POLITECNICO DI TORINO

Collegio di Ingegneria Aerospaziale, Meccanica, dell'Autoveicolo e della Produzione

**Master of Science in**
**Automotive Engineering**

Master's Thesis

# Analysis, modeling and simulation of the production processes for prototype bodywork components

**Supervisor**

prof. Franco Lombardi

**Candidate**

Riccardo Calza

September 2018

*To my family*

# Contents

# Figures

# Tables

# Abstract

This work is the report of a three moths internship developed at Eurodies Italia S.r.l., an Italian company located in the area of Turin, master manufacturer of prototype bodywork components for the most important automotive OEMs.

After acquiring a first general overview of their specific industrial processes, a modeling and simulation study was performed, aimed at providing the company with tools, methods and suggestions to increase its productivity. This Thesis reports such study, as well as the suggestions that may be useful for the company, and for other firms operating in such sector.

The first chapter explains why a medium *tier-2* company of the automotive sector is an interesting object for a research study: several key figures of the European and Italian automotive market are reported, both at a financial level and at an industrial and society level.

The second chapter focuses on the company itself, reporting and analyzing all the industrial and production processes that are needed to make a prototype bodywork component: starting with the activity diagram, all the tasks that are performed in Eurodies, from the construction of tools to the last finishing activity, are explained in detail.

Subsequently, Chapter 3 reports some of the issues observed in the company, which this Thesis wants to point out. The possible causes of the reduction in productivity that affects Eurodies (and many other similar companies of the sector) are analyzed, in order to make clear why such work of modeling and simulating the industrial processes was meaningful.

The fourth chapter starts from a brief description of FlexSim, the powerful simulation software used for our analysis. It then proceeds with a very detailed explanation of how the model of Eurodies was built on such software, starting from a *simplified model* and then introducing the actual full model. This chapter also contains the description of how time data about the duration of manufacturing activities was obtained and analyzed.

Chapter 5 describes how the simulation activity was conducted, introducing the concept of "mix of components" being produced, and explaining how five different *mixes* were tested, in order to discover which type of mix allowed to spend the minimum amount of time on Non Value Added (NVA) activities.

Finally, the sixth chapter reports and discuss the results that were obtained: mixes containing the lowest number of *chassis internal reinforcement* were the most performing.

As being developed at the end of this work, the Conclusions chapter gives a better understanding of the reasons why this thesis, rather than being a collection of exact results and prescriptions to the company, is actually meant to suggest a brand new model and a method that can be successfully utilized to increase productivity in a company that produces automotive prototype components.

Chapter 1

# Introduction

Cars and buses provide freedom and mobility for all, providing us with direct access to education, health and employment. Trucks and vans deliver the goods and services that are taken for granted in our daily lives, carrying 75% of freight transported over land and delivering 14 billion tons of goods per year. Many of our essential public services - such as postal, waste and emergency services - are delivered by cars, trucks and vans.

Europe's cars, vans, trucks and buses are the cleanest, safest and quietest in the world. Europe leads the way in clean production, with decreasing quantities of water and energy used to manufacture a vehicle, and much less $CO2$ and waste produced in the process.

This Master thesis follows from several months of analysis of an Italian medium/small company that operates in the automotive sector, producing prototype bodywork components for passenger cars and other kinds of vehicles. This firm, called Eurodies Italy S.r.l., is located in Avigliana, 25 kilometres away from downtown Turin.

As an Introduction to this work, it is necessary to consider some figures that explain why a small tier-2 company of the automotive sector is an interesting object of study and analysis for a Master Thesis.

As said above, cars are fundamental in today's society: no one is willing (for practical or psychological reasons) to live without a car. In addition to this intrinsic importance of motor vehicles, the economic importance of the sector must be taken into account.

According to the "Internal Market, Industry, Entrepreneurship and SMEs" department of the European Commission (2018), the automotive industry is crucial for Europe's prosperity. The sector provides jobs for 12 million people and accounts for 4% of the EU's GDP. These 12 million jobs can be subdivided into manufacturing (3 million), sales and maintenance (4.3 million), and transport (4.8 million). The EU is among the world's biggest producers of motor vehicles and the sector represents the largest private investor in research and development (R&D).

Economically speaking, the automotive industry is not only a great contribution to GDPs and governments revenue by itself, but it also has an important multiplier effect in the economy. It is important for upstream industries such as steel, chemicals, and textiles, as well as downstream industries such as ICT, repair, and mobility services. Speaking about government revenue, the most important figure that could be quoted here is the tax contribution from motor vehicles: in just 15 EU countries, this number is equal to almost €396 billion.

The automotive sector is also crucial for its ability to drive innovation. As Mario Draghi (2007) said, the innovative capacity of a country leads to goods, services, organization of the productive process of better and better quality. Innovation of product and process is what sustains long term growth, increasing overall system productivity. According to the European Automobile Manufacturers Association (2018), European OEMs have spent around 50 billion euro in 2015 for innovation. Speaking about knowledge networks that are present within the automotive supply chain, some peculiarities can be highlighted:

- The global dimension of innovation. Large OEMs utilize resources that are diffused at an international level. In particular, they show the tendency to use a limited number of global platforms for motor vehicles, that is, if a car is built for a precise market, it will have the features requested by those costumers, but it will also show the technology used in other models of the same platform.

- The development of innovation process. In the automotive sector, innovation has become a fundamental aspect. The introduction of electronic components has increased the number of technological fields involved in the production, and the growing competitive pressure has forced the OEMs to speed up the R&D process, decreasing its cost. Therefore, car manufacturers began to utilize labs and test centers spread all over the world, to develop and validate new products.
- The relationship with suppliers. Along the automotive supply chain, an important part of the innovation and technology contribution comes from the components makers, who often develop their products autonomously.
- Collaborations for research activity. Applied research, in the automotive field, is often preceded by a base research activity, shared by different companies. Often, OEMs sign agreement to jointly develop a new technology, which can be used and customized by all of them. Sometimes, base research is performed by autonomous actors, such as universities and specialized research centers.

The economic importance of the automotive sector in Europe has been presented, as well as its fundamental contribution to the overall level of innovation of European industries. Another reason why the automotive sector must not be neglected by lawmakers is the large number of jobs that it provides.

According to a research performed by the Commission for Industry, Commerce and Tourism of the Italian Senate (2015), the automotive sector has still a relevant role in the western economies. Considering both the industrial phase (first transformation activities and final manufacturing and assembly), and the distribution phase, the whole supply chain generates almost 5% of the GDP in Italy. This figure is similar in other developed economies, except for Germany, whose automotive sector is even more productive.

Basing on the 2014 data of the ANFIA (Associazione Nazionale Filiera Industria Automobilistica), the total number of employees in the automotive supply chain is over 1,2 million units in Italy, with relevant effects on the ability to create wealth in different

Italian regions. In Italy, the industrial phase generates around 28 billion euro of added value and employs more than 500 thousand people, contributing to 2% of the GDP. The distribution phase creates value for about 40 billion euro and employs 700 thousand people.

Another figure that must not be neglected is the great ability of demand creation: in Italy, every euro of added value in the manufacturing phase of the automotive sector sustains other 2,2 additional euro in other fields of the economy.

Basing on a more recent study of Centro Studi Promotor (2017), the total spending for cars in Italy was €189 billion in one year, equal to 11% of the GDP. More than 2 million new passenger cars were registered, and forecasts indicate that market levels similar to the pre-crisis ones will be reached in 2019 (two years earlier than the recovery of the pre-crisis levels of GDP, expected for 2021).

The European countries where the most vehicles are produced are Germany, Spain, France, the United Kingdom, Czech Republic and Italy.

Compared to other European economies, Italian automotive supply chain is made up of a greater number of companies. Therefore, similarly to its economy in general, also Italian automotive supply chain is characterized by the great importance and the significant weight of small companies.

Starting from the ‘80s, the automotive sector has been affected by a reconfiguration of its supply chain, characterized by a progressive de-verticalization, pushed by the need of decreasing costs, and of increasing flexibility. This was the response to the technological progress and to the change in demand (growth of emerging countries, diversification of costumer needs and wants in mature markets).

This outsourcing process has strengthened the role of suppliers. More precisely, supply chain has started to be organized in a hierarchical way, guided by first level suppliers (tiers 1), having a direct contact with the automotive companies (Original Equipment Manufacturer, OEM); below, we find second level suppliers (tiers 2), specialized in the production of specific components; tiers 3, which produce standardized components, and so on, until we reach activities with a lower added value.

Although components-making has a significant role in the Italian automotive supply chain, among the first 100 global supplier we can find only one Italian company (Magneti Marelli). Italian components, in fact, belong to the tiers 2 category, that is, specialized suppliers. These are firms that develop and produce a specific component or a subsystem for a determined model of car or platform; they can include process specialists (experts in the metal sheet stamping or in the diecasting, for instance), but also specialists with further competences in manufacturing and assembly.

The fact of not being included in the tiers 1 means that Italian components-makers cannot have a position of supply chain coordination. Nevertheless, specialized suppliers present some characteristics that are worth focusing on:

- compared to tiers 1, specialized suppliers perform generally less complex activities, but still characterized by a technological content that, when exploited in the right way with investments in innovation, can lead to a significant gain in competitiveness;
- while complex systems suppliers must build their plants close to the assembly plant, due to transport costs and just in time obligations, specialized suppliers are less influenced by these factors and have a relatively greater freedom in choosing the location of their plants;
- for the reasons explained in the previous point, therefore, specialized suppliers are able to remain in the territory where they have always been, maintaining relationships and at the same time, enlarging their networks beyond national borders, obtaining more efficient synergies and interactions. For example, several

> Italian components-makers have reacted to the reduction in national production, by increasing their international links and diversifying their customers.

Intermediate manufacturing activities have a predominant role in Italy (24%), more than in the other countries. Final manufacturing activities, differently, are more important in Germany (40%) and in France (19%), while they have a relatively low weight in Italy, where they account for the 12%.

Eurodies Italia S.r.l. is located exactly in this production segment (automotive sector, intermediate manufacturing activities). It is a medium company, with around 160 employees and annual revenues of circa 25 million euro.

Since prototypes are mainly used for testing the final product, it may be thought that the role of Eurodies will be less and less important in the future, with the advent of powerful simulation technologies. On the contrary, in the last years, the demand of prototypes by the OEMs has shown a stable increase.

There are multiple reasons: firstly, the credibility that Eurodies has gained in its sector, increasing stably its productive capacity and its technological level during the years (for example, with the purchase of two new latest generation presses in 2015 and 2016), in order to be able to satisfy *more* costumers and satisfy them *better*, with higher and higher quality products.

More importantly, carmakers have the need to face an increasing segmentation of demand: more differentiated demand means more models, and more models mean a greater number of prototypes needed for crash tests and validation. In addition, the end of financial crisis that hit the entire world in the last decade caused the largest OEMs to come out with many new models at the same time, in order to try to recover from the years of crisis. These reasons make prototype demand for Eurodies increase exponentially in the last 3-4 years.

The increase in productive capacity and in the experience and competence of employees and operators has allowed Eurodies to accept also some *small series* order, that is, orders of some thousands (or tens of thousands) units that last some years and guarantee the company a safe and continuous cash flow. This small series are usually components of particular sport-premium models, produced in very low volumes.

In any case, the company's core business is still prototype production: that is what guarantees the highest profits. The obligations of Eurodies towards its customers do not end at the moment of delivery, but may continue subsequently: in some cases, they cooperate with the OEM in the series production industrial phase, for example supplying them the CAD models of the dies. The dies, even after prototype production has ended, are kept in Eurodies' warehouse for a certain number of years: they are property of the customer, who can take them at any time. This request of keeping the dies available for such a long period of time (it could even be more than 10 years) is explained by two reasons:

1) the costumer could, in the future, launch a new version of the same model that was produced using those dies. In this case, the dies can be reutilized after a simple milling operation;
2) the costumer could need Eurodies to produce *series* components for a certain period of time, for different reasons. For example, if the *series dies* owned by the OEM break down, the carmaker may ask Eurodies to integrate their series production until the dies are fixed.

The next chapter analyzes in detail the industrial processes that Eurodies utilize to supply its costumers with high quality products in a relatively short time.

Chapter 2

# Industrial and production processes in Eurodies Italia

With reference to Figure 1 and Figure 2, which show the activity diagram, the entire process performed by Eurodies in order to produce a certain amount of components, from the moment in which the order is received to the delivery, is now presented and described. Subsequently, each phase is explained in greater details, with a technical description of the process when needed.

The industrial process for the realization of a prototype bodywork component starts with the delivery, by the costumer company, of the CAD model of the requested piece. Eurodies Italia's engineers, starting from such model, derive the models of mold and counter-mold, more commonly called die and punch (or generally, dies). Such dies will be mounted on the presses for the sheet metal working operations, such as drawing, flanging, etc.. The Computer Aided Design software used for this activity is Catia by Dassault Systèmes.

Before actually building the dies, the model needs to be validated with a simulation. An engineer specialized in simulations uploads the CAD models of die and punch on a software, which simulates the drawing process with a Finite Element Method (FEM) analysis. The software is called Autoform. If the simulation does not highlight particular critical issues, the models of the dies are approved and sent to the CAM department, where the toolpaths for the milling machines are studied and defined.

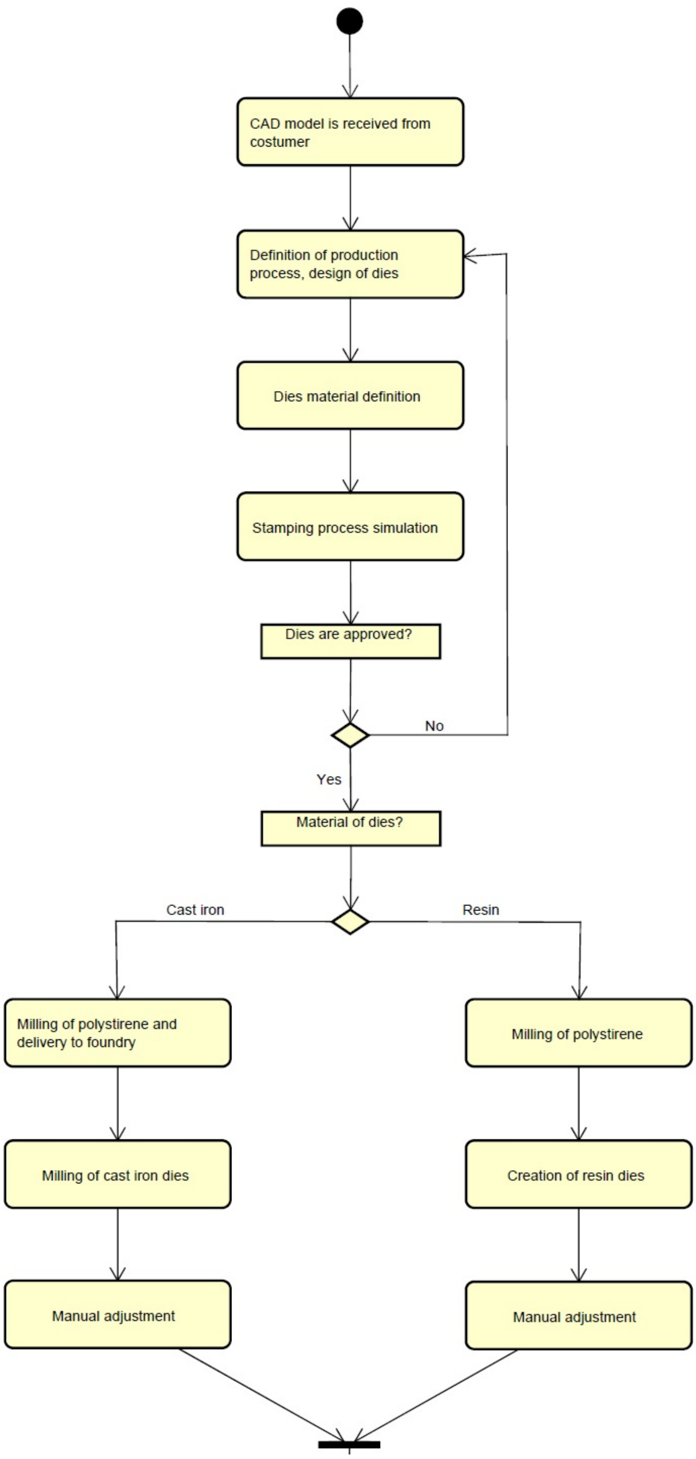



*Figure 1: Activity diagram of industrial processes in Eurodies (first part)*

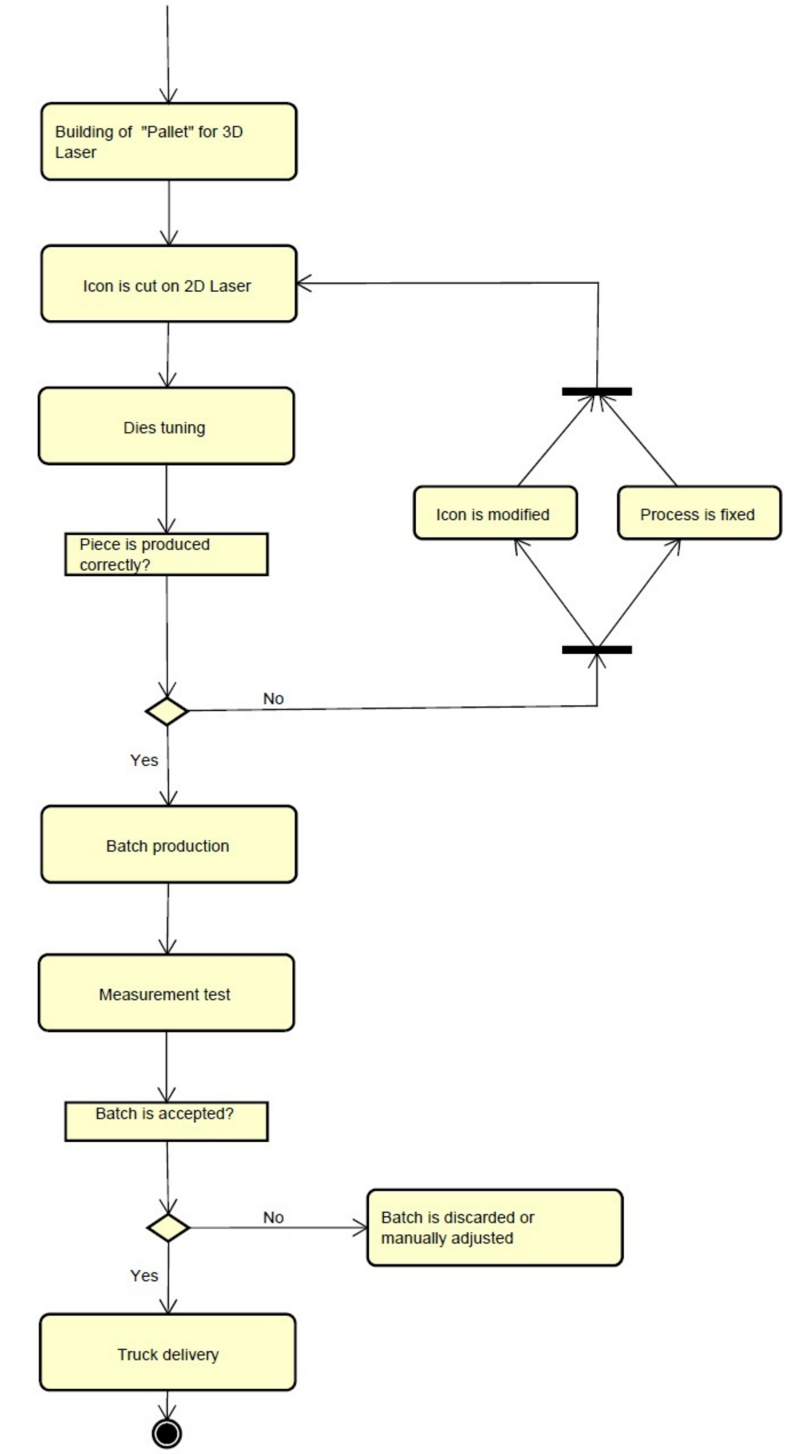



*Figure 2: Activity diagram of industrial processes in Eurodies (second part)*

Dies are built in polystyrene, utilizing a CNC 5-axes milling machine. The polystyrene dies are then sent to a foundry that, with an expendable-mold casting process, transforms the polystyrene shape in the permanent cast iron tool. The cast iron used for this operation is not high quality, since in this case the priority is to keep costs low, rather than make a very durable die set.

The rough cast iron dies are delivered from the foundry to the Avigliana plant of Eurodies, where they are worked by different CNC milling machines. The first operation is called *spianatura* (flattening) and it is necessary to make the bottom of both die and punch perfectly flat, in order to obtain a flat surface on which the dies can be laid for subsequent operations. This operation is often outsourced to third companies, since it a very costly one in terms of machine-hours, but it is not particularly complex. The flattened dies are then delivered back to Eurodies, where several large milling machines continue their construction. Such milling machines have different levels of power and precision: for the first roughing a powerful, yet less accurate machine is utilized; for the subsequent pre-finishing and finishing the choice falls upon more precise machines (usually the newest), which guarantee better dimensional tolerances.

Finally, die and punch are finished off by hand (with files and sandpaper) by specialized operators, the so-called *aggiustatori.*

Once the tools are ready (tools, or tooling, is the generic term for the dies), the punch is transported to the metal carpentry area, where the so-called *pallet* is built. In this context, the pallet is a support for the semifinished piece, on which the component will be laid after drawing, for the laser trimming operations. The construction of the pallet follows this procedure: the punch is laid on the floor or on a large metal plate; the carpenters build a support made up of different iron rods, cut of the appropriate length, so that the geometry of the component is followed. The carpenters, then, lay the upside-down pallet on the punch, applying molten resin on the parts where the support touches the punch. When the resin dries, the result is the "pallet", a support that perfectly follows the geometry of the punch, and therefore of the semifinished component. Figure 3, below, shows a finished pallet, ready to be transported to the 3D laser area, in order to be used for the laser roughing or laser finishing operation.

*Figure 3: A so-called "pallet" (support for the semifinished component)*

In the subsequent phase, die and punch are mounted on a hydraulic press, which will be used for the drawing operation. Nevertheless, before undergoing the drawing process in the press, the metal sheet must be trimmed by the two-dimensional laser to obtain the appropriate shape, determined in order to avoid possible wrinkles and defects. The rectangular blanks of metal sheet are cut by the laser machine with two degrees of freedom (plane movement), and the positioning of the metal sheet in such machine is performed automatically with a suction cup manipulator and comb manipulator.

The shaped metal sheet that is the result of such operation is called *blank outline* or "icon".

As was anticipated, while the 2D laser is cutting the blanks according to the appropriate blank outline, the operators perform the operation of *dies mounting.* The heavy tools are transported with an overhead crane and positioned on a sliding plate, that moves them under the press, as shown in Figure 4. Some areas of such photograph, showing finished or semifinished parts, have been blurred due to industrial secret reasons.

*Figure 4: Mounting of die and punch on the hydraulic press*

As it was said above, the drawing operation is performed in a hydraulic press: since the dies built at a prototype level are not perfect (due to the very short time obligations required by the costumer), it is sometimes necessary to use some "empirical solution" to allow the material to flow properly between the dies in the critical parts. For example, pieces of nylon are added in those points, as well as lubricants such as oil or fat.

The blankholder is often not perfectly flat, and it lies on the "candles" (hydraulic actuators located in the lower part of the press) in an irregular fashion. In such a situation, specialized operators realize the problem during the phase called *dies tuning* – the first tryout of the dies after they are mounted on the press – and correct the issue inserting one or more shims between the candles and the blankholder. Figure 5 shows such "empirical solution": since the blankholder bottom is not perfectly flat and therefore the force is not equally distributed, the operators specialized in dies tuning have inserted small portions of metal sheet between the blankholder itself and the candles, in order to even out the holding force during drawing.

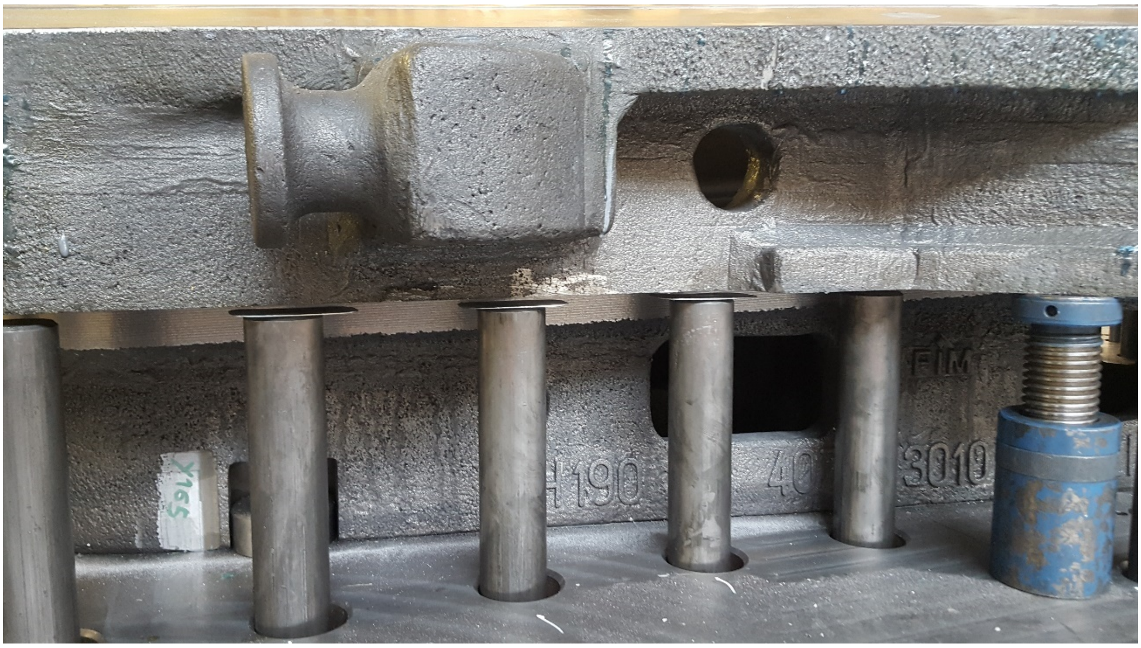



*Figure 5: Shims inserted between "candles" and blankholder*

After the dies tuning, the actual production phase begins. The activity diagram of such phase can be seen in Figure 7: the blanks are cut by the 2D laser, according to the appropriate blank outline and are transported into the presses area, where they undergo the first press operation, that is, drawing.

After the drawing operation, the semifinished items are moved to the 3D laser area and laid on the *pallet*. Here, 5-axes CNC robots cut the metal sheet according to the "laserpaths" designed by the engineers of the laser office, obtaining the final measures of the piece and creating slots and holes. Such operation is shown in Figure 6, where the geometry of the piece has been concealed by blurring, due to industrial secret reasons. Looking at such photograph, the function of the so-called pallet can be seen and understood: it is necessary to hold the piece in the correct position with minim dimensional tolerances, so that the laser can obtain an almost perfect final geometry.

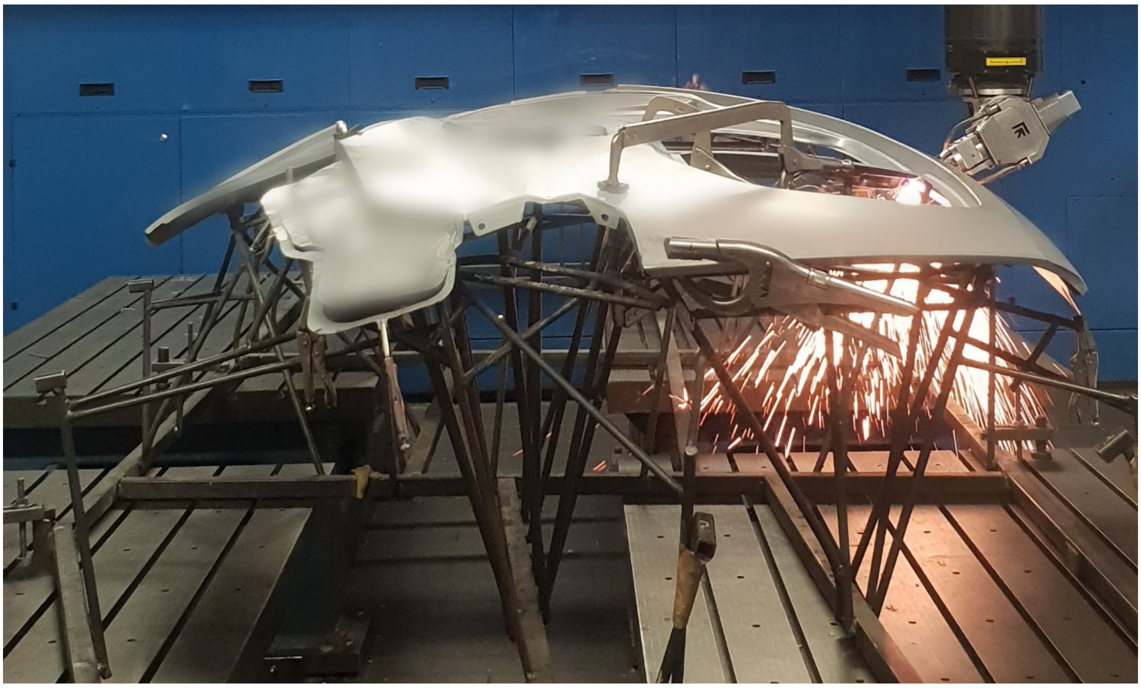


*Figure 6: 3D laser trimming operation*

Following the activity diagram, after drawing a decision node can be seen. In fact, for very simple pieces, the drawing operation is enough to obtain the final geometry, with just a finishing laser trim: in this case, the first and only press operation is called "dry drawing" (*imbutitura a secco)*, and it is performed without blankholder. For components with a more complex geometry, other press operations become necessary. For example, a *redrawing* may be needed (an operation that "fixes" the precise dimensions and the final geometry of the component, often performed on the same dies used for the drawing, with different tool pressions); or one or more *flanging* operations, needed to obtain the areas of the components that have a bending angle greater than 90 degrees.

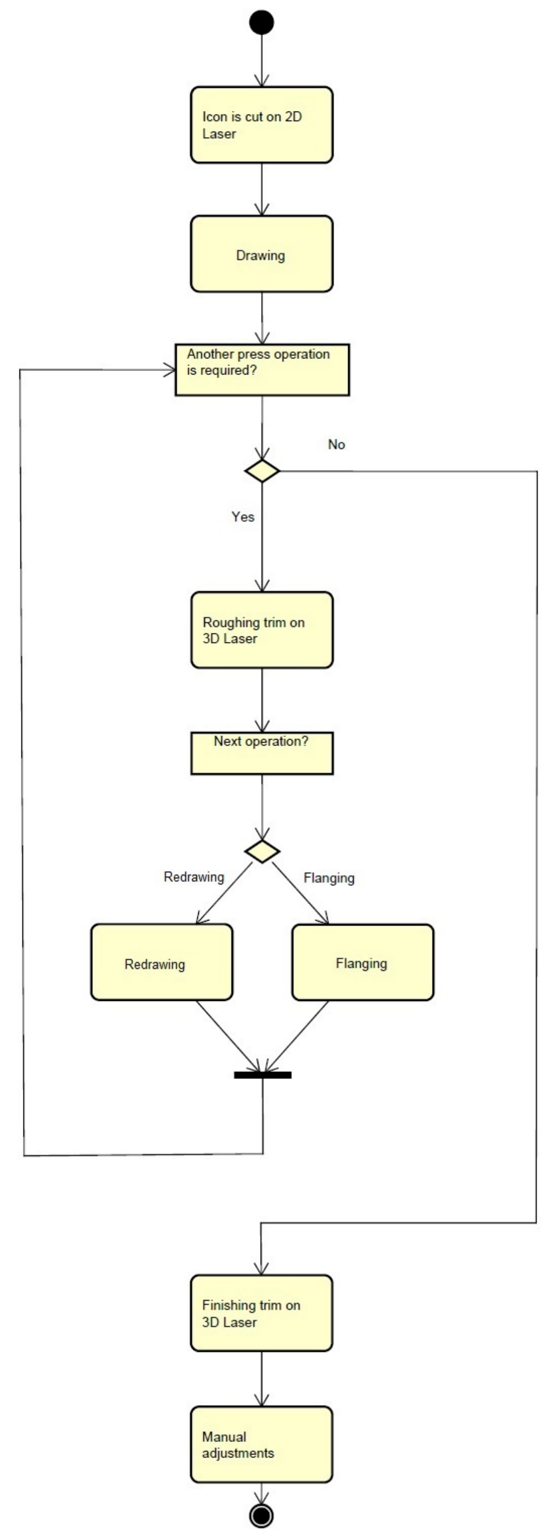



*Figure 7: Activity diagram of the prototype component production phase*

With reference to the same figure, looking at the activity diagram it can be noted that among press operation it is almost always necessary to perform a 3D laser trim. Summing up, a component that is "averagely complex" to produce needs a sequence of operations similar to the following: blank outline cut on the 2D laser, drawing, 3D laser roughing trim, redrawing, flanging, 3D laser finishing trim.

This sequence is not the same applied to all the components that are produced by Eurodies, since prototypes are always new and different by definitions, and working cycles show important variations. Nevertheless, such sequence is well representative of the average cycle adopted in the company, and therefore it will be considered as the "standard cycle" in the rest of this Thesis work.

Finally, the prototype components are manually adjusted and finished by specialized responsibles, called "metal sheet beaters" (*battilastra*): the final result is a component that perfectly satisfies the requested dimensional and geometric tolerances, produced in a really short time at a relatively low cost. The respect of tolerances and the precision of dimensions are verified randomly in the testing area: these data are not only used by Eurodies to internally check the quality of their production, but are also requested by the costumer companies, in order to have a numerical proof of the quality of the components that they are about to pay and have delivered.

## 2.1 Modeling of dies

Once the CAD models of the commissioned pieces are received, the CAD department starts to hypothesize which operations will be needed to produce the component. All the operations introduced in the last section are considered, both executed by a machine (press or laser) and manual ones. Clearly, in the prototype field the objective is to keep costs as low as possible; therefore, in this design phase the engineers try to obtain the final piece with the lowest number of operations. In fact, more press operations mean more dies to be produced, which have an extremely high cost, and more laser operations means a longer cycle time and more machine-hours and man-hours.

When the production cycle has been defined, the dies are designed on the software Catia, by offsetting the surface of the component, and adding the necessary material to support such surface during the drawing.

At the same time, the engineers decide which material should be used for the dies, choosing among:

- cast iron, the most common material, more costly but durable
- steel, chosen for small dies, its advantage is that it is only machined in the milling machines, without having to wait for the foundry to provide the casting
- resin, much cheaper but not durable, it is used when the order is of few pieces

## 2.2 Simulation of drawing

As Fan et al. (2006) explain in their paper, design methods for sheet metal forming have always been based on trial-and-error. Nevertheless, because of the recent demand for higher precision and reliability in components produced with this process, traditional empirical methods have become inadequate to provide a solution. Therefore, the Finite Element Method (FEM) has started to be gradually adopted by companies that operate in this sector, in oder to forecast the formability of sheet metal during drawing. The complex physical mechanisms involved in the sheet metal working processes create a high order non-linear problem. Nonlinearity is caused both by contact and friction, and by the large displacement and important deformation. In addition, the problem is made even harder to be solved analytically, because of several material behaviours that show non-linearity, such as plasticity, visco-plasticity and damage. "Therefore, numerical techniques, such as the finite element method (FEM), are usually used to deal with this kind of problem. FEM can provide not only the final results, but also the information of intermediate steps, like the distributions of displacement, stress, strain and other internal variables. Due to its versatility, FEM has been widely used in various fields. For two-dimensional studies of sheet forming processes, various finite element analyses have been performed by the implicit method applying the direct matrix solver. The implicit method is usually efficient in providing an accurate solution in simple cases. Due to the success in applying the two-dimensional FEM, some attempts have been made to extend the implicit method to solve three-dimensional problems" (Fan, et al., 2006).

Eurodies decided to make use of one of these softwares that solve numerically three-dimensional problems in sheet metal forming simulations. However, the engineers know perfectly that the results of such simulations are far from having a high accuracy, and will rarely predict the actual behaviour of the blank during drawing.

Nevertheless, after the design of the dies is concluded on Catia, the software Autoform allows to simulate the operations that will be performed during the production phase. If the results of the simulation do not highlight critical issues, the design of the dies is approved, and the project moves on. Otherwise, if there are critical issues, the design of the dies is modified, or the production cycle is changed.

## 2.3 Casting process

As anticipated, the dies used for presses operations (drawing, redrawing, flanging) are manufactured starting from a cast iron shape, created in an expendable-mold casting process.

Groover (2010), in his book about manufacturing processes, explains that "casting is a process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity". The word casting is used both to indicate the process, and for the resulting part.

Casting can be considered one of the most versatile manufacturing processes, due to the great number of shape casting methods available. As every production process, casting has both advantages and disadvantages. The most significant advantages are:

- casting allows to obtain complex geometries, both external and internal, that would be very difficult to create with machining techniques
- several of the casting methods are "capable of producing parts to net shape. No further manufacturing operations are required to achieve the required geometry and dimensions of the parts. Other casting processes are near net shape, for which some additional shape processing is required (usually machining) in order to achieve accurate dimensions and details" (Groover, 2010)
- casting processes can also produce parts of very large dimensions
- material versatility. Basically any metal that can be molten to liquid state could be used for casting.

Disadvantages are multiple and diverse: poor mechanical properties, porosity, bad precision in dimensional tolerances and poor surface finish; as well as safety hazards for the operators that have to manipulate hot molten metals.

Casting processes can be subdivided into two categories, depending on the type of mold that is utilized: expendable mold and permanent mold. Expendable molds are made of sand or plaster, mixed with some binders in order to keep their form. When the casting is solidified and must be extracted, expendable molds have to be destroyed to remove the part from the interior.

The most utilized typology of expendable mold process is sand casting. In this method, molten metal is poured into a sand mold, that is destroyed to extract the casting when the metal has hardened.

Groover (Groover, 2010) also introduces some terminology: the mold "is made of two halves: cope and drag. The cope is the upper half of the mold, and the drag is the bottom half. These two mold parts are contained in a box, called a flask. In sand casting (and other expendable-mold processes) the mold cavity is formed by means of a pattern, which is made of wood, metal, plastic, or other material and has the shape of the part to be cast". As said above, the pattern used for the production of dies castings in Eurodies Italia are made of polystyrene. Thanks to the binder, after packing sand around the pattern and removing the pattern from the mold, the sand maintains its form and creates a cavity. The pattern is almost always oversized, because of the phenomenon of shrinkage of metal, as it solidifies.

## 2.4 Milling process

When the castings of the dies are delivered back to Eurodies, from the foundry, the longest and most expensive process in the production of the tools begins: milling.

As Groover (2010) explains, in milling, a rotating tool with multiple cutting edges is fed slowly across the work material to generate a plane or curved surface. Unlike drilling and other machining operation, the feed motion has a direction that is perpendicular to the axis of the tool. Such tool is called a milling cutter and the cutting edges are called teeth. Milling is defined as an "interrupted cutting" process, since the teeth of the cutting tool enter and exit the workpiece at each revolution. Such discontinuous cutting creates cyclical impacts, causing physical and thermal shock at every rotation: for this reason, the geometry of the milling cutter and its material must be chosen keeping in mind these demanding conditions.

There are two types of milling: periphery milling and face milling. The next paragraph focuses on the latter, since it is the one used in the production of dies. "In face milling, the axis of the cutter is perpendicular to the surface being milled, and machining is performed by cutting edges on both the end and outside periphery of the cutter. As in peripheral milling, various forms of face milling exist: (a) conventional face milling, in which the diameter of the cutter is greater than the workpart width, so the cutter overhangs the work on both sides; (b) partial face milling, where the cutter overhangs the work on only one side; (c) end milling, in which the cutter diameter is less than the work width, so a slot is cut into the part; (d) profile milling, a form of end milling in which the outside periphery of a flat part is cut; (e) pocket milling, another form of end milling used to mill shallow pockets into flat parts; and (f) surface contouring, in which a ball-nose cutter (rather than square-end cutter) is fed back and forth across the work along a curvilinear path at close intervals to create a three-dimensional surface form" (Groover, 2010). This kind of curvilinear control for the motion of milling cutter is used also to machine the internal cavities of molds and dies: in this case, the operation is called die sinking.

Milling machines generally have a rotating spindle, on which the cutting tool is mounted, and flat surface on which the workpart is positioned and fastened. There are obviously many subcategories of milling machines, which can be classified into the following types: knee-and-column, bed type, planer type, tracer mills, and CNC milling machines. All the machines that are present in Eurodies Italia Srl belong to the fifth typology. Computer numerical control milling machines are milling machines in which the cutter path is controlled by alphanumerical data rather than a physical template. They are especially suited to profile milling, pocket milling, surface contouring, and die sinking operations, in which two or three axes of the worktable must be simultaneously controlled to achieve the required cutter path.

## 2.5 Drawing process

Once the dies are ready, after milling and manual adjustment, they are mounted on the press and "tuned" by specialized operators. Subsequently, the first press operation can be performed on the metal blank: drawing.

Drawing is a sheet metal forming process used to make cup-shaped or other complex concave parts. It is performed by pushing a metal sheet into the opening of a die with a punch, while the blank is generally held in its position by a part of the die, called blankholder.

The drawing process will be now explained shortly, introducing the basic drawing operation, that is, drawing of a cup shaped part. "A blank of diameter $D_b$ is drawn into a die cavity by means of a punch with diameter $D_p$. The punch and die must have corner radii, given by $R_p$ and $R_d$. If the punch and die were to have sharp corners ($R_p$ and $R_d$ = 0), a hole-punching operation (and not a very good one) would be accomplished rather than a drawing operation. The sides of the punch and die are separated by a clearance c. This clearance in drawing is about 10% greater than the stock thickness:

$$c = 1.1\ t$$

The punch applies a downward force F to accomplish the deformation of the metal, and a downward holding force $F_h$ is applied by the blankholder. As the punch proceeds downward toward its final bottom position, the work experiences a complex sequence of stresses and strains as it is gradually formed into the shape defined by the punch and die cavity" (Groover, 2010). The process starts when the punch hits the blank and starts to push it downwards, performing a bending operation. The sheet is bent around the corners of the dies, while the outside part of the blank moves towards the center. This movement, though, is not excessive: the blankholder keeps the metal sheet flat and does not allow a too large flow towards the center. As the punch keeps moving, the portion of metal that has been bent over the die corner is subject to a straightening action. In fact, the metal at the bottom of the piece has been pushed downwards, but the metal that has been bent must be straightened in order to be pulled into the clearance. While this happens, the metal that is flowing down to form the walls of the cylinder (or cup) must be replaced by the material that was held between die and blankholder: such material is *drawn* towards the cavity of the die, and this movement gives the name to the *drawing* process.

As it was just explained, the metal must flow between blankholder and the outer perimeter of the die: it is clear that friction between the sheet metal blank and the dies, in this context, must be overcome. At first, static friction prevents the metal to move, until it begins to slide; subsequently, dynamic friction slows down its flowing movement. The two parameters that govern the process are such friction and the blankholder holding force: both can be modified externally, since the friction can be reduced applying lubricants, and the blankholder force is a machine parameter that can be set on the press computer.

Not only friction, but also compression occurs in the outside perimeter of the metal sheet. As the material in this part of the blank is pulled toward the center, the outer edge becomes smaller. Nevertheless, the volume is constant: for this reason, the metal becomes thicker in the edge area. If the blankholder force is not enough, this may result in wrinkling, one of the most common defects that occur in the drawing process.

Since the wrinkles cannot be removed once they are present on a workpiece, this blankholder force is seen as a critical factor: if it is too low, wrinkling occurs; if, on the contrary, it is too large, the metal cannot flow toward the center and it can break or stretch. The specialized operators of Eurodies, when they determine the correct blankholder pressure, have to find a balance between these factors.

## 2.6 Redrawing process

Redrawing, as the name suggests, is a second drawing operation. It is needed for workpieces of large dimensions and complex geometry, and it allows to obtain the proper final geometry when the drawing operation alone is not sufficient. It is usually performed using the same dies used for the drawing, but often the blankholder is not utilized. As it was explained in a previous section, a drawing performed without blankholder is defined as "dry drawing".

The redrawing process is not only needed to fix the final geometry and prevent the springback, but it is sometimes useful to stamp some particulars that were not possible during the drawing. For example, the area around slot and holes is stamped in the redrawing, because such holes and slots are not yet present when the part is drawn, since they are cut by the 3D laser in a subsequent operation.

## 2.7 Flanging process

Flanging is a metal sheet forming operation in which a portion of a sheet or of a semifinished product is bent along a straight or curved line, of an angle equal or greater than 90 degrees. If the angle were less than 90 degrees, flanging would not be necessary, since the drawing or redrawing dies are capable of producing such angles. Eurodies Italia performs flanging on components that, by design, need an L-shaped profile on some sides, such as front fenders or roofs.

Essentially, flanging is a bending operation. Groover (2010), in his book about manufacturing, defines bending, in sheet-metalwork, "as the straining of the metal around a straight (or curved) axis. During the bending operation, the metal on the inside of the neutral plane is compressed, while the metal on the outside of the neutral plane is stretched. The metal is plastically deformed so that the bend takes a permanent set upon removal of the stresses that caused it". Such process does not modify the thickness of the blank, but only the direction of its axis in certain parts. Similarly to drawing, also bending and flanging are performed on an industrial press, with punch and die. The two common bending methods and associated tooling are V-bending, performed with a V-die; and edge bending, performed with a wiping die. Bending operations made in Eurodies Italia S.r.l. are all of the second type: edge bending involves cantilever loading of the sheet metal. A tool called pressure pad is utilized to hold the workpiece on the die, while the punch pushes the part to bend around the corner of the die itself. Particular attention must be paid to the phenomenon called springback: not all the energy transmitted from the punch to the workpiece is used for plastic deformation, a part of such energy remains stored into the component as elastic energy, causing the bent portion of the blank to recover partially towards its original shape once the punch moves back upward and releases the workpiece. The springback, therefore, is defined as the "increase in included angle of the bent part relative to the included angle of the forming tool after the tool is removed. This is expressed as:

$$SB = \frac{\alpha' - \alpha'_t}{\alpha'_t}$$

where SB = springback; a′ = included angle of the sheet-metal part, degrees; and $a'_t$ = included angle of the bending tool, degrees" (Groover, 2010). The increase in bending angle is not the only the only effect caused by springback: another, less visible, effect is the increase in the bend radius, still caused by elastic recovery.

Keeping in mind that the springback is proportional to Young modulus E and to the yield strength Y of the material, it can be tried to compensate for such phenomenon in different ways. The most used methods are overbending and bottoming. The former consists in making the bending angle of dies and punch smaller than the nominal angles of the final component, so that when the springback occurs, the angle goes back to its specified value. The latter, bottoming, is performed squeezing the workpiece in the bend area, plastically deforming it and "fixing" the geometry.

## 2.8 Description of industrial press

Nearly all of the preceding pressworking operations are performed with conventional punch-and-die tooling. The tooling is referred to as a die. It is custom-designed for the particular part to be produced. Such tools (punch and die) are mounted on a machine called press.

As Groover (2010) describes, a press used for sheet metalworking is a machine tool with a stationary bed and a powered ram (or slide) that can be driven toward and away from the bed to perform various cutting and forming operations. The relative positions of the bed and ram are established by the frame, and the ram is driven by mechanical or hydraulic power. When a die is mounted in the press, the punch holder is attached to the ram, and the die holder is attached to a bolster plate of the press bed.

Cattell (2008), in his paper about industrial presses, explains that presses fall into four main categories: mechanical, hydraulic, servo, and pneumatic. Each category derives its name from the drive source that generates the pressure (force) on the die to form the finished stamping. Each category can be further divided into one of two different frame designs: straight-side or C-frame. Each type of press can have single or double-slide (ram) connections. Straight-side presses have two sides and four to eight guideways for the slide. This reduces the deflection and enables them to handle off-center loads better. Mechanical and hydraulic presses, the two typologies present in Eurodies Italia's Avigliana plant, are now described in greater detail.

Mechanical presses can be subdivided by the type of drive transmission that applies force on the punch: flywheel, single-geared, double-geared, double-action, and eccentric-geared.

"All are powered by an electric motor that drives a large flywheel. The flywheel stores kinetic energy, which is released through various drive types. For each 360-degree cycle of the press, or stroke, energy in the flywheel is consumed as the part is made in the die. This causes the flywheel to slow, usually between 10 and 15 percent. The electric motor then restores this lost energy back into the flywheel on the upstroke of the press. The press is then ready for the next cycle" (Cattell, 2008). To stop and start the press, you use an electronic control to a clutch and brake, which in turn disengages the flywheel to the press drive. Most clutches and brakes are spring-applied and have either pneumatic or hydraulic releases. The stopping time of the clutch and brake is critical in determining both the speed that the press can be run and the safety of the operator and die.

Hydraulic presses have advanced dramatically over the years with new technologies and improvements in electronics and valves. They are especially suitable for deep-draw applications, because they can apply full tonnage over the complete length of the stroke. In addition, the velocity that the slide travels as it closes the die can be programmed, as well as the fast return of the punch. The stroke can be programmed to any distance needed, thus achieving the maximum SPM available with the pump design. A hydraulic press is powered by a hydraulic pump, pumping oil into a hydraulic cylinder or cylinders that drive the slide down. Pressure can be preset, and once achieved, a valve can activate pressure reversal, so no overload can occur. With this press design and its applications, the die tends to guide the press, so the guiding systems do not have to be as accurate as with a progressive-die mechanical press. Hydraulic press production speeds normally are lower than those achieved with a mechanical press. These presses are available with one or more independently operated slides, called single action (single slide), double action (two slides), and so on. Double-action presses are useful in deep drawing operations where it is required to separately control the punch force and the blankholder force.

Eurodies Italia, in the Avigliana plant, owns around 20 presses, 6 of which of very large dimensions. Only one of these six is a mechanical press, all the others are hydraulic presses. Four of the 6 machines of large dimensions are latest-generation presses built by the company Gigant Industries: two Gigant machines similar to the ones present in Eurodies are shown in Figure 8.


*Figure 8: Hydraulic presses built by Gigant Industries*

## 2.9 3D Laser trimming process

After the blank has undergone the drawing process on the press, the semifinished prototype is transported to the 3D laser area and clamped on the *pallet*, as shown in Figure 6 at the beginning of this chapter. Here, the powerful laser robots perform on the piece the roughing trim or the finishing trim, cutting the unnecessary portions of material, and creating holes and slots. Such machine is an anthropomorphic robot arm with a laser cutter mounted on the tip: this tool generates a powerful beam of light, capable of cutting steel and aluminium.

The generation of the laser beam involves stimulating a lasing material by electrical discharges or lamps within a closed container. As the lasing material is stimulated, the beam is reflected internally by means of a partial mirror, until it achieves sufficient energy to escape as a stream of monochromatic coherent light. Mirrors or fiber optics are typically used to direct the coherent light to a lens, which focuses the light at the work zone. The narrowest part of the focused beam is generally less than 0.32 mm in diameter. Depending upon material thickness, kerf widths as small as 0.10 mm are possible. In order to be able to start cutting from somewhere other than the edge, a pierce is done before every cut. Piercing usually involves a high-power pulsed laser beam which slowly makes a hole in the material, taking around 5–15 seconds for 13 mm stainless steel, for example.

The parallel rays of coherent light from the laser source often fall in the range between 1.5–2.0 mm in diameter. This beam is normally focused and intensified by a lens or a mirror to a very small spot of about 0.025 mm to create a very intense laser beam. In order to achieve the smoothest possible finish during contour cutting, the direction of beam polarization must be rotated as it goes around the periphery of a contoured workpiece. For sheet metal cutting, the focal length is usually 38–76 mm.

Advantages of laser cutting over mechanical cutting include easier workholding and reduced contamination of workpiece (since there is no cutting edge which can become contaminated by the material or contaminate the material). Precision may be better, since the laser beam does not wear during the process. There is also a reduced chance of warping the material that is being cut, as laser systems have a small heat-affected zone.

Laser cutting for metals has the advantages over plasma cutting of being more precise and using less energy when cutting sheet metal; however, most industrial lasers cannot cut through the greater metal thickness that plasma can. Newer laser machines operating at higher power (6000 watts, as contrasted with early laser cutting machines' 1500 watt ratings) are approaching plasma machines in their ability to cut through thick materials, but the capital cost of such machines is much higher than that of plasma cutting machines capable of cutting thick materials like steel plate.

# Chapter 3

# Company critical issues

The job performed by Eurodies Italia is extremely variable and difficult: it is difficult to forecast the production trend, and there may be problems and mishaps that prevent the plant from having a linear production.

The main reason for this is the type of product made by the company. The production of prototypes makes the industrial phase much more complex, with respect to the series production. This is proven also within Eurodies itself, which has also few orders of "small series" components: these never show problems and it easy to forecast the trend of production, the productivity of employees and the quantity of material waste.

On the contrary, the production of prototypes is characterized by an extremely variable production rate, with high material waste, despite the great experience of the specialized employees.

The problems that the company has to face have mainly two reasons: the type of production (prototype-making) that causes great difficulties in sequencing and scheduling of orders, and the dimensional growth that Eurodies has had in the last years. The fact that the company has grown from around 40 to around 160 employees, without a real company reorganization and a change of work methodologies and of information transfer, created many inefficiencies.

It may also be thought that the second reason is somehow linked to the first: the continuous necessity to focus on production did not allow Eurodies to utilize time and resources for a work methodologies reorganization.

Another problem shown by Italian companies of this sector is the separation between design phase and production phase. When the design of the dies is approved by the responsible person, his role is over, and the designer does not receive any feedback on possible problems caused by the dies during production. Furthermore, press operators do not receive the results of the simulation that should theoretically indicate which zones of the piece are the most critical.

The lack of information flow in both directions leads to a lack of *continuous learning* by the designer who, without receiving feedback on his work, cannot modify his work methodology or make the simulation more reliable. For the operators, the lack of information about the results of the simulation makes the job harder, since they do not know what to expect from the first press hit.

A problem that should be considered is the absence of data collection during production. The only relevant data, in Eurodies Italia, is the quantity of pieces produced at the end of the shift. No data is collected about the exact quantity of defectives or of material waste. No information is stored, about the main problems that the operators had to face during the shift: such information, if available, would be useful to understand how to increase the effectiveness of the dies for the next order of a similar component. Recently, Eurodies has understood the importance of creating statistics on errors and defectives that are detected in the production phase, in order to be able, among others, to look for correlation between the errors themselves and the utilized material or the shape of certain pieces.

They are considering ways to collect this information without interrupting or slowing down the operators' work, especially the ones working at the presses. It is not an easy task, because there is no availability of a reliable and affordable technology to automatically detect defects.

A less efficient solution would be the introduction of papers to be filled by the operators, indicating the number of pieces produced correctly, the number of defectives, the reason of the defects and the type and location of the defect on the piece. This solution would be very easy to implement, but it would then require an employee to manually copy such information to the computer database. It was thought, therefore, to adopt a tablet located next to the machine, instead of the papers to be filled. The tablet would be connected to the company network and would automatically transfer information to the database. This second solution looks clearly more efficient, and the implementation of tablets connected to the network is surely not difficult or particularly expensive.

Another problem that Eurodies Italia must face is the calculation of the order profit. As of now, decisions about the typology of material to be used, about the icon shape (and therefore the nesting and the quantity of material that is necessary) are taken directly during production by the manufacturing responsible. This, together with the lack of information about the man-hours spent by the single operator on the single order, leads to the impossibility of a systematic forecast of the order profit. Decisions about offers to be made to costumers are therefore taken by the top management, based on their personal experience, without precise information on the historical profitability of similar components. Such information would allow Eurodies to be more competitive on the market, knowing in advance whether to accept an order or not – or whether to increase the offer.

Let us now consider the main general issues that Eurodies Italia wants to improve: the low productivity. It is possible to identify three main causes of the reduction of average productivity in the company:

- Disorganization of the warehouse

- Lack of scheduling
- Responsibility conflicts

The warehouse is filled with both raw material (sheet metal – steel and aluminium) of various dimensions and thickness, and semifinished components. During the years, an automatic method to track which and how many items enter and leave the warehouse was not implemented. The stock inventory of the raw material is updated by the head of the warehouse at least once a week, manually, on an Excel spreadsheet. Nevertheless, between these updates, the position and quantity of material are changed, and this leads to major inefficiencies due to the waste of time, which is spent looking for the right pallet that contains the correct sheet metal. Even worse is the problem linked to the residual quantity of raw material: if it is not updated correctly, the wrong information about the amount of sheets that are available leads to errors on orders or to slowing down of the production, due to the lack of material itself.

For the semifinished products, on the contrary, no information is stored anywhere, and the position and quantity are remembered by heart by the forklift or press operators. It is easy to imagine how this leads to several different problems: waste of time due to the need of "looking for items", transfer of wrong information among operators responsible for one manufacturing phase and the ones responsible of the subsequent phase or, in extreme case, the need to repeat production because some pieces have been lost.

In order to increase the productivity of the operators, it would be necessary to schedule production in a structured way. As of now, scheduling is performed by the head of production, without having any information coming from the other industrial divisions. Furthermore, it is performed with a too short temporal horizon, often only daily. It may happen, therefore, that the production of a component that had been programmed for one day cannot be executed because the dies are not ready yet, and this causes a modification of the production that had been forecasted for the 2D laser. Or else, for example, the so-called *pallet* (support for the component when it is laser trimmed) is not ready to be utilized, but at the same time the press department is giving maximum priority to the same component, uselessly. One of the reasons why scheduling is not considered essential by Eurodies is the need for flexibility that the production of prototypes requires. In fact, it often happens that the production program must be modified because some order is taking longer than what had been forecasted (due to errors, large number of defectives, or bad-quality pieces being produced). A simple solution to this issue would be to perform a scheduling not daily, but weekly, leaving some empty "temporal buffers", that will be filled by the prolonging of problematic orders. Collecting data and information about the necessary cycle time for every single phase of manufacturing process, for every "type of product", it would be then possible to create a statistical database to make scheduling more and more efficient. Programming on a weekly basis would allow automatic machinery (such as the 2D laser) to work continuously, also at night, in a coordinated way.

Third and last factor that causes a reduction in productivity has to be identified in the so-called responsibility conflicts. In Eurodies Italia, it is often not clear who should take responsibility to perform a certain task. Different people of different department can decide what a certain tool or machine should do, at the same time. This leads to conflicts among employees, besides a non-structured production activity. It is not rare to see an operator that receives instructions on what task he should perform by a supervisor, but then the task is modified after a short time by a different supervisor. It is clear that a lot of time is wasted by this change of task. A better circulation of information within the departments could be a solution to this last issue (but not only to this one, since a good circulation of information in a company is fundamental for increasing productivity and product quality).

In the company, knowledge is linked to single people and often it is stored in files (like Excel spreadsheets), accessible to only one or two people. This makes programming and producing harder, when even only one of the "key employees" is missing. This problem is being addressed right now, when this Thesis is being written, with the implementation of a management software, common to all the company's departments, which will make available to all employees all the needed information. This should, in the future, avoid that the absence of certain key people determines a worse production flow.

Chapter 4

# Model

Since it is clear that the main plant of Eurodies Italia shows several inefficiencies and a productivity that is definitely far from its optimum, during the research work that preceded the writing of this Thesis, assumptions were made about possible ways of increasing such productivity and reducing inefficiencies.

As usual, in such situations, modifications to the production process and to the plant, as well as to the number of resources, need to be tested and validated with a simulation. Simulation involves the building of a model that represents a real system or process, in a computer-based environment. After setting the parameters of the system or process, and after deciding a simulation time or some "end-of-simulation" conditions, the model is run in order to observe the behavior of the system and to monitor some selected variables. In the specific field of manufacturing simulation, staffing requirements, processing equipment, material handling equipment, work-in-process, storage space, floor plan design, and various policies and procedures can be altered in the model to evaluate their impact on the efficiency and effectiveness of the process. Users may test any and all options, not just for their impact on the system, but to find the best combination of operational characteristics to optimize performance and reduce costs (FlexSim Software Products Inc, 2014).

Among the several commercial software programs that perform manufacturing simulations, FlexSim (FlexSim Software Products, Inc.) was chosen to model and simulate the production processes of Eurodies Italia. FlexSim is 3D simulation software designed for modeling processes. Processes include manufacturing, packaging, warehousing, material handling, supply-chain, and many others. FlexSim is equipped with a powerful array of tools that run the gamut from a 'true-to-scale' 3D display to a comprehensive collection of statistical reports that can immediately shed light on any aspect of performance in the process. FlexSim uses a four-step method to model any given process system. First, the process's CAD-based physical layout is created or imported, and relevant processing objects are added to represent the process. Second, the flow of the items that are going to be processed is designed using click-and-drag connections - easy as defining the flow in a flow chart. Third, the user will detail the objects with processing parameters such as process time, routing logic, conveyor speeds, staff requirements, material handling options, and visualization options. Fourth, the relevant evaluative metrics are defined using easy-to-use pick list options and wizards (FlexSim Software Products Inc, 2014). Then the model is run, and the process comes to life in virtual 3D.

In the following section our model of Eurodies production process is shown and explained in detail.

## 4.1 Simplified model

Before presenting and explaining the actual model of Eurodies' plant, a simplified model with just one machine per typology is shown. In such a way, it is easier to describe the parameters adopted and how the data about times and pieces were collected. With reference to Figure 9, seven types of model objects can be identified:

1) Source
2) Queue
3) Processor
4) Sink

5) Dispatcher
6) Operator
7) Transporter

Each of these objects is described in the next paragraphs, after a brief explanation of the logical flow of the model.

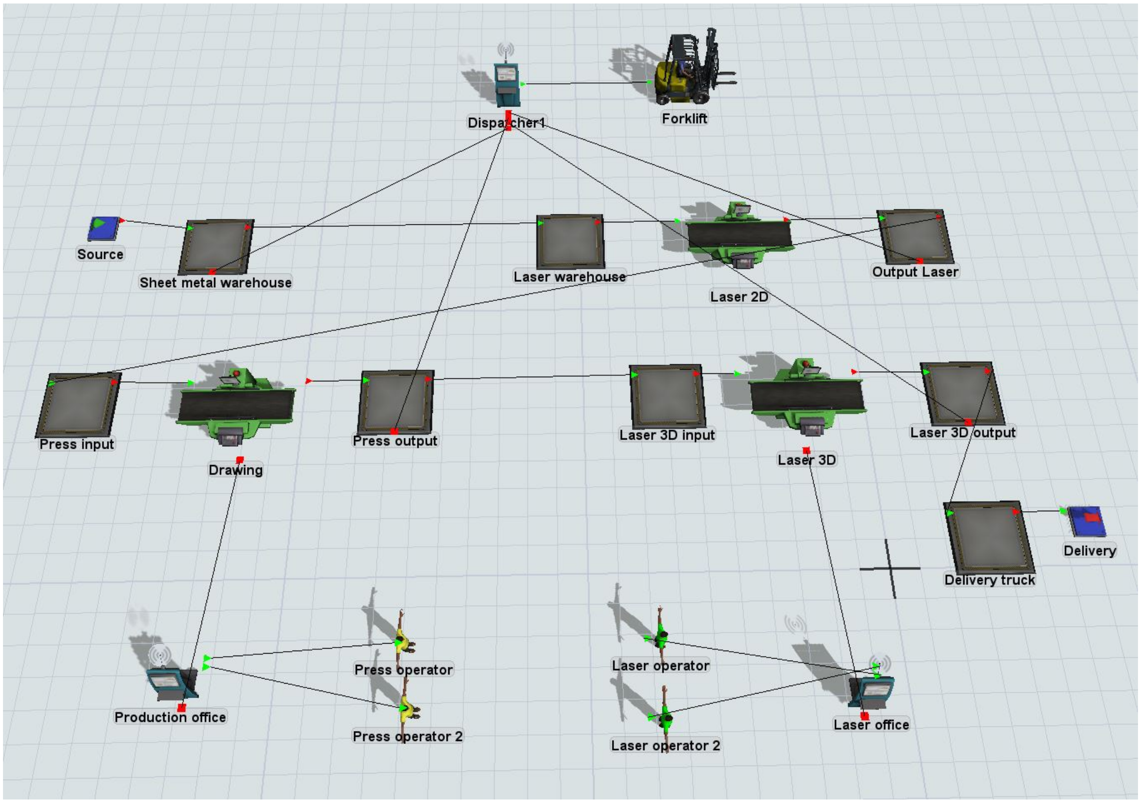



*Figure 9: Simplified model*

Figure 9 shows the single-flow model, with only one machine per type. The raw material (sheet metal) is generated from the *source* and stored in the *sheet metal warehouse*. It is then loaded by the forklift and transported to the *laser warehouse,* which cuts it according to the necessary icon shape. The 2D Laser stores the icons in the *output laser* queue, where they wait to be moved to the *press input* one. Subsequently, the press performs the drawing operation, and the semifinished products are stored in the *press output* queue. Finally, they are transported to the 3D laser, which concludes the process, by performing the finishing trimming operation. Finished products are moved to the delivery truck, which transports them out of the plant, to the *sink*. The model shows three more elements: a forklift, used for moving material and products, four operators, who operate the machines, and three *dispatchers*, who dynamically assign resources (operators and transporters) to the machine or queue that requires them.

In the following sections, each object is shown, and the parameters that characterize it are described.

### 4.1.1 Source and sink

A source is the object that generates items: in our case, it generates raw material (metal sheet blanks). Figure 10 shows the properties tab of a source. The *Arrival Style* can be parametrized with an inter-arrival time, deterministic or statistically distributed, or with an arrival schedule. In our model, the latter was chosen, because it allows to set the quantity per arrival, creating batches.

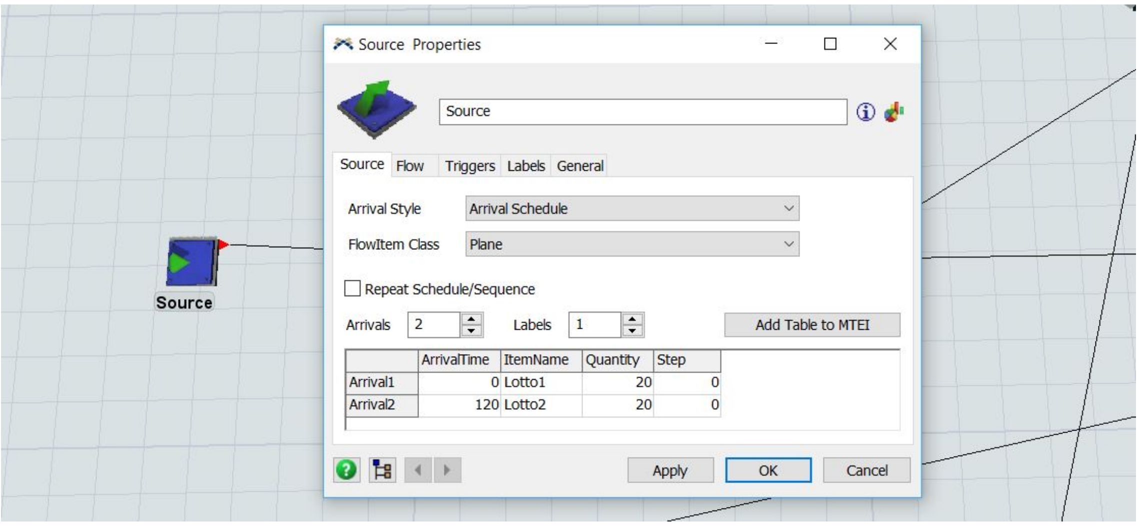



*Figure 10: Source properties*

The **batch size** was chosen to be **20 pieces**, since several months of observations in the plant showed that such a quantity is a good statistical representation of the number of pieces that OEMs ask Eurodies Italia to supply, in their first order.

A sink is simply the object that destroys items: it is the last step of every model and it is sometimes considered when looking at simulation statistics, as the object where some data such as "output per hour" are computed.

### 4.1.2 Queue

A queue is the model object where items wait to be transported or processed. The maximum number of items that a queue can contain may be set in the properties, as well as the output logic (FIFO – First In First Out, or LIFO – Last In First Out), as Figure 11 shows.

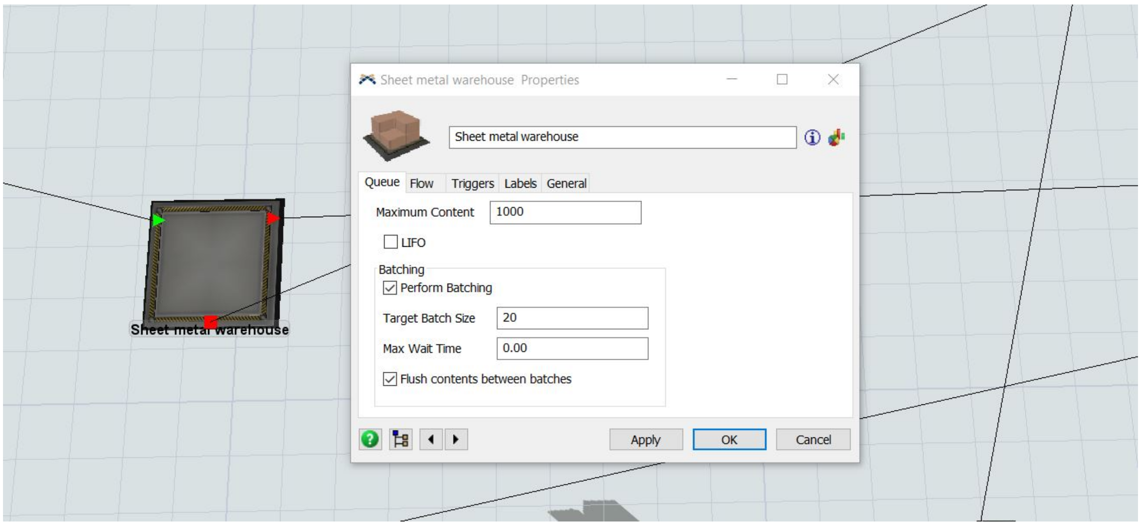



*Figure 11: Queue properties*

As anticipated in the previous paragraph, the batch size is set to 20, for the entire model. The option "Flush content between batches" means that the queue will not accept new items until the current batch has moved out.

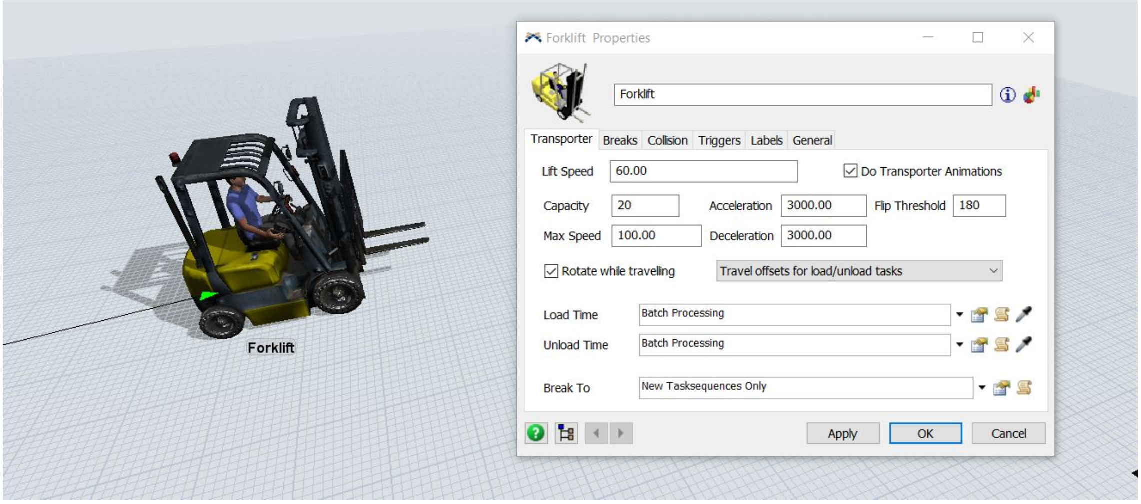



*Figure 12: Transporter properties*

### 4.1.3 Transporter

A transporter object is the generalization of a simple forklift. It is used to move items from a queue to another one, in a more realistic way than the "instantaneous" movements without transporter. The properties tab of a Transporter can be seen in Figure 12: acceleration and maximum speed are the most important parameters to be set. Since the forklifts in Eurodies Italia can reach a maximum speed of 6 km/h, the corresponding parameter in the model has been set to the equivalent speed in meters per minute (100 m/min).

The loading and unloading times have been parametrized according to the "Batch processing" logic, that is, the loading time is applied once to the batch, instead of once per item. In order to assign a value to this loading/unloading times, a statistical distribution was considered more significant than a deterministic value. Several time measurements were performed in the plant, timing the loading and unloading operation of several pallets by different forklifts. The resulting times were interpolated empirically on a Microsoft Excel spreadsheet, obtaining a beta distribution with the following parameters:

```
beta(0.3, 1, 3, 8)
```

that is, a = 0.3, b = 1, $\alpha$ = 3 and $\beta$ = 8. The plot of such distribution can be seen below, in Figure 13.

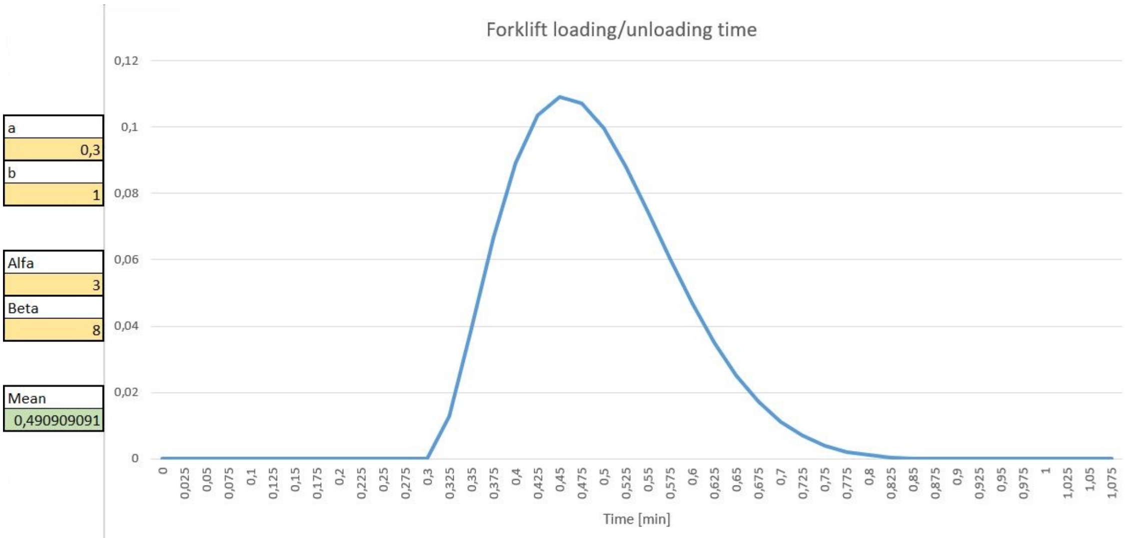



*Figure 13: Distribution of times for forklift loading/unloading*

### 4.1.4 Operator

In our model, operators are utilized to operate presses and 3D lasers. Observations in the plant showed that, normally, two operators are present next to the machines for the production of prototypes. Therefore, in the Processors' properties, as shown below in a subsequent paragraph, the parameter "Use operators for process/setup: number of operators" was set to 2. Figure 14 shows, on the left and center, an Operator object and its properties tab, and, on the right, the MTTR/MTBF parameters that were used to model the "coffee breaks".

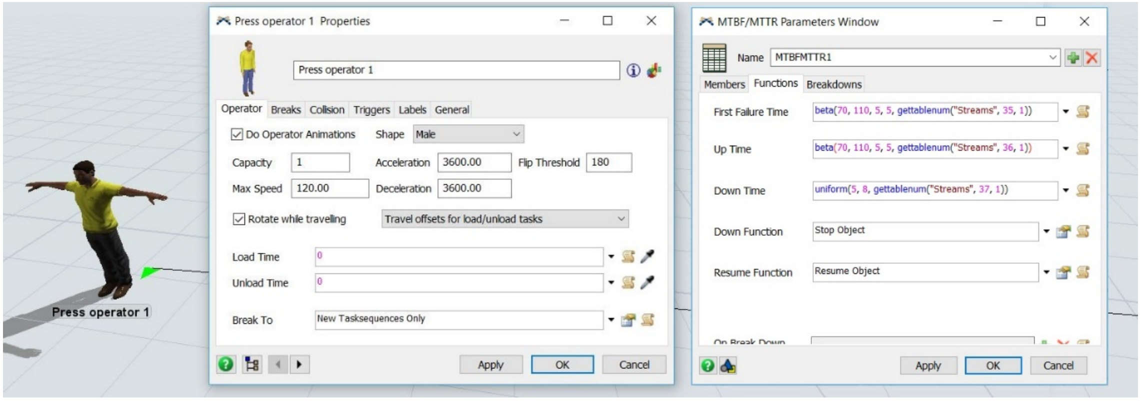



*Figure 14: Operator properties and MTBF for operators' breaks*

During the observation period in the plant, it was noticed that operators do not have a fixed break time, but they are free to have a coffee break several times per shift. To add this behaviour to the model, the function MTTR/MTBF (Mean Time Through Repair/Mean Time Between Failures) was utilized, where the "failure" is the break, and the "repair time" is the duration of the break itself. In order to avoid the infinite of the normal distribution, the beta distribution was chosen also in this case, with a mean of 90 minutes between breaks. Furthermore, in order to have a symmetric curve, the parameters alpha and beta had to be set equal to each other:

```
beta(70, 110, 5, 5)
```

that is, $a = 70$, $b = 110$, $\alpha = 5$ and $\beta = 5$. Figure 15, below, shows the plot of such distribution. Concerning the MTTR, that is, the break duration, a uniform distribution between 5 and 8 minutes was considered appropriate to parametrize the real behaviour of the operators.

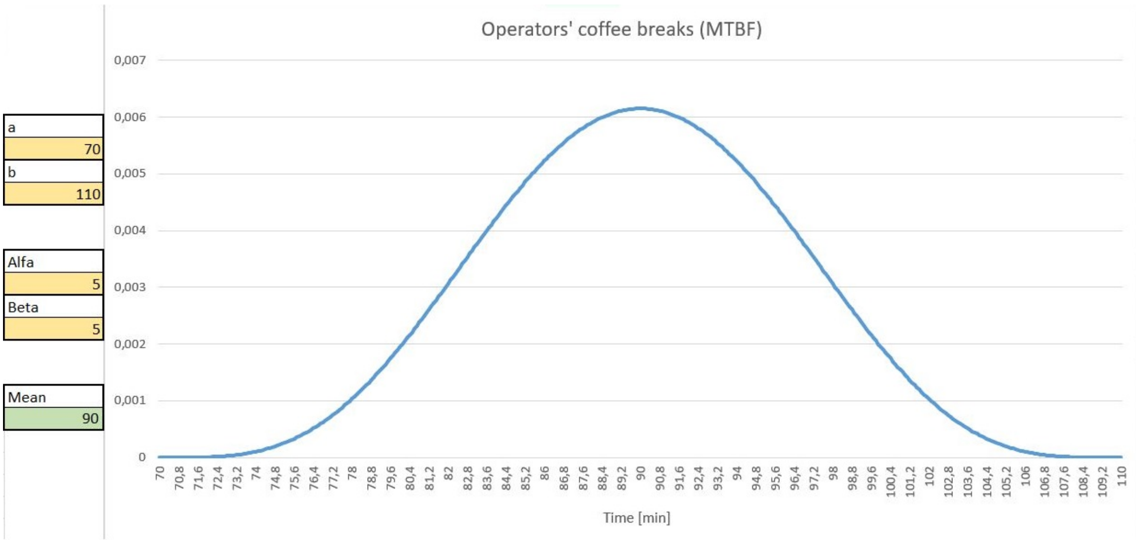



*Figure 15: Time distribution of operators' breaks (MTBF)*

### 4.1.5 Dispatcher

A dispatcher is the object that assigns operators and transporters to the different tasks. A dispatcher, together with its properties tab, can be seen in Figure 16. Its parameters are not particularly interesting or difficult to determine.

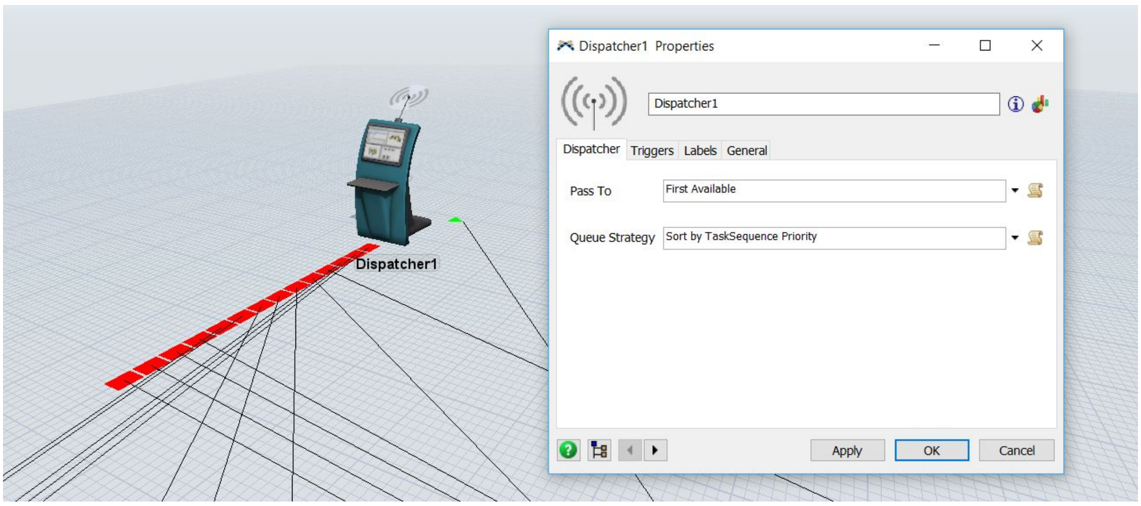



*Figure 16: Dispatcher properties*

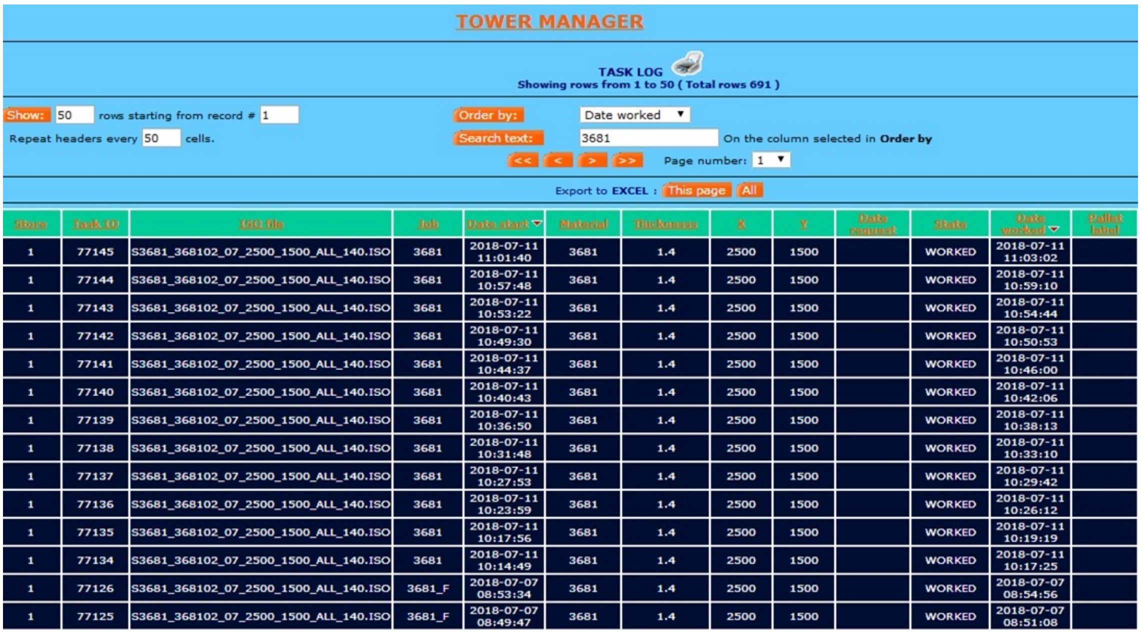
### 4.1.6 Processors

A processor is the model object that perform a manufacturing operation on an item. The most important parameters for such objects are process time and set-up time. In this paragraph, the three types of working centers present in our model will be considered: 2D laser, press and 3D laser. The time measurements that were performed in the plant, together with the statistical calculation that led to determination of the appropriate distribution for process and set-up times.

a) 2D Laser

The two-dimensional laser that is present in Eurodies Italia for icon cutting is a modern automatic machine (with automatic warehouse), built by Prima Industrie: it is a "flexible, user-friendly and compact flat CO2 laser cutting machine with automatic management of materials and thicknesses" (Prima Power, 2017). The machine computer traces and stores the processing times of every single piece, making it easy to download them and perform statistical calculations. Figure 17 shows a screenshot of the software that manages the operativity of 2D Laser and automatic warehouse: looking at the rightmost column, it is clear that the difference between the "time worked" of two subsequent rows is equal to the cycle time for cutting that item.

Since the number of time data available in this situation was not very large, it was decided to use the Flexsim statistical tool called "continuous empirical distribution", which interpolates classes of data (provided in a table as histogram data) and returns as output a number continuously distributed between the lower and upper limit of each class, according to the percentage probability in the other column of the table. The data that were inserted in the Flexsim's global table for 2D Laser times are shown in Figure 18, as well as the resulting distribution (plotted on Microsoft Excel).




| Store | Task ID | ISO file | Job | Date start | Material | Thickness | X | Y | Date request | State | Date worked | Pallet label |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 77145 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 11:01:40 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 11:03:02 | |
| 1 | 77144 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:57:48 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:59:10 | |
| 1 | 77143 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:53:22 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:54:44 | |
| 1 | 77142 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:49:30 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:50:53 | |
| 1 | 77141 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:44:37 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:46:00 | |
| 1 | 77140 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:40:43 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:42:06 | |
| 1 | 77139 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:36:50 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:38:13 | |
| 1 | 77138 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:31:48 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:33:10 | |
| 1 | 77137 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:27:53 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:29:42 | |
| 1 | 77136 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:23:59 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:26:12 | |
| 1 | 77135 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:17:56 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:19:19 | |
| 1 | 77134 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681 | 2018-07-11 10:14:49 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-11 10:17:25 | |
| 1 | 77126 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681_F | 2018-07-07 08:53:34 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-07 08:54:56 | |
| 1 | 77125 | S3681_368102_07_2500_1500_ALL_140.ISO | 3681_F | 2018-07-07 08:49:47 | 3681 | 1.4 | 2500 | 1500 | | WORKED | 2018-07-07 08:51:08 | |

*Figure 17: 2D Laser software (processing times)*

| From | To | Probability |
|---|---|---|
| 0 | 0,5 | 0,00 |
| 0,5 | 1 | 0,00 |
| 1 | 1,5 | 0,022 |
| 1,5 | 2 | 0,065 |
| 2 | 2,5 | 0,000 |
| 2,5 | 3 | 0,022 |
| 3 | 3,5 | 0,022 |
| 3,5 | 4 | 0,674 |
| 4 | 4,5 | 0,087 |
| 4,5 | 5 | 0,043 |
| 5 | 5,5 | 0,043 |
| 5,5 | 6 | 0,000 |
| 6 | 6,5 | 0,000 |
| 6,5 | 7 | 0,022 |
| 7 | 7,5 | 0,000 |

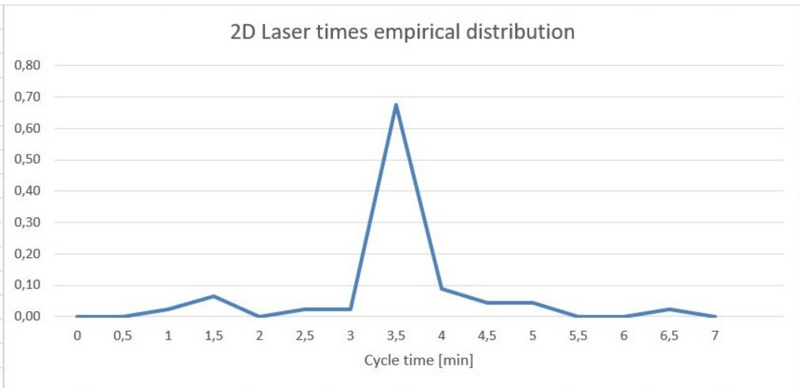



*Figure 18: Empirical distribution resulting from 2D Laser times*

Since the Primapower PLATINO® is fully automated and can generally work without an operator, also during the night, in our model's "Laser 2D" processor properties, no operator is required.

b) Press

More than 20 presses are present in Eurodies Italia's plant in Avigliana. Six of these are modern triple-effect machines equipped with a computer controller, used for the production of pieces that require large dies or the presence of all three "effects" (punch, blankholder and cams). Since, in this case, the machine computer does not record cycle times, time measurements had to be performed "by hand".

As an example, we will describe here how the drawing time for a prototype roof panel was measured and how the resulting distribution was determined. In the Eurodies plant in Avigliana, direct observation of the drawing operation of a batch of 20 roof panels led to the availability of a small set of cycle time data. Measurements were performed "by hand", with a stopwatch. Times were arranged in a histogram fashion, as Figure 19 shows. Instead of using the FlexSim tool "empirical continuous distribution", we looked for an actual distribution that could describe in a satisfactory way the trend of times.

| Cycle times | From | To | N |
|---|---|---|---|
| 5,50 | 5 | 5,24 | 0 |
| 5,72 | 5,25 | 5,49 | 0 |
| 5,80 | 5,5 | 5,74 | 2 |
| 5,82 | 5,75 | 5,99 | 3 |
| 5,90 | 6 | 6,24 | 5 |
| 6,01 | 6,25 | 6,49 | 4 |
| 6,10 | 6,5 | 6,74 | 1 |
| 6,12 | 6,75 | 6,99 | 0 |
| 6,13 | 7 | 7,24 | 2 |
| 6,17 | 7,25 | 7,49 | 0 |
| 6,27 | 7,5 | 7,74 | 0 |
| 6,33 | 7,75 | 7,99 | 1 |
| 6,40 | 8 | 8,24 | 1 |
| 6,45 | 8,25 | 8,49 | 0 |
| 6,50 | 8,5 | 8,74 | 0 |
| 7,07 | 8,75 | 8,99 | 1 |
| 7,20 | 9 | 9,24 | 0 |
| 7,80 | 9,25 | 9,49 | 0 |
| 8,10 | 9,5 | 9,74 | 0 |
| 8,88 | 9,75 | 9,99 | 0 |

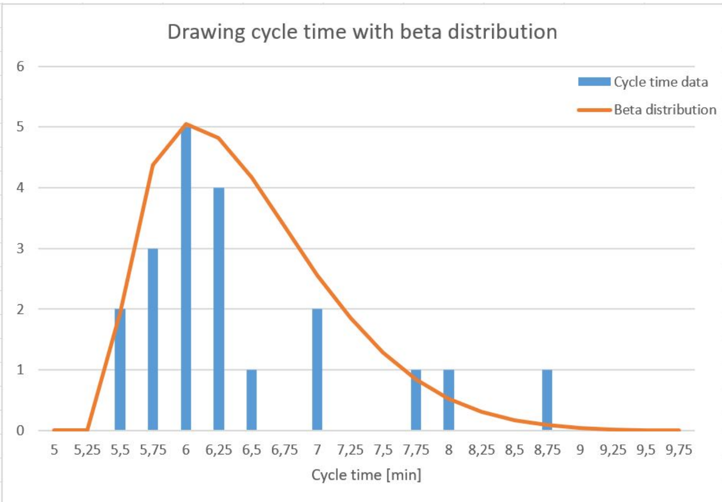



*Figure 19: Histogram of the drawing cycle time and beta distribution*

The powerful beta distribution was chosen, and its 4 parameters were determined in an empirical way, on an Excel spreadsheet, comparing the histogram data with the value of the beta distribution, setting the parameters so that the difference between histogram and beta distribution was minimized.

The resulting parameters, determined in this empirical way, were then inserted in the "process time" section of the properties tab of the Drawing press, as follows:

```
beta(5.4, 11, 1.9, 8)
```

that is, a = 5.4 minutes, b = 11 minutes, $\alpha = 1.9$ and $\beta = 8$.

The other important parameter to be set in the processors' properties is the set-up time. In our case, industrial presses require a rather long set-up, which involves mounting the dies on the press plates. Since Eurodies Italia has a production volume that is relatively small, it is not economical for them to adopt SMED solutions (Single Minute Exchange of Dies), like companies that operate in mass production. Therefore, dies are transported with a bridge crane and manually mounted on the press, operation that requires from 45 to 90 minutes. Systematic data about set-up times were not available, and it was not possible to measure a satisfactory amount of set-up operations to perform statistical calculation. As a consequence, during interviews with the operators, it was discovered that the process takes from 45 to 90 minutes, as specified above, and it was hypothesized that the distribution between such values is uniform. The parameter set-up time in the drawing press properties was then set as:

$$\begin{cases} 0 & \mathit{if\ the\ item\ type\ does\ not\ change} \\ \texttt{duniform(45, 90)} & \mathit{if\ the\ item\ type\ changes} \end{cases}$$

that is, no set-up time between items of the same batch, and a uniform distribution with min = 45 minutes and max = 90 minutes, if the batch changes. The resulting properties tab of the press is shown below in Figure 20.

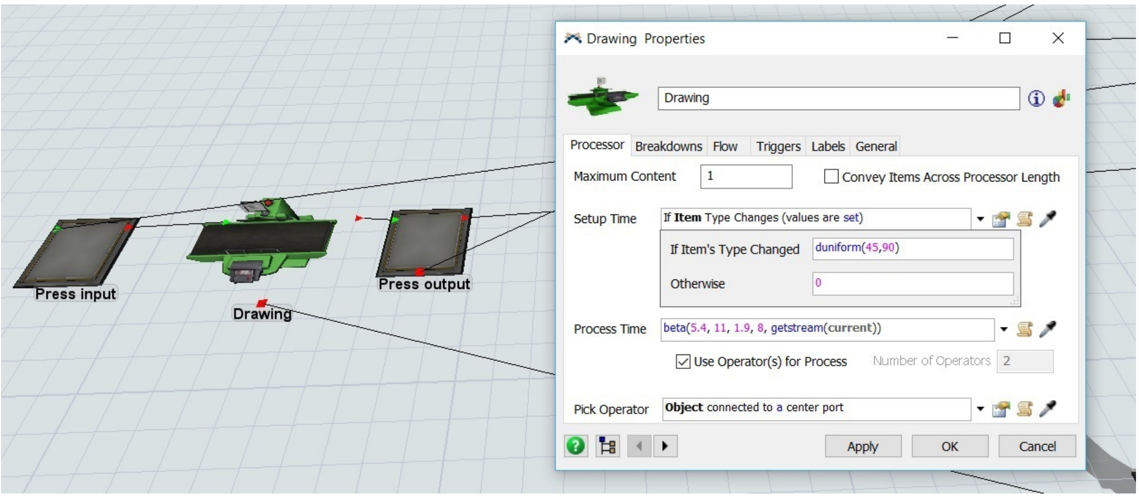



*Figure 20: Processor properties (press)*

c) 3D Laser

Eurodies Italia's plant is equipped with three modern three-dimensional laser cutting machines, built by Prima Industrie and called Prima Power OPTIMO®. As the Prima Power lasers brochure explains, "OPTIMO® is the laser machine by Prima Power for the high precision cutting and welding of large and very large three-dimensional parts. Its wide work envelope, over 11 $m^3$, sets no limits to the size of the components which can be processed. OPTIMO is suitable for a variety of cutting and welding applications. OPTIMO is a high performing machine with excellent accuracy and quality. Its design allows an easy access to the work area and the integration with a wide range of solutions for workpiece support and handling" (Prima Power, 2018). OPTIMO is computer numerically controlled and has a user-friendly operator interface, as well as programming software. Nevertheless, the software unfortunately does not record cycle times: also in this case, it was necessary to manually record the trimming cycle times of the roof panels batch, in order to obtain some time data. Similarly to what had been done for the drawing operation, the time taken for trimming operation in the 3D laser work center has been measured with a stopwatch, and the resulting data have been organized in a histogram on a Microsoft Excel spreadsheet. Finally, the histogram data have been interpolated with a beta distribution, having parameters as follows:

```
beta(5, 7, 2.3, 8.5)
```

that is, a = 5 minutes, b = 7 minutes, $\alpha$ = 2.3 and $\beta$ = 8.5.

The set-up time for the 3D laser trimming operation involves the replacement of the so-called pallet, with the pallet specifically built for the new workpiece. In addition, the new CNC program has to be loaded and launched on the machine computer. It is a much faster operation than the presses set-up, which involves the movement of cast iron dies, which weigh up to hundreds of tons. Time data about 3D laser set-up were missing, and also in this case it was necessary to determine them in a rough way with interviews, basing on operators' experience. Operators claimed that the set-up operation for the 3D laser machines takes from 10 to 25 minutes. Because of the lack of time data, no distribution could be built, and we had to hypothesize a uniform distribution between those two extremes. Similarly to what had been done for presses, the set-up was inserted in the 3D lasers properties as:

$$\begin{cases} \texttt{0} & \textit{if the item type does not change} \\ \texttt{duniform(10, 25)} & \textit{if the item type changes} \end{cases}$$

that is, no set-up time between items of the same batch, and a uniform distribution with min = 10 minutes and max = 25 minutes, if the batch changes. The resulting properties tab of the 3D Laser is shown below in Figure 21.

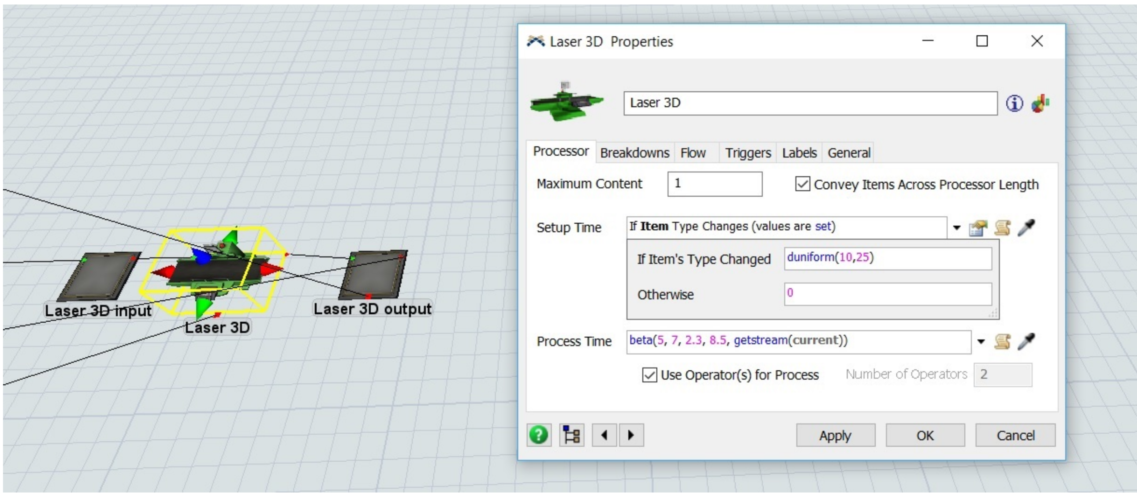



*Figure 21: 3D laser properties*

### 4.1.7 Simulation

Such a simple model is appropriate only to evaluate the time in system of a particular item, that is, to simulate and compute the total cycle time necessary to produce a piece or a batch. It is possible to use the "experimenter" tool to launch a certain number of simulations in a row, and to obtain statistical data about their results. The results of 400 replications of the simulation of the model described in the previous paragraphs are reported below.

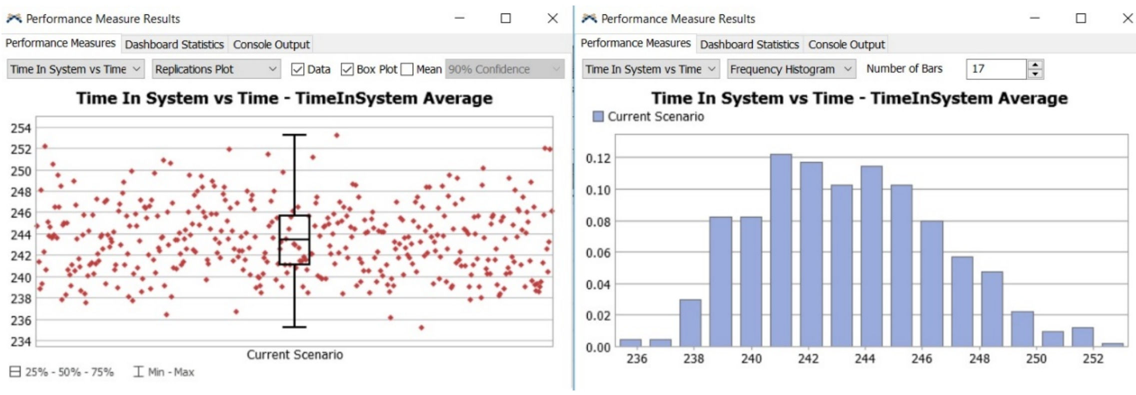



*Figure 22: Replication plot and frequency histogram of Time in System*

The measurement that was considered is the "Time in system" of the batch of 20 pieces, in minutes.

Figure 22 shows the replications plot and the frequency histogram of the "time in system" for the 400 replications of the simulation. The total cycle time for the production of a batch of 20 roof panels, including set-up times, was:

| | | |
|---|---|---|
| Mean: | 243.42 | minutes |
| Std. dev.: | 3.29 | minutes |
| Min: | 235.23 | minutes |
| Max: | 253.21 | minutes |

It is clear that, increasing the number of units per batch, the cycle time for the production of one piece decreases, because each set-up is used to produce more pieces. Nevertheless, as was said before, 20 is appropriate and realistic in the very context of Eurodies Italia.

## 4.2 Extended model

The last paragraphs described the so-called simplified model, with just one machine per type and one flow of material and semifinished items. It is clear that such a model is useful to make considerations about the cycle time when no queues are present, since the only non-added-value (NAV) activities that are performed in the simplified model are set-ups and forklift transportation. Nevertheless, it is also clear that such a model is not an accurate representation of the real Avigliana plant of Eurodies Italia: more machines per type are present in the plant (for instance, three 3D lasers and over 10 presses) and more orders are produced at the same type, meaning more batches of items with different production cycle circulating in the plant in one fixed moment of time. In order to model and simulate on Flexsim such a complex situation, it was necessary to extend the simple model presented above, increasing the number of machines and of operators, and inserting in the model a greater number of “item types”, with different production times. This section, after describing the general layout of the extended model, highlights and explains the differences with the simple model. Figure 23, below, shows this more realistic model. It must be noted that the position of machines and warehouses is the same as the layout of the plant, including distances and paths. In this way, the movements of the forklift in the simulation perfectly trace the movements of the real forklifts in the plant. With reference to the figure, the material warehouse can be seen on the left: from there, the forklift moves the metal sheet blanks batch to the two-dimensional laser, following the mandatory paths drawn on the ground.

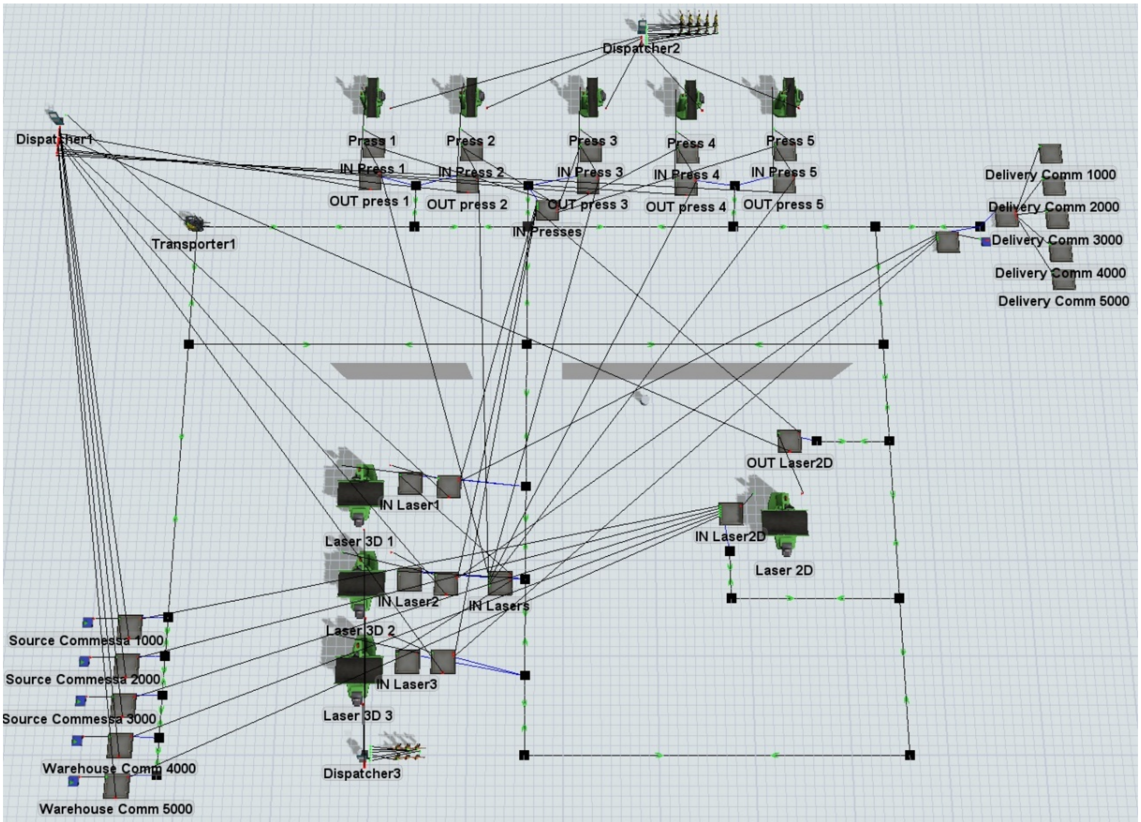



*Figure 23: Extended model on Flexsim*

From the 2D laser, the blanks that have been cut according to the icon shape are moved towards the five presses, which have a central "input queue" that sorts the batch to the first press available. Subsequently, the semifinished items are transported to the three 3D lasers, with their central "input queue" similar to the presses one. Here, they undergo the roughing trimming operation and are sent back to the presses. Each manufacturing operation increases a "label" of the item, a numerical counter that indicates which step of the cycle the item has just undergone, so that the "output queue" knows where to send the batch next. After the roughing laser cut, the pieces are sent to the presses for the redrawing and the flanging operations, and finally are moved back to the three-dimensional lasers, for the finishing cut. In the end, the completed batches are transported to the delivery area where they are stored.

Instead of explaining all the details of the extended model (most of which have already been considered in the previous section), the following paragraphs focus on the differences between simple and extended models. In fact, those are the refining features that make this model realistic and accurate. In particular:

- layout (and distances) similar to the ones of the actual plant
- increased number of machines
- increased number of item types
- introduction of "Step" label
- total of 6 steps in the production cycle
- each item type has different manufacturing times for every step

### 4.2.1 Layout similar to the actual plant

After spending several months in the production plant of Eurodies Italia, it was not difficult to replicate the plant layout in the extended model. Figure 24, below, shows a portion of the map of the plant. In the upper part, the presses can be seen (in light blue): it must be noted that our model presents only 5 presses – the large ones – because

Eurodies own also medium and small presses. In the middle, the three 3D lasers, as well as the larger 2D laser with its automatic warehouse, can be seen in purple.

Not only the disposition of machines in the model is an accurate replication of the real plant, but also the distances between them. Furthermore, the mandatory paths that the forklift must follow in the model replicate the actual paths and passageways between the three buildings of the plant (“Capannone A”, “Capannone B”, “Capannone C”). In such a way, having set the maximum speed that the forklift can reach, the time needed to move material and semifinished items from a machine to another is particularly accurate.


*Figure 24: Map of the plant*

### 4.2.2 Increased number of machines

As anticipated, the extended model does not have just one machine per type (that is, one 2D laser, one press and one 3D laser). In this case, it was chosen to produce a precise replication of the actual manufacturing floor: therefore, 5 presses and 3 three-dimensional laser were inserted in this model. The two-dimensional laser is still one, because that is the case in the Avigliana plant. In such a way, a greater number of production orders (with all their 6 steps) can be fulfilled at the same time and the behaviour of the real plant, where many orders at the same time are processed on many working centers, can be simulated.

### 4.2.3 Increased number of steps in production cycle, introduction of "step" label

Eurodies Italia produces a great variety of bodywork elements: some are plain and particularly easy to produce, like small interior body reinforcements, which require just one or two operations (drawing and finishing laser cut). Some others, like the large automotive side frames, require a grater number of operations, up to 6 or 7. In order to obtain a model that well represents the complexity of productive operations in Eurodies Italia, it was chosen to have items with six steps in the manufacturing cycle:

1. Blank outline cutting on 2D laser
2. Drawing
3. Roughing cut on 3D laser
4. Redrawing
5. Flanging
6. Finishing cut on 3D laser

A so-called "label" was added to each item of each batch, a numerical counter that starts from 0 when the raw material is generated in the warehouse. The label is then increased by 1 by every machine that performs a manufacturing operation on the workpiece (2D laser, press, 3D laser). In this way, it is easy to track which step of the process the item must undergo next.

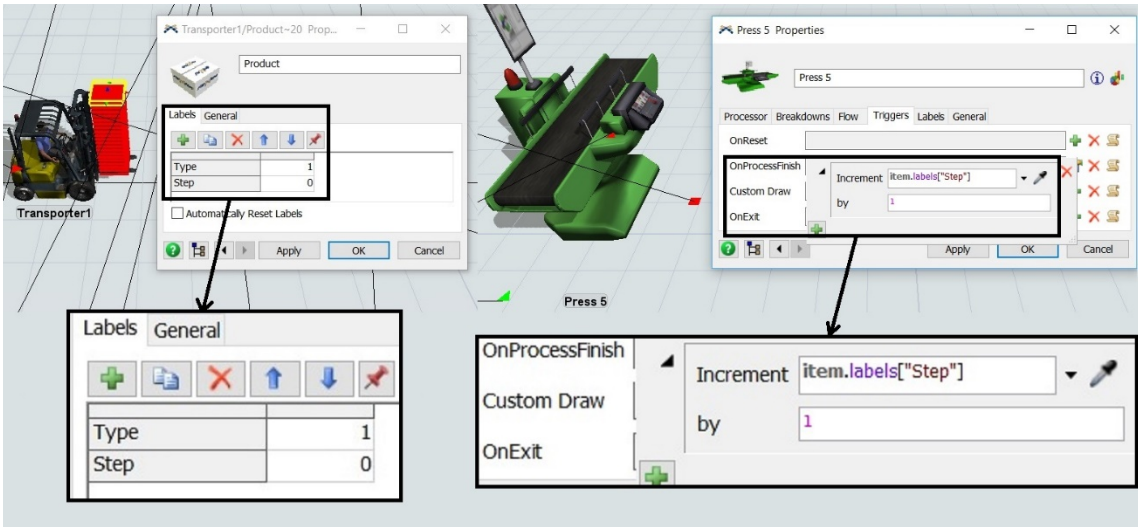



*Figure 25: Label "step" in a product's properties*

Figure 25 shows, on the left, the label "Step" in the item properties: its value is zero because the item has just been generated by the source. On the right, in the properties tab of one of the presses, it can be seen that a "trigger" has been set, so that the value of the item's label increases by 1 when the process finishes.

### 4.2.4 Increased number of item types and different manufacturing times

As anticipated, the single item produced in the simplified model does not represent the actual complexity of production activities in Eurodies Italia. For the extended model, it was decided to insert 5 different item types, that is, five different products manufactured at the same time. Looking at Figure 23, at the beginning of this section, the five sources can be seen on the bottom left. Clearly, it is possible to modify the model in order to have as many items as desired, in order to simulate and test even more complex situations.

The five products are not fixed, but can be chosen among 15 different products, whose manufacturing times were available after stopwatch measurements. In the same way in which the times for the roof panel in Paragraph 4.1.6 had been measured and the beta distributions had been determined, times and distributions for other products were determined. In the end, we had data about:

- 5 side frames
- 5 roof panels
- 5 internal chassis reinforcements

Manufacturing times for every product are reported below in Table 1, in the usual format that indicates the beta distribution parameters. For example, the drawing time of the first side frame is:

```
beta(5, 10, 2.3, 8)
```

which means, times distributed according to a beta distribution with parameters a = 5 minutes, b = 10 minutes, $\alpha = 2.3$ and $\beta = 8$.

*Table 1: Distribution of times for every process step of each component*

| | Step 2 (Drawing) | Step 3 (Roughing) | Step 4 (Redrawing) |
|---|---|---|---|
| Side frame 1 | beta(5, 10, 2.3, 8) | beta(8, 13, 3.3, 7.0) | beta(3, 7, 2.3, 8.0) |
| Side frame 2 | beta(12, 16, 2.5, 5) | beta(10, 16, 2.3, 8.0) | beta(5, 10, 2.5, 5.0) |
| Side frame 3 | beta(7, 13, 1.3, 5.0) | beta(7, 14, 2.5, 6.5) | beta(4, 8, 2.8, 7.0) |
| Side frame 4 | beta(9, 14, 3, 6.0) | beta(9, 15, 2.7, 8.5) | beta(5, 9, 2.3, 6.5) |
| Side frame 5 | beta(8, 12, 2.0, 5.0) | beta(8, 12, 2.0, 7.5) | beta(4, 9, 2.5, 6.0) |
| Roof panel 1 | beta(5.4, 11, 1.9, 8) | beta(4, 6, 2.3, 7.5) | beta(5, 7, 2.3, 8.0) |

| | | | |
|---|---|---|---|
| Roof panel 2 | beta(8, 12, 2.3, 7.0) | beta(6, 9, 2.0, 7.0) | beta(5, 9, 2.5, 7.0) |
| Roof panel 3 | beta(6, 11, 2.0, 8.0) | beta(4, 7, 2.3, 6.5) | beta(4, 7, 2.7, 7.0) |
| Roof panel 4 | beta(4, 8, 2.3, 8.0) | beta(3, 7, 3.0, 7.0) | beta(3, 7, 2.5, 6.0) |
| Roof panel 5 | beta(8, 13, 2.3, 5.0) | beta(4, 7, 2.3, 8.0) | beta(6, 9, 2.7, 7.0) |
| Reinforcement 1 | beta(2, 6, 2.3, 8.0) | beta(2, 4, 2.5, 6.0) | beta(2, 5, 2.2, 7.0) |
| Reinforcement 2 | beta(3, 7, 2.0, 7.0) | beta(4, 8, 2.5, 7.0) | beta(3, 6, 2.3, 8.0) |
| Reinforcement 3 | beta(3, 5, 2.5, 8.0) | beta(3, 7, 2.7, 8.0) | beta(2, 4, 2.3, 6.0) |
| Reinforcement 4 | beta(1, 5, 2.1, 6.0) | beta(2, 5, 2.7, 6.5) | beta(1, 3, 2.3, 8.0) |
| Reinforcement 5 | beta(2, 8, 2.3, 7.5) | beta(4, 7, 3.3, 7.5) | beta(2, 6, 2.7, 7.5) |

| | Step 5 (Flanging) | Step 6 (Finishing) |
|---|---|---|
| Side frame 1 | beta(5, 9, 2.3, 8.0) | beta(9, 15, 3.0, 7.5) |
| Side frame 2 | beta(7, 12, 3, 8.0) | beta(11, 17, 2.5, 8.5) |
| Side frame 3 | beta(6, 11, 2.3, 6.0) | beta(8, 14, 2.7, 6.5) |
| Side frame 4 | beta(7, 11, 2.3, 8.0) | beta(10, 16, 2.5, 8.0) |
| Side frame 5 | beta(6, 10, 2.3, 4.0) | beta(9, 14, 2.3, 7.0) |
| Roof panel 1 | beta(6, 10, 3, 7.0) | beta(6, 8, 2.3, 8.5) |
| Roof panel 2 | beta(7, 10, 3.3, 8.0) | beta(5, 10, 2.5, 6.0) |
| Roof panel 3 | beta(5, 9, 2.3, 8.0) | beta(5, 8, 3.3, 6.5) |
| Roof panel 4 | beta(4, 8, 3, 7.0) | beta(4, 8, 2.7, 8.0) |
| Roof panel 5 | beta(7, 11, 3, 8.0) | beta(5, 9, 3.0, 7.0) |
| Reinforcement 1 | beta(3, 7, 2.3, 8.0) | beta(6, 10, 3.3, 6.0) |
| Reinforcement 2 | beta(1, 7, 2.3, 8.0) | beta(6, 11, 2.7, 7.0) |
| Reinforcement 3 | beta(3, 6, 2.3, 8.0) | beta(5, 9, 2.7, 8.0) |
| Reinforcement 4 | beta(1, 5, 2.3, 8.0) | beta(4, 8, 2.3, 7.5) |
| Reinforcement 5 | beta(2, 5, 2.3, 8.0) | beta(7, 13, 2.0, 7.5) |

It is interesting to notice that the three categories of components have different manufacturing times: *side frames* are the most complicated piece to produce, due to their large dimensions and complex geometry, and therefore require a longer time for their production. *Roof panels* are large, but their geometry is less complex, so they are averagely faster to produce. Internal chassis *reinforcements* are even faster, but they present slots and similar openings: for this reason, their drawing/redrawing time is generally shorter, but their 3D laser trimming time is longer, with respect to roof panels. In order to summarize the above considerations, Table 2 shows the average expected value for each components category, and for each production step.

*Table 2: Average Beta expected value of every manufacturing process step*

| | Sides | Roofs | Reinforcements |
|---|---|---|---|
| Avg. **drawing** time expected value [min] | 9.50 | 7.39 | 3.14 |
| Avg. **laser roughing** time exp. value [min] | 9.83 | 4.96 | 3.89 |
| Avg. **redrawing** time expected value [min] | 5.44 | 5.47 | 2.69 |
| Avg. **flanging** time expected value [min] | 7.40 | 6.85 | 2.89 |
| Avg. **laser finishing** time exp. value [min] | 10.90 | 6.02 | 6.79 |

Chapter 5

# Simulation

As it was explained above, one of the worst organizational problems in Eurodies is the absence of sequencing and scheduling of orders. The head of production decides daily which orders must be produced in each shift, according to urgencies and to his experience. The "mix of products" that is produced during the shift, therefore, is not determined following calculations or temporal considerations, but only decided depending on which order is more urgent at the moment.

This Thesis wants to lay the foundations for a future solution of such problem. In order to have an effective scheduling of production orders, it is necessary to determine which "mix of products" is the most efficient for the plant, considering the time needed for production of the whole set of different batches. Our extended model, together with the "Experimenter" tool of the FlexSim software, is perfectly suited to simulate the behaviour of the production floor, as a response to different set of products.

Such tool, shown in Figure 26, allows users to change a certain number of parameters (*variables*), in order to obtain a set of scenarios. In our case, the parameters are the 5 products that must be produced, chosen among the 15 available products, whose times have been measured.

Before testing several different mixes of products, it was necessary to determine which "types of mix" were meaningful to be investigated. Reminding that the types of product are 3 (side frame, roof panel, chassis reinforcement) and the model's shop floor produces 5 products at the same time, all the following combinations are possible:

- 5 roofs
- 5 sides
- 5 reinforcements
- 4 sides, 1 roof
- 4 sides, 1 reinforcement
- 3 sides, 2 roofs
- 3 sides, 2 reinforcements
- 3 sides, 1 roof, 1 reinforcement
- 2 sides, 2 roofs, 1 reinforcement
- …

for a total of 21 combinations.

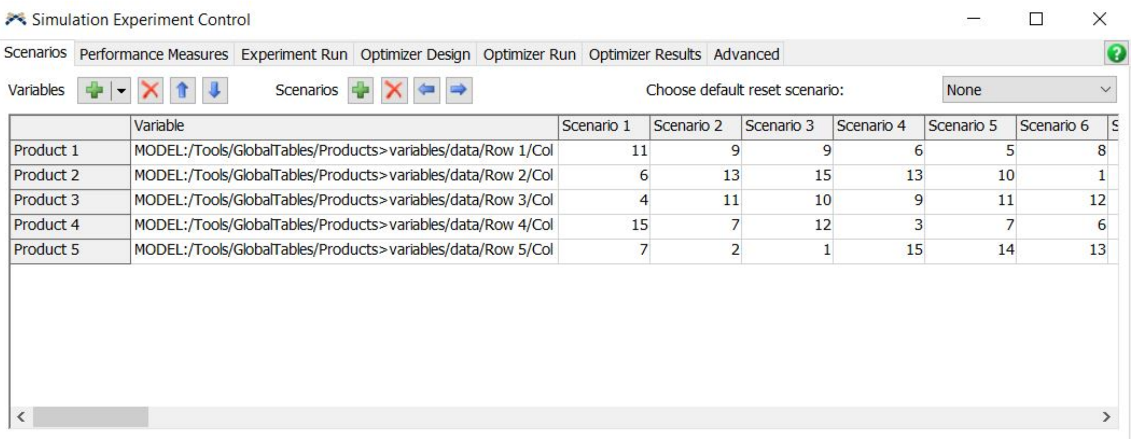
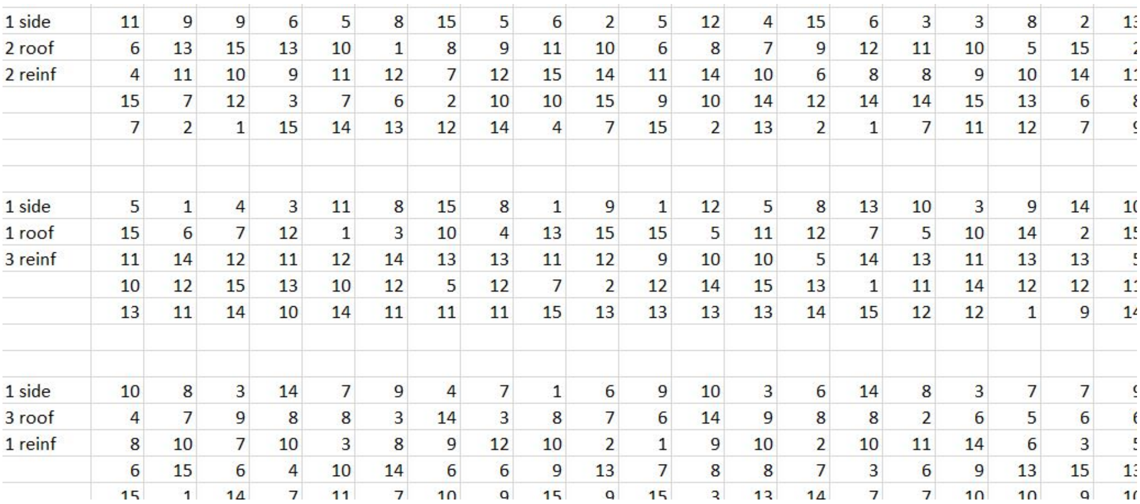



*Figure 26: FexSim's experimenter*

Nevertheless, after thorough observations in the plant, it was noticed that few side frames are produced in Eurodies, generally, no more than 1 or 2 per month and no more than one at same time. Following this observation, and excluding the mixes that did not have all the three product types, it was decided to consider only the following 5 combinations:

- 1 side, 2 roofs, 2 reinforcements (***Mix 1***)
- 1 side, 1 roof, 3 reinforcements (***Mix 2***)
- 1 side, 3 roofs, 1 reinforcement (***Mix 3***)
- 1 side, 4 roofs (***Mix 4***)
- 1 side, 4 reinforcements (***Mix 5***)

It was then necessary to generate random sets of 5 numbers, according to such "types of mix". With reference to Table 1, the side frames are in the rows 1-5, the roof panels in the rows 6-10 and the chassis internal reinforcements in the rows 11-15. A Microsoft Excel add-on tool was utilized to generate 100 sets of 5 random numbers for each of the 5 "types of mix": for example, for the first type of mix, the parameters were *1 number from 1 to 5, 2 numbers from 6 to 10, 2 numbers from 11 to 15.* Figure 27 shows a portion of the Excel spreadsheet that contains the 500 sets of 5 random numbers, 100 for each type of mix.



| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 side | 11 | 9 | 9 | 6 | 5 | 8 | 15 | 5 | 6 | 2 | 5 | 12 | 4 | 15 | 6 | 3 | 3 | 8 | 2 | [illegible] |
| 2 roof | 6 | 13 | 15 | 13 | 10 | 1 | 8 | 9 | 11 | 10 | 6 | 8 | 7 | 9 | 12 | 11 | 10 | 5 | 15 | [illegible] |
| 2 reinf | 4 | 11 | 10 | 9 | 11 | 12 | 7 | 12 | 15 | 14 | 11 | 14 | 10 | 6 | 8 | 8 | 9 | 10 | 14 | [illegible] |
| | 15 | 7 | 12 | 3 | 7 | 6 | 2 | 10 | 10 | 15 | 9 | 10 | 14 | 12 | 14 | 14 | 15 | 13 | 6 | [illegible] |
| | 7 | 2 | 1 | 15 | 14 | 13 | 12 | 14 | 4 | 7 | 15 | 2 | 13 | 2 | 1 | 7 | 11 | 12 | 7 | [illegible] |
| | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 1 side | 5 | 1 | 4 | 3 | 11 | 8 | 15 | 8 | 1 | 9 | 1 | 12 | 5 | 8 | 13 | 10 | 3 | 9 | 14 | [illegible] |
| 1 roof | 15 | 6 | 7 | 12 | 1 | 3 | 10 | 4 | 13 | 15 | 15 | 5 | 11 | 12 | 7 | 5 | 10 | 14 | 2 | [illegible] |
| 3 reinf | 11 | 14 | 12 | 11 | 12 | 14 | 13 | 13 | 11 | 12 | 9 | 10 | 10 | 5 | 14 | 13 | 11 | 13 | 13 | [illegible] |
| | 10 | 12 | 15 | 13 | 10 | 12 | 5 | 12 | 7 | 2 | 12 | 14 | 15 | 13 | 1 | 11 | 14 | 12 | 12 | [illegible] |
| | 13 | 11 | 14 | 10 | 14 | 11 | 11 | 11 | 15 | 13 | 13 | 13 | 13 | 14 | 15 | 12 | 12 | 1 | 9 | [illegible] |
| | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 1 side | 10 | 8 | 3 | 14 | 7 | 9 | 4 | 7 | 1 | 6 | 9 | 10 | 3 | 6 | 14 | 8 | 3 | 7 | 7 | [illegible] |
| 3 roof | 4 | 7 | 9 | 8 | 8 | 3 | 14 | 3 | 8 | 7 | 6 | 14 | 9 | 8 | 8 | 2 | 6 | 5 | 6 | [illegible] |
| 1 reinf | 8 | 10 | 7 | 10 | 3 | 8 | 9 | 12 | 10 | 2 | 1 | 9 | 10 | 2 | 10 | 11 | 14 | 6 | 3 | [illegible] |
| | 6 | 15 | 6 | 4 | 10 | 14 | 6 | 6 | 9 | 13 | 7 | 8 | 8 | 7 | 3 | 6 | 9 | 13 | 15 | [illegible] |
| | 15 | 1 | 14 | 7 | 11 | 7 | 10 | 9 | 15 | 9 | 15 | 3 | 13 | 14 | 7 | 7 | 10 | 10 | 9 | [illegible] |

*Figure 27: Sets of random numbers*

Looking back to Figure 26, it is now clear that such sets of 5 random numbers are used as the variables of 100 scenarios, run by the experimenter. During each repetition of the simulation, each machine reads which product is being manufactured and, according to the row number, reads the processing time from Table 1, as shown in Figure 28, where the table "Data" is the Flexsim's model equivalent of Table 1.

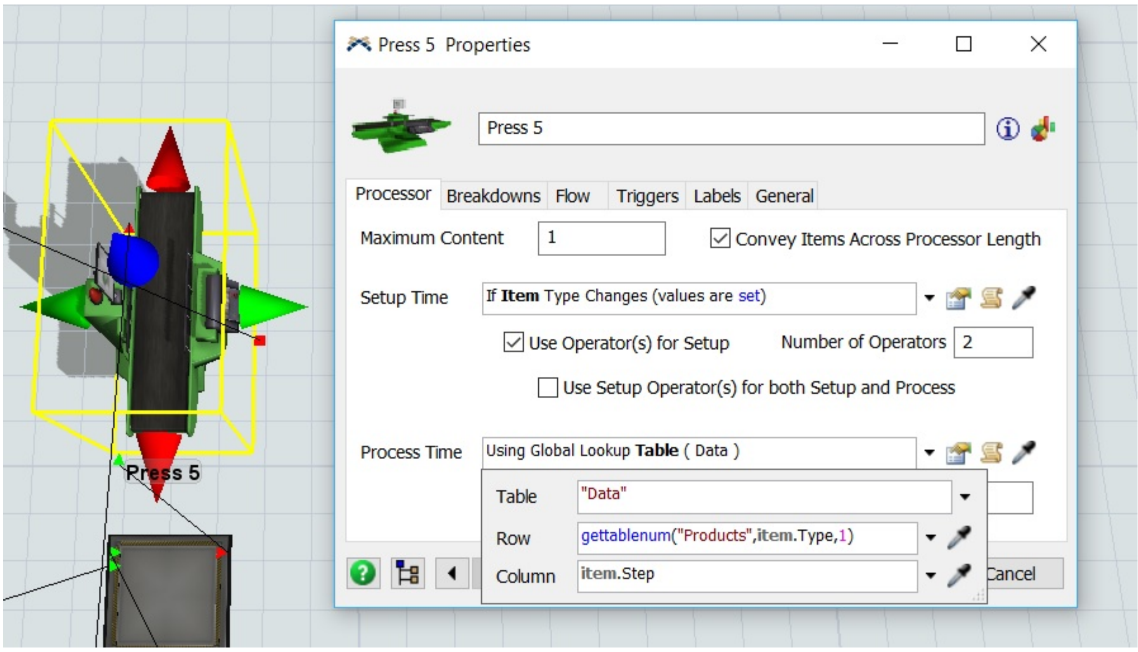



*Figure 28: Press properties, showing the parameter "Process time from table"*

## 5.1 Output measures

As it was anticipated, the goal of this simulation is to determine which one of the 5 types of mix has the highest time productivity, or better, which one shows the least amount of Non Value Added activities (in our case, waiting in queue).

The procedure is as follows:

1) Determine the ideal manufacturing time of a mix

2) Launch the simulation of 100 scenarios of a mix and compute the average "time in system" of the items
3) Calculate the percentage of NVA (Non Value Added) time:

$$\%t_{NVA} = 100 \cdot \left(1 - \frac{t_{ideal}}{t_{in\ system}}\right)$$

Let us see every step in detail:

1) The ideal manufacturing time of a batch is calculated as the weighted average of the sum of expected values of the beta distributions. For example, the average drawing time of the 5 roofs is determined as the average of the 5 beta's expected values:

*Table 3: Parameters for the drawing of the 5 roofs, expected values of the betas*

| | **Roof 1** | **Roof 2** | **Roof 3** | **Roof 4** | **Roof 5** |
|---|---|---|---|---|---|
| **a** | 5.4 | 8 | 6 | 4 | 8 |
| **b** | 11 | 12 | 11 | 8 | 13 |
| **α** | 1.9 | 2.3 | 2 | 2.3 | 2.3 |
| **β** | 8 | 7 | 8 | 8 | 5 |
| Expected value | 6.47475 | 8.98925 | 7.00000 | 4.89320 | 9.57534 |

Computing the average of the last row, one gets the average expected value for the roof panels drawing time, that is, 7.3865 minutes.

This same procedure was repeated for all five steps in the manufacturing cycle, and for all the 15 products: the resulting average expected values for processing time are reported below in Table 4 (all times are expressed in minutes).

*Table 4: Processing times for each step and each product type*

| | Drawing | Roughing | Redrawing | Flanging | Finishing | **Total time** |
|---|---|---|---|---|---|---|
| Sides | 9.499 | 9.835 | 5.444 | 7.399 | 10.901 | **43.078** |
| Roofs | 7.387 | 4.958 | 5.469 | 6.852 | 6.023 | **30.689** |
| Reinf.s | 3.140 | 3.889 | 2.689 | 2.893 | 6.789 | **19.402** |

Since the model works by batches of 20 items, it is necessary to multiply by 20 the weighted average of the five products, according to the "type of mix". For example, for *Mix 1*, made of 1 side, 2 roofs and 2 reinforcements, the ideal processing time will be:

$$t_{ideal} = 20 \cdot \frac{1 \cdot 43.08 + 2 \cdot 30.69 + 2 \cdot 19.40}{5} = 573.04\ min$$

Repeating this calculation for the other four mixes, one gets the ideal manufacturing time for one "average batch" of all the 5 types of mix. These results are reported in Table 5.

*Table 5: Ideal manufacturing times for the five mixes*

| | Composition | $t_{ideal}$ |
|---|---|---|
| Mix 1 | 1 side, 2 roofs, 2 reinforcements | 573.04 min |
| Mix 2 | 1 side, 1 roof, 3 reinforcements | 527.89 min |
| Mix 3 | 1 side, 3 roofs, 1 reinforcement | 618.19 min |
| Mix 4 | 1 side, 4 roofs | 663.34 min |
| Mix 5 | 1 side, 4 reinforcements | 482.75 min |

2) The second step is needed to determine the average *actual* cycle time for the production of one batch, when the system is full.

The parameter measured by the statistical tools of FlexSim, which can be used for this purpose, is the so called "Time in system". This tool measures the time spent by each batch in the system, from the moment in which it is generated by the source to the moment in which it is destroyed by the sink.

Within the Experimenter, it is possible to ask the program to record the average Time in system for *all* the batches that are generated in a certain period of time, for all the scenarios. It was necessary to determine the period of time in which the WIP (Work In Progress) is constant, in order to avoid to collect data in the ramp up period when the system is not saturated. With reference to Figure 29, the data about the WIP were downloaded into an Excel spreadsheet and moved to Matlab, where the WIP curve was interpolated with a polynomial of degree 10. The derivative of such polynomial was computed: the first zero of the derivative is where the WIP curve flattens after the ramp up, that is, the end of such transient period. Figure 30 shows the graph of such derivative. This calculation was repeated for the five mixes, and after checking where the ramp up ended, for each of the mixes, the simulation time where data are collected was set from t = 3000 min to t = 5000 min.

After the experiment is run, all the results are copied on an Excel spreadsheet, in order to compute the final average between the average cycle time of all the scenarios. Repeating this process for the other 4 mixes, one gets the whole set of 5 "average time in system", shown in Table 6.

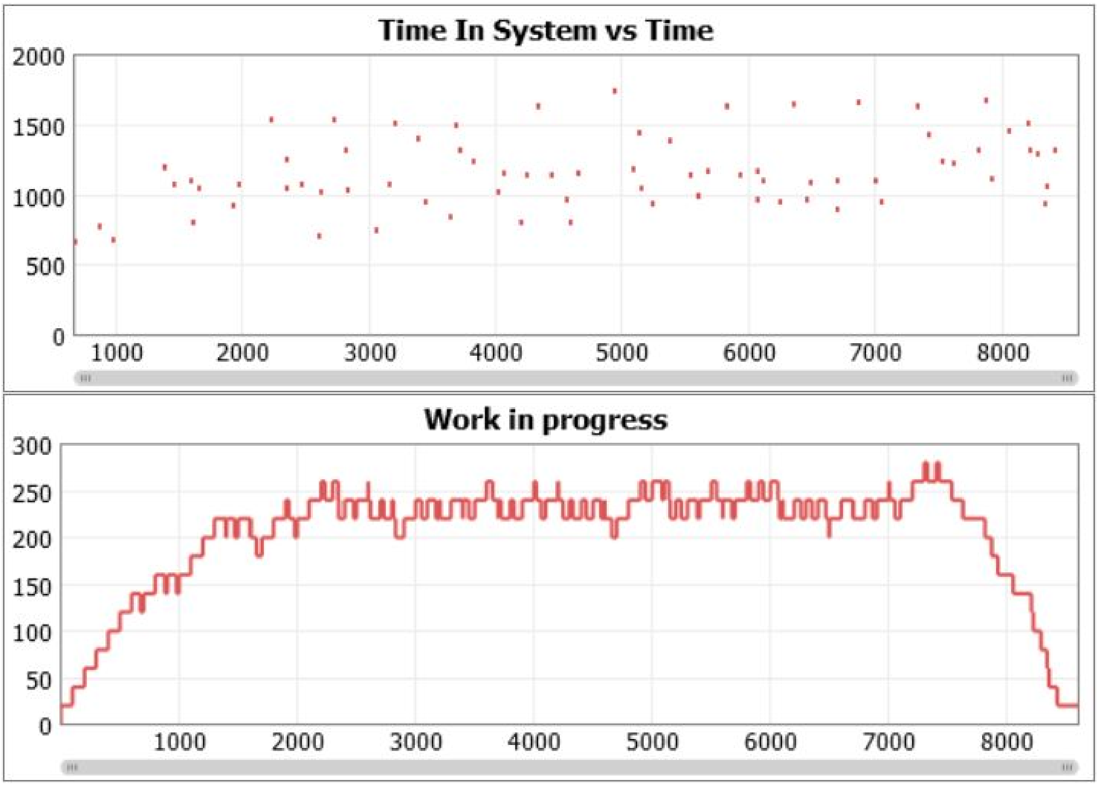



*Figure 29: Work In Progress graph*

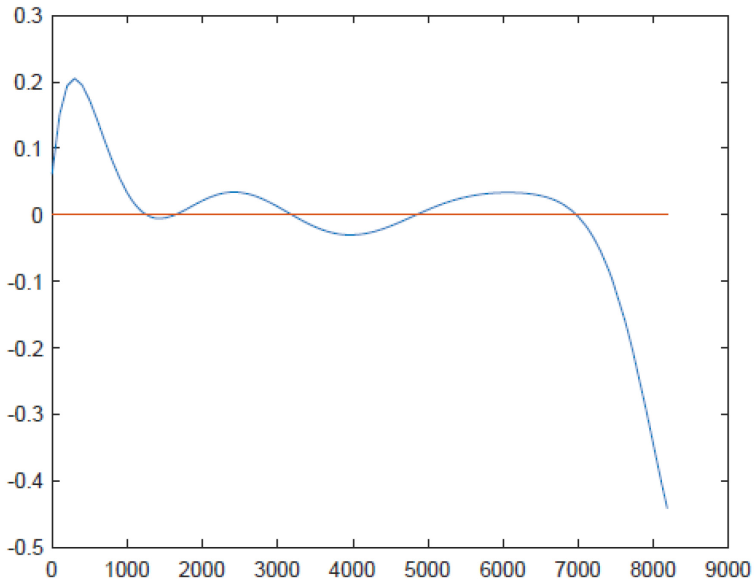



*Figure 30: Derivative of the WIP curve*

*Table 6: Average time in system for the five mixes*

| | Composition | $\overline{t_{insystem}}$ |
|---|---|---|
| Mix 1 | 1 side, 2 roofs, 2 reinforcements | 1383.04 min |
| Mix 2 | 1 side, 1 roof, 3 reinforcements | 1342.30 min |
| Mix 3 | 1 side, 3 roofs, 1 reinforcement | 1395.16 min |
| Mix 4 | 1 side, 4 roofs | 1433.50 min |
| Mix 5 | 1 side, 4 reinforcements | 1280.74 min |

3) The last step is the actual calculation of NVA time. In this context, non-value-added activities are:
   - Transportations
   - Queues
   - Operators' breaks
   - Set-ups
   - Loading and unloading from the forklift

As it was anticipated at the beginning of this section, the calculation of the NVA time is straightforward and it is performed according to the following formula:

$$\%t_{NVA} = 100 \cdot \left(1 - \frac{\overline{t_{ideal}}}{\overline{t_{in\ system}}}\right)$$

Table 7 shows the results of such computation, which are commented in the next chapter.

*Table 7: Resulting NVA time for each mix*

| | Composition | $\%t_{NVA}$ |
|---|---|---|
| Mix 1 | 1 side, 2 roofs, 2 reinforcements | **58.57%** |
| Mix 2 | 1 side, 1 roof, 3 reinforcements | **60.67%** |
| Mix 3 | 1 side, 3 roofs, 1 reinforcement | **55.69%** |
| Mix 4 | 1 side, 4 roofs | **53.73%** |
| Mix 5 | 1 side, 4 reinforcements | **62.31%** |

## 5.2 Limitations of the model

Clearly, the implemented model that represents Eurodies Italia's production shopfloor shows some limitations, that are considered in the following.

1) No data about defectives

Data about the number of defectives were not available and it was decided not to implement them in the simulation. Therefore, in the model, 100% of the produced components are good, there is no scrapping or reworking, which is different from what it happens in real life.

Nevertheless, our model considers the actual "production process" for the prototypes, excluding the so-called *dies tuning* phase, where the most defects and ruptures happen.

2) Set-up times are just hypothesized

The distributions of set-up times were obtained with interviews to the operators, since they are excessively long to be measured. Both the times suggested by the press operators and the ones told by the laser operators were coherent, and they were considered reliable.

3) Components may need a number of manufacturing steps different from 5

In reality, not all the components that are produced by Eurodies need all the steps that are depicted in the model (drawing, laser roughing, redrawing, flanging, laser finishing). Some pieces just need two operations, or even one for some very simple components. In the model, on the contrary, all the items must undergo all the 5 manufacturing processes.

4) The 2D Laser can operate during the night shift

The two-dimensional laser used for cutting the metal sheet according to the blank outline is fully automated, with an automatic warehouse that loads and unloads the machine. Therefore, the 2D laser can also work at night, when no operator is present. In our model, this possibility was not included, because the time was not subdivided into shifts.

5) Beta distributions for manufacturing times determined from a small number of data

The time measurements performed with a stopwatch were around 20 for every component: not enough to obtain completely robust statistical data.

Chapter 6

# Results and discussion

The percentages of time spent on Non Value Added activities can be utilized to order the mixes, obtaining the following:

1. Mix 4
2. Mix 3
3. Mix 1
4. Mix 2
5. Mix 5

where the first one is the mix with the least amount of NVA time (i.e. the "best mix") and the last one is the mix with the greatest amount of NVA time. In order to make some considerations on such result, it is useful to look at the composition of mixes, shown in Table 8 below. Since the average values for cycle time, that were shown in Table 6 in the previous chapter, come from the average of 500 numbers (100 scenarios times 5 replications), it was decided to compute the standard deviation of such sets of data, which is shown below in the same Table 8.

At least two considerations can be made, just looking at such table. As the number of chassis internal reinforcements in the mix increases, the time that is wasted in queues and other nonproductive activities increases as well. In addition, reinforcements are the typology of product that guarantees to Eurodies the lowest order profit: therefore, inserting them in a mix looks twice harmful.

*Table 8: NVA time and time in system std deviation for the five mixes*

| | Composition | $\%t_{NVA}$ | $t_{insystem}$ std deviation |
|---|---|---|---|
| Mix 4 | 1 side, 4 roofs | 53.73% | 85.603 |
| Mix 3 | 1 side, 3 roofs, **1 reinforcement** | 55.69% | 106.85 |
| Mix 1 | 1 side, 2 roofs, **2 reinforcements** | 58.57% | 134.67 |
| Mix 2 | 1 side, 1 roof, **3 reinforcements** | 60.67% | 138.72 |
| Mix 5 | 1 side, **4 reinforcements** | 62.31% | 143.17 |

The second consideration about Table 8 is the following: as the NVA time increases (together with the number of reinforcements in the mix), also the standard deviation of the average time is system increases noticeably. This increased variability among cycle times could be the reason of the loss in efficiency.

After obtaining these results, it was considered interesting to investigate the causes of such correlation between number of reinforcements in the mix and time unproductivity of the system. Why do the chassis reinforcements "slow down" the shopfloor?

In order to look at what actually happened during the about 1000 minutes of cycle time, it was thought to consider the FlexSim dashboard tool called "Item Trace Gantt", or item Gantt chart. Such tool shows where each item is located in every moment of time (queue, transporter, processor), as Figure 31 shows.

The figure shows, as examples, three boxes containing the details of three "locations" of the products. For instance:

```
OUT press 5: 2455.26 – 2688.07 (232.81)
```

means that the item called Product 389 has remained in the output queue of Press 5 from time t = 2455.26 min to time t = 2688.07 min, for a duration of 232.81 minutes. It is clear that reading manually data from the chart is inconvenient and time-consuming, especially when such a great amount of item is produced in every simulation (75 batches of 20 pieces → 1500 pieces).

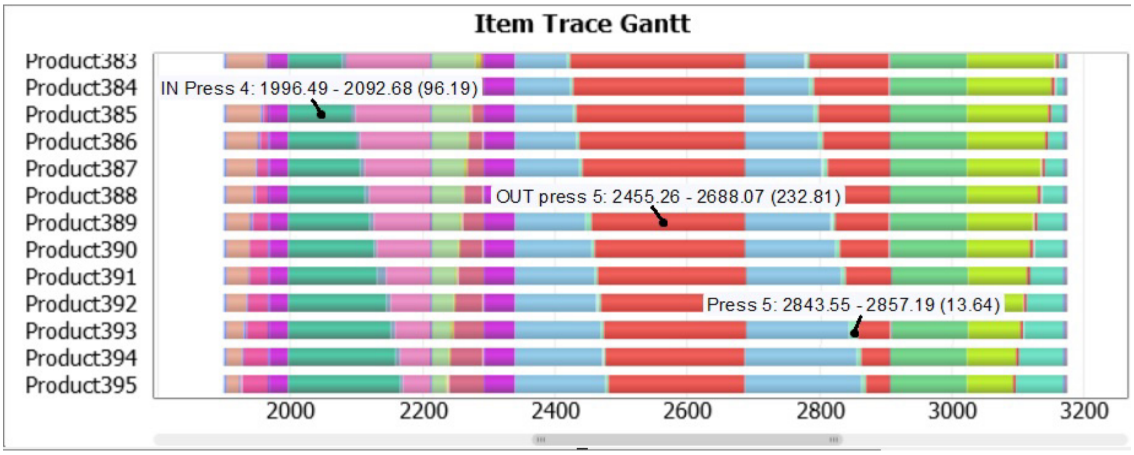



*Figure 31: Item Gantt chart*

Therefore, the tool "export data as CSV" was utilized: this tool downloads the time data (both start time and end time) for every step and every item and saves them in a CSV file, readable by Microsoft Excel.

Five simulations for each of the 5 types of mix were launched, with different products mixes, and the CSV file with the Gantt data was obtained from every simulation. A portion of an Excel spreadsheet resulting from one of these CSV files is shown in Figure 32.

Subsequently, the difference between each couple of start and end value was computed, and the average among the durations of all the items was calculated. This procedure led to the results shown in Figure 33. In such figure, showing a portion of the same Microsoft Excel spreadsheet of the previous image, the average duration for every step of the manufacturing cycle can be seen on the left.

| Product402 StartTime | Product402 EndTime | Product402 Object | Product403 StartTime | Product403 EndTime | Product403 Object | Product404 StartTime | Product404 EndTime | Product404 Object |
|---|---|---|---|---|---|---|---|---|
| 2000 | 2001,010064 | Warehouse Comm 1( | 2000 | 2001,010064 | Warehouse Comm : | 2000 | 2001,010064 | Warehouse Comm 1( |
| 2001,010064 | 2003,118721 | Transporter1 | 2001,010064 | 2003,118721 | Transporter1 | 2001,010064 | 2003,118721 | Transporter1 |
| 2003,118721 | 2070,308202 | IN Laser2D | 2003,118721 | 2066,941091 | IN Laser2D | 2003,118721 | 2061,903533 | IN Laser2D |
| 2070,308202 | 2073,605042 | Laser 2D | 2066,941091 | 2070,308202 | Laser 2D | 2061,903533 | 2066,941091 | Laser 2D |
| 2077,438472 | 2078,75147 | OUT Laser2D | 2073,605042 | 2078,263913 | OUT Laser2D | 2070,308202 | 2078,263913 | OUT Laser2D |
| 2078,75147 | 2079,585804 | Transporter1 | 2078,263913 | 2079,585804 | Transporter1 | 2078,263913 | 2079,585804 | Transporter1 |
| 2079,585804 | 2096,80178 | IN Presses | 2079,585804 | 2096,80178 | IN Presses | 2079,585804 | 2096,80178 | IN Presses |
| 2096,80178 | 2103,727662 | IN Press 4 | 2096,80178 | 2205,297493 | IN Press 4 | 2096,80178 | 2209,041264 | IN Press 4 |
| 2103,727662 | 2205,297493 | Press 4 | 2205,297493 | 2209,041264 | Press 4 | 2209,041264 | 2212,845338 | Press 4 |
| 2205,297493 | 2286,446915 | OUT press 4 | 2209,041264 | 2286,446915 | OUT press 4 | 2212,845338 | 2286,446915 | OUT press 4 |
| 2286,446915 | 2288,169821 | Transporter1 | 2286,446915 | 2288,169821 | Transporter1 | 2286,446915 | 2287,773184 | Transporter1 |
| 2288,169821 | 2393,106259 | IN Lasers | 2288,169821 | 2393,106259 | IN Lasers | 2287,773184 | 2393,106259 | IN Lasers |
| 2393,106259 | 2464,974726 | IN Laser3 | 2393,106259 | 2461,075122 | IN Laser3 | 2393,106259 | 2457,067427 | IN Laser3 |
| 2464,974726 | 2468,455154 | Laser 3D 3 | 2461,075122 | 2464,974726 | Laser 3D 3 | 2457,067427 | 2461,075122 | Laser 3D 3 |
| 2471,250359 | 2472,831375 | OUT Laser3 | 2468,455154 | 2472,831375 | OUT Laser3 | 2464,974726 | 2472,403646 | OUT Laser3 |
| 2472,831375 | 2473,493791 | Transporter1 | 2472,831375 | 2473,493791 | Transporter1 | 2472,403646 | 2473,493791 | Transporter1 |
| 2473,493791 | 2473,883283 | IN Presses | 2473,493791 | 2473,883283 | IN Presses | 2473,493791 | 2473,883283 | IN Presses |
| 2473,883283 | 2473,883283 | IN Press 4 | 2473,883283 | 2476,648394 | IN Press 4 | 2473,883283 | 2480,091438 | IN Press 4 |
| 2473,883283 | 2476,648394 | Press 4 | 2476,648394 | 2480,091438 | Press 4 | 2480,091438 | 2483,893803 | Press 4 |
| 2480,091438 | 2541,173193 | OUT press 4 | 2483,893803 | 2541,173193 | OUT press 4 | 2486,71332 | 2541,173193 | OUT press 4 |
| 2541,173193 | 2545,333182 | IN Press 4 | 2541,173193 | 2549,539331 | IN Press 4 | 2541,173193 | 2553,809479 | IN Press 4 |
| 2541,173193 | 2545,333182 | Press 4 | 2545,333182 | 2549,539331 | Press 4 | 2549,539331 | 2553,809479 | Press 4 |
| 2545,333182 | 2632,932001 | OUT press 4 | 2549,539331 | 2632,932001 | OUT press 4 | 2553,809479 | 2632,932001 | OUT press 4 |
| 2632,932001 | 2634,731003 | Transporter1 | 2632,932001 | 2634,731003 | Transporter1 | 2632,932001 | 2634,731003 | Transporter1 |

*Figure 32: Gantt chart data*

| Average values - Mix 1 Scenario 3 | | | | |
|---|---|---|---|---|
| | | | | |
| Warehouse | 1,16 | | Transporter: | 8,64 |
| Transporter | 2,30 | | CODE Presse: | 392,64 |
| IN Laser2D | 33,90 | | CODE Laser 2D | 33,90 |
| Laser 2D MANUFACTURING | 3,47 | | CODE Laser 3D: | 347,17 |
| OUT Laser2D | 34,35 | | CODE Delivery | 70,09 |
| Transporter | 1,34 | | LAV LASER 2D | 3,47 |
| IN Presses | 5,61 | | LAV PRESSE | 19,74 |
| IN Press | 112,16 | | LAV LASER 3D | 14,17 |
| Press MANUFACTURING | 8,32 | | OTHER | 1,55 |
| OUT press 4 | 48,74 | | TOT | 891,36 |
| Transporter | 1,17 | | | |
| IN Lasers | 56,08 | | | |
| IN Laser | 68,30 | | | |
| Laser 3D 3 MANUFACTURING | 5,99 | | | |
| .... | .... | | | |

*Figure 33: Average queue time and manufacturing time for one mix*

Subsequently, since each item is worked in the same manufacturing center multiple times (twice on the laser machine, and three times on the press), the durations belonging to the waiting time and manufacturing time of the same working center were added up, leading to the results shown on the right.

Notice that, in Figure 32, "CODE" means *queues*, and "LAV" stands for *manufacturing*. Subsequently, the procedure was repeated for all the five types of mix: Table 9 summarizes the results obtained in this way.

*Table 9: Average queue time and manufacturing time for the five mixes*

| | Mix1 | Mix2 | Mix3 | **Mix4** | **Mix5** |
|---|---|---|---|---|---|
| Transporter | 9,06 | 9,16 | 8,89 | 9,25 | 9,01 |
| **CODE Presse** | 25,85 | 23,19 | 27,06 | **29,34** | **21,96** |
| CODE Laser 2D | 1,68 | 1,69 | 1,69 | 1,69 | 1,70 |
| **CODE Laser 3D** | 15,74 | 18,26 | 12,23 | **9,70** | **20,73** |
| CODE Delivery | 3,45 | 3,46 | 3,24 | 3,17 | 3,68 |
| LAV LASER 2D | 3,48 | 3,51 | 3,54 | 3,50 | 3,53 |
| LAV PRESSE | 22,71 | 19,72 | 25,60 | 28,22 | 17,32 |
| LAV LASER 3D | 13,95 | 13,87 | 13,95 | 13,62 | 14,10 |
| TOT | 95,93 | 92,84 | 96,20 | 98,48 | 92,06 |
| $\Sigma\ t_{NVA}$ | 55,78 | 55,74 | 53,11 | 53,15 | 57,09 |
| $\%t_{NVA}$ | 0,58 | 0,60 | 0,55 | 0,54 | 0,62 |

It is important to highlight that, for the results shown in the previous table, the durations of the queue were divided by 20, in order to refer the times to a single item, and not to the whole batch.

Looking at Table 9, and specifically at the emboldened values, it is possible to make further considerations. Mix 4 is the "best mix", and Mix 5 the one showing the greatest inefficiency: if we look at the average duration of laser queues and press queues for these two mixes, it can be noted that Mix 4 has the longest press queue and the shortest laser queue, whereas Mix 5 has the longest laser queue and the shortest press queue.

Therefore, it may be hypothesized that the longer time needed by the reinforcements for the finishing laser trim is one of the causes of the greater inefficiency of the mixes that contain more reinforcements. In fact, the machines that are able to perform such machining on the workpieces are only three, compared to the five presses. For this reason, since the reinforcements need much shorter press processing, compared to the other types of components, several of the five presses could be idle for a greater percentage of time in the mixes with more reinforcements, while the laser area behaves as a bottleneck.

It may be thought, then, that it would be sufficient for Eurodies to avoid producing chassis internal reinforcements, and focus on the other typologies of components. The reasons behind such a decision would be at least two: the first is the reduction in shopfloor production efficiency that such components cause, as it was explained right above; the second, more economical, is that reinforcements, even if they were produced with 100% efficiency, are the components that ensure the lowest order profit.

This solution, nevertheless, is not applicable in Eurodies because the company does not accept orders by its costumers for single components, but for "sets" of pieces. Therefore, to accept the order for a profitable side frame, it might be necessary for them to accept also an order for the production of several internal reinforcements, if these belong to the same set.

We now suggest a different possible solution to this issue. In the area of Turin, there are many other companies that operate in the same sector as Eurodies, producing the same type of component, but of smaller dimensions, and having a definitely lower level of technology. Their ability to compete on the international market is surely lower than the one of Eurodies, also for their lower perceived credibility and reliability. These smaller companies focus almost entirely on the internal market, and receive a definitely lower amount of orders, with respect to Eurodies.

Therefore, Eurodies could accept orders in synergy with these other companies, creating a sort of partnership and then acquiring the production orders of the most profitable and efficient components contained in the "macro-order". This kind of partnership would benefit Eurodies Italia, increasing its productivity and its influence on the territory, but at the same time it would benefit also the other minor companies interested by the alliance, because it would increase their own production level and their turnover.

Besides the clear advantages that Eurodies would obtain by doing so, such as the possibility to take advantage of all its productive capabilities without wasting financial and temporal resources on less profitable components, the company would also further increase its international links, because the foreign carmakers that are currently its costumers would be able to order even more components to Eurodies, which they trust as a validated supplier of high quality prototypes. At the same time, the subcontractors could decrease their dependence upon the local automakers, entering an international market that would ensure them more contracts and higher profits, allowing them to gain international credibility and to be "known" by foreign automakers, which up to this moment do not consider them as possible suppliers, due to their smaller dimensions.

Chapter 7

# Conclusions

At the end of this Master's Thesis, it is necessary to define in which way the obtained results can be useful for Eurodies and for similar companies that operate in the sector of automotive bodywork prototype production.

As it was anticipated in the section about model limitations, our model does show several approximations: despite being as accurate as possible, it is clear that a shopfloor model built on a simulation software cannot track and predict all the variables that influence production in real life. Time data about process durations were so scarce and the production cycles for prototype-making are so complex and variable, that it was not possible to obtain results that are completely accurate and realistic.

Nevertheless, the general idea and the work methods and procedures that were utilized to obtain such results are correct and they allow to make the considerations that are reported in Chapter 6.

This Thesis wanted to show how process simulation software, in particular FlexSim, can be very useful also for medium-small industries like Eurodies Italia. When more data will be available, with the implementation of Industry 4.0 tools and methodology (which is recently starting to be applied in a broader pool of companies in Italy), a model like ours could be made more accurate and utilized everyday in order to plan production, deciding how to build the "mix", i.e. which components are manufactured at the same time, so that inefficiencies and queues are reduced.

Another way in which FlexSim could be successfully utilized is to predict the impact of a change in the shopfloor layout, before making an important investment like the purchase of a new machine (which often have prices in the order of hundreds of thousands of euros). If the company implemented a FlexSim model similar to ours, they could simulate the variation of performance caused by an additional work center – maybe a new 3D laser – and the investment decision would be supported by a more rigorous *case study* basis. For example, Eurodies has recently moved its productive activities to the Avigliana plant, from its previous plant located in Rivoli. The new layout, with the location of all the machines and production lines were decided basing on experience: if a tool like FlexSim had been used, many different possibilities for the position of the machines in the new plant's buildings could have been simulated in order to choose the most efficient for the movements of material and semifinished products.

The objective of this Master's Thesis, therefore, is not providing a company with certain data and with a defined new work methodology: it is rather to provide the company with the *idea* that a new methodology is possible and profitable. Our model shall be made available to Eurodies, as a basis from which they can start, in order to improve their decision-making process in such a variable and difficult sector like the production of prototype components.

# References


ACEA, 2018. *Statistics Key Figures.* [Online]
Available at: https://www.acea.be/statistics/tag/category/key-figures

Cattell, D., 2008. Stamping 101: Anatomy of a Mechanical Press. *Stamping Journal.*

Draghi, M., 2007. *Dalla ricerca all'innovazione per la crescita economica.* Camigliatello Silano, Scuola Normale Superiore di Pisa.

European Commission, 2018. *Automotive Industry.* [Online]
Available at: https://ec.europa.eu/growth/sectors/automotive_en
[Accessed 10 Luglio 2018].

Fan, J. et al., 2006. 3D finite element simulation of deep drawing with damage development. *International Journal of Machine Tools & Manufacture,* Volume 46, pp. 1035-1044.

FlexSim Software Products Inc, 2014. *FlexSim Brochure.* [Online]
Available at: https://www.flexsim.com/wp-content/uploads/2014/06/FlexSimBrochure.pdf

Groover, M. P., 2010. *Fundamentals of Modern Manufacturing.* IV ed. Hoboken, NJ: John Wiley & Sons, Inc..

Prima Power, 2017. *Laser Platino.* [Online]
Available at: https://www.primapower.com/platino/

Prima Power, 2018. *The Laser | 3D Line (Brochure).* : .

Unioncamere & Prometeia S.p.a., 2015. *Il settore automotive nei principali paesi europei,* Roma: Commissione Industria, Commercio, Turismo del Senato della Repubblica italiana.

# Ringraziamenti

A conclusione di questo lavoro di ricerca, che rappresenta il termine del mio percorso universitario di cinque anni, vorrei ringraziare tutte le persone che mi hanno sostenuto e supportato, in modi differenti, in modo che tale percorso fosse praticamente privo di difficoltà e intoppi.

Prima di tutto i miei genitori, che mi hanno aiutato moralmente ed economicamente, credendo nelle mie capacità, supportandomi con i loro consigli e il loro sostegno affettivo, e appoggiandomi in tutte le mie scelte di carriera e di vita.

Un ringraziamento, poi, va a tutti i miei parenti (Ludovica, zii, zie e cugini) che sono sempre stati disponibili ad aiutarmi e a sostenermi durante questi cinque anni, e tutti quelli precedenti.

Vorrei anche ringraziare i miei amici, sia quelli di Sanremo (Andrea, Federico, Luca Tommaso e gli altri), sia quelli di Torino (Luca, Raffaele, Riccardo e tutti gli altri) per aver portato un po' di leggerezza e divertimento in un periodo che sarebbe stato altrimenti impegnativo e stressante. Un ringraziamento particolare a Margherita, che ha revisionato questa Tesi, prendendosi il tempo e l'impegno di leggere 85 pagine in inglese.

Un grande ringraziamento anche a Michela, per avermi s**o**pportato per la maggior parte di questo periodo di studi, che si conclude oggi.

Ringrazio le persone che ho conosciuto in America e in Germania, con cui ho stretto amicizie profonde e durature. Fra gli altri, cito Gabriele e Stefano, Antonio, Lavinia, Paolo, Simone e Tommaso.

Un ringraziamento a tutti i miei compagni di piano del Collegio, di quattro piani diversi, che sono stati i miei "coinquilini" per cinque anni.

Grazie anche a Gabriele, che ha collaborato con me in questo lavoro di ricerca: auguri per il proseguimento della tua carriera con il Master di secondo livello in Sports Engineering.

Infine, vorrei ringraziare i miei colleghi dell'MBA che ho iniziato la settimana scorsa. Anche se vi ho appena conosciuto, sono sicuro che contribuirete in modo eccezionale alla mia crescita personale e professionale.

Torino, 18 settembre 2018

Grazie a tutti!