufacturing steps, or are not yet been received from suppliers in case of BUY items. In those cases, the traceability of the item is ensured by the link contained in the Programma di lavoro and redirecting to the dashboard page described in the information flows section, so that the picking operator knows immediately where to search for the item or what to do, avoiding phone calls or walking to any upstream department that may be involved. Two main cases of expected red light situation were found during the analysis and a logic for kit preparation in those cases has been defined:

- Moulds internally made curing in autoclaves during the night. This is a frequent case: moulds are cured in autoclaves in the night shift, then prepared for lamination in moulds extraction and preparation room and finally taken to clean room. As a result of this situation, if kit preparation is performed in the evening for the day after, moulds are not yet available for the manufacturing. In those cases the moulds will be placed in kits as soon as they are available from preparation by a selected operator of moulds extraction and preparation shop, expectedly the morning of the same day scheduled for lamination.

- Moulds/patterns purchased from suppliers. A certain percentage of moulds and patterns, according to available capacity, is provided by external suppliers. It may happen that the material is scheduled for delivery the same day of lamination or it has been delayed by the suppliers: in cases like this the items are clearly not available for kit preparation during the evening. If the delivery is scheduled for the day intended for lamination the moulds/patterns will need to be picked by the picker operator as soon as they are received at composites receiving area and delivered to the moulds shop for their preparation, from there a selected operator of that job shop will place the item in the kit box or will provide it directly at the workstation of the involved clean room operators, thus avoiding kit preparation at all.

In both these cases a lack of traceability is shown as in the current AS IS situation, because the picking and moving of moulds/patterns is not registered in any software, being them routed to clean room directly from upstream departments and not picked from a warehouse. In this latter case the movement would have been registered on GG2: in the TO BE situation it has been decided to accept and keep this missing traceability step in order to streamline the operations, basing the tracing of the moulds/patterns in this particular case just on the output of C3 Tracer i.e. the last registered manufacturing step. The full traceability of the part will be restored after lamination, when the mould/pattern will be placed in a warehouse and registered on GG2, ready for a future manufacturing cycle.

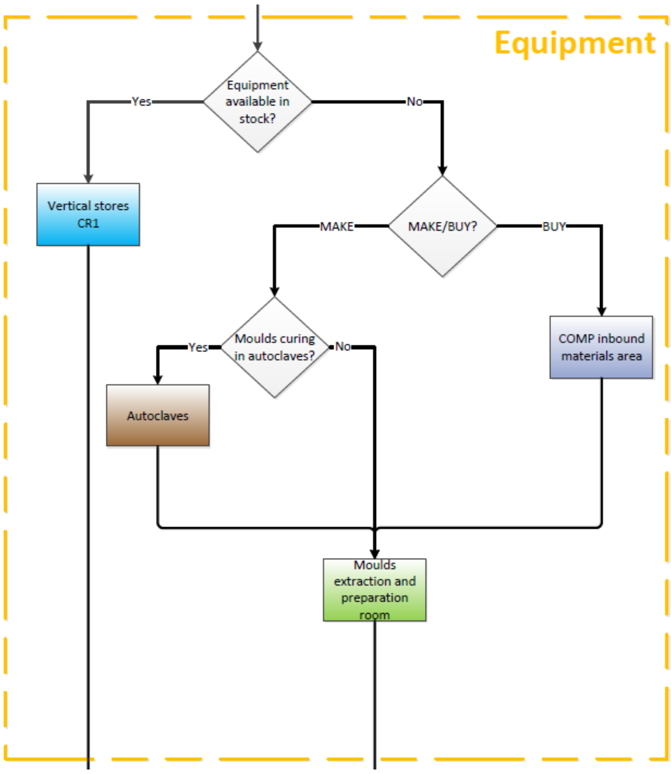


Figure 45- Overview of the TO BE materials flows associated with the equipment

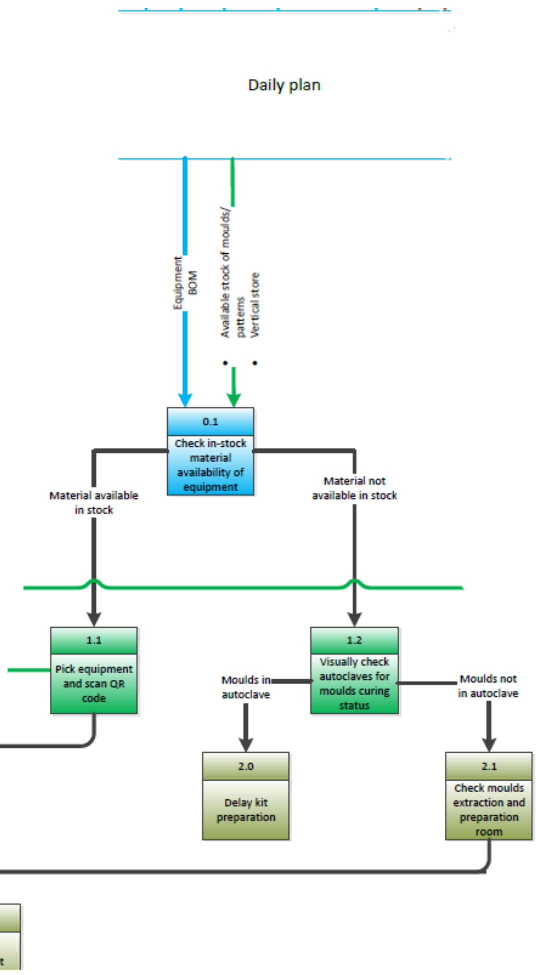


Figure 46- Focus on the TO BE information and processes associated with the equipment

- Inserts

One of the greatest expected advantages obtained with the kit preparation process introduction is to streamline operations and solve issues related to inserts picking activity: in the to be scenario they will be picked in advance and placed in the kit boxes together with the other materials needed by retrieving the information about which items to pick directly from the newly designed Programma di lavoro, thus eliminating the inefficient activities related to the use of Clean Room Desktop for inserts picking as described in the AS IS situation analysis.

In a green light case the picker will read the vertical store and tray location of the inserts searched directly from the daily plan dashboard. He/she will then perform the picking, registering the activity on GG2 by scanning the QR code associated to the item, and finally placing the material in the proper kit box.

In a red-light scenario instead, as described in the information flows section, more details about the most probable location of the missing items will be provided by accessing the link related to the items themselves in the Programma di lavoro. As shown in the TO BE flowchart, the missing insert case has been analysed with a slightly greater level of detail compared to the carbon ply kits and moulds/patterns case, being it a quite common and particularly critical situation. The analysis has been targeted in detailing the most common causes of missing insert, as found to happen in the AS IS situation, and in defining for each a logic to be followed to address the problem and create the kit in those cases in which not all the material can be placed in the box at the same time.

If the missing component is an internally made item, as understood by checking the dashboard of the Programma di lavoro, it follows that it must be checked in the upstream departments because, for many reasons, it is not yet available from the previous manufacturing steps. The most effective tools to address this situation are C3 Tracer and CCQ light (to check if inserts are in quality control departments), again directly accessible in the same dashboard page of the daily plan.

On the contrary, if the missing insert has been purchased from a supplier, the main information useful to trace it and accessed from the dashboard page is the OdA status or LEGO: the former giving the information about whether the item has been delivered to the composites plant's receiving area or not, the latter instead giving clues about possible delays in the delivery from suppliers or the information about the reception of material at the central good's receiving area. If, as understood from the dashboard, the part has already been received at the composites plant it means that it is most likely stored on a shelf in that area: the item can be immediately picked there and included in the relevant kit. In the case, instead, in which an item has been already received by the supplier but not yet delivered to the composites plant, it means that most likely it has been received at the central goods receiving area and it is waiting for delivery to composites by the milk run. The information about when and if a part has been loaded on a milk run shuttle can be retrieved by GG2, accessing it from the same dashboard page.

In case the item has not been delivered yet to any of the receiving areas, as checked from the LEGO information given in the dashboard page, further investigation needs to be done. The delivery can have already been scheduled and confirmed to be in-time by the supplier, in this case it is still possible to include the item in the relevant kit but the operation will be performed the day after, as soon as the missing part will be delivered and made available to the clean room logistic operator: in this case he/she will take the item directly from the goods receiving area to the clean room, including it in the kit box and tracing the movement by associating the item's OdP to the one of the connected laminate in the "Distinta C3" section of this latter. As a last analysed case we considered that of a BUY insert mistakenly not ordered by the purchasing department: this case, rare yet happened and particularly disrupting for daily operations, can be detected in advance again from the dashboard page given the lack of an associated OdA on C3 or LN, and dealt with by rescheduling the manufacturing of the item after having contacted the purchasing department.

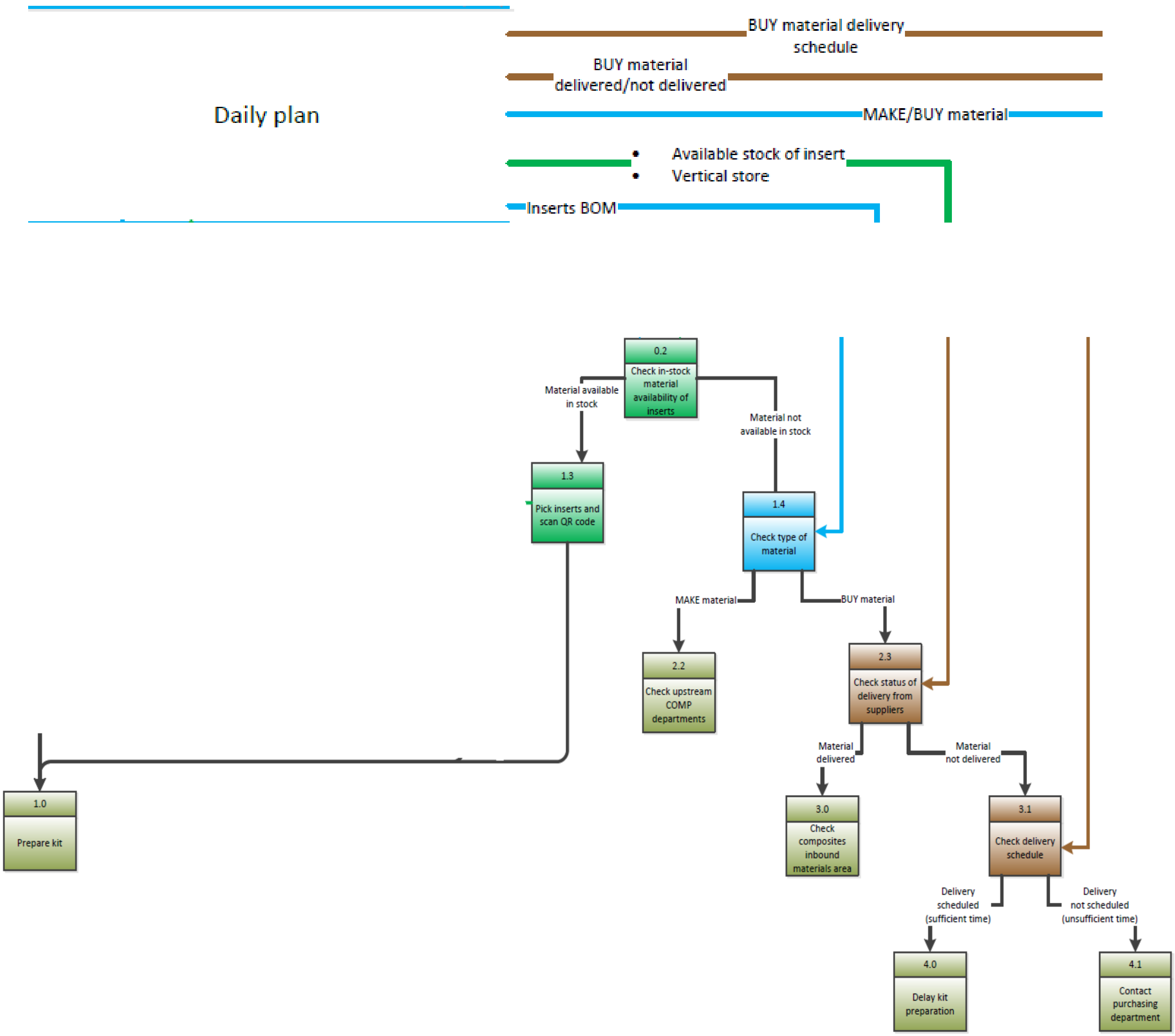


Figure 47- Focus on the TO BE information flows associated with inserts picking

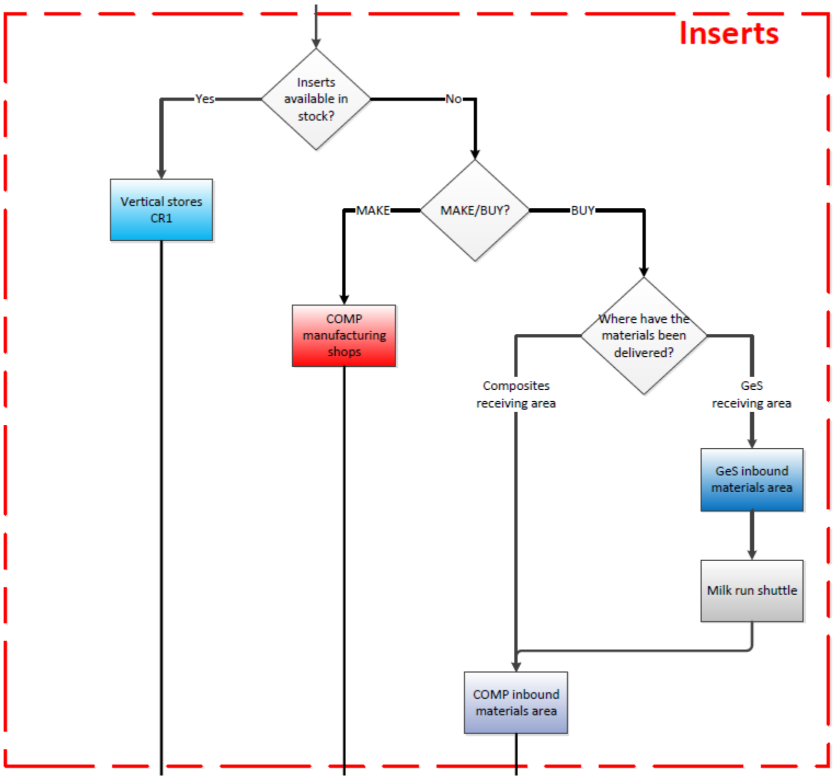


Figure 48- Focus on the TO BE materials flows associated with inserts picking

- Operator's activity and post-lamination materials flow

Once the kits for all the operators of clean room 1 have been completed they are stored on a dedicated rack in clean room. At the beginning of the morning shift operators can access clean room and, by checking the daily program, they are able to pick the kit assigned to them.

The operations downstream the kit preparation process and the information flows are unchanged compared to the AS IS situation because they are not affected by any improvement plan: once the assigned kits are retrieved by operators, they can log in to CR Desktop in any workstation in clean room and perform the manufacturing. Ideally, operators do not need to leave their workstation anymore to pick materials and tools. The items available later in the day for any possible reason, for example being them manufactured by the upstream departments or received by suppliers not in time for kit preparation, are delivered to the logistics responsible operator as soon as they are available and placed by him in the proper kit boxes: again the information about which kits a missing item belongs can be easily accessed by the dashboard of the daily program.

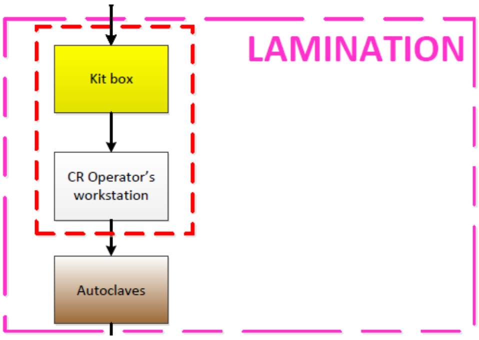


Figure 49- Focus on the TO BE material flows associated with lamination and curing phases

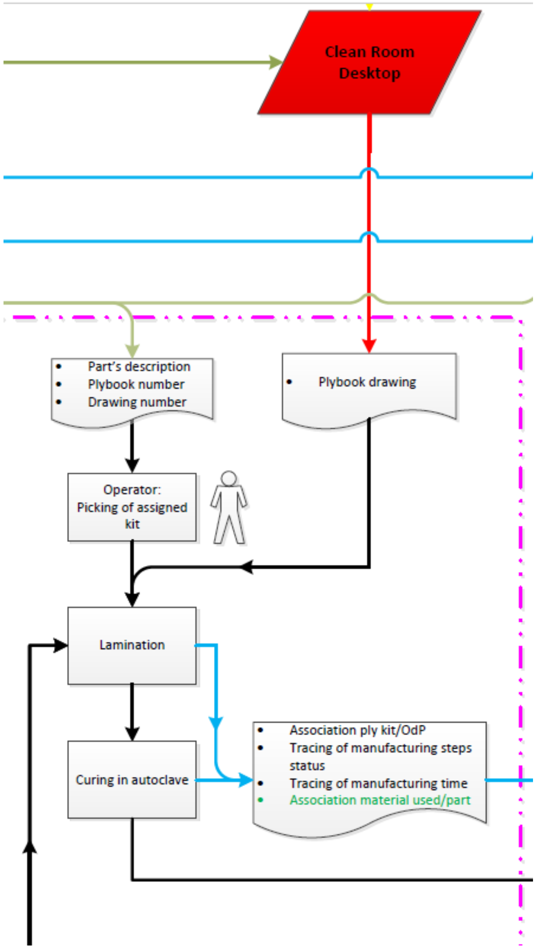


Figure 50- Overview of the information and processes associated with the TO BE lamination and curing phases

After extraction of parts from moulds in moulds extraction room, exactly as in the current situation, moulds are prepared for another manufacturing cycle and, according to the daily plan, they are routed back to clean room or stored in a vertical store for future need. In this latter case the only news compared to the AS IS situation is clarified: being now moulds/patterns traced on GG2 instead that on C3, their QR code must be scanned to register on GG2 the storing of the item in a warehouse. In case of moulds/patterns routed back to clean room, instead, the movement is not traced on a dedicated software and cannot be rebuilt from C3 Tracer either until the lamination process is performed in clean room and the manufacturing step registered on C3 Tracer itself. This last case represents a lack of traceability because the items are moved from one shop to another without being traced, but it is acceptable in order to streamline the operations and because in the standard situation the moulds/patterns may be either in extraction room, in clean room or in a warehouse (traced on GG2 in this last case): the untraced locations of the items, thus, is limited to one of those two first possibilities and there is a low consequent probability of completely losing trace of the materials.

Same thing holds for parts extracted in moulds preparation rooms: they can be stored in a warehouse by registering the movement on GG2 or they can be directly routed to the next department requiring that item. In this latter case the same traceability issue already described for moulds/patterns routed back to clean room holds and, as before, it has been decided to retain the partial lack of traceability associated with this situation because it is assumed that the part is immediately used for manufacturing: as soon as an operator of any department downstream moulds extraction room will register any manufacturing step performed with that part, it will immediately be traceable again by using C3 software.

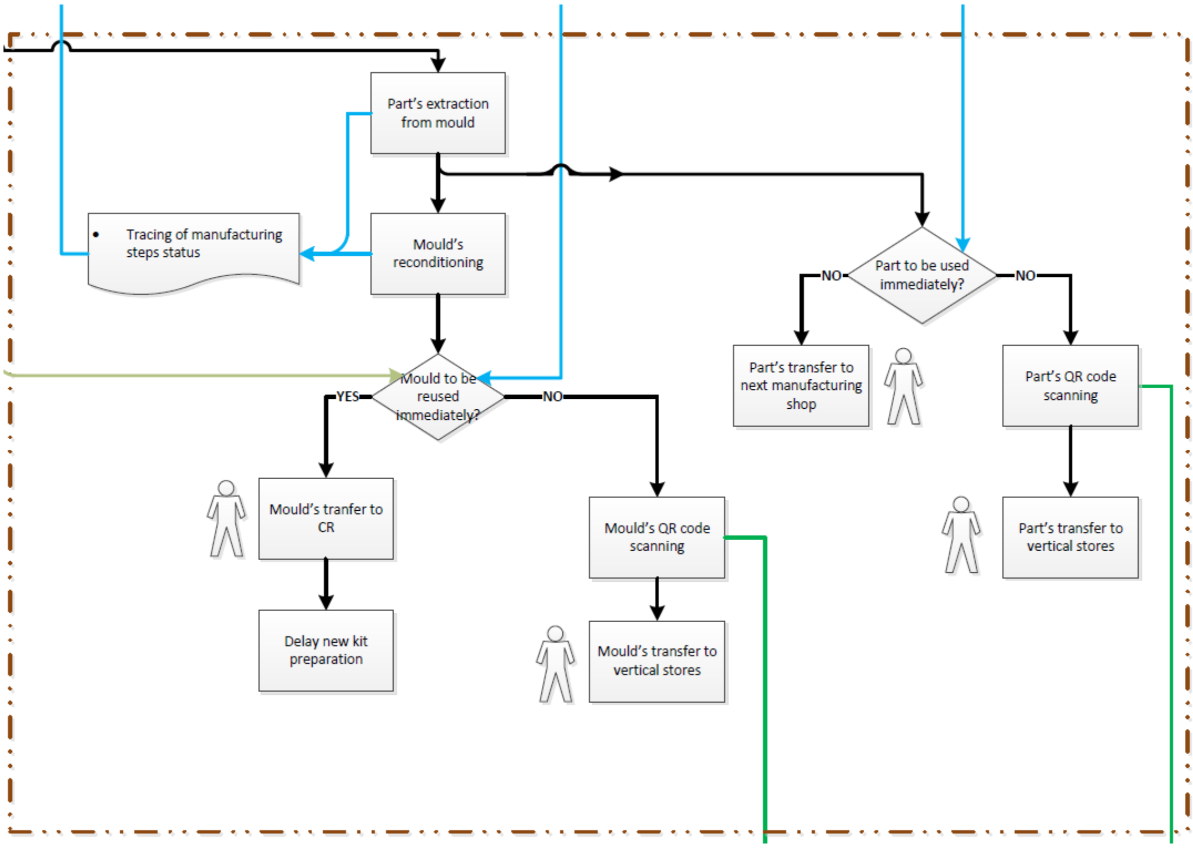


Figure 51- Overview of the information and processes associated with the TO BE post-lamination phase

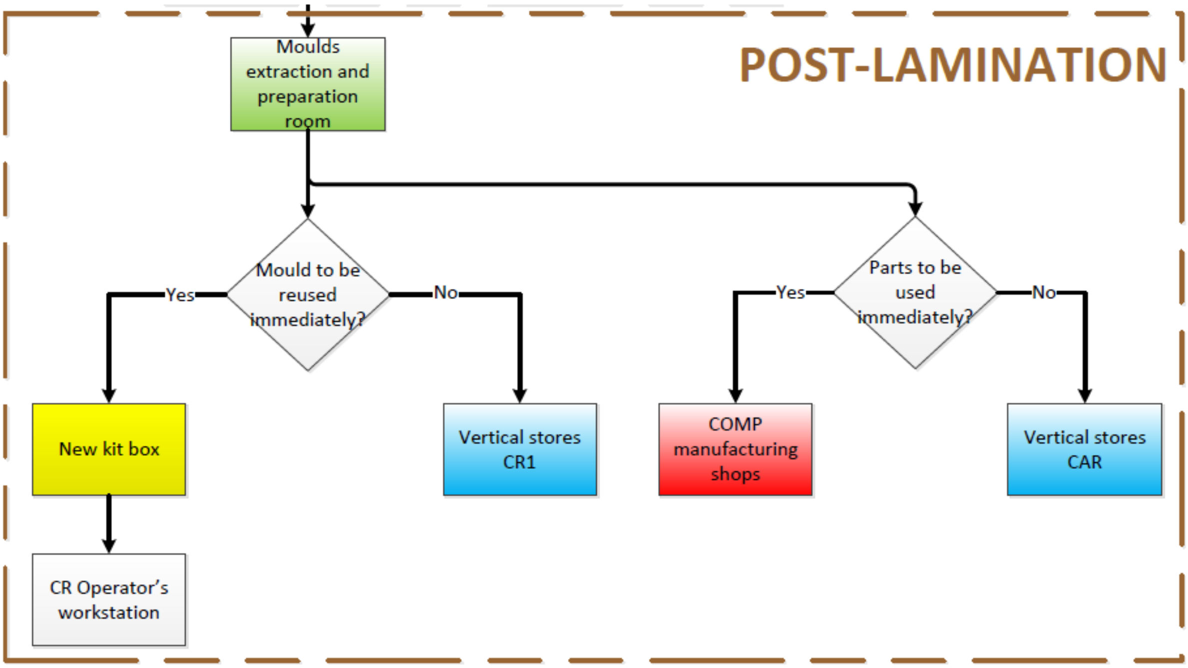


Figure 52- Overview of the materials flows associated with the TO BE post-lamination phase

4.4.3 Body shop: information flows

After the analysis of the current situation of body shop has been developed, the information collected and the mapping reported in the flowchart annexed has been used as a starting point for the design of a to be scenario featuring the kit preparation process.

With the same logic followed for clean room 1, the to be flowchart for the body shop is aimed on the one hand at designing the new information flow necessary to effectively sustain the kit preparation process, while on the other hand at mapping how the kit preparation can be implemented and integrated in the current body shop environment by defining a logic suitable for this purpose and by analysing how the kit preparation process will have to deal with the out of stock situations described before to effectively solve them.

Following from the AS IS analysis, it is clear that a large amount of different software is used in the body shop environment to access a series of different information. The to be scenario aims to streamline this information flow by making the proper data available to the user at the very beginning of every manufacturing steps taking place in the body shop, i.e. in the moment of material search.

As shown in the flowchart, the core software on which the to be information system will rely are the MES software C3 and the WMS one GG2: the infrastructure for the kit preparation process is exactly the same as already described for clean room 1 environment, given the need of a shared solution to the operator's movement waste. It is worthwhile to remark that the target of the kit preparation introduction project has been, from the very beginning of the analysis, that of designing a unique tool able to work in both clean room 1 and body shop, providing a full integration with the current information system and procedures and a shared underlying logic.

It is for this reason that, as a first and major change of the to be information flow compared with the current state, the planning method currently followed in the body shop to manage the daily operations must be switched to a new one: the actual Excel spreadsheets developed by product family responsibles and body shop floor managers must be dismissed in favour of the tool "Gestione pianificazione" of C3, as currently already used in clean room environment. The use of such feature of C3 is a basic requirement, as it allows to share the newly designed software developments for the picking list generation among clean room and body shop: in absence of its use for the daily planning, it would be impossible to automatically retrieve the list of material and its availability/position in the supply chain given the impossibility for C3 to understand which item has been planned for production on a certain day. This change involves first the product family responsibles, who will be in charge of performing a weekly planning on C3 by constantly updating the scheduled dates for production of the OdPs associated to their product family. Then, it involves the body shop floor managers, who will plan the daily activities by assigning the assemblies scheduled for production, as indicated by the planning department and the product family responsibles, to the body shop operators. This requirement is the basic one required to generate the newly designed "Programma di lavoro", having the same format as the one already introduced for the clean room 1, being the same tool. As described in the to be information flow for clean room and here briefly recalled, the new "Programma di lavoro" is intended to be on the one hand a picking list of all the items needed for production of the bonded assemblies as performed in the body shop, and on the other hand it has been designed as a dashboard constantly updated to collect all the traceability information about parts required for manufacturing but missing from the vertical stores, in order to give the best possible information about the location of a searched item in its supply chain.

The only difference from the tool introduced in clean room 1 is the type of parts shown: here the bill of materials of a scheduled item must be filtered in order to show only the items required for the bonding phase, while in clean room 1 it was filtered to include only those materials needed for the lamination phase of the manufacturing cycle.

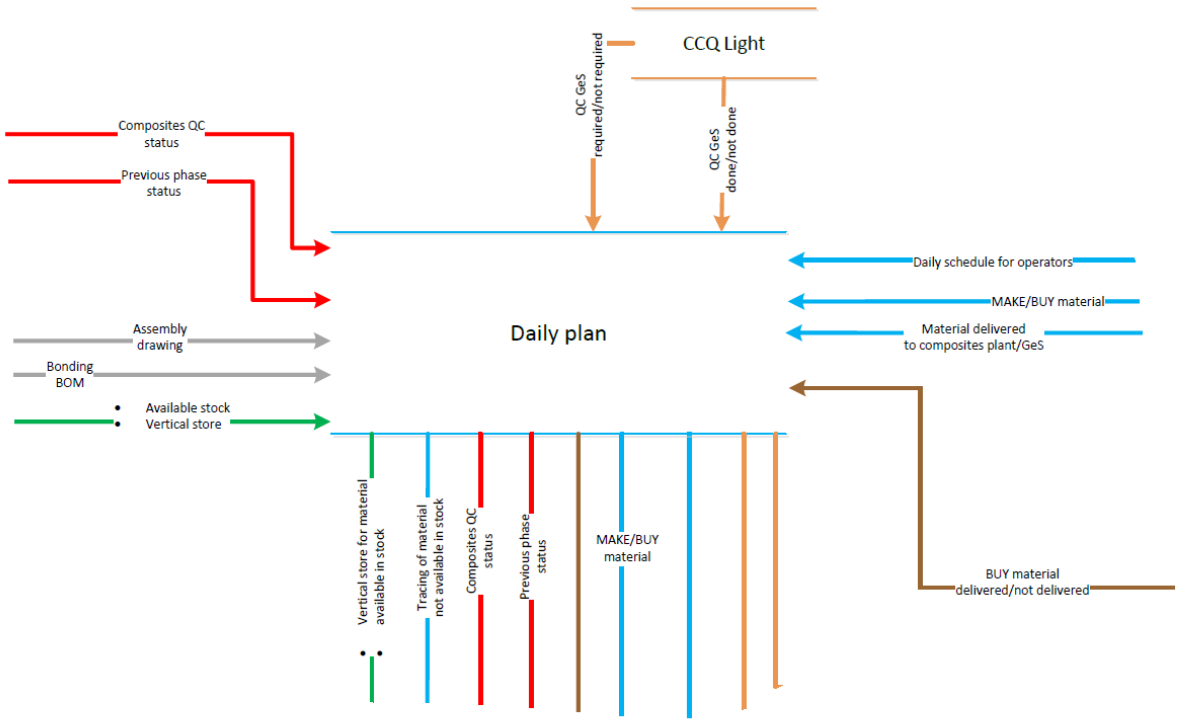


Figure 53- Overview of the information flows converging in the TO BE Daily plan for Body shop

All the redesigned information flow of the TO BE situation is stemming from the new Programma di lavoro and will be available at a glance to the body shop floor managers or the product family responsibles whenever an out of stock of an item required for manufacturing is detected: the software and type of information included are those introduced in the tool description in the clean room 1 section of this thesis. Those sources allow to solve the several different cases reported in the previous material flows analysis by providing the required information that in the AS IS situation needed to be retrieved by several different softwares or by means of phone calls, and that in the future TO BE situation will be, instead, collected in one single dashboard page accessible directly via the new Programma di lavoro. This solution is aimed at providing visibility about the traceability of a product across the supply chain and at offering a data-based solution to the most frequent causes of out of stocks as experienced in the daily body shop's operations, achieved by building a software framework able to standardize all the common practices already adopted to deal with those situations in the current scenario.

4.4.4 Body shop: material flows

The following material flows analysis related to the TO BE situation has been developed with the target of defining how the newly designed kit preparation process will be affected by the peculiar material flows of the body shop environment: the same flows introduced and analysed in the AS IS section, indeed, have now been integrated with the kit preparation creation process in order to highlight when this is applicable immediately (OK situation) and when it should be delayed (NOK situation). The final goal of the analysis hereby presented has been that of predicting possible implementation problems for the kit preparation process and of assessing its suitability and required features to ease the search of missing items across their supply chain.

Once the newly designed daily plan has been generated then, ideally the evening before a specified working day, the search for material is performed by the dedicated logistic operator. He/she can access the daily plan in electronic format and follow the traffic light logic implemented by this tool, as described in the to be clean room information flow: in case of green light, meaning the searched material is available in the required quantity in a vertical store, its location is shown directly in the daily plan and it can be immediately picked and placed in a single kit box, registering the movement on GG2 by scanning the QR code of the picked item. This procedure holds true for any type of material involved in the body shop environment, being it laminates, tooling or inserts.

In case an item is found to be missing from the vertical stores, instead, a red-light situation arises and the operator, by accessing the link to the dashboard page associated to the searched item, can have at a glance all the available information related to its traceability.

- Laminates

A red-light situation for laminates may lead both to an OK and to several NOK kit preparation cases. If accessing the dashboard page of the searched laminate it is verified that the item is a MAKE one and that the last manufacturing phase before bonding has been already marked and closed, it means that most likely the part is stored in the upstream department responsible for that last production step performed and can be picked there. In this case the item is available for kit preparation, it must be picked by the logistic operator and placed in a single kit box. Given the impossibility of tracing the movement of a part picked directly from a previous department with the WMS software GG2, the picking of the item and placing in the kit box is traced on C3 by associating the item itself to the OdP of the assembly in which it will end up in the Distinta C3 section of the assembly's OdP itself: this means that as soon as a part is placed in a kit associated to an assembly assigned for manufacturing, it is not available anymore for other productions and should be not removed from the kit itself, in order to maintain a full traceability of the item.

Besides this single OK case for kit preparation though, all the other situations acknowledged in the AS IS material flows lead to a NOK kit preparation. This is the case of MAKE items that will be delivered JIT from the previous manufacturing steps the same day planned for their bonding in the body shop, or the equivalent case of BUY laminates that will be delivered by suppliers JIT for the subsequent bonding phase. Moreover, a NOK situation is experienced as well when the parts are received at the central receiving area instead that at the composites plant: regardless of whether they will be checked by the quality department or not, BUY laminates received at the central receiving area need to be delivered to composites plant by a milk run shuttle running at fixed time schedules, so that it is impossible to include them immediately in the kit. The result of a NOK situation as the ones just described is that the kit cannot be completely made due to the unavailability of all the items required, but still it can be completed the day after JIT for the start of the bonding phase: the underlying logic of these

NOK situations is that they are not the standard desired scenario but still they are manageable with the kit preparation process by simply delaying the kit preparation.

A different situation is experienced for all those branches of material flows leading to a rescheduling of the manufacturing performed in the body shop: those are NOK situations by definition and are more serious compared with the NOK status described before, given the impossibility to manage them even with a delayed kit preparation process. In those cases, the bonding phase for that assembly must be rescheduled due to a delay in the delivery of the laminates and the whole process shown in the flowchart leading to a kit preparation must be run again from the very beginning until it is reached an OK or NOK situation that can be dealt with by a late kit preparation.

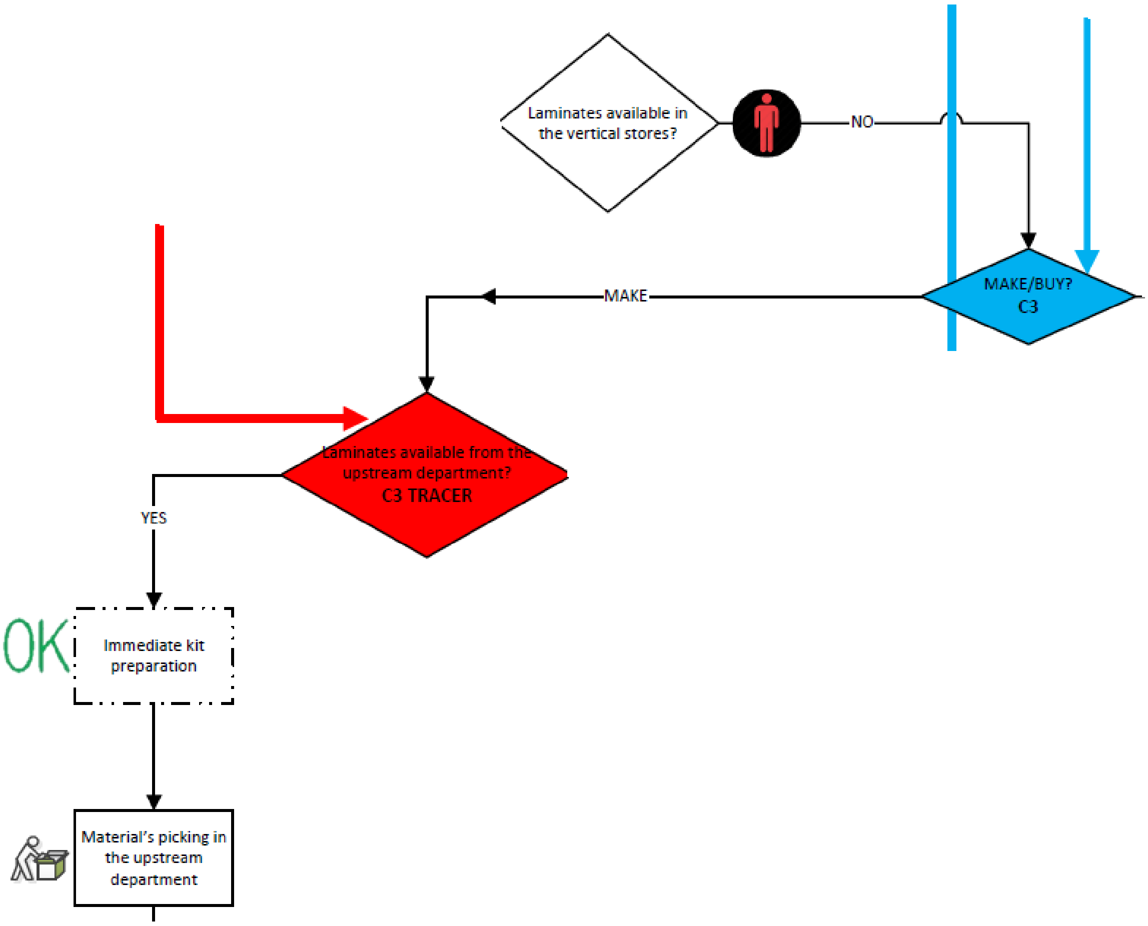


Figure 54- Focus on the processes leading to a OK kit preparation for laminates

- Bonding jigs and inserts

The material flows for bonding tooling and inserts leading to kit preparation is completely comparable to what just described about laminates as regards the possibility of leading to an OK or a NOK kit preparation case. In both cases, indeed, we can find two OK cases for immediate kit preparation process: one is the best case scenario in which the searched equipment or insert is found available in stock in a vertical store, while the other is the case in which a MAKE item has already been produced and it is stored in the upstream department responsible for the last cycle step before the bonding phase, being it a manufacturing or a quality control one. Those two situations, as described in the laminates section, can be dealt with by immediately picking the material in the location indicated by the dashboard page associated to the searched code and putting it the kit box. Again, for items picked from other departments, the traceability will be ensured by associating the part's OdP with the assembly's one in the Distinta C3 section at the moment of putting the parts in the kit box.

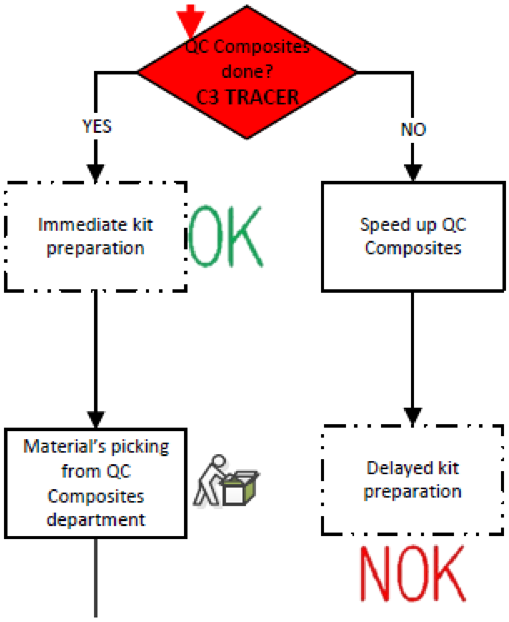


Figure 55- Focus on the process leading to a OK kit preparation for equipment

All the other cases experienced lead, instead, to a NOK kit preparation, being it manageable by a late kit preparation process or leading to a reschedule of the production: as already described for laminates, the former is the case of all those items that will be delivered JIT for production on the same day of the bonding phase, thus impossible to kit in advance but still able to be kitted JIT prior to the manufacturing process in which they are required. The latter, instead, is the case of all those MAKE and BUY items that, due to delay or problems experienced in their sourcing process, will not be available for production, thus forcing to reschedule it and run again the kit creation process as soon as they will be received.

- Operator's activity and post-bonding flows

The operator's activity is basically unchanged compared with the AS IS situation: the kit boxes prepared by the logistic operator will be stored on dedicated shelves and associated to the name of the operator in charge of producing each specific assembly. At the beginning of the shift, operators will pick the assigned kits and will reach their workstations to perform the manufacturing. The material and information output of their action is unchanged compared to the AS IS situation.

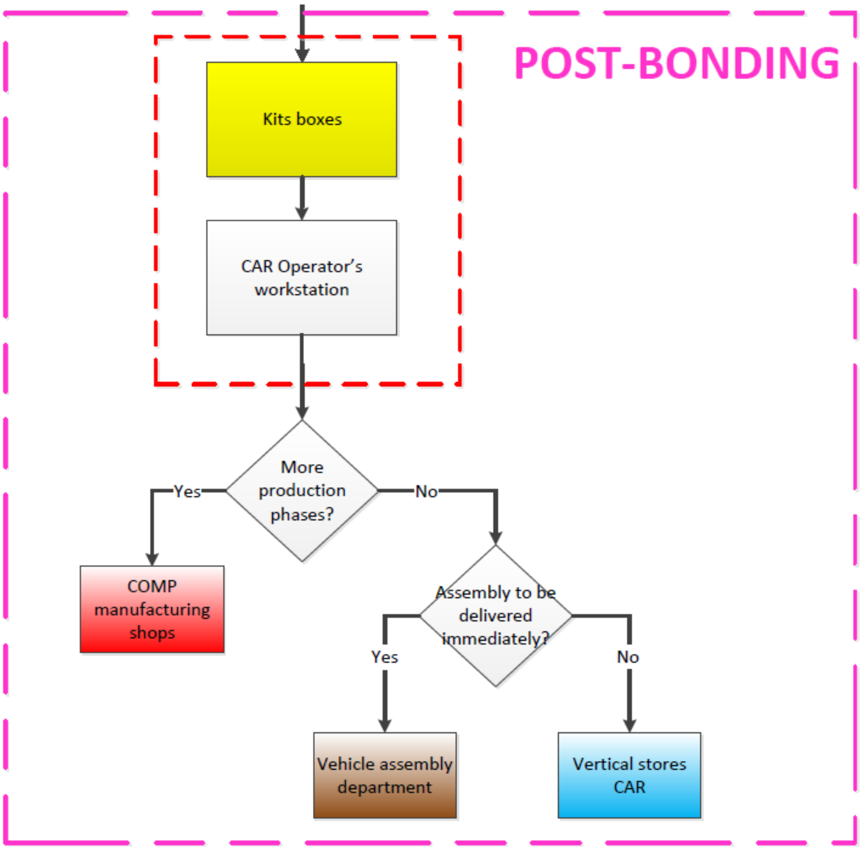


Figure 56- Overview of the material flows associated with the TO BE bonding and post-bonding phases

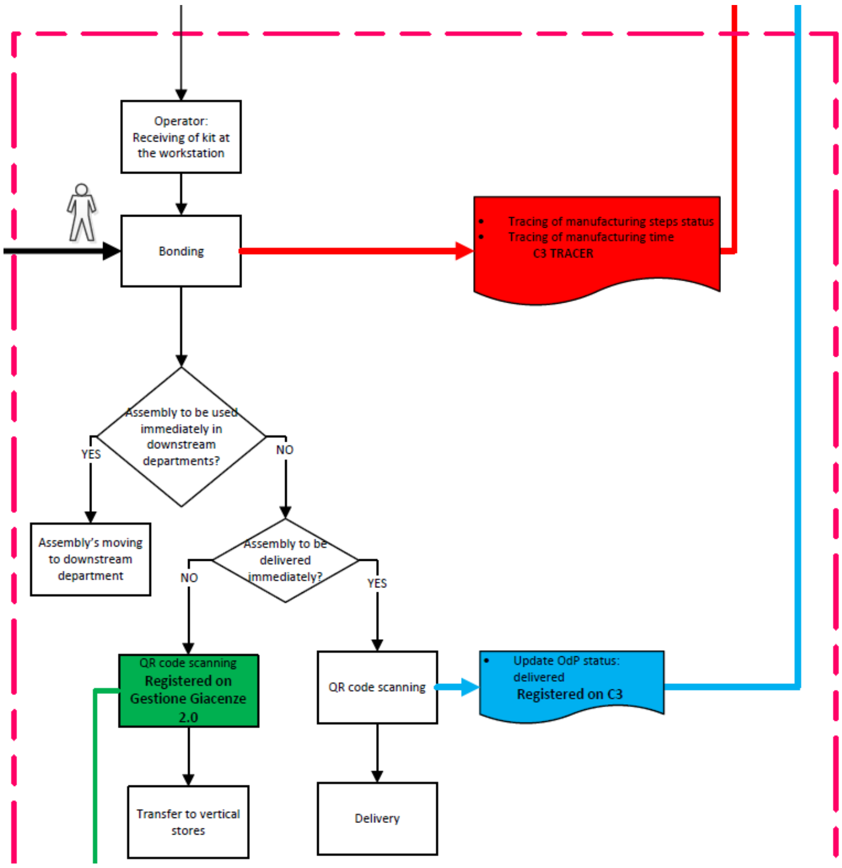


Figure 57- Overview of the information and processes associated with the TO BE bonding and post-bonding phases

As a further comment to this section it is worthwhile to note that the role of the kit preparation process as designed for the body shop environment is dual. On the one hand we have that of streamlining the daily operations already performed in the AS IS situation by the logistic operators by providing them with the full picking list of the items required for a manufacturing shift at a glance and in an automatic way. On the other hand, though, the kit preparation process and particularly the C3 tool developed to sustain it is targeted at supporting the product family responsibles and floor managers in their search for materials across their whole supply chain: given the peculiarities and time constraints proper of the body shop environment, it has been fundamental to develop a tool not just able of extracting a picking list to perform a simple retrieval of materials, but able to recover the information about those items in order to sustain the operations right from the planning phase up to the actual physical kit preparation.

4.5 Practical implementation

4.5.1 Planned introduction steps

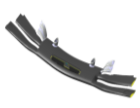
After the analysis of the current situation in clean room and body shop and the design of a new scenario featuring the kit preparation, the introduction of the process has been broken down into some implementation steps. The approach in kit preparation development has been careful and gradual for many reasons:

- Switching from the current material flows management method in clean room 1 and body shop to the new kit preparation process is a potentially disrupting innovation involving all the operators working in the analysed shops. In order to achieve that, a robust process must be developed and introduced step-by-step without causing major disruptions in the shop floors' daily activity.
- Given the highly non-standardized production performed in clean room 1 and body shop, a large number of individual cases exist. They need to be acknowledged through practical implementation of the kit preparation process and integrated with it by standardizing the most recurrent ones and defining standard operating procedures to deal with those exceptions difficult to effectively be integrated with the new logistic concept. Some of these cases can be taken into account from the very design phase of the kit preparation process, while others require to gradually implement the concept to be identified and dealt with step-by-step.
- As described in the previous section of the thesis, one of the core steps in the kit preparation process implementation involves the development of new features of the MES software C3. It was decided to allocate the task to internal software development resources, so that a division into smaller development steps was necessary to properly fit with the resources' capacity. Moreover, any software release entails a thorough debug phase before making any tool available to the shop floors and the operators. By splitting the development into smaller steps it was possible to focus on the debug of any phase, releasing tools and features ready to be used by operators without the need for further refinement of the software later in the deployment path.

Given those points, the following steps for kit preparation process implementation has been defined:

1. Development of the C3 tool to generate the complete list of all the materials needed to perform the manufacturing, starting from the daily plan as prepared by floor managers. The list of this first step should contain:
    a) Complete BOM of all the items required to laminate/bond a part, filtered to include just the materials required in the specific shop. This means that in a clean room environment just those parts needed for lamination must be incorporated in the BOM, while in a body shop environment just those required for bonding, in order to avoid confusion and speed up picking process.
    b) Grouping of the items of point a) according to their type. For the two separate cases of clean room and body shop we will have respectively ply kits, tooling, inserts and laminates, tooling, inserts, commercial codes.
    c) Association of the BOM with the father's production order.
    d) Association of the previous points a) and b) with the operator assigned for production of any specific item and the related manufacturing phase allocated.

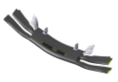
As just introduced, the first implementation step is intended as a rough picking list of all the materials needed for manufacturing on a considered day of production: note that it does not contain the location of the searched items in the related vertical stores, thus still relying on the use of PDAs to retrieve that information from GG2.

	Codice disegno	Descrizione	Osservazioni	Seq.	Attività
	610802018	FWM / 4A / 18 - LAMINAZIONE		20	Laminazione e preparazione sacco

		Codice	Descrizione	Quantità	Checklist
	INSERTI	610742658	PRESA PRESSURE TAPPING FW - MK3	12	✓
		610748734	FWM/1A/18 - BALLAST SUPPORT - BONDED PAD	1	
ID Operatore		610748735	FWM/1A/18 - BALLAST SUPPORT - BONDED PAD	1	
Cognome / Nome		610801932	FWM/4A/18 - LAMINAZIONE - RHC RWD OB	1	
Ruffatto / Matteo		610801933	FWM/4A/18 - LAMINAZIONE - RHC RWD OB	1	
Turno		610801934	FWM/4A/18 - LAMINAZIONE - RHC CENTER	1	
		610801935	FWM/4A/18 - LAMINAZIONE - RHC BAG SUPPORT	1	
		610801936	FWM/4A/18 - LAMINAZIONE - RHC BAG SUPPORT	1	
Mattina		610801949	FWM/4A/18 - LAMINAZIONE - SPAR	1	
		610802034	FWM/4A/18 - INSERTO FWM / HANGER / VANE	1	
		610802035	FWM/4A/18 - INSERTO FWM / HANGER / VANE	1	
	TOOLING	**Codice**	**Descrizione**	**Quantità**	**Checklist**
		610805542	ASSY_MFP_1_FWM/4A/18 - LAMINAZIONE	1	✓
		610805545	PART_MFP_1.1_FWM/4A/18 - LAMINAZIONE	1	
		610805547	PART_MFP_1.2_FWM/4A/18 - LAMINAZIONE	1	
		610805550	PART_TSL_1.3_FWM/4A/18 - LAMINAZIONE	1	
		610805551	PART_TSL_1.1_FWM/4A/18 - LAMINAZIONE	1	
		610805552	PART_TSL_1.4_FWM/4A/18 - LAMINAZIONE	1	
		610805553	PART_TSL_1.2_FWM/4A/18 - LAMINAZIONE	1	
	PELLI	**Codice**	**Plybook**	**Quantità**	**Checklist**
		610802018	610802018	1	✓

Figure 58- Mockup of the Step 1 software tool developed for CR1 and Body shop

2. Full implementation of the dashboard tool to localize all the parts of point 1 in their vertical stores or in their supply chain, when not available in stock. The logic underlying the dashboard page and its information content has been described in the TO BE scenario analysis of this thesis: this second and last implementation step is targeted at the full development and introduction of the IT infrastructure needed to effectively sustain and allow the kit preparation process starting from the MES software C3.



ID Operatore	
Cognome	Nome
Ruffatto	Matteo
Turno	
Mattina	

Codice disegno	Descrizione	Osservazioni	Seq.	Attività
610802018	FWM / 4A / 18 - LAMINAZIONE		20	Laminazione e preparazione sacco

	Codice	Descrizione	Quantità	Status	Magazzino	Ubicazione	Checklist
INSERTI	610742658	PRESA PRESSURE TAPPING FW - MK3	12		ALI-E	3	✓
	610748734	FWM/1A/18 - BALLAST SUPPORT - BONDED PAD	1		maggiori informazioni		
	610748735	FWM/1A/18 - BALLAST SUPPORT - BONDED PAD	1		ALI-E	2	✓
	610801932	FWM/4A/18 - LAMINAZIONE - RHC RWD OB	1		CR1-H	12	✓
	610801933	FWM/4A/18 - LAMINAZIONE - RHC RWD OB	1		maggiori informazioni		
	610801934	FWM/4A/18 - LAMINAZIONE - RHC CENTER	1		maggiori informazioni		
	610801935	FWM/4A/18 - LAMINAZIONE - RHC BAG SUPPORT	1		maggiori informazioni		
	610801936	FWM/4A/18 - LAMINAZIONE - RHC BAG SUPPORT	1		maggiori informazioni		
	610801949	FWM/4A/18 - LAMINAZIONE - SPAR	1		CR1-H	6	✓
	610802034	FWM/4A/18 - INSERTO FWM / HANGER / VANE	1		CR1-H	6	✓
	610802035	FWM/4A/18 - INSERTO FWM / HANGER / VANE	1		CR1-H	6	✓
TOOLING	**Codice**	**Descrizione**	**Quantità**	**Status**	**Magazzino**	**Ubicazione**	**Checklist**
	610805542	ASSY_MFP_1_FWM/4A/18 - LAMINAZIONE	1		maggiori informazioni		
	610805545	PART_MFP_1.1_FWM/4A/18 - LAMINAZIONE	1		Z - Sottoscala Clean Room 1	1 - Cassetto 1	✓
	610805547	PART_MFP_1.2_FWM/4A/18 - LAMINAZIONE	1		Z - Sottoscala Clean Room 1	1 - Cassetto 1	✓
	610805550	PART_TSL_1.3_FWM/4A/18 - LAMINAZIONE	1		maggiori informazioni		
	610805551	PART_TSL_1.1_FWM/4A/18 - LAMINAZIONE	1		maggiori informazioni		
	610805552	PART_TSL_1.4_FWM/4A/18 - LAMINAZIONE	1		maggiori informazioni		
	610805553	PART_TSL_1.2_FWM/4A/18 - LAMINAZIONE	1		maggiori informazioni		
PELLI	**Codice**	**Plybook**	**Quantità**	**Status**	**Freezer**	**Ubicazione**	**Checklist**
	610802018	610802018	1		CR1	VASC F	✓

Figure 59- Mockup of the Step 2 software tool developed for CR1 and Body shop

After the starting of the software development phase according to the previous points, a slight modification in the implementation steps has been introduced, in order to speed up the kit preparation process introduction and allow for a more meaningful debug phase to test more advanced features of the newly designed tool from the very beginning of its development.

1.1 Development and introduction of the C3 tool to generate the full list of materials required for manufacturing on a selected day, starting from the daily plan as generated by floor managers. The amount of information present in this updated introduction step is comparable to that described in the previous point 1), though with the fundamental addition of the location of the searched items when they are found to be available in stock.

Moreover, in this point 1.1) a first step towards the traffic light logic implementation of the step 2) has been introduced by highlighting with a red colour material required for manufacturing but not available in a vertical store, as retrieved from GG2.

In contrast to the previous point 1), though, this new implementation step will not feature the ply kit associated to a part to be manufactured in clean room 1, the association of the operator with the assigned manufacturing phase, nor the grouping of items according to their type as described in the point b) for both clean room and body shop cases. Additionally, following from the need to use built-in features of the WMS software GG2 for searching the availability in stock of the required items, the graphical representation has been changed and simplified as compared with the previous point 1). All those changes did not affect usability of the tool and the scope of the project as regards the initial implementation step 1), while at the same time speeding up the software development phase.

Step 2), instead, remains unchanged compared with the previous planned implementation step, so that overall the software tool developed will converge with the initially designed one.

4.5.2 Physical process design

Once the implementation steps have been defined and agreed with the software development resources, the details of the physical kit preparation process have been addressed and designed. In particular, the base logic to be followed for grouping parts in kits and to manage the information content introduced by the new designed software tools have been defined.

4.5.3 Analysis of the logics for grouping materials in kits

The choice of the underlying logic for grouping parts in kits is particularly critical for the effectiveness and requirements of the kit preparation process. Based on the peculiar characteristics of the production of clean room 1 and body shop, three possibilities have been identified and analysed:

1. *One kit for each part (KPP- "kit per parte")*. This is the easiest possible logic to be implemented for kit preparation. It requires that all the items belonging to the BOM of a single part scheduled for manufacturing are placed in a single dedicated kit box, associated to the related operator. This logic has the following advantages:
   - Robustness. Assigning a dedicated box to each part is the most robust solution since it nullifies the possibility of confusing items belonging to different parts and to forget them while manufacturing. Given that a kit following the KPP logic will contain only those items belonging to a single part, there is no source of confusion with items belonging to other parts (as would be with a KPP SX/DX or KPO logic, as will be described below) and it is practically impossible to forget parts in the kit because the box must be fully emptied during the manufacturing phase.

   - Time. KPP logic allows for the fastest possible operations when picking the material from the box to use it in the manufacturing phase: limiting the number of items in a box to that strictly necessary for the production of a single part allows to avoid wastes of time in searching for an item among the others, thus reducing to a minimum the time spent for retrieving the material from the kit itself.

- Traceability. Collecting all the items associated with a part in a single kit box allows to ensure the traceability of the materials even after they are kitted and placed in the box. Given that in the TO BE designed scenario the association between the items and the kit boxes they are grouped in is not registered in any software, the one-to-one correspondence between parts and kits ensured by the KPP logic allows the full traceability of the related items, that are necessarily stored in the single kit associated with the part itself.
- Flexibility. KPP logic allows to cover a broad variety of possible cases happening in clean room and body shop environments related both to organizational and to product-specific issues: dedicating a single box for each part, indeed, allows to manage those parts whose production takes many days and is performed by several operators in parallel. Since the kit is product-related, it will be the same throughout all the working days required for production, irrespectively of the operators assigned to it day by day: the kit will be a single box from which all the items will be picked when needed, JIT for the scheduled manufacturing phase.

KPP logic is suitable to cover in a robust and complete way the great majority of scenarios that may possibly happen in clean room 1 and body shop, coming though with the major drawback represented by the large number of physical kits needed. KPP, indeed, requires to create as many kits as the number of parts scheduled for production on a working day: in peak production periods and especially in clean room 1, where the capacity is larger, this means a lot of kits to be prepared and stored, having a large impact on the internal layout of the shops. Based on a comparable peak production period from the previous season, indeed, the following data representative of a worst-case scenario can be obtained.

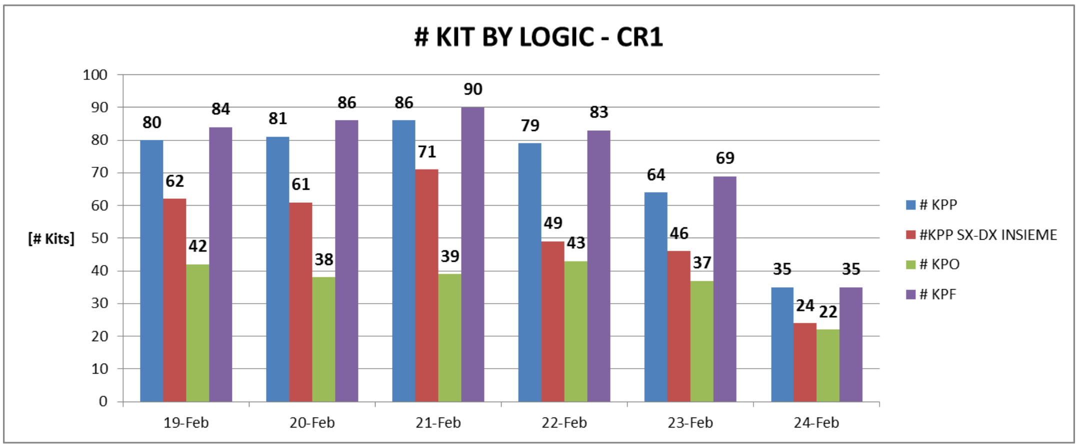


Figure 60- Analysis of the number of kits according to different logics analysed in a peak production period

The number of kits created in clean room 1 with the KPP logic is, on average, 72 per day: this means that every evening one or more dedicated logistic operators must prepare 72 kits for the day after, collecting all the items required and placing them in the single boxes associated with parts. The large amount of kits has an important influence particularly on the space required not only for storing them after they have been prepared, but also to store them while they are created and the material picked. Given the lack of available space in the composites plant this requirement is a key factor to keep into consideration in deciding the logic to be followed for kit preparation process.

2. *One kit for a symmetrical pair of the same parts (KPP SX/DX- "kit per parte SX/DX)*. This method for kit preparation requires to include in a single kit boxes all the items required to manufacture a symmetrical pair of the same part. A particularly common situation in clean room 1 environment, indeed, is that an operator is assigned to the production of both the left and right version of the same part. Those parts fundamentally behave as two distinct parts, having different -yet symmetrical- BOMs and tooling: the possibility of merging them in the same kit box stems from the fact that usually they are assigned to the same operator for production. KPP SX/DX takes advantage of this situation, allowing basically to obtain the same benefits associated to the KPP method, though with the important advantage of reducing the number of necessary kits. Compared with the KPP logic, indeed, KPP SX/DX allows for an average 25% reduction of the overall number of kits, depending on the number of symmetrical products scheduled for production in the selected day, as it is reported in the previous graph. A lower number of kits entails a corresponding saving of time, manpower and space required for their preparation and storing, thus partially solving these issues connected to the use of a KPP logic.
   KPP SX/DX, though, shows also some disadvantages, the most obvious one being that it is suitable just for symmetrical parts: implementing a KPP SX/DX logic for non-symmetrical products is equivalent to create the kit with a KPP logic, thus falling back in the previous case. Another point making the logic unsuitable to cover all the possible cases that may happen in clean room and body shop, is that KPP SX/DX logic requires both the parts to be assigned to the same operator: again as in the previous case, if the parts are assigned to two different operators they basically behave as two separate products so that they must be included in two different kits, thus falling back to the KPP case.

3. *One kit for each operator (KPO- "kit per operatore")*. This logic for kit preparation requires that the items necessary for manufacturing all the parts associated to each operator in the daily plan are grouped into the same kit box: KPO means basically collapsing many KPP-based kits into the same box, associated to the related operator and covering his/her whole working day. As for the KPP logic, KPO shows some advantages:
   - Kit's handling. With the KPO logic every operator is associated with only one single box, covering the whole working day. This fact makes it easier to handle the kits, since the whole handling is reduced to that of one single box, instead of the many boxes associated with the KPP logic, both in the kit preparation and the kit utilization phases.

- Space utilization. KPO logic is associated to the least possible number of kits created, their quantity being equal by definition to the number of operators active in the shop floor each day: according to the data presented in the KPP section related to clean room 1, the equivalent number of kits created with a KPO logic is on average 47% lower compared with that obtained with the first method. As a consequence the space occupied by kits is much lower compared with that required with a KPP logic, with a reduced need throughout all the kit lifecycle: preparation when picking the material, storing before the beginning of the shift and utilization at the workstation by the operators.

KPO, though, shows some relevant disadvantages and difficulties, potentially highly impacting on its implementation:

- Limitation on physical space available in the kit. Fitting all the items necessary for the manufacturing of the assigned parts in one single box (or more than one, though always following the KPO logic by including all the necessary items as per the daily plan, irrespectively of the part they belong to) may not be always possible due to the limited dimensions of the boxes themselves. Particularly in clean room, indeed, often moulds/patterns and carbon fabric kits are of large dimensions and it is not possible to fit multiple items like those in boxes as required by definition of the KPO logic. This is a major constraint limiting the applicability of the KPO method for kit preparation: in the worst case scenario items are included in more than one kit box per operator exploiting all the available space to fit the largest possible amount of material according to the daily plan, thus enlarging the number of actual kits compared with the theoretical one and moving towards that obtained with a KPP logic.

- Organizational and product-specific issues. KPO logic is not suitable to be used with production cycles requiring more shifts or even days. By definition of KPO every kit should include just the materials required for a single day of manufacturing as obtained by the daily program: in case the lead time is longer than one working day, KPO implies that the daily prepared kit should include only those items scheduled to be used that specific day by each operator, which means KPO logic is converted into a KPF method. This latter shows many implementation difficulties, as will be described below in more detail.

- Mixing of items in the same kit. By definition, the KPO logic requires to mix in the same kit box all the items necessary to manufacture the different parts assigned to each operator on a specific day. According to the complexity of those parts' BOMs, a kit may contain a potentially high number of items, particularly in the case of commercial codes and small elements. This fact represents a relevant source of confusion and time waste for the operators when picking the materials from the kit box: since the items are mixed they

must first be identified, located in the kit box and only after picked and used for production. Enlarging the number of elements contained in the kit the time required to perform those operations, as well as the risk of selecting the wrong item, increases accordingly.
In order to limit this risk, a physical separation between items belonging to different parts in the kit box would be useful to avoid risk of mixing: this solution, though, is hard to implement given the high types and dimensions variability of the items that must be included in a kit, constantly changing on a day-to-day basis.

4. *One kit for each manufacturing phase (KPF- "Kit per fase")*. This logic for kit preparation is the theoretical ideal target to be achieved, coming with some major advantages but also with some implementation difficulties making it unsuitable to fit the current clean room and body shop environments. KPF method requires to include in every kit only those items necessary to cover the specific manufacturing phase assigned for a working day: the daily program in clean room and body shop, indeed, is now configured as a phase-based program, meaning that specific phases of the manufacturing cycle are assigned to each operator for completion in the selected day. This fact allows to cover the wide variety of cases that may possibly arise in production, ranging from simple parts whose manufacturing in clean room or body shop is completed in one single day, to more complex parts requiring few days in each shop, to exceptional cases such as the chassis or the floor, requiring weeks to be completed. Breaking down the production cycle to be performed in each shop into simpler phases allows to schedule with more precision the daily activity of the operators, by assigning them single phases day-by-day rather than the whole production of the item. Given this fact, KPF shows some main advantages:
    - *Integration of kit preparation with the daily plan*. KPF logic would fit perfectly the phase-based scheduling method used in clean room and body shop: every kit, indeed, contains just the items necessary to cover the phases planned for the day after, so that each scheduled phase will correspond to a kit in a one-to-one ratio.

    - *Product-specific issues*. KPF is particularly suitable to cover those parts requiring more than one day for manufacturing, and also those exceptions that, such as the aforementioned chassis or the floor, require many weeks and several phases to be completed. Preparing a dedicated kit for every production step, indeed, allows to provide the operators with the only items required for the specific phase scheduled. Breaking down the whole amount of material required to manufacture a product into several kits prepared day-by-day according to the schedule allows to reduce confusion and streamline material flows: every kit box, indeed, will be completely emptied during the day of manufacturing, so that no remaining parts have to be managed, as it would be the case with a KPP logic.

- *Time spent in retrieving parts from the kits*. Given the fact that one KPF kit contains just the amount of material required to complete the assigned production step, the number of items per kit is reduced to the minimum possible level compared with the previous analysed methods. As a consequence, the time spent in searching for a specific item into the kit box and the risk of confusion when picking materials from it is reduced to the minimum level as well.

KPF logic, though, shows also some major disadvantages highly impacting on its practical implementation:

- *Number of kits*. KPF method for kits preparation comes with the largest possible number of kits to be prepared every day. Compared with KPP logic, indeed, KPF potentially leads to a higher number of boxes to be prepared and stored, depending on how many phases of a single part are scheduled for production each day: if a KPP logic requires to collect all the items in a single product-specific box, KPF instead requires to split those items into the different production phases in which the manufacturing cycle is subdivided, thus potentially multiplying the number of boxes in the shop floor.
  A higher number of kits, as mentioned before, not only requires more time and manpower to be prepared and handled, but also a larger space availability for their preparation and storage prior to the picking by the operators for production.

- *Lack of information*. The biggest problem connected to the KPF logic is the lack of information about the association between manufacturing steps and items required in each. Manufacturing cycles, indeed, are reported in a simplified form on the C3's OdP section of every part scheduled for manufacturing, so that with the current information availability about manufacturing steps, it would be impossible to associate precisely an item to the specific production phase it will have to be used in. This holds true simply because manufacturing cycles are not described from a material use point of view, but are defined based on the broader production phases required to manufacture an item from the raw material up to the delivery. This fact is verified for common parts requiring more than one day for production: manufacturing cycles for products like the chassis or the floor are more detailed and an association item-phase may be performed in those cases, but for the large majority of parts this is not possible given the low-level detail in which the production cycle is reported on C3. Moreover, the association between items and phases they have to be used in is not registered in any form on C3. With the current information structure, on which the newly designed tool for kit preparation will rely as described in the TO BE information flow section, the association item-phase is not provided: the tool allows to extract the full BOMs of all the parts scheduled for manufacturing, but their filtering according to their association with a specific phase of the cycle is impossible, since it is a piece of information which is not managed in any software available.

Performing this connection would be possible just with the experience of a skilled logistic operator who would have to manually select the products from the general picking list associated to the part, pick the material identified as connected to the phase scheduled for that specific date, and finally create the kit. The robustness in this case would be very poor, highly relying on single operators' activity and personal knowledge rather than on information retrieved from C3 and collected in the proper form in the picking list given by the newly designed tool described before.

All the previous logics were taken into account and evaluated, finally choosing the KPP for both clean room and body shop mainly for the sake of its robustness and flexibility to cover all the cases that may possibly happen in the two shop floors.

5. Conclusions

5.1 Expected results and benefits for the company

The kitting introduction process described above has been developed with the general aim of shortening the lead time of composites laminated and bonded parts, by identifying and eliminating wastes related to operators' movement and time spent in retrieving the material needed for manufacturing. This target is part of the broader objective of reducing the time to market of strategic composites assemblies which are subjected to a fast development rate, thus requiring a comparable fast production for the subsequent testing and eventually for the track use: this general target of reducing the time to market is the strategic objective pursued by all the Lean activities performed in the production facilities of Gestione Sportiva division.

As a final target of the project, some estimates were made about the benefits brought by the kit preparation process introduction: the following numbers were developed by evaluating the expected outputs of the designed process with the shop floor staff and responsibles, so as to roughly quantify the targets associated with the materials' and information flows' management methods proposed. It was estimated that the newly designed process will allow to reach the following targets, compared with the original situation:

- *95% of product types covered in clean room 1 and body shop*. The kit preparation process will allow to cover the vast majority of products manufactured in CR1and body shop thanks to the KPP logic. Given its robustness and flexibility, a product-specific kit is able to cover all the cases possibly happening in clean room 1, such as for example: complex products requiring more days to be produced, simple laminates that can be completed in one single day, assemblies requiring many operators working together, cases in which the material is delivered JIT from different sources as well as cases in which all the required material is immediately available in-stock, cases in which not all the material required is immediately available however it is possible to start the production and complete the kit at a later moment, upon reception of the missing items. These are just some of the cases experienced in practice in the two environments that we weekly monitored in order to validate the proposed KPP logic and kitting process. The 90% target has been set acknowledging that some very complex products, namely the floor and the chassis, will still need to be handled with the traditional material retrieval and presentation strategy: indeed, due to their complexity, dimensions, variability (this latter just for the floor case) and production lead time (particularly in the chassis case, requiring many weeks), the kitting process proposed is unsuitable to fit their specific needs, so that the current methodologies to manage and retrieve the material needed will continue to be employed.

- *90% of time savings in operator's movement and time spent in searching for material*. The kitting process proposed above has been found capable of significant savings in the time and movement spent by the operators of both CR1 and body shop to search for and retrieve materials required for manufacturing. At full capacity, the operators will need to directly access the vertical stores just in the aforementioned 5% of the cases (mainly chassis and floor) that will need to be dealt with in the traditional way. As a consequence, 90% of the current average time spent in searching for materials will be saved, with a residual 10% of time remaining to account for the inherent variability of the shop floors' operation and for the exceptions. The 90% time saving accounts also for the considerable time spent by product family responsibles and floor managers in finding an item not available in-stock in the vertical stores: when the dashboard to trace the materials required will be at full capacity, all the available information about the traceability of a certain item will be presented in one single page, thus resulting in a valuable tool to plan in advance the production (by possibly rescheduling a certain phase if an item is missing) and shorten the time required to find out-of-stock parts.

- *25% increase of logistic time by dedicated kitting operators*. As described in the literature review section of this thesis, it is an inevitable fact that the time saved by operators thanks to the use of kits must be spent in creating those kits by dedicated logistic operators. The 25% increase is a worst case scenario based on the observations performed about the number of kits required and the number of items to be included in those kits in a peak production period. This increase in the time spent in creating kits is one drawback of the kitting process: it is anyway acceptable thanks to the shifting of the non value-added activities related to material search and retrieval from the shop floor staff to the kitting operator.

- *10% increase in the floor space required*. Given the choice of the KPP logic, which comes with a very large number of kits compared with the other logics analysed, the floor space to create and store the kits before their delivery to the point of use is set to increase by a provisional estimate of 10%. The larger floor space required by kit preparation process is another inherent drawback of this material presentation strategy, as found in the literature review: according to the data introduced in the kitting logics analysis, the floor space required in peak production period is expected to be considerable and a suitable area must be found within the shop floors.

Product types covered by KPP logic	Time savings	Total logistic time	Floor space requirement
+95%	-90%	+25%	+10%

Figure 61- Summary of the expected benefits and drawbacks for the company

Overall, it is expected that the composites plant benefits from the kit preparation process by experiencing a strong reduction in the wastes associated with operators' movements and time spent finding the material. With the step 2, moreover, a valuable tool for the planning department, the product family responsibles and the shop floor managers will be provided:

this will allow to reduce the number of out-of-stock experienced by uncovering them in advance with respect to the manufacturing phase in which they should be used, possibly rescheduling the production or delaying the kit preparation process until the complete reception of all the required items if compatible with the time schedule. This last point has been reported as particularly important by all the stakeholders of the process: they highlighted the Lean need to visually manage the production and material availability from a single, user-friendly software tool, target that we aim to accomplish with the step 2 introduction.

5.2 Limitation of the thesis project

5.2.1 Time availability

The thesis here introduced has been developed as part of a project lasted from September to March 2019. During this time span, the kit preparation process has been fully analysed, designed, validated and planned for implementation but, due to the time constraints of the project, it has not been deployed in the composites plant. Time availability has been a major constraint in the development of the project and its implementation, particularly because the analysis and design of kitting process had to deal with the bottleneck represented by the software development. Given the large importance of information availability and network transparency in a ETO environment, the development of the software tool to generate the picking list of all the materials needed has been set as first priority in the kitting process implementation: due to the limited capacity of the internal software developed resources, though, the first drafts of the tool were available just at a late date of the 6 months' time span, so that the following steps were unfortunately impossible to carry on in the remaining available period.

Time availability has been particularly critical for the kitting process introduction in body shop. This last shop, as described in the related TO BE situation, need as a first step to move its daily planning on the "Gestione pianificazione" tool of C3, being it the basic requirement to use the newly designed software tool to perform the picking and trace the materials in their supply chain. At the moment the body shop staff has not been able to switch the daily planning to the aforementioned C3 tool, so that, due to this project's time limitation, the tool has now been introduced and tested just in the Clean room 1 environment.

5.2.2 Debug of the developed software tool

The implementation of the kit preparation process has been delayed also due to some problems experienced in the first debug phase of the software tool. Upon the release of the test version, indeed, a thorough debug phase has been performed to test the accuracy of the data provided in the picking list. At the present moment, the software tool developed for the first step of the kit preparation project has been developed and introduced in CR1, resulting in the following facts.

Even though a detailed description of this phase is not relevant to the kit preparation process analysis, it is meaningful to give a brief description of the problems experienced during the debug performed:

- *Absence of equipment in the picking list*. Due to an unused workflow in the PLM software Windchill, the BOM of a large majority of parts (on average 60% in the days considered in the debug) did not show the equipment required for their manufacturing, potentially resulting in a kit with missing items. Finding and solving the workflow required to involve the ICT department, consequently resulting in a time consuming activity.

- *Bonding equipment in the lamination BOM*. Roughly 15% of parts presented in the daily program of the considered days included some bonding and machining tools in the picking list generated for the kit preparation serving the lamination phase in CR1. Those tools are generally used in the body shop, thus resulting wrongly present in the picking list of the manufacturing phase performed in CR1. The problem is two-fold: on the one hand, not all the bonding and machining tools are external to the use in CR1, some of them required instead to be used during the lamination phase. On the other hand, there is not a clear way of distinguishing a priori between equipment to be used in CR1 and equipment to be used in body shop. The most robust solution required to involve the technical office to develop and agree among parts designers and industrialization designers a new tooling structure to assign each tooling to the appropriate manufacturing phase, right from the structure on the PLM Windchill and downstream to the software tool developed for the kit preparation. This step is particularly time consuming requiring many stakeholders to develop and agree on a shared and robust solution, resulting currently an open problem.

- *Tooling BOM*. In CR1 some 20% of the cases of moulds assigned for lamination reported the absence of the related tooling, i.e. of the associated pattern. This means that, following a KPP logic, the kit prepared for the lamination of a mould would have missed the presence of the equipment to create that mould. Further analysis showed that this is due to the fact that each mould is decomposed in its constitutive parts and each part is assigned for lamination: a bug in the software tool for the picking list prevented the proper association between the part of the mould assigned for manufacturing and the part of the pattern representing its tooling. The bug was easily solved, but finding the problem required a not negligible time.

- *Others*. 5% of various other bugs, for the moment neglected being minor and not deeply affecting the robustness of the data presented for picking.

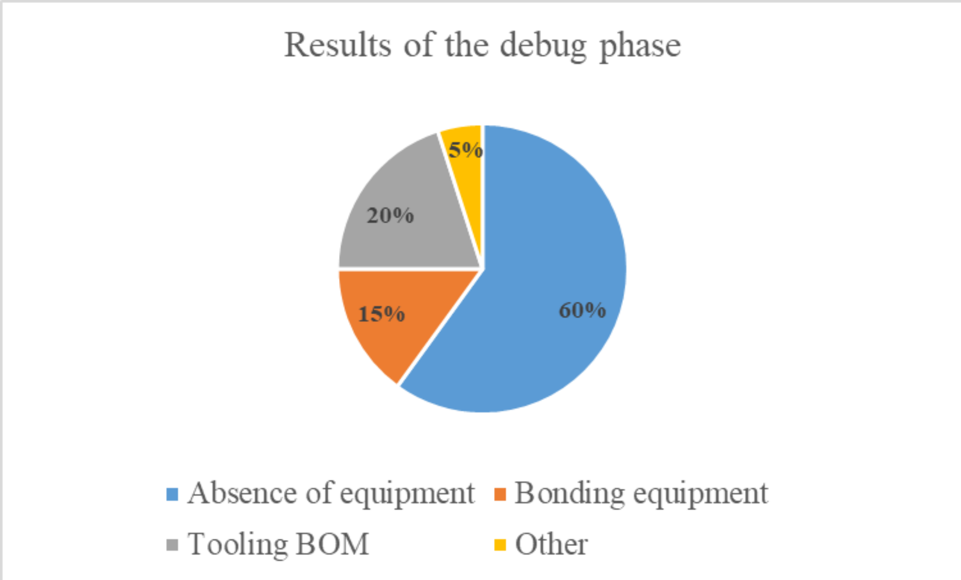


Figure 62- Summary of the outcome of the debug phase performed on the Step 1.1 software tool

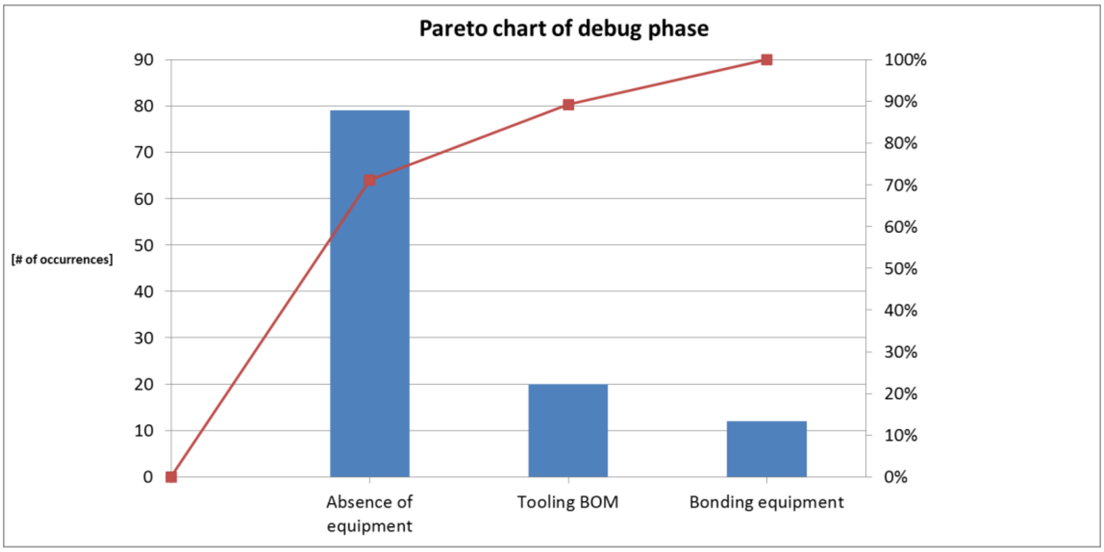


Figure 63- Pareto chart focused on the main bugs encountered in the debug phase. Note that minor bugs (i.e. the "Others" previously introduced) are excluded

5.3 Next steps for the company

As a conclusion to this thesis, some next steps for the Ferrari and particularly for the Lean implementation in the composites production plant will be discussed.

- *Kit preparation project*. The next steps for the full implementation of the kit preparation project are coherent with those described in the implementation plan.
    1. Currently a simplified version of the software tool developed for the step 1 has been introduced and is live in production. A more refined debug phase is required to provide completely robust data to support picking operations.
    2. Once the data provided by the tool are robust, the physical kit preparation process will need to be tested by means of a pilot project involving some logistic operators and shop floor staff. The aim of this phase is that of

measuring an average time required to prepare a kit, validating by practical evidence the choice of KPP logic and fine-tuning the materials and information flows connected to the kitting process that may have not been captured by the performed analysis.

3. The body shop will need to use C3 to perform the daily scheduling of the job shop, which is a fundamental requirement for the use of the developed software tool. This is the highest priority for the body shop, in order to realign its status with that if CR1.
4. Once the tool will be employed also in body shop, a dedicated debug phase will need to take place to verify that the data presented are robust and complete also for this shop floor. The debug will need to be followed by a preliminary physical kit preparation process to test the logic in an experimental way.
5. As soon as the physical process will be refined for both shops, the kitting process can be ramped-up to the whole number of operators as the only admitted way of presenting materials to the point of use.
6. Concurrently to the physical test of kitting through pilot projects in CR1 and body shop, the phase 2 of the software should be developed. From the software point of view, the target tool in terms of information provided and graphical representation is that reported in the previous section of the thesis, and this should remain the final target.
7. Once the software tool will be fully tested and operative, after a thorough debug phase, the integration of kitting process with the traceability provided by the tool itself will need to be physically tested and implemented in the job shops, according to the TO BE scenarios described in the previous analysis. The project may be considered as closed when the kit preparation process will be stable, efficient and effective in wastes reduction and materials delivery to the point of use.

- *Lean strategy*. A possible future step for the company to pursue is that of continuing its path towards Lean implementation in the composites plant, with the possibility of extending it to the mechanical components production plant. Education and participation of operators and responsibles will be a key driver in this Lean implementation path, as well as the strong support of the management.
  Implementing Lean in a stable way in such a complex environment requires to dedicate resources and time in process mapping, process analysis and Lean development. A future step for Ferrari may be that of creating a stable Lean group in the manufacturing areas, able to gain expertise and adapt Lean tools to the peculiar and unique characteristics of Formula 1 production environments. This group should ideally be fully dedicated to Lean implementation and would have the potentiality of obtaining strong production lead time reductions as well as money savings by finding, analysing and solving wastes in a dedicated and full-time way, especially by creating a robust and stable Lean culture among all the stakeholders.

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