APPLICATION OF LEAN MANUFACTURING ON SHELL AND TUBES HEAT EXCHANGERS PLANT

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ABSTRACT

Located on the industrial zone of Cassano D´adda, Lombardia, Emmegi S.p.a is a manufacturer of heat exchangers since 1975. The company started as a small manufacturer of shell and tubes heat exchangers. Nowadays, these types of products represent 10% of the earnings while air-oil heat exchangers represent the other 90%. Both products are important for the company as Shell and tubes are sold mainly to the same customers of air-oil heat exchangers, providing an advantage over their competitors.

Since the beginning to 2008, Emmegi was merged to a stable European market with a demand in constant increase justifying a make to stock policy with results of 30 million euros per year. Due to the crisis in 2008, the market turned uncertain with a decreasing demand leaving Emmegi at the edge of bankrupt as it was forced to discard 5 million euros on obsolete inventories.

As a recovery plan, production policy was changed from make to stock to a pull productive system in order to reduce risks and financial costs. Anyway, the company maintains the same productive line for shell and tube heat exchangers than three decades ago. Apart from that, their low profits together with their complex financial position, does not encourage huge investments on the productive line, leading Emmegi to considering discontinuing shell and tube heat exchangers production and appeal to outsourcing.

In this complicated context, the thesis focuses on applying Lean Manufacturing policies in order to keep the shell and tube heat exchangers line aligned to a pull productive system, increasing profits and reducing risks. The Lean approach will imply modifications on the entire productive line by applying changes on: the productive process, layout, working stations and supply chain policies.

1. INTRODUCTION TO LEAN PHILOSOPHY

1.1 HISTORY

Lean philosophy was born in Japan as a proposal of Taiichi Ohno who suggested some tools and ideas to improve Toyota productivity when the Second World War was finished. When Ohno studied the big American car producers such as Ford and General Motors, he found inefficiencies that limited productivity.

Ohno introduced the concept of Muda, which means remove activities with no value added. All companies look forward to maximize their earnings by increasing their sales maintaining costs or by reducing costs. Increasing sales generally gives marginal results and nowadays markets tend to be consolidated so companies are more orientated to reduce costs. The traditional point of view tends to reduce costs by removing some product function, reducing used materials for production or reducing elaboration time.

As a starting point, Lean approach is based on the fact, independently of their complexity, have activities that generate no added value. This type of activities can be removed and customers will perceive no change in the output. Lean approach aims to reduce costs by removing all these activities.

1.2 WASTES

It is important to mention that these activities that produce no added value are useless but according to the current state of the productive system, they are indispensable but are potentially removed by an intervention or improvement. In order to remove these activities, first it is necessary to identify those activities that generate added value; those that generate no value added but can be removed on the short period and those that can be removed within a long period of time.

Activities considered wastes can be categorized in 8 classes as shown at **Figure 1.1:**

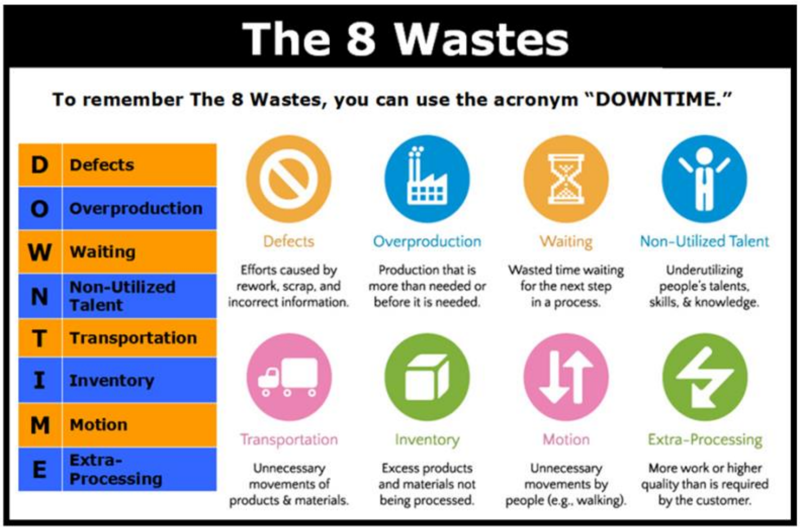


Figure 1.1: Eight type of wastes according to Lean Philosophy.

1.3 TOOLS

In order to remove wastes, Ohno establishes concepts, tools and a procedure to put into practice. **Figure 1.2** shows Lean manufacturing structure:

Figure 1.2: Lean manufacturing structure.

One of the pillars for Lean production is Pull system also known as Just in Time (JIT). In other words, produce only what market demands, when it demands it and where it demands it. The main benefit of this idea is to avoid having a huge warehouse of finished production and reduce movement of both finished and unfinished inventory and raw material. One of the difficulties to face when working on a pull system appears when providing time of suppliers is longer that production time forcing to store raw material.

The second pillar of Lean philosophy is Jidoka which means produce correctly without defects. The only way a piece exits a productive process and passes to the next one is if the activity was performed on the correct way avoiding final defects or reprocessing. Each worker has the responsibility of certifying that the process was executed on the correct way and in case it wasn´t, production must be stopped until the process is performed correctly. By introducing this concept, Ohno establishes the idea of automation under auto-control. To put in practice Jidoka, Ohno proposed some technics such as Poka Yoke which reduce mistakes as much as possible by introducing behaviour-shaping constraints. Lean philosophy makes reference to zero defects which means that there´s a possibility of mistake associated to human errors but in case there´s a mistake, it is responsibility from the same worker to repair it.

More tools like Kaizen, standardization and Heijunka were also introduced by Ohno to put in practice Lean philosophy. Kaizen dynamic consists on constant improvement to palliate mudas (wastes). On the other hand, Heijunka has as aim to absorb possible fluctuations of the demand by producing on small batches of different products on the same productive line. This principle looks to reach the one piece flow principle. Heijunka also allows the removal of mudas by favouring work standardization.

Introduced Lean structure, the metaphor of the sailing ship shown at **Figure 1.3** clearly justifies the implementation of these concepts and tools.

Figure 1.3: Ship metaphor of wastes and losses.

The ship represents the company while water represents the inventory level and rocks the different inefficiencies of the productive system. Traditional approach tends to increase inventory level in order to cover all these inefficiencies. On the other hand, Lean philosophy focuses on decreasing inventory level as much as possible by removing rocks from the bottom.

2. PRODUCT DESCRIPTION

2.1 INTRODUCTION TO HEAT EXCHANGERS

Shell and tubes heat exchanges, consist on an external tube welded to a perforated plate on both tips where inner tubes come welded to the plate as well. The inner tubes carry water at natural temperature, more or less 20ºC. Due to the friction between water and tubes, a pump is required since pressure at the end of the section is higher that pressure at the entrance. The same occurs with oil carried inside the cavity of the external tube. According to the conduction formulae described below, heat is transferred from hot oil to cold water:

$$\frac{dq}{dt} = -k.a.\frac{dT}{dx}$$

The variable *k* represents the conductivity coefficient associated to the material, for this reason, inner tubes are made of copper being a good thermal conductor with a high coefficient of thermal conductivity. The contact area is another variable that influences on conduction. To maximize contact are between oil and copper tubes, baffles are inserted to make oil pass through sinuously. By integration of the formulae, heat transfer is proportional to temperature difference between water flowing in contact with the inner face of the copper tube and the oil in contact with the outer face.

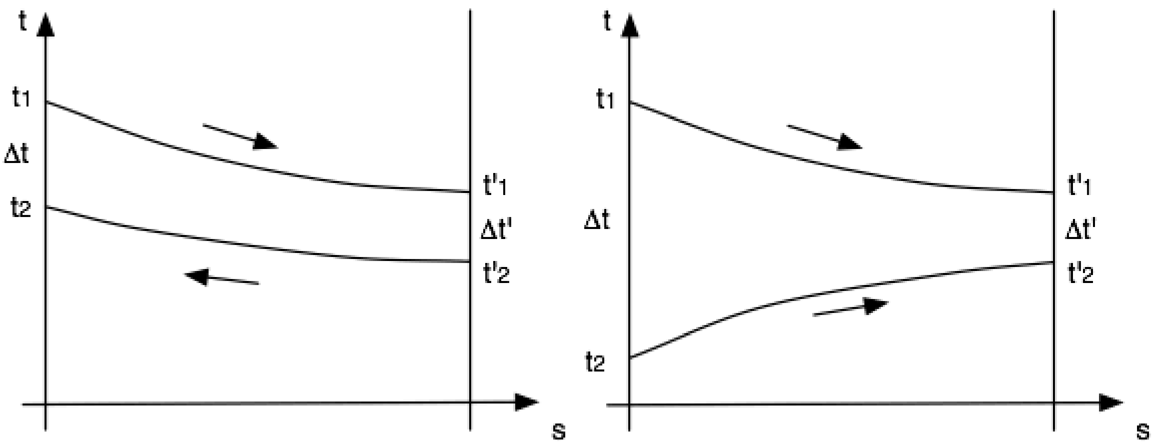
Another variable to take into account is the flow of fluids since the heat power transfer described above gives as a result the specific heat power transferred. In other words, it must be integrated to all the control volume giving as a result a linear proportion with the flow.

Quoting Bernoulli`s formulae,

$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + z_1 + W = h_f + \frac{V_2^2}{2g} + \frac{P_2}{\gamma} + z_2$$

Where *V* is velocity, *P* pressure, *z* refers to potential energy and sub-indexes *1* and *2* refer to input and output respectively. The variable *h* makes reference to enthalpy and *W* to work. Loses present inside the copper tubes and inside the cavity were oil flows is reflected as a pressure fall. For this reason, the amount of baffles inserted to maximize oil circuit must take into account that increasing baffles increase pressure fall so the pump requirements increase as well.

Regarding to fluids flow, shell and tubes heat exchangers are divided in two categories, parallel flow or counter flow. In the case of parallel flow, water and oil flow in the same sense while in counter flow ones, they flow oppositely. The following graph shows temperature variation for both types.



Counter flow Parallel flow

Figure 2.1: Types of shell and tubes heat exchangers.

Since counter flow heat exchangers allow hot fluid to reach lower temperature, Emmegi produces counter flow ones.

Based on concepts described above, Emmegi proposes customers a heat exchanger that fits their power heat transfer requirement studying length, diameter, flow and temperature of fluids.

2.2 DESCRIPTION AND NOMENCLATURE

Each heat exchanger produced by Emmegi has a Product name containing the product class and dimension. Since there are two main types of products, letters contain the product class. **Figure 2.2** contains the different classes and processes contained on each of these classes.

	SHELL CUT	INNER TUBES CUT	WASH	ASSEMBLE	BRAZING		TIG WELDING	BORING	QUALITY CONTROL
					MANUAL	SEMI-AUTOMATIC			
MG 54	X	X		X	X				
MG 60	X	X		X	X				X
MG 80	X	X	X	X		X			X
MG 81	X	X	X	X		X			X
MG 130	X	X	X	X		X			X
MG131	X	X	X	X		X			X
MGB 80	X	X	X	X			X	X	X
MGB 130	X	X	X	X			X	X	X
MGB 131	X	X	X	X			X	X	X

MG 54-60 CLASS
MG CLASS
MGB CLASS
SUBLCASSES

Figure 2.2: Product classification based on activities involved in the productive process.

As shown on the figure, a product of MG class is characterized by including a brass piece welded by brazing while products of class MGB contain no brass but an iron piece which is welded by TIG to the external tube.

After product class, the first number represents the diameter of the shell tube being 54mm, 60mm, 80mm, 114mm, 130mm, 155mm, 168mm or 219mm. Since two exchangers of the same class with the same shell diameter may have different number of inner tubes, this distinction is marked by changing the last digit on the diameter. For example, a product MG 80 and a MG 81 belong to the same class, both have a diameter of 80mm but they have different amount of inner tubes. The second number sets the distance between oil input and output called interaxis. The last number indicates the amount of passages of water.

NOMENCLATURE		
MG 130-535-1	Diameter: 130mm Interaxis: 535mm	Inner tubes: 76 Passages: 1 Brass collector
MG 131-535-1	Diameter: 130mm Interaxis: 535mm	**Inner tubes: 136** Passages: 1 Brass collector
MG 131-535-4	Diameter: 130mm Interaxis: 535mm	Inner tubes: 136 **Passages: 4** Brass collector
MGB 131-535-4	Diameter: 130mm Inner tubes: 136	Interaxis: 535mm Passages: 4 **Iron Tubular plate**

Figure 2.3: Nomenclature method based on product properties.

2.3 MATERIALS

Before studying the processes held to produce the different products on the catalogue, it is necessary to understand the components and materials included on each product.

Shell:

Shell is a synonym for the external tube of the device. When selecting the material, the main variable to take into account is the atmosphere in which the product will be exposed. This means, corrosion risk, salts on atmosphere, temperature, among others. The principal material used is Fe360 being the cheapest one and it is suitable for non-aggressive atmospheres. In case of aggressive atmosphere, depending on the product class, Brass or AISI 316 is used. Anyway, all products are painted with a protective paint.

Inner tubes:

Tubes through which water flows cooling oil by conduction. The material selected must have a high conduction coefficient since these tubes are in contact on the outer side with hot oil conducting heat to water on the inner side. The diameter plays also a key role since the amount of heat transferred is also proportional to the contact section. Generally, inner tubes are made of copper due to its low cost and high conduction coefficient. In case the product is submerged into a harsh atmosphere, the material used is cupronickel or Aisi.

Baffles:

Semi-circular discs assembled and spaced by a determined distance so as to make oil flow a longer distance increasing contact with the inner tubes and time inside the heat exchanger. The material used is generally brass with the exception of heat exchangers with external shell of Aisi using Aisi baffles. It is important to select properly the baffles material to avoid creating a galvanized cell inside the tube causing possible perforation on tubes.

Tubular plate:

These plates close hermetically the cavity inside the external tube. Tubular plates contain holes where inner tubes are then inserted to form the skeleton. The material of the tubular plate depends on the material of the external tube being iron or Aisi generally. The majority of products are used in non-aggressive atmosphere so iron is suitable.

Input/output water:

Also called covers. These covers are assembled in most cases to the tubular plate or brass collector depending on the product. For those products with brass shell, covers are brazed. Hosepipes are connected to the covers conforming water input and output. Cover`s design define the amount of passages in the oil circuit and varies depending on the diameter of the product.

Oil Input/Output:

These sleeves are connected to oil conduct. According to the flow requirement, the diameter of the Input/Output may vary.

Spacers:

Spacers consist on tubes of wider diameter than the inner tubes inserted in order to fix baffles on a determinate length.

Brass collector:

This component is specific for the MG class. The function of the brass collector is the same as the tubular plate and the oil Input/Output in one piece. The advantage of this component is that the plate and the oil Input/Output are already joint avoiding one welding operation saving time and making production more fluid by removing steps.

Table 2.4 contains all components needed for each products elaboration.

MATERIALS USED				
COMPONENT	**MATERIAL**	**PRODUCT FAMILY**		
		MG 54 + 60	MG 80 + 81 + 130 + 131	MGB
SHELL	IRON		X	X
	BRASS	X		
	AISI			X
INNER TUBES	COPPER	X	X	X
	CUPRONICKEL	X	X	
	AISI			X
BAFFLES	BRASS	X	X	X
	AISI			X
TUBULAR PLATE	IRON			X
	BRASS	X		
	AISI			X

SPACERS	COPPER	X	X	X
	CUPRONICKEL	X	X	
	AISI			X
INPUT/OUTPUT SLEEVES	IRON			X
	BRASS	X		
	AISI			X
COVERS	BRASS	X	X	X
	AISI			X
BRASS FUSION	BRASS		X	

Figure 2.4: Components and materials present on each product.

The wide variety of products in catalogue, diameters, lengths, models and materials for production offered, force Emmegi to have a certain quantity of frozen capital in raw materials and inventories in order to satisfy client`s demand. Each component varies depending the diameter, number of inner tubes and client`s requirement added to the demand volatility carry significant costs of storage and manipulation of inventories.

2.4 PRODUCTIVE PROCESS

Precedence diagrams explain the difference between MG`s products productive process and MGB`s one. The main difference is localized on the welding process due to the different materials that require diverse type of welding.

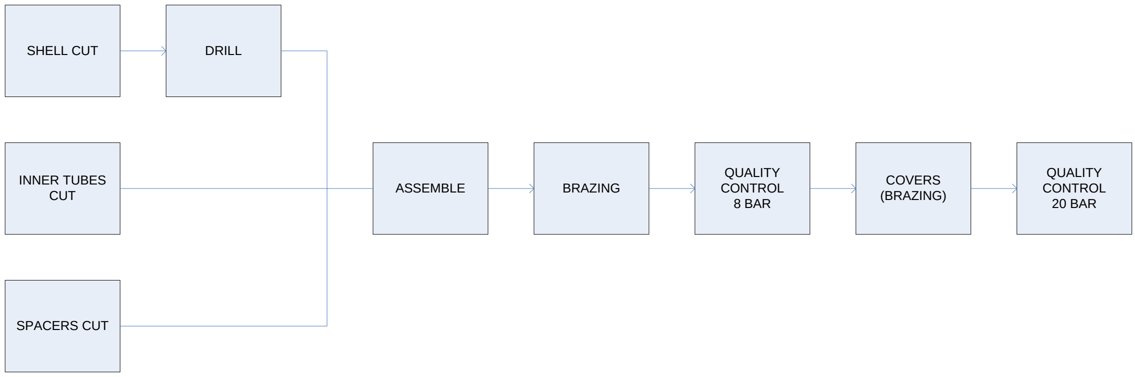


Figure 2.5: Precedence diagram for MG 54-60 products.

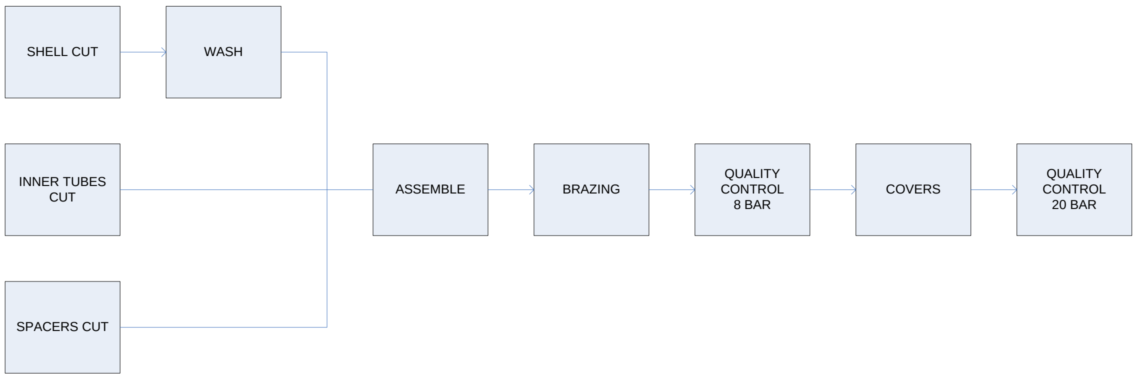


Figure2.6: Precedence diagram for MG products.

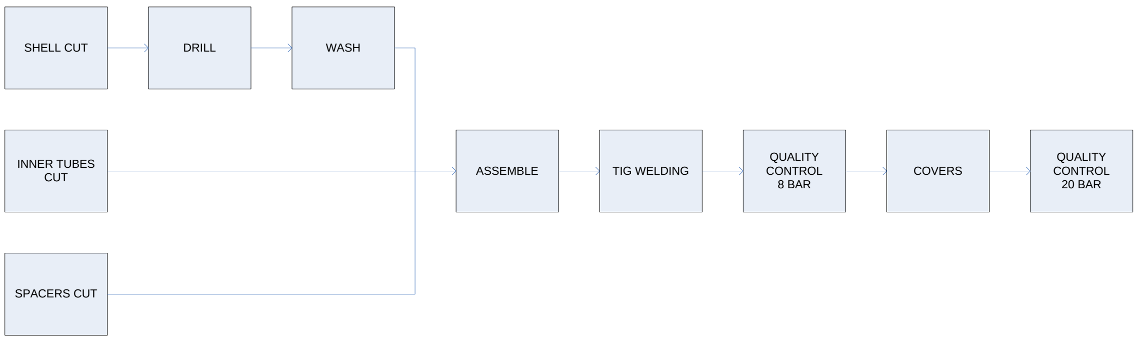


Figure 2.7: Precedence diagram for MGB products.

Shell cut:

Six meter tubes are unloaded from trucks and stored beside the cutting machine. Depending on the rotation index of the tube, they are stored on the different shelves leaving the most frequent tubes on the most accessible shelves, being these ones Iron 80mm and 130mm. Tubes are picked from the shelves and placed in the cutting machine that can be programmed to cut diverse lengths automatically. In order to avoid scrap as much as possible, the first shells to be cut are the longest ones.

Regarding to manipulation, tubes with diameter smaller than 80mm can be picked from the shelves and placed in the machine by a single operator. For those tubes wider than 80mm, two operators are needed to manipulate the tubes. The wider tubes like 219mm and those stored on the higher shelves must be handled with the auto elevator.

Drilling:

All products without the brass fusion must be drilled so as to weld the oil Input/Output directly to the tube. Those tubes containing brass fusion avoid drilling process are MG products with diameter over 80mm.

Drilling process consists on performing two holes of one inch or one inch and a half, depending on the oil flow, where the Oil Input/Output sleeves come welded afterwards. Another hole of smaller diameter is drilled on the opposite side of the tube where another drainage sleeve comes then welded.

Inner Tubes cut:

Inner tubes, as Shells, arrive by truck in boxes that are stored on shelves beside the cutting machine. From the shelves, tubes are placed on the machine by 4 to 6 simultaneously depending on the diameter of the tubes being cut. The machine has a program able to set the length and amount of tubes required and the machine cuts automatically and informs when the whole process is over. The operator only needs to refill the tubes in the machine.

Spacers cut:

Spacers consist on the short remaining pieces of inner tubes that, due to their small length, are useless as inner tubes for a smaller heat exchanger. These pieces are inserted concentrically in order to fix baffles in a determinate position. In other words, products with inner tubes of 7mm have spacers of 9 mm inserted between each baffle to fix it. Spacers are cut manually and machine capacity allows cutting 5 or 6 tubes simultaneously depending in the diameter.

Assemble:

Assembling process consists on placing one tubular plate or brass fusion, depending on the product, on the table and inserts four inner tubes in the holes shown in the next figure (**Figure 2.8**):

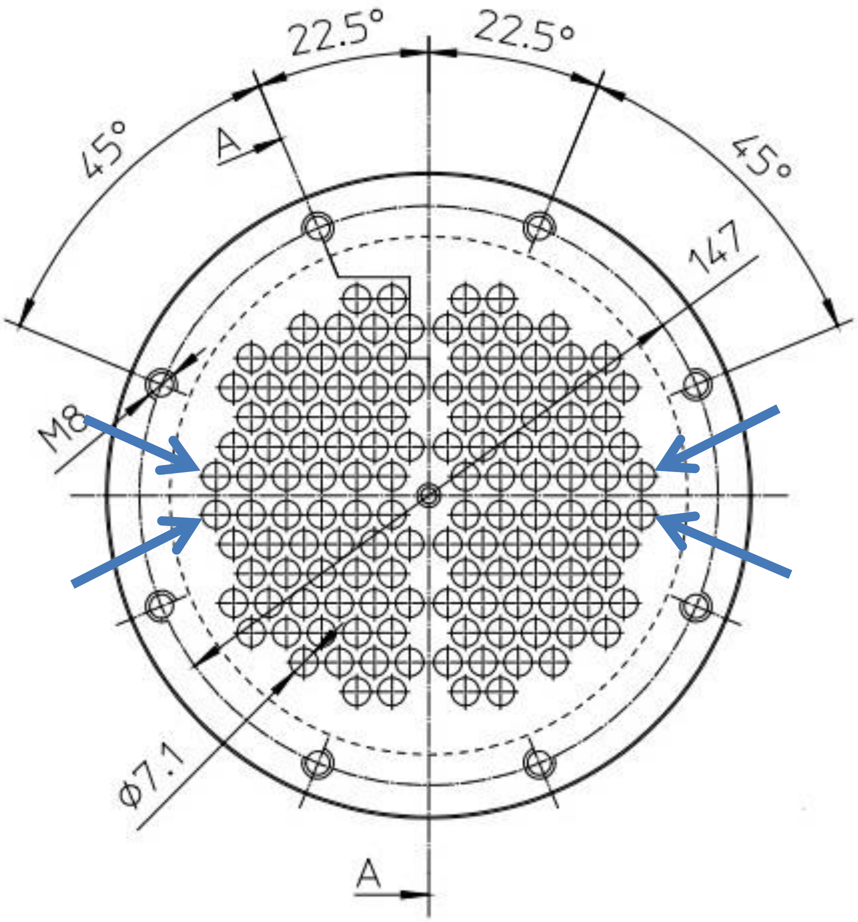


Figure 2.8: Tubular plate indicating holes where the inner tubes and spacers are inserted.

Once the inner tubes are inserted, spacers are introduced concentrically followed by a baffle repeating this sequence according to the quantity of baffles conforming the product. When the structure is already finished, the remaining holes are filled with the rest of the inner tubes. It is important to align properly plates and baffles in order to have a sinuous oil flow. Finally, the shell is placed and the other tubular plate or collector respectively closes the structure.

For those products with the inner tube brazed automatically or semi-automatically to the tubular plate, silver alloy rings are placed on each tube ending to automatize the process. Afterwards, a plate that fixes the rings is set in one of the edges and the same procedure is performed on the other edge. This step only is required for those MG products with diameter 80mm or wider.

Brazing:

As shown in the precedence diagram above, MG products are welded by brazing with an alloy material containing silver. This process can be manual, semi-automatic or automatic.

Manual: Only MGE, MGC y MG 54/60 products have brass Shell so they must be brazed manually. Having the inner tubes to close between each other, alloy rings cannot be placed so it is not possible to automatize the process. The operator must braze using a silver alloy string, one by one each of the inner tubes to the tubular plate ant the tubular plate to the shell. These products have the oil Input/Output sleeves and covers brazed as well. Sleeves must be perfectly aligned so the operator uses a calibrator to verify the alienation and interaxis simultaneously. Once braze is finished, the product is sent to quality control and in case there are no leakages, covers are welded with an orbital brazing.

Semi-automatic: The skeleton is introduced in an oven were each silver alloy ring on each inner tube ending melts welding the inner tube to the brass fusion. Once the tube is removed from the oven, the operator checks if there are visible leakages between the tubes and the tubular plates and after correcting them, he proceeds to the orbital brazing to weld the Shell with the brass fusion. Then the piece is rotated, the plate holding the other edge alloy rings is removed and the exact procedure is performed for the opposite face of the piece. In case the piece is too heavy, the operator must screw two sticks inside the Input/Output sleeves in order to be able to rotate and handle the piece. If the piece is small and light enough, the operator uses a gripper.

Automatic: Automatic brazing consists on a three station robot where the first one heats the upper face of the tube, the second one performs the orbital brazing and the third station allows the operator check the brazing and rotate the piece removing the plate holding the silver alloy rings. The automatic brazing works on two products simultaneously but the set up and cleaning time is too long so the robot is worth when the batch is over 40 products.

T.I.G. welding:

TIG welding is divided in two steps. The first step consists on the orbital welding performed by a semi-automatic machine that rotates the tube while welding but an operator must be verifying the result. The second step is based on welding the Input/Output sleeves to the shell but before the operator must align correctly the sleeves with a calibrator. Finally the drainage sleeve is welded following the same procedure as the Input/Output sleeves.

Boring:

In case of products MGB, inner tubes are not welded to the tubular plate. An operator bores each tube to the tubular plate attaching them by mechanical deformation. One of the faces of the tube is placed in front of the boring machine and a plate is attached to the other face so as to avoid the inner tubes to slip backwards when boring. Once the plate is fixed, the operator sets up the boring machine depending on the diameter and length of the piece. The two possible variables to take into account when performing the set-up of the machine are the power supplied by the machine which is proportional to the diameter and length of the inner tubes and the boring head depends on the diameter of the inner tubes.

Each of the tubes comes bored before rotating the pieces, removing the plate and repeating the same procedure on the other face. Once the piece is finished, it is placed on a trolley and then moved to quality control station.

High pressure quality control (20 bar):

Quality control must be realized since there are leakages that are not visually detectable. Quality control is performed in two stages. The first one checks the oil circuit connecting a hosepipe to the oil Input/Output sleeves. Once connected the hosepipe, the piece is submerged in water and a 20 bar pressure test is performed. In case there is a leakage, bubbles come up and it is possible to localize the leakage and send the piece back to welding station were the leakage is repaired.

Covers assemble:

Approved the first quality control stage, covers and fixing supports are assemble. This process consists on aligning covers with the tubular plate or brass fusion respectively inserting insulation between to avoid leakages. The covers are screwed with 6 or 8 screws depending the cover design and supports are inserted between the cover and the screw head.

Low pressure quality control (8 bar):

The second stage of quality control consists on testing the water circuit. Two stopples are places on the oil Input/Output sleeves to avoid water entering inside the oil circuit. Then, two hosepipes are screwed to the water circuit entrance and exit. The procedure is exactly the same as the high pressure quality control but instead of 20 bar, 8 bar pressure is applied. If there are bubbles coming out of the tube, the piece is sent to welding station, in case no leakages are identified, the product is ready to be sent to painting.

Painting:

Since there are strict regulation in terms of security and environment, a painting machine requires several characteristics that make outsourcing the most suitable solution. Each day, a truck takes the new batch of products to be painted and delivers the products already painted. The mean time for painting varies between 2 or 3 available days depending on the product and the type of painting demanded.

Packing and shipping:

Once received the painted products, they are stored provisionally and then moved to the finished product shelves. When the order is completed with all the products of the same client ready to be delivered, the whole order is consolidated and the package is placed on the shipping area waiting the truck to deliver the order.

3. DIAGNOSTIC

3.1 DEMAND ANALYSIS

3.1.1 Last year`s demand

In order to study the demand of the last periods, it is important to classify the catalogue to be able to understand the difference on the product demand. Emmegi has two types of products differentiating each other in the productive process and the materials. Products belonging to the MG class contain a brass fusion supplied by a provider being these components brazed to the Shell as described on chapter 2. On the other hand, products belonging to the MGB class have an iron tubular plate welded by TIG welding to the Shell. The catalogue is divided in MG, MGE and MGB; being MG and MGE almost the same product in terms of productive process but MGB has a significant difference, reason why MGB belongs to another product class.

In **Table 3.1 appendix**, products shaded in grey are those products with a monthly mean demand over 10 products, actually being produced by batch. The other products are produced by order. The table contains 280 different products between 1st January 2013 and 31st August 2014 where only 11 products complete over 40% of the total demand.

According to the classification mentioned above, the study is based on the most representative products of each class subdivided in subclasses depending on the characteristic property of each product which is the diameter. **Tables 3.2, 3.3 y 3.4** show the influence of each subclass based on the quantity of products demanded and based on billing.

INFLUENCE ACCORDING QUANTITY DEMANDED					
MG 54-60	MG 80	MGB 80/87	MG 130-131	MGB 130-131	TOTAL
981,00	4321,00	202,00	1609,00	401,00	7514,00
13,06%	57,51%	2,69%	21,41%	5,34%	100,00%

Table 3.2: Influence of each subclass based on the quantity demanded.

INFLUENCE ACCORDING BILLING					
MG 54-60	MG 80	MGB 80/87	MG 130-131	MGB 130-131	TOTAL
87387,54	990506,73	53986,22	848889,47	200982,64	2181752,60
4,01%	45,40%	2,47%	38,91%	9,21%	100,00%

Table 3.3: Influence of each subclass based on billing.

BILLINIG/ QUANTITY RATIO				
MG 54-60	MG 80	MGB 80	MG 130-131	MGB 130-131
0,31	**0,79**	**0,92**	**1,82**	**1,73**

Table 3.4: Rate between billing and quantity demanded.

In terms of production, the most significant product to the firm is the MG 80 but in terms of billing, the most significant one is the MG 130-131. MG 130-131 represents the most significant product in the billing/demand rate as well.

3.1.2 Monthly demand

Based on data of the past year, it is possible to infer the causes of the variability on demand from month to month as shown in **Figure 3.5**:

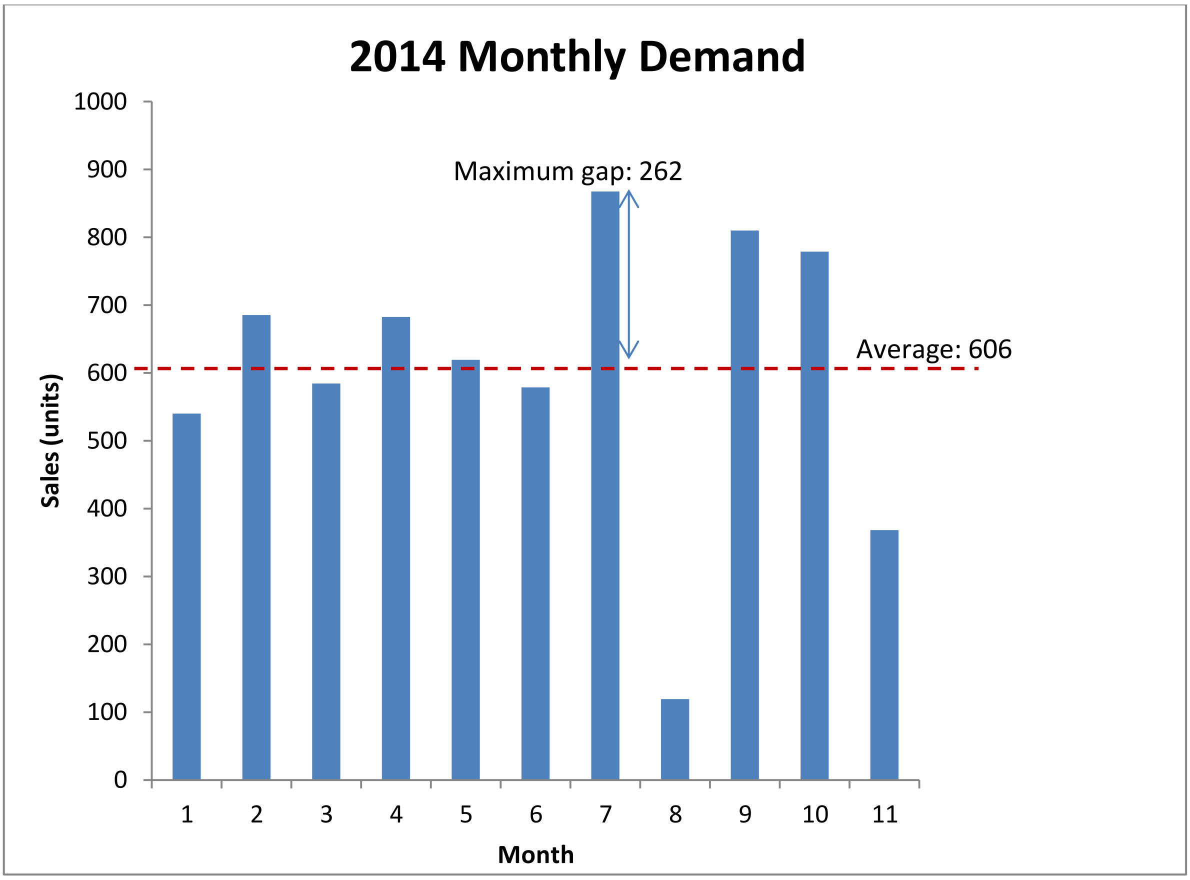


Figure 3.5: Year 2014 monthly demand.

From the graph it is possible to deduce that there is a significant variability on months 7, 8, 9 and 10 due to the vacation period held in August. In order to satisfy the demand, Emmegi must over produce on the rest of the months to balance the period of inactivity. This is the only significant factor to take into account when studying seasonality along months since excluding August; the demand is stable with no evidence of seasonality or important variations.

3.1.3 Class monthly variation in the past year

After studying the demand on the past year, it is possible to analyse the demands behaviour by month of the different product categories and aggregated also by product families

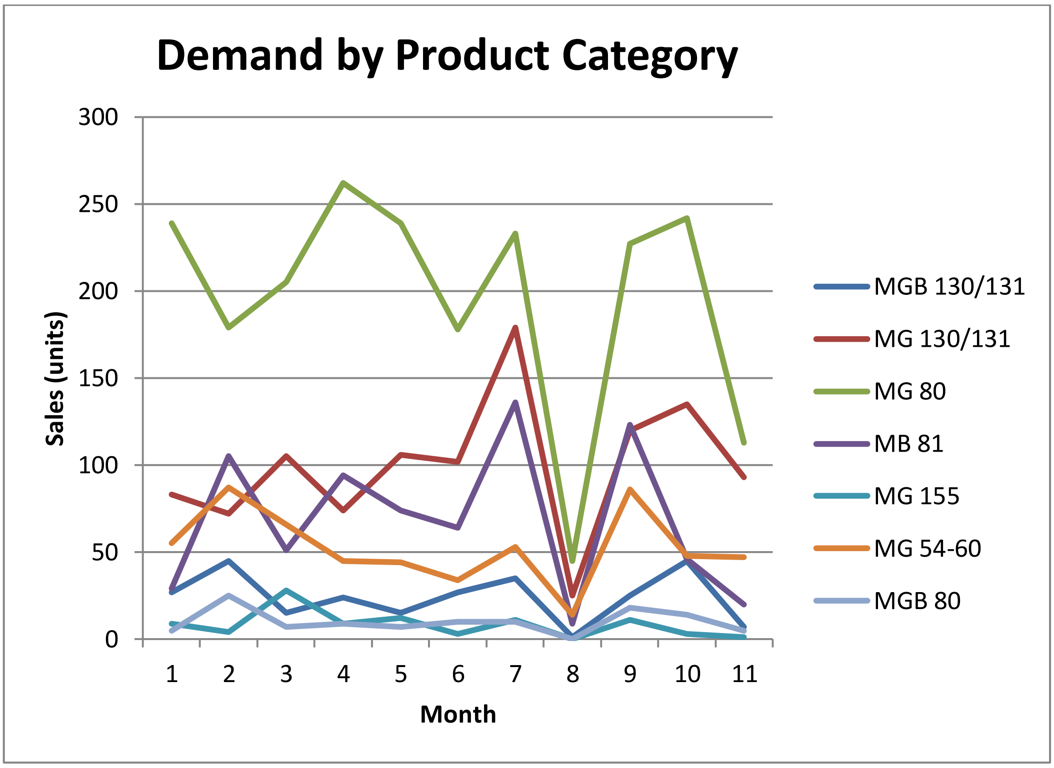


Figure 3.6: Demand by product category.

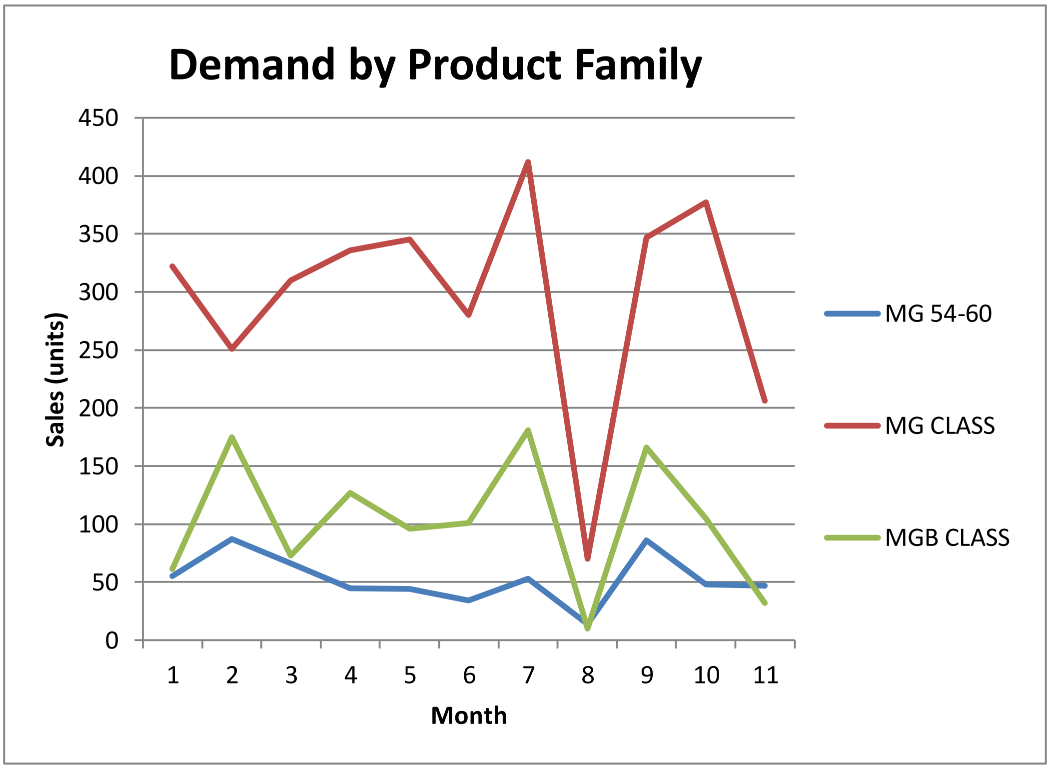


Figure 3.6 BIS: Demand by product family

As mentioned above, there is an important fluctuation in August due to the vacations period, but taking into account the graph above, there is a notable variation between months in all categories and families. It is important to understand the fluctuation of demand on each month in order to plan the supply of materials and components that differ between product classes. When studying the standard deviation, the months to take into account are those were demand is stable, in other words, exclude July and August were vacations modify the monthly demand mean.

STANDARD DEVIATION OF THE MEAN DEMAND											
Product	Mth 1	Mth 2	Mth 3	Mth 4	Mth 5	Mth 6	Mth 10	Mth 11	Std dev (Q)	Mean (Q)	Var. Coeff
MGB 130/1	27	45	15	24	15	27	45	7	13,8	25,6	53,79%
MG 130/1	83	72	105	74	106	102	135	93	20,6	96,3	21,42%
MG 80	239	179	205	262	239	178	242	113	48,9	207,1	23,63%
MG 81	29	105	51	94	74	64	46	20	29,8	60,4	49,41%
MG 155	9	4	28	9	12	3	3	1	8,7	8,6	100,87%
MG 60	55	87	66	45	44	34	48	47	16,5	53,3	30,90%
MGB 80	5	25	7	9	7	10	14	5	6,6	10,3	64,87%

Table 3.7: Monthly demand standard deviation.

For those product classes with low demand, volatility is higher as shown by the relative standard deviation, in other words, the Variation Coefficient that compares the standard deviation of the product with the one of the mean. Taking into account the high volatility of demand and the amount of products in catalogue, it is not profitable to have inventories with all products due to the storage cost, frozen capital, high Cash to Cash index and the necessity of a warehouse able to store so many products. At the same time, it is difficult to have a supply policy of raw materials due to the variability on demand month by month.

3.2 ORDER ANALYSIS

Another important fact to take into account when analysing the demand, is to understand the procedure in which customers make their orders. Based on the historical data of the orders of the past two years, the next figure contains the amount of order lines requested in a single order. This means that if an order contains one product MG 80-535-2 and three products MG 130-1135-4, then one unit is added to 1 product per order line and 1 is added to 3 products per order line. **Figure 3.8** contains the statistics of order lines of the past two years:

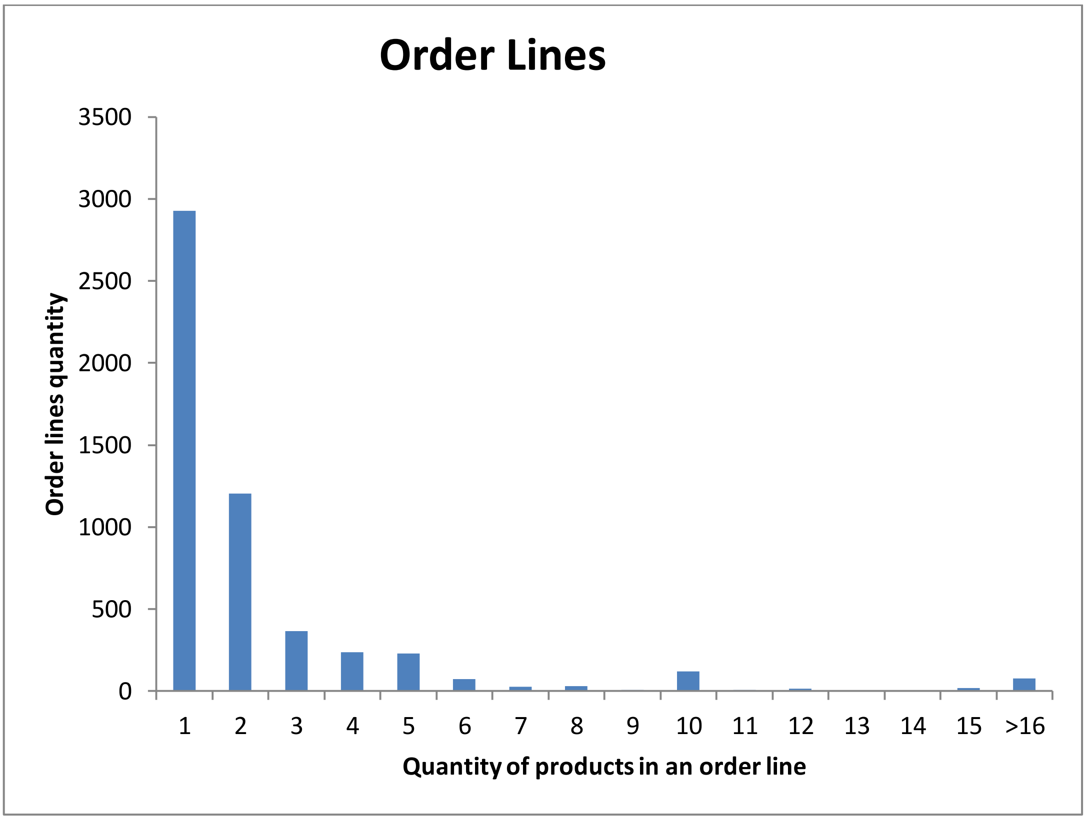


Figure 3.8: Mean of order lines per order

By observing the graph, it is possible to deduce that the majority of the order lines contain very few products. From a total of 5362 order lines analysed, 2928 contain a single product which represents 54% of the order lines. Taking into account that some products are produced by batch production, a huge amount of orders must be compiled to reach a number of products to fill a batch. By compiling orders, there is a saving on set up times but on the other hand, MRP has to organize orders involving managing time. So as to create a whole batch of identic products, many late orders are forwarded so other orders suffer delays and longer lead time since these products must wait a whole batch with newer orders to be completed.

3.3 LEAD TIME TO CLIENTS

The Company records the information of the orders made in the database of the ERP system. This ERP system provides the following information which can be used to make different statistics:

- Product code and description
- Ordered Quantity
- List price
- Adjusted price
- Date in which the order was registered (generally one or two days after the client makes the order)
- Date in which the system expect to take raw materials
- Date in which the order is expected to be finished.

- Date when the production was finished.

The software is able to know the date in which the commercial department arranged to hand in the product, but the system has no record of the date the client desiderates the product to be delivered. The production management department merge orders with similar products demanded relatively close in order to facilitate the welding process and to set up the automatic brazer so the information provided by the system is not entirely trustful.

Regarding to delays, the system is not allowed to insert a justification of the delays so as to analyse them afterwards and find solutions or to understand the main causes of fluctuations of production times.

There are some cases in which a customer asks for an exact product as one which is already in stocked as a finished product differing on the amount of passages. For those cases, it is possible to change covers which are the only piece that differs from these two products with different passages. These orders are registered usually as products with less than a week of production. An example could be a customer who demands a MG 130-535-1 and Emmegi has a MG 130-535-2, in this case, it is possible to change covers taking less than five minute.

When analysing mean Lead time, it is necessary to discard those cases that alter the mean and increase the standard deviation. These cases are principally vacation days, non-workable days, and cases of cover changing like the one described above. During vacations, Lead time becomes too long altering the statistics. In case of covers changing the opposite happens. Discarding all these cases, mean Lead time is 21 days but registers show a real value of 25,6.

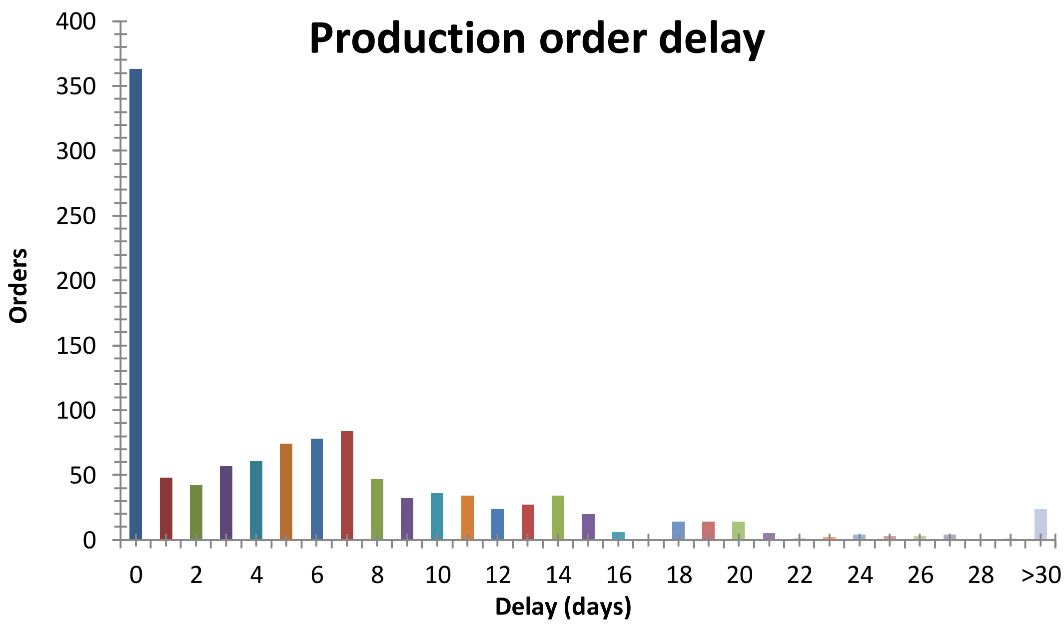


Figure 3.9: Production order delay.

Figure 3.9 contains delays of the past year were 629 out of 920 orders were delivered with delay. This means that 68% of the products weren`t delivered during the expected time.

However, the MRP takes a margin of 4/5 days to avoid deliver the product in delay. According to the database, delays overpass 4 days. From the 68% of the orders with delay, 61, 5% are over 5 days and 40% were delivered to clients with delay.

Although it is not possible to understand if causes are lack of raw materials, wrong planning or operator's inefficiency, it is important to know the current state of Emmegi.

3.4 INVENTORIES STUDY

3.4.1 Inventory's policy

Actually there is a stable economic situation for the Company due to the policy adopted on the last year to reduce stocks. Before the European crisis, the company used to reduce unit price by scale economy generating high levels of inventories, nowadays, the company tends to a pull philosophy to avoid high cost of frozen capital and reduce the production of obsolete products. However, when analysing the supplier's policy, some pieces have a minimum order quantity inducing to a low rotation index. Other components, present unclear replacement policy from small orders to satisfy clients demand to high quantity orders to get discounts and reduce administration costs.

The ERP system contains the mean quantity ordered of each component. With the price of the last order, an esteem of the actual inventories was calculated. In some cases, the last order consist on an urgent supplier so the price could represent a fake value so the last order price was compared to the mean cost to avoid overvalue inventories. Anyway, the last order's cost was similar to the mean order cost so the last order cost was taken for all components.

Merging the components type, the results obtained are the following:

ANNUAL INVENTORIES			
COMPONENT	COSTO (EURO)	PORCENTAJE	FAMILIA USO
BRAZING ALLOYRINGS	€ 7.886,97	2,67%	MG
BRAZING ALLOY STRING	€ 16.087,89	5,45%	MG
BRASS FUSION	€ 100.070,13	33,88%	MG
COVERS	€ 84.544,20	28,62%	MG+ MGB
SPECIAL SLEEVES+AISI	€ 8.219,53	2,78%	MGB
SLEEVES(80/81/130/131)	€ 1.867,82	0,63%	MGB
TUBULAR PLATES FOR OTHER PRODUCTS+AISI	€ 17.732,17	6,00%	MGB
TUBULAR PLATE(87+130+131)	€ 3.432,00	1,16%	MGB
SHELL	€ 14.403,63	4,88%	MG+ MGB
INTERNAL TUBES	€ 41.135,32	13,93%	MG+MGB
TOTAL	€ 295.379,64	100,00%	

Table 3.10: Total annual inventories.

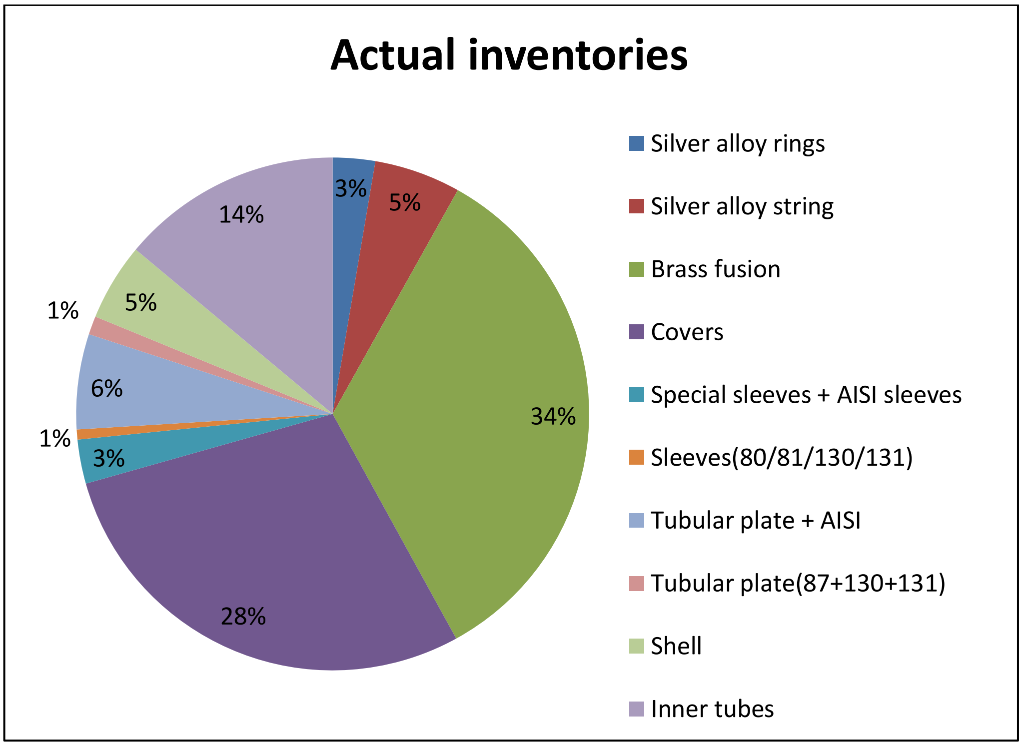


Figure 3.11: Actual inventories composition

Figure 3.11 shows a 33, 8% of inventory's cost consists on brass fusions used only for those products of MG class. The main causes of this high inventories are:

- High unitary cost of components: Each product requires 2 collectors. Each collector costs from 15 to 35 euros per piece depending on the product, representing a mean of 23% of the total material cost.
- Minimum order quantity: Collectors are special components produced exclusively for Emmegi. For this reason, the supplier requires a minimum order quantity to make profitable the production. Then, Emmegi is obliged to have a constant level of inventories with low rotation index. Reorder time is 45 workable days approximately.
- Design variability: Since collectors have included the oil input/output, then there are many variables influencing the collector's design. For the tubular plates, the diameter and amount of internal tubes define the tubular plate's design. For the brass fusions, the variables are the same as the tubular plate in addition to the diameter of the oil input/output and brass fusions are not symmetrical so there is a left and right one.
- Demand volatility, reorder time and the extended catalogue force to have high levels of security stocks of each component.

Other significant part of inventories is represented by inner tubes and covers used in all products having even more design variability. Covers vary depending on the amount of passages required by the client being 1, 2 or 4.

There is a high influence of alloy rings and alloy strings used for brazing which take place on the productive process of MG class only. Being materials with low impact in terms of storage space, the rotation index is almost 50 days and 8% of inventories are associated to these materials.

3.4.2 Inventories' Rotation

Due to the high diversity of products in catalogue, there are many raw materials in the warehouse to analyse all the rotation indexes. Based on the most representative products for the company, the rotation indexes are the following:

ROTATION BY PRODUCT					
MG 80-310-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS
BOBINE LEGA 4576 D.0.7 MM	13,19	13243,81	GR	15690,01	16,88
BOBINE LEGA 4576 D.2 MM	21,44	15750,06	GR	30330,48	10,39
ANELLI D. 7x0.7 LEGA 4576 RICOTTO	23,19	29477,51	NR	61390,09	9,60
TUBO RAME 7x0.6 CRUDO	8,75	2986,93	KG	2346,67	25,46
TUBO Fe360 80x1.5 TOLL. UNI EN 10305-03	5,77	885,52	KG	458,57	38,62
COLLETTORE DX MG 80 D.15001	6,83	456,56	NR	280,18	32,59
COLLETTORE SX MG 80 D.15002	5,83	503,39	NR	263,52	38,21
COPERCHIO ANTER.MG80/4 D.16041	7,71	444,75	NR	308,15	28,87
COPERCHIO POST. MG80/4 D.16121	12,49	274,58	NR	308,15	17,82
MG 81-560-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS
BOBINE LEGA 4576 D.0.7 MM	13,19	13243,81	GR	15690,01	16,88
BOBINE LEGA 4576 D.2 MM	21,44	15750,06	GR	30330,48	10,39
ANELLI D. 7x0.7 LEGA 4576 RICOTTO	23,19	29477,51	NR	61390,09	9,60
TUBO RAME 7x0.6 CRUDO	8,75	2986,93	KG	2346,67	25,46
TUBO Fe360 80x1.5 TOLL. UNI EN 10305-03	5,77	885,52	KG	458,57	38,62
COLLETTORE DX D.15003C MG 81	6,08	198,61	NR	108,41	36,64
COLLETTORE SX D.15004C MG 81	6,40	188,57	NR	108,41	34,79
COPERCHIO ANTER.MG80/4 D.16041	7,71	444,75	NR	308,15	28,87
COPERCHIO POST. MG80/4 D.16121	12,49	274,58	NR	308,15	17,82
MG 130-535-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS
BOBINE LEGA 4576 D.1 MM	12,74	4395,33	GR	5028,22	17,48
BOBINE LEGA 4576 D.2 MM	21,44	15750,06	GR	30330,48	10,39

TUBO RAME 9x0.75 CRUDO	7,10	1926,43	KG	1227,67	31,38
COLLETTORE DX MG 130 D.15005C	6,02	133,97	NR	72,46	36,98
COLLETTORE SX MG 130 DIS.15006C	6,39	126,32	NR	72,46	34,87
COPERCHIO ANT.LAVOR.MG 130-131 4 VIE	6,79	288,50	NR	175,91	32,80
COPERCHIO POST.LAVOR.MG 130-131 4 VIE	7,94	224,08	NR	159,79	28,05
MG 131-831-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS
BOBINE LEGA 4576 D.0.7 MM	13,19	13243,81	GR	15690,01	16,88
BOBINE LEGA 4576 D.2 MM	21,44	15750,06	GR	30330,48	10,39
TUBO RAME 7x0.6 CRUDO	8,75	2986,93	KG	2346,67	25,46
TUBO Fe360 130x2 TOLL. UNI EN 10305-03	5,66	1525,47	KG	775,63	39,33
COLLETTORE DX D.15009C MG 131 2"BSP	2,74	190,51	NR	46,84	81,35
COLLETTORE SX D.15010C MG131 2"BSP	3,05	145,98	NR	39,95	73,08
COPERCHIO ANT.LAVOR.MG 130-131 4 VIE	6,79	288,50	NR	175,91	32,80
COPERCHIO POST.LAVOR.MG 130-131 4 VIE	7,94	224,08	NR	159,79	28,05
MGB 80-500-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS
TUBO RAME 12x0.75 CRUDO	4,21	1035,62	KG	391,50	52,90
TUBO Fe360 80x1.5 TOLL. UNI EN 10305-03	5,77	885,52	KG	458,57	38,62
PIASTRA TUBIERA D.15120A MGB 80	9,52	32,87	NR	28,10	23,39
COPERCHIO ANTER.MG80/4 D.16041	7,71	444,75	NR	308,15	28,87
COPERCHIO POST. MG80/4 D.16121	12,49	274,58	NR	308,15	17,82
MANICOTTO 1 1/2"BSP L=34.5 R.40	7,62	43,05	NR	29,48	29,21
MGB 80-500-4 AISI 304					
DESCRIPCIÓN DE ARTÍCULO	ÍNDICE DE ROTACIÓN	INVENTARIO MEDIO	UNIDAD ES	CONSUMO MENSUAL MEDIO	DÍAS DE COBERTURA
TUBO AISI 304 12X0.75	9,03	74,12	KG	60,08	24,67
TUBO AISI 304 80x1.5	2,20	16,65	KG	3,29	101,17
PIASTRA TUBIERA D.15140 MGB80 AISI 304	4,26	13,68	NR	5,23	52,28
COPERCHIO ANTER.MG80/4 D.16041	7,71	444,75	NR	308,15	28,87
COPERCHIO POST. MG80/4 D.16121	12,49	274,58	NR	308,15	17,82
MGB 130-535-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS

TUBO RAME 9x0.75 CRUDO	7,10	1926,43	KG	1227,67	31,38
TUBO Fe360 130x2 TOLL. UNI EN 10305-03	5,66	1525,47	KG	775,63	39,33
PIASTRA TUBIERA D.15126B MGB 130	6,75	44,56	NR	27,00	33,01
COPERCHIO ANT.LAVOR.MG 130-131 4 VIE	6,79	288,50	NR	175,91	32,80
COPERCHIO POST.LAVOR.MG 130-131 4 VIE	7,94	224,08	NR	159,79	28,05
MANICOTTO 1 1/2" FE R.65 D.16271	8,21	102,59	NR	75,63	27,13
MANICOTTO FE 1/4'GAS (NERO) H.11	6,36	132,62	NR	75,76	35,01
MGB 131-535-4					
DESCRIPCIÓN DE ARTÍCULO	ROTATION INDEX	MEAN INVENTORY	UNITS	CONSUME PER MONTH	COVERAGE IN DAYS
TUBO RAME 7x0.6 CRUDO	8,75	2986,93	KG	2346,67	25,46
TUBO Fe360 130x2 TOLL. UNI EN 10305-03	5,66	1525,47	KG	775,63	39,33
PIASTRA TUBIERA D.15126B MGB 130	6,75	44,56	NR	27,00	33,01
COPERCHIO ANT.LAVOR.MG 130-131 4 VIE	6,79	288,50	NR	175,91	32,80
COPERCHIO POST.LAVOR.MG 130-131 4 VIE	7,94	224,08	NR	159,79	28,05
MANICOTTO 1 1/2" FE R.65 D.16271	8,21	102,59	NR	75,63	27,13
MANICOTTO FE 1/4'GAS (NERO) H.11	6,36	132,62	NR	75,76	35,01

Table 3.12: Rotation indexes of the diverse raw materials by product.

From **Table 3.12**, it is possible to deduce:

Rotation index of brass fusions varies between 2, 7 to 6, 7 which represents a low index. This means that some of the brass fusions remain useless for more than 4 months. Being these the most expensive components, it is a clear evidence of an inefficient inventory policy due to the minimum order quantity required by the supplier.

Shell tubes rotation index is similar to brass fusion's one. Due to the manoeuvrability of the 6 meters tube each time the truck arrives, the number of tubes must be significant in order to stop production to store tubes as less as possible. The difference with the brass fusions is the low cost of the shell tubes representing no threat to the company.

Cover`s rotation index varies between 6, 8 to 12, 49. The high cost of each cover forces the company to reduce the time these components remain in deposit.

Due to the complexity to estimate the demand of components such as tubular plates and oil input/output sleeves, the rotation indexes should remain as low as possible since these components are bought depending on orders.

3.5 TIME STUDY

3.5.1 Historical times

Nowadays, the Company bases the production time previsions based on historical times saved in the ERP database. These times were registered more than 15 years ago with no update. **Table 3.13 appendix** shows the historical times for most representative products.

The table contains some irregularities on the records like the washing time that remains constant to all products, independently of the length, diameter or material. In case of TIG welding of MGB class, time for 80 mm diameter tubes overpasses welding time of 130 mm diameter tubes.

Concerning to the productive stations, the ERP divides the whole production chain in 5 or 6 stations depending on the product class, which means that some of this stations contain many processes that can be developed in parallel. For example, the ERP has only one time for the entire process of shell, internal tubes and spacers cut, but these activities can be developed in parallel leaving the time recorded in the database useless when analysing the productive system.

3.5.2 Estimated time based on timing

It is necessary to obtain an esteem of the real times to be able to perform a productive process study and find possible improvements. Due to the high diversity of products, it is not possible to take exact times of all products since many products have a demand of one product per year so it would be necessary a whole year to record times for the entire catalogue. In most processes, time varies significantly with diameter. In other processes like boring, it is possible to calculate the time to bore one tube and multiply the time recorded with the amount of tubes in the product. **Tables 3.14 to 3.21 appendix**, contain times recorded for each station.

Based on the times obtained, it is possible to calculate a pending and intersection and used them to interpolate times for products with the same diameter but diverse length. **Tables 3.22 to 3.26 appendix**, have pending and intersections for all the working stations.

After interpolating times, it is possible to perform a table with the estimated times for each product (**Table 3.27 appendix**).

Comparing historical records with estimated times; there is a significant difference between the time the Company expects to produce and the real time taken. **Table 3.28** has the variation between estimated time and historical times recorded in the database.

TIME VARIATION [s] (ESTIMATED– HISTORIC)	
MG 54-60	-186,00
MG	485,21
MGB	-147,57

Table 3.28: Time variation between times estimated by interpolation and historical times.

3.5.3 Adjusted time by inefficiency

Time study realized above does not take into account different coefficients of inefficiency as inactivity, material scrap, productive processes defect and fatigue.

Material scrap:

There are two processes which generate significant material scrap: Shell tube cut and internal tube cut. Shells arrive in tubes of 6 meters, placed on the cutting machine and cut automatically. The tube is cut until the remaining is shorter than the shorter product in the catalogue. Depending the diameter, the pessimist approach is to esteem the scrap as the length of the shorter tube which represents 2, 33% of material cost according the ERP. From the scrap, 15% can be recovered and sold to the supplier. Moreover, shell represents 1% of the total cost of production so the iron tube discarded represents a 0, 02%.

Copper tubes arrive as 6 meters tubes as well and the procedure is exactly the same as the shell tubes. The difference is that the remaining tubes shorter than the shorter tubes in the catalogue are used as spacers so the internal tubes scrap is negligible.

Defective products:

Analysing records from the past two years, the first defect is localized in the high pressure were leakages are found in the brass pieces and brazing process. During the low pressure quality control, leakages are found in the brass covers present in all products. **Table 3.29** contains the defects of the past two years.

COVERS						
	2014			**2013**		
	QUANTITY	DEFECTS	%	QUANTITY	DEFECTS	%
MG 80 MG 81	1347	49	3,64%	537	28	5,21%
	1025	17	1,66%	294	32	10,88%
	679	20	2,95%	198	2	1,01%
	2284	0	0,00%	882	0	0,00%
	2284	0	0,00%	882	0	0,00%
MG 130 MG 131	484	15	3,10%	181	7	3,87%
	174	21	12,07%	148	23	15,54%
	129	3	2,33%	114	0	0,00%
	1348	22	1,63%	506	9	1,78%
	1309	57	4,35%	504	30	5,95%
MG 155	187	13	6,95%	37	0	0,00%
	162	6	3,70%	37	0	0,00%
TOTAL	11412	223	1,95%	4320	131	3,03%

BRASS FUSIONS						
	2014			2013		
	QUANTITY	DEFECTS	%	QUANTITY	DEFECTS	%
MG 80	2181	180	8,25%	718	21	2,92%
	2034	33	1,62%	718	0	0,00%
MG 80 SW	521	1	0,19%	252	2	0,79%
	444	0	0,00%	217	0	0,00%
MG 81 + MG 81 SW	812	8	0,99%	331	6	1,81%
	812	0	0,00%	331	0	0,00%
MG 130 + MG 130 SW 1" 1/2 BSP	5	0	0,00%	220	41	18,64%
	531	82	15,44%	29	5	17,24%
	5	0	0,00%	220	0	0,00%
	531	22	4,14%	29	1	3,45%
MG 131 + MG 131 SW 1" 1/2 BSP	153	15	9,80%	171	19	11,11%
	317	20	6,31%	0	0	0,00%
	77	6	7,79%	159	0	0,00%
	319	1	0,31%	0	0	0,00%
MG 131 + MG 131 SW 2" BSP	329	39	11,85%	139	13	9,35%
	272	2	0,74%	124	0	0,00%
MG 155	163	11	6,75%	31	0	0,00%
	163	0	0,00%	31	0	0,00%
TOTAL	9669	420	4,34%	3720	108	2,90%
NO REPAIRABLE		**28**	**6,67%**			

Table 3.29: Defects detected on the hydraulic quality control.

For those defects identified on brass fusions, there is an increasing trend based on 2, 90% defective units found in 2013 to 4, 34% found in 2014. The main cause that justifies the increasing trend is the antiquity of the matrix used by suppliers resulting in leakages over time. On the other hand, brass covers show a decreasing trend respect to the past two years registering 3, 08% in 2013 and 1, 95% in 2014. Defects on brass covers are usually repaired but 6, 67% of brass pieces are non-repairable.

Products with leakages are sent to welding station to be re-heated and the leakage is repaired adding welding alloy. Once repaired, it is necessary to repeat the quality control process. In case the piece satisfies the quality control, additional costs for repairing the piece are 10% of welding alloy and 1, 15% of total cost. In addition, the quality control time is doubled carrying an operating cost.

For those cases were the piece cannot be repaired, the whole piece is discarded which represent loses of 82% of the total cost.

Fatigue:

Based on ILO (International Labour Organization), each activity has a fatigue coefficient associated according to the influence on the productivity of the worker. Factors taken into account to calculate the fatigue index are the ergonomic position, work monotony, working atmosphere, noise, physical effort, visual tension and concentration requirement.

Table 3.30 contains fatigue indexes for each of the working station.

FATIGUE COEFFICIENTS		
	MG	**MGB**
SHELL CUT	8%	8%
DRILL	8%	8%
INTERNAL TUBES CUT	10%	10%
ASSEMBLE	10%	10%
WASH	8%	8%
WELDING	15%	13%
BORING	0%	6%
QUALITY CONTROL	8%	8%
COVER ASSEMBLE	8%	8%

Table 3.30: Fatigue coefficients for each working station based on the ILO.

Taking into account all factors mentioned above and inactivity, **Tables 3.31 and 3.32** contain percentages applied to calculate adjusted time due to inefficiencies on workforce and extra material respectively (see **Table 3.33 appendix**).

WORKFORCE		
	WORKFORCE INCREASE	WORKFORCE IMPLIED
INCAPACITY	0,09	ALL
BRASS FUSION LEAKAGE	4,34%	BRAZING (MG)
COVER LEAKAGE	2,50%	2xASSEMBLE + 2xCOVERS
NON REPAIRABLE PRODUCTS	0,29%	ALL BUT COVERS (MG)
DICARDED MATERIALS	0,00%	

Table 3.31: Adjustments on workforce.

MATERIALS			
	MATERIALS INCREASE	MATERIALS IMPLIED	% OF IMPLIED MATERIAL
INCAPACITY	0		
BRASS FUSION LEAKAGE	0,04%	10% WELDING MATERIAL (MG)	10%
COVER LEAKAGE	0,25%		10%
NON REPAIRABLE PRODUCTS	0,25%	85% OF COSTS (MG)	
DICARDED MATERIALS	0,02%	SHELLS	2%

Table 3.32: Adjustments on materials.

3.6 CURRENT STATE

By studying the current state of the productive system, it is possible to know the time involved by each of the working stations. Based on the demand analysis performed on section 4.1, the current state is based on a weighted average related to the quantity produced of each product. Taking this weighted average, it is possible to estimate the average time of each product on each working station to calculate an average total production time for each product of each category. On **Table 3.34** each of the stations contains the average process time for each product class based on the weighted average.

CURRENT STATE					
	STD MG 54/6	STD MG	STD MGB	STD MG 130-535	STD MGB 130-535
CUT1 [s]	103,30	217,43	351,18	412,43	410,99
DRILL [s]	48,36	0,00	160,60	0,00	168,67
CUT2 [s]	131,99	368,68	536,28	525,53	523,86
WASH [s]	20,66	112,45	187,95	225,35	205,47
ASSEMBLE [s]	237,27	299,78	342,47	409,42	407,96
BRAZING [s]	902,52	987,46	0,00	1380,35	0,00
TIG WELDING [s]	0,00	0,00	1641,81	0,00	1698,72
BORING [s]	0,00	0,00	1595,27	0,00	1564,55
QUALITY CONTROL (20 BAR) [s]	100,75	239,67	293,64	290,97	275,28
COVERS [s]	9,95	333,97	392,51	546,70	456,59
QUALITY CONTROL (8 BAR) [s]	115,35	267,86	313,71	330,46	295,90
TOTAL [s]	**1670,15**	**2827,30**	**5815,43**	**4121,20**	**6007,99**

Table 3.34: Current State.

These values represent the time the Company takes to produce each product class. To reach these values, standard times were taken with inefficiency indexes as well. When analysing the demand of each product class, MGB has, in average, larger tubes than MG class so comparing the average time of each class is not an accurate way of comparing times between different classes. To compare production times between classes it is necessary to take replaceable products. On the table above, there is a comparison between a MG 130-535 and a MGB 130-535 which are replaceable products. The example in the table shows that MGB product takes 45% more time to be produced than its equivalent on the MG class.

3.7 VALUE STREAM MAPS

From the Company's database it is possible to get all the information needed to construct the Value Stream Map. Since there are many components and materials, it is necessary to identify which are the critical materials for the different processes in terms of costs and consume. Based on the inventories` study, the critical components are:

- Iron tube for external tube
- Copper tubes for inner tubes
- Brass fusions for MG class
- Tubular plate for MGB class
- Alloy rings and strings for brazing of MG class

Figures 3.35, 3.36 and 3.37 represent the Value Stream Map for MG, MGB and MG 50-60 classes respectively.

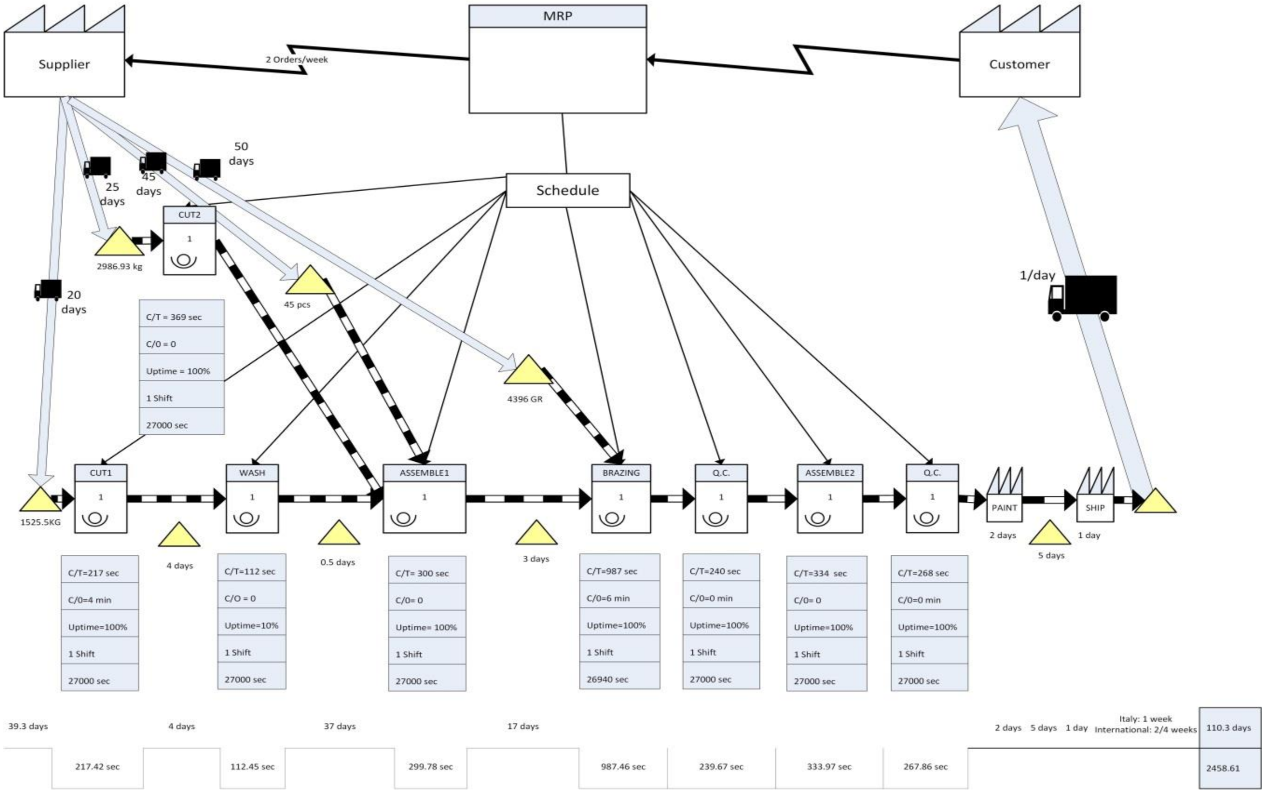


Figure 3.35: MG Value Stream Map.

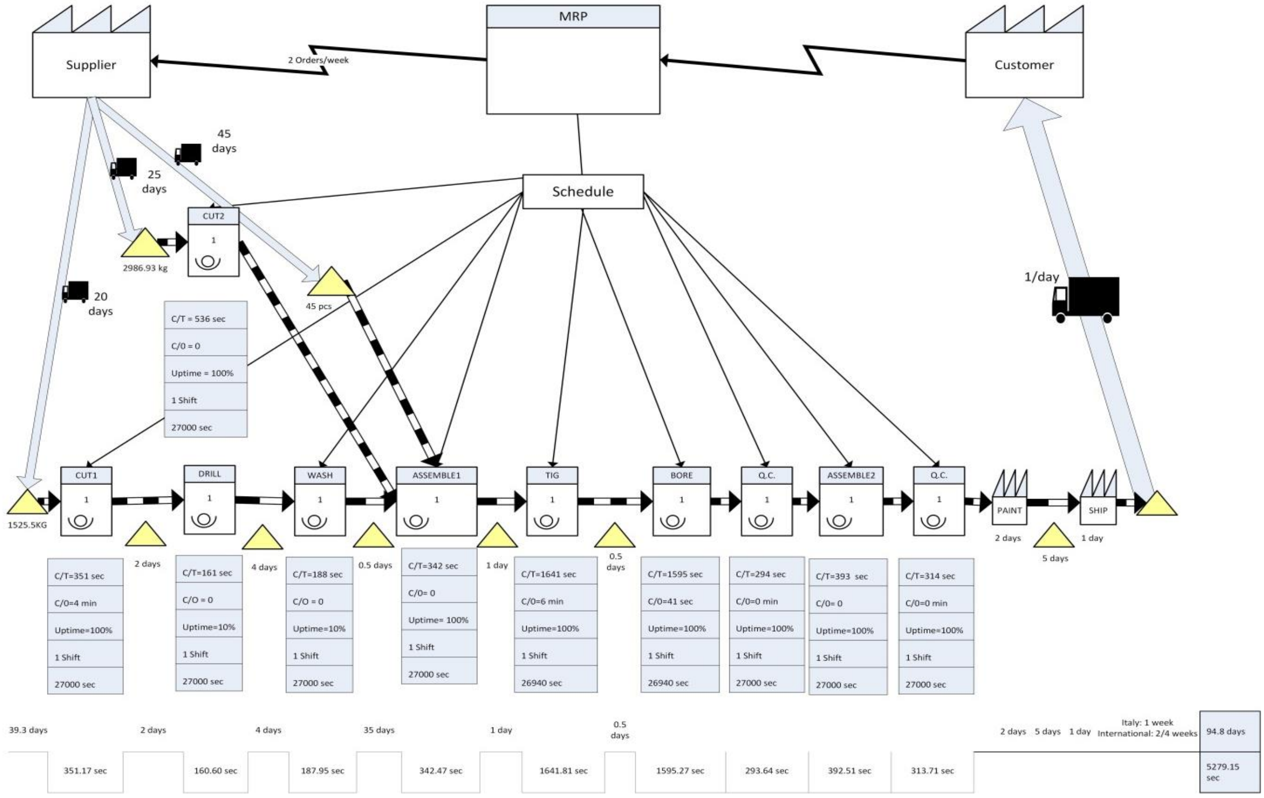


Figure 3.36: MGB Value Stream Map.

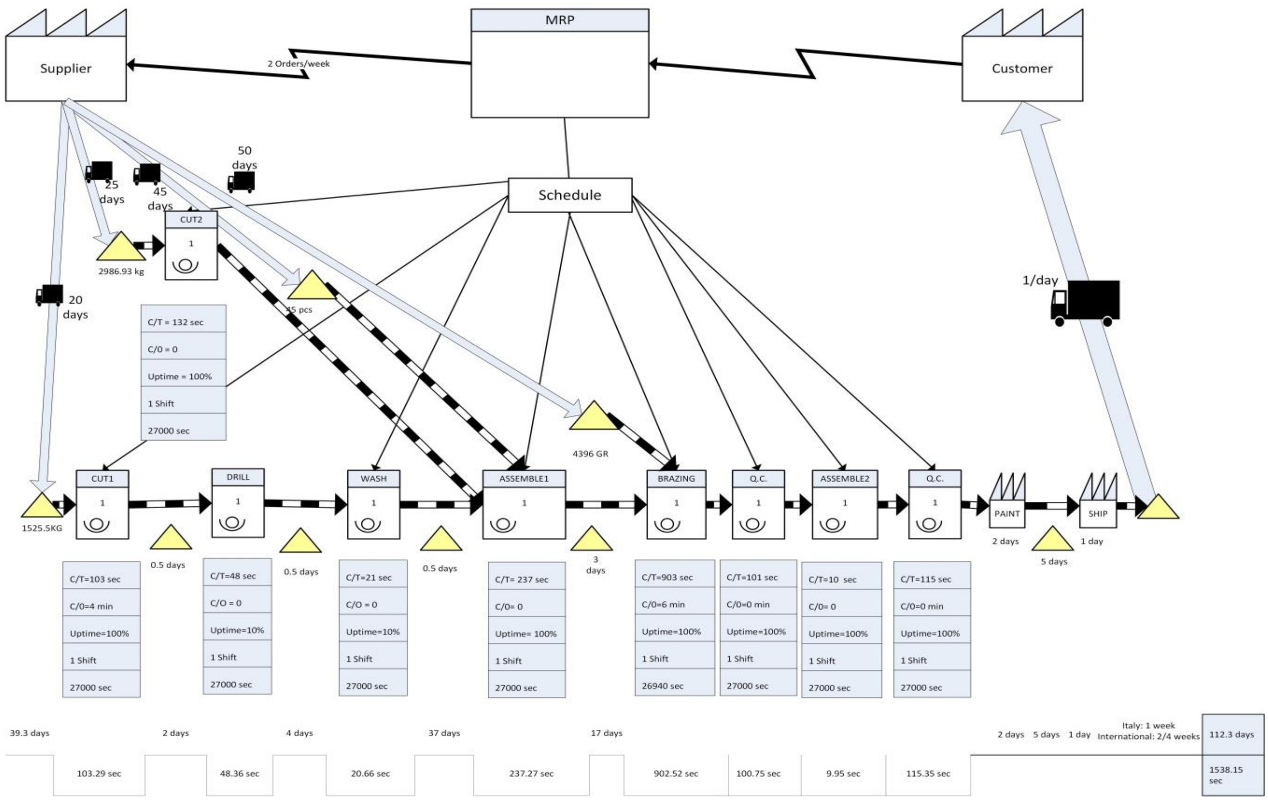


Figure 3.37: MG 54-60 Value Stream Map.

As mentioned above, MG production consists mostly in 80mm products while MGB products are mostly of 130mm. Since 130mm products have longer throughput time than 80mm products, this difference is reflected in the average total time per class between MG and MGB class. So as to perform an accurate comparison between classes, it is necessary to take replaceable products, in other words, products with the same properties and performance. **Figures 3.38 and 3.39** compares the Value Stream Maps of two replaceable products (MG 130-535 and MGB 130-535).

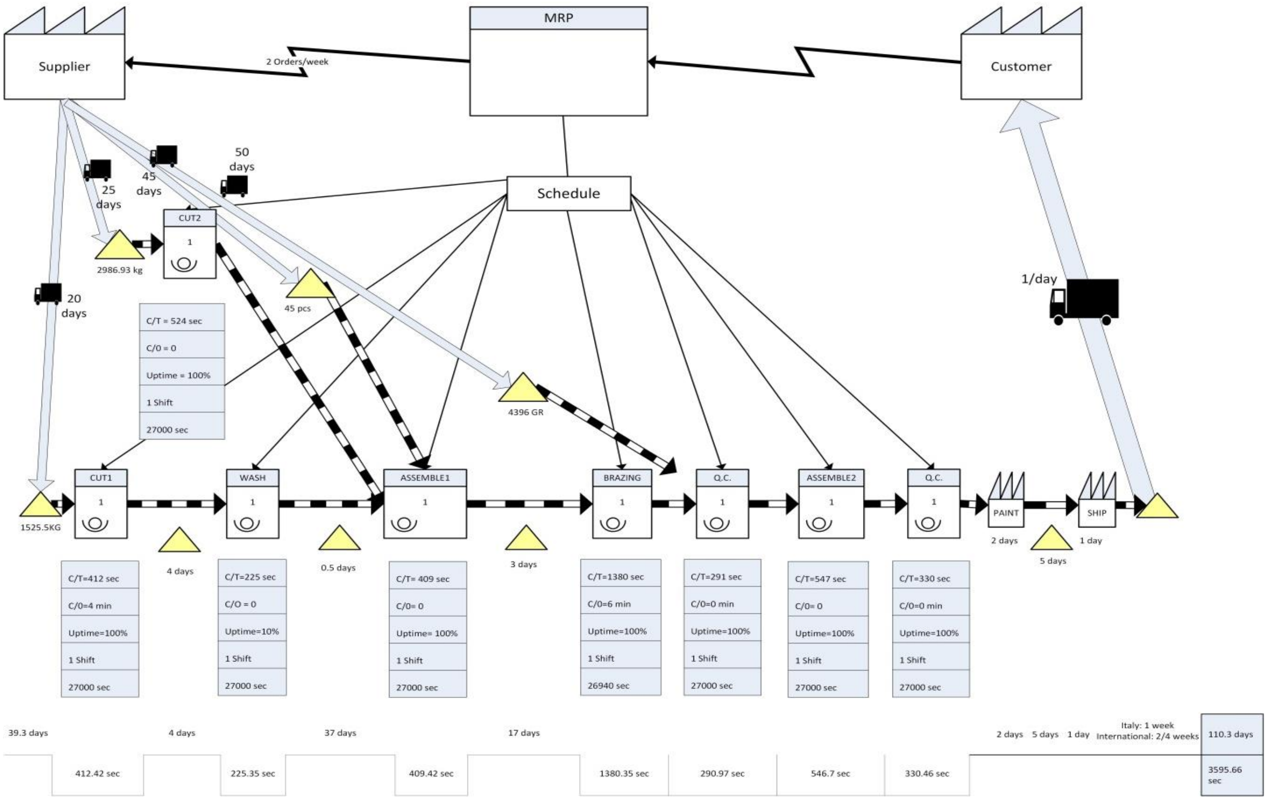


Figure 3.38: MG 130-535 Value Stream Map.

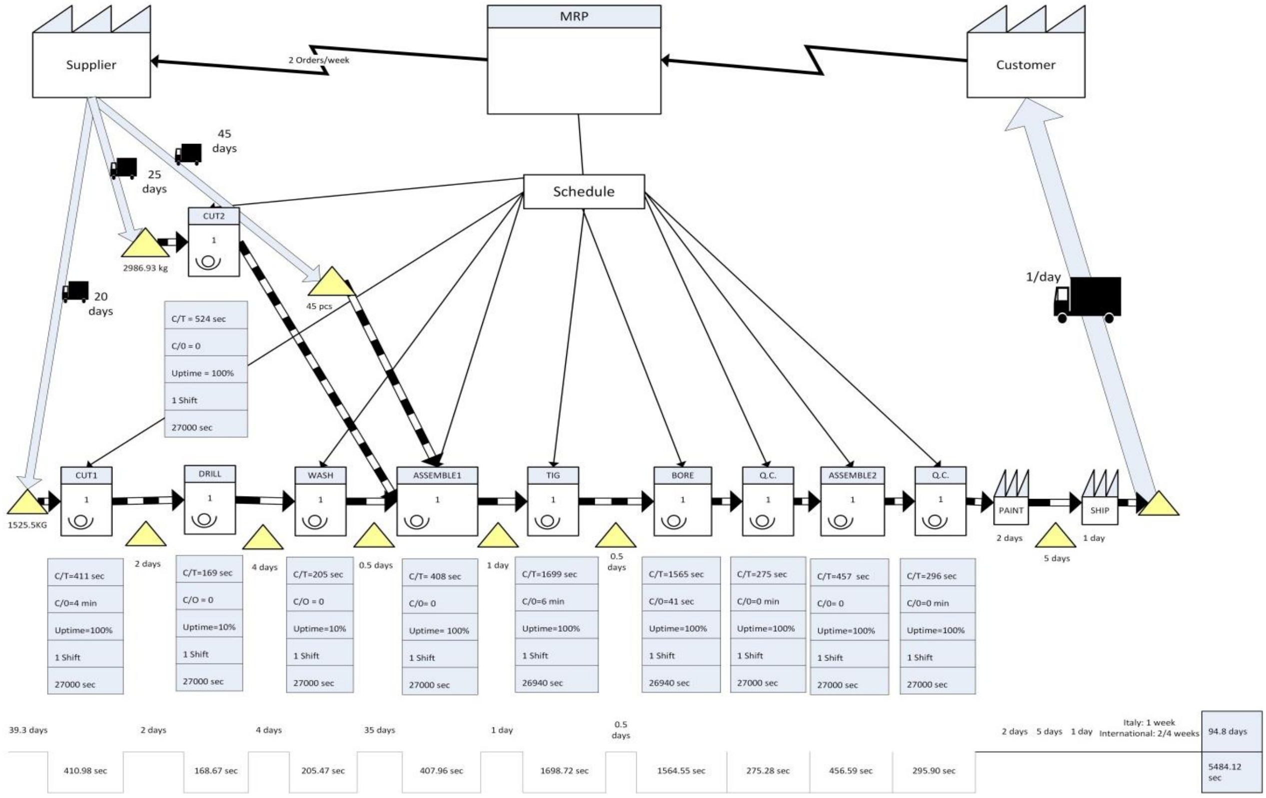


Figure 3.39: MGB 130-535 Value Stream Map.

3.8 LAYOUT STUDY

Actually the fabric is centralized on the brazing station in order to prioritize the production of MG class that represent 80% of the actual production.

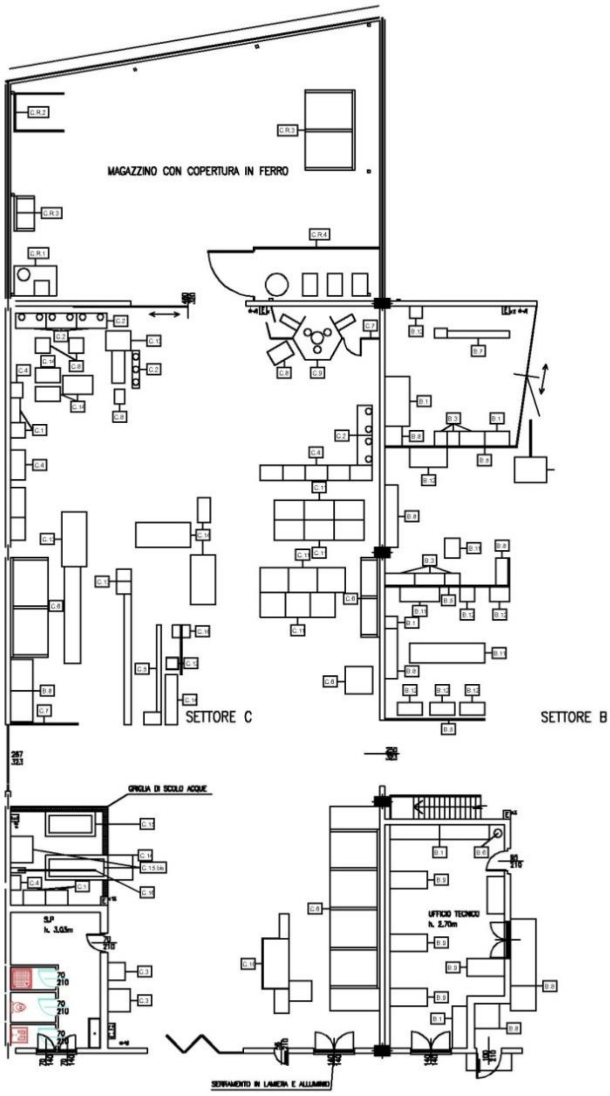
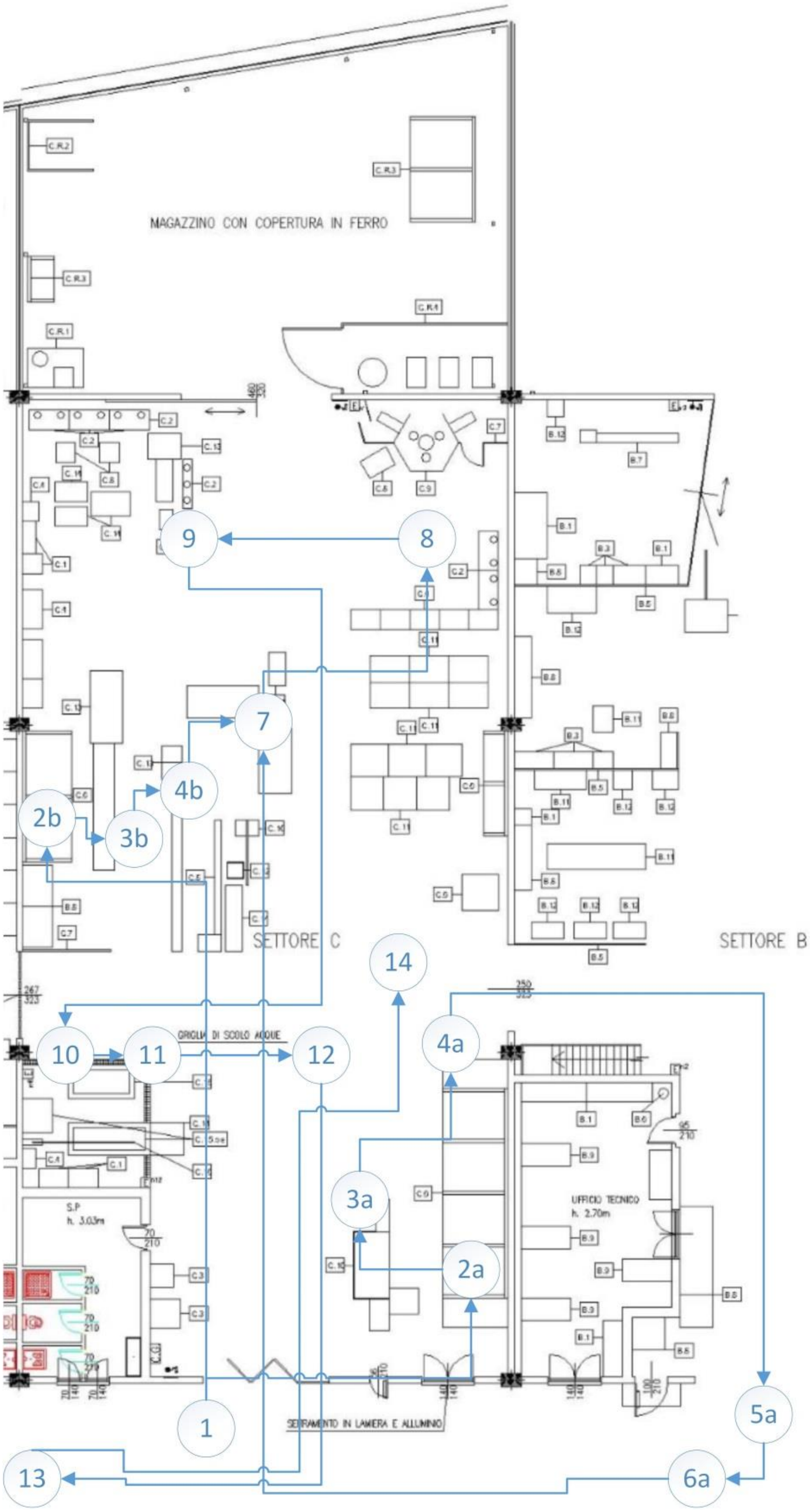


Figure 3.40: Actual Layout of production sector.

Figures 3.41, 3.42 and 3.43 contain the different spaghetti diagrams for each product class proving a high inefficiency on the actual layout by causing intersections and delays between the work stations.



References
1. Materials reception
2a. External tubes storage
3a.External tubes cut
4a. Batch consolidation delay
5a. Wash delay
6a. Wash
2b. Internal tubes storage
3b. Internal tubes cut
4b. Spacers cut
7. Assemble
8. Silver rings collocation
9. Brazing
10. Covers assemble
11. Quality control
12. Painting shipping
13. Painted tubes reception
14. Temporary storage

Figure 3.41: MG class Spaghetti diagram.

References
1. Materials reception
2a. External tubes storage
3a. External tubes cut
4a. Batch consolidation delay
5a. External tubes drill
6a. Batch consolidation delay
7a. Wash delay
87a. Wash
2b. Internal tubes storage
3b. Internal tubes cut
4b. Spacers cut
9. Assemble
10. TIG welding
11. Boring
12. Covers assemble
13. Quality control
14. Painting shipping
15. Painted tubes reception
16. Temporary storage

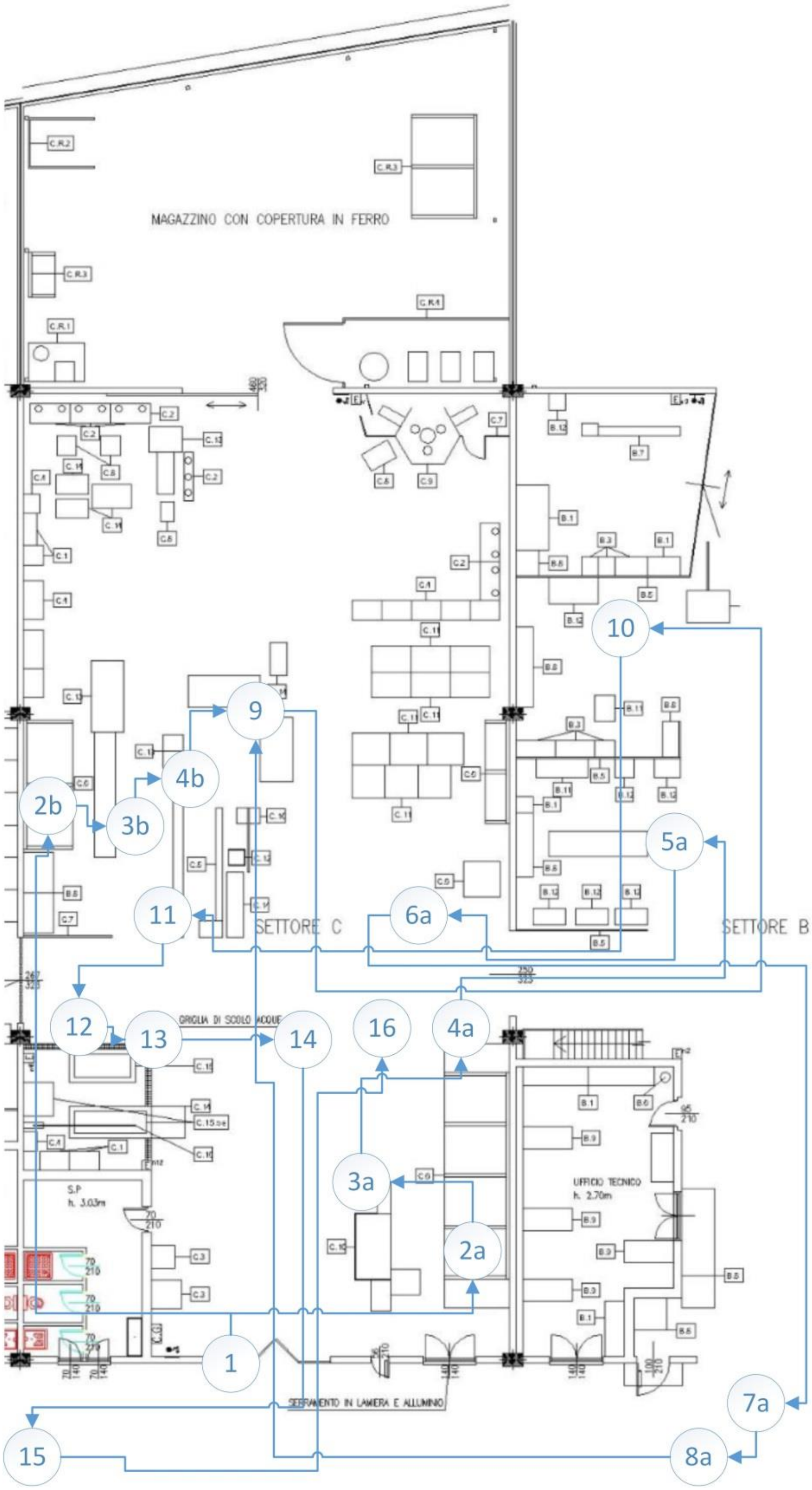
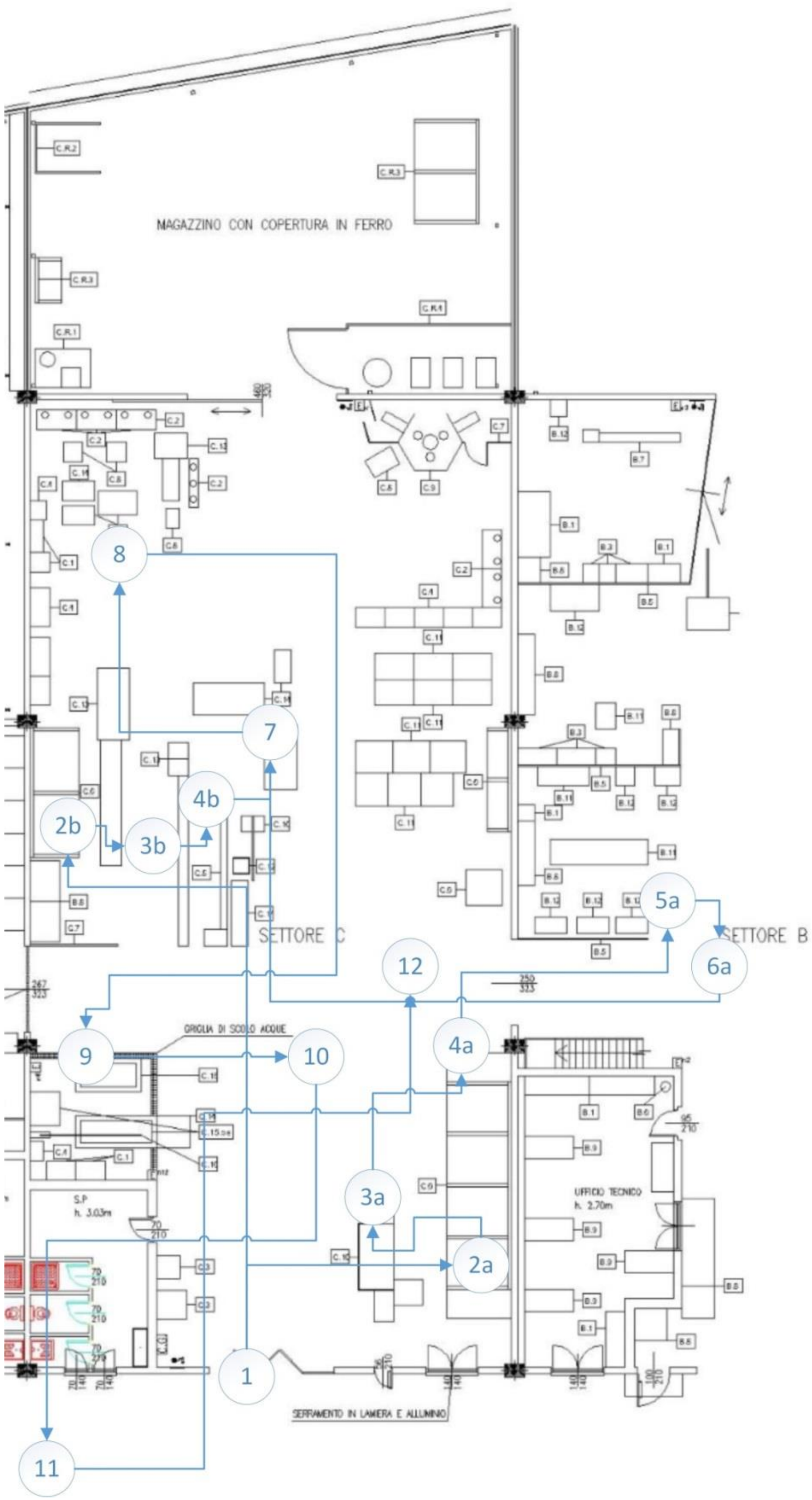


Figure 3.42: MGB class Spaghetti diagram.



References
1. Materials reception
2a. External tubes storage
3a. External tubes cut
4a. Batch consolidation delay
5a. External tube perforation
6a. Batch consolidation delay
2b. Internal tubes storage
3b. Internal tubes cut
4b. Spacers cut
7. Assemble
8. Brazing
9. Quality control
10. Painting shipping
11. Painted tubes reception
12. Temporary storage

Figure 3.43: MG 54-60 class Spaghetti diagram.

3.9 COSTS AND EARNINGS STUDY

3.9.1 Costs

To calculate the production costs, the company has, in the database of the ERP system, the costs of raw materials and the respective amount of raw material consumed on the production of each product. The ERP system takes this data and calculated automatically the cost of production. On the other hand, the company sets a workforce cost as 0, 36€ per minute. **Tables 3.44, 3.45 and 3.46 appendix** contain costs based on historical times, estimated times and adjusted times. Also, the company sets an 18% operative cost to prorate the fixed costs including electricity, taxes, financial costs, etc.

As mentioned above, for an accurate time study it is necessary to compare replaceable products to have a notion of the costs difference between the different product classes.

REPLACEABLE PRODUCTS COSTS COMPARISON								
TYPE	D [mm]	L [mm]	WORKFORCE COST	MATERIALS COST	PAINT	OPERATIVE COST	TOTAL COST	Δ TOTAL COST
MG	130	535	24,73 €	239,14 €	10,49 €	274,35 €	323,73 €	23,71%
MGB	130	535	36,05 €	163,25 €	10,00 €	209,30 €	246,97 €	
MG	131	535	27,22 €	229,67 €	11,21 €	268,09 €	316,35 €	19,08%
MGB	131	535	45,94 €	161,20 €	9,80 €	216,94 €	255,99 €	
MG	130	285	20,70 €	209,86 €	7,39 €	237,95 €	280,78 €	24,31%
MGB	130	285	32,78 €	140,33 €	7,00 €	180,11 €	212,53 €	
MG	130	845	29,72 €	256,75 €	14,24 €	300,70 €	354,83 €	13,09%
MGB	130	845	40,10 €	207,55 €	13,70 €	261,35 €	308,40 €	
MG	131	831	31,98 €	302,26 €	14,81 €	349,05 €	411,88 €	22,06%
MGB	131	831	49,81 €	208,85 €	13,40 €	272,06 €	321,03 €	

Table 3.47: Cost comparison between replaceable products.

Table 3.47 shows that cost for MGB products are from 13% to 24% lower despite the higher production times and hence, a higher workforce cost. This difference resides on the higher material costs of the MG class. Workforce cost represents 15% of operative cost, painting 5% and materials 15% approximately. Consequently, it is important prioritize the optimization of materials costs over the efficiency of workforce.

3.9.2 Earnings and Margins

Once calculated the respective costs, it is possible to proceed to calculate earnings through the difference between the list price and the total cost. It is important to mention that list prices are subjected to posterior discount depending on the client. So, **Tables 4.48, 4.49 and 3.50 appendix** contain earning and margins based on the price list previous to the discount.

Table 3.51 show earnings and margins for each product class based on a weighted average and **Table 3.52** has the respective variations between earnings and margins obtained with historical, estimated and adjusted times.

HISTORICAL TIMES EARNINGS AND MARGINS		
	EARNINGS	MARGINS
MG 54/ MGE 60	€ 90,55	57,09%
MG 80-81	€ 229,15	64,48%
MGB 80	€ 267,08	67,41%
MG 130-131	€ 527,35	62,32%
MGB 130-131	€ 500,97	65,05%

ESTIMATED TIMES EARNINGS AND MARGINS		
	EARNINGS	MARGINS
MG 54/ MGE 60	€ 92,03	58,06%
MG 80-81	€ 226,80	63,80%
MGB 80	€ 265,65	66,99%
MG 130-131	€ 521,16	61,56%
MGB 130-131	€ 503,28	65,33%

ADJUSTED TIMES EARNINGS AND MARGINS		
	EARNINGS	MARGINS
MG 54/ MGE 60	€ 89,07	56,10%
MG 80-81	€ 222,67	62,63%
MGB 80	€ 260,74	65,56%
MG 130-131	€ 512,82	60,56%
MGB 130-131	€ 493,45	64,04%

Table 3.51: Earnings by class based on a weighted average.

EARNINGS AND MARGINS VARIATION (ESTIMATED-HISTOIRICAL)		
	EARNINGS	MARGINS
MG 54/ MGE 60	€ 1,48	0,97%
MG 80-81	-€ 2,35	-0,68%
MGB 80	-€ 1,43	-0,42%
MG 130-131	-€ 6,19	-0,76%
MGB 130-131	€ 2,31	0,28%

EARNINGS AND MARGINS VARIATION (ADJUSTED-ESTIMATED)		
	EARNINGS	MARGINS
MG 54/ MGE 60	-€ 2,96	-1,96%
MG 80-81	-€ 4,13	-1,17%
MGB 80	-€ 4,91	-1,42%
MG 130-131	-€ 8,35	-1,00%
MGB 130-131	-€ 9,83	-1,29%

Figure 3.52: Earnings and margins variation.

As the times and costs study, take a weighted average might be improperly to compare the different classes, so once more, it is necessary to take replaceable products as shown in **Table 3.53.**

EARNINGS AND MARGINS COMPARISON BETWEEN REPLACEABLE PRODUCTS								
TYP	D [mm]	L [mm]	OPERATIVE COST	TOTAL COST	PRICE	EARNINGS	Δ COST	MARGINS
MG	130	535	274,35 €	323,73 €	768,38 €	444,65 €	23,71%	57,87%
MGB	130	535	209,30 €	246,97 €	663,32 €	416,35 €		62,77%
MG	131	535	268,09 €	316,35 €	819,88 €	503,53 €	19,08%	61,42%
MGB	131	535	216,94 €	255,99 €	732,33 €	476,34 €		65,04%
MG	130	285	237,95 €	280,78 €	676,71 €	395,93 €	24,31%	58,51%
MGB	130	285	180,11 €	212,53 €	556,20 €	343,67 €		61,79%
MG	130	845	300,70 €	354,83 €	911,55 €	556,72 €	13,09%	61,07%
MGB	130	845	261,35 €	308,40 €	827,09 €	518,69 €		62,71%
MG	131	831	349,05 €	411,88 €	1.236,00 €	824,12 €	22,06%	66,68%
MGB	131	831	272,06 €	321,03 €	901,25 €	580,22 €		64,38%

Table 3.53: Earnings and margins comparison between replaceable products.

Although MGB products have lower costs than MG products, the company offers MG products as a higher quality product with higher list price equating the cost difference proved above giving as a result similar earnings.

4. VOC (Voice of clients)

In every engineering thermic equipment, not only thermic efficiency has to be taken into account, but also the economic efficiency of it. After the heat exchanger has been installed, a certain temperature gradient must be achieved that could be reduced in case the heat exchanger is bigger, but at the same time this implies a bigger cost of raw materials, space, energy consumption, etc. Therefore, every client, depending on their own needs, space available, efficiency required, environment where is installed, among others; has an optimal heat exchanger necessity. Emmegi has the possibility of offering a wide range of products that has the capability of fulfilling every client needs.

Based on the information obtained by the commercial department in Emmegi, more than 90% of the clients have not got any knowledge about the heat exchanger that adequately fulfils their needs and therefore base their decision on the manufacturing company that produces the heat exchangers. This reason leads us to consider that the client can be flexible to new Emmegi suggestions in case a new product is being offered. On the other hand, on most clients there is always a negative to changes that can be hard to change in some cases.

At first, it was considered that surveys and interviews might be an adequate possibility to understand clients' needs and wants, but later we realized that this information will probably not be realistic due to a couple of matters. Firstly, as heat exchangers are sold to intermediaries to be later sold to the final client, it is hard to get reliable information. Secondly, shell and tube heat exchangers are technical products and there is a huge lack of information regarding what clients do really need.

Another piece of information that must be considered is how clients buy heat exchangers. According to the Commercial Department, more than 30% buys in a 1 for 1 way, this means that the client buys one product to replace an older one that works inefficiently or does not work at all. To avoid large Lead Time offered by Emmegi and heat-exchanger market in common, clients are forced to have a stock of products to be able to replace them quickly. Therefore, clients have a waste of space, frozen capital and possibility of obsolescence that imply extra costs in every business.

Based on these factors and taking into account that the relationship among price-quality of the product aims to a low/medium market, we have been able of distinguishing the principal factors of importance for our clients:

- Price
- Lead Time of producer
- Duration of the product
- Performance of the product

Due to the impossibility of being able to establish a reliable VOC, with the help of the Chief from the Commercial Department at Emmegi, with more than 20 years working at the company, we have been able of establishing an approximate importance of the client in each of these mentioned items

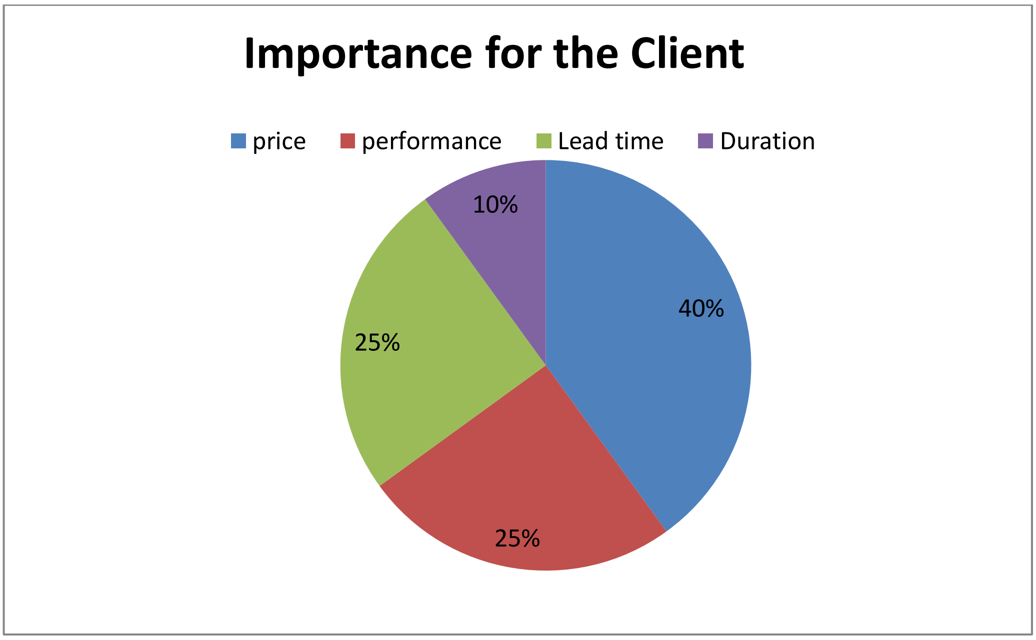


Figure 4.1: Percentage of importance for clients divided in four main attributes.

5. IMPROVEMENT OPPORTUNITIES

Based on analysis of the information collected throughout the Project, the following improvement opportunities were proposed with the aim of converting the productive process of Shell and tube heat exchangers into a Lean productive system.

- Eliminating the gamma of products with high defectiveness rate and standardizing production.
- Redesigning Layout.
- Eliminating Batch production.
- Reduction of inventories.
- Modifying working stations.
- Placing a *Supermarket* of external tubes.

5.1 ELIMINATING MG GAMMA AND STANDARIZING PRODUCTION

When Emmegi started producing Shell and tube heat exchangers, it was thought that TIG welding wasn't as reliable as Brazing. Therefore, the company started offering a Brazing type product as higher quality and TIG welding as a lower one. Nowadays, both welding techniques have the same performance, so from a technical and performance point of view, both comparable products have the same qualities.

Another characteristic that must be held into consideration to decide whether these products are effectively replaceable for our clients is the products' dimension. The distance among inter-axis, this means the distance between the two oil entrances must be the same in cases in which the clients' installations have fixed entrances (old technology which is almost no longer used). Furthermore, in a vast minority of cases there is a space restriction that can make products Irreplaceable.

Table 5.1 compares costs among two replaceable products. In the following table we can observe that, even though cost related to workers is higher on the MGB class, the overall cost of the MG product is always between a 13% and a 25% higher than the MGB class.

COMPARISON AMONG REPLACEABLE PRODUCTS								
TYPE	D [mm]	L [mm]	COST OF LABOUR	COST OF RAW MATERIALS	PAINT	OPERATIVE COST	TOTAL COST	Δ TOTAL COST
MG	130	535	24,73 €	239,14 €	10,49 €	274,35 €	323,73 €	23,71%
MGB	130	535	36,05 €	163,25 €	10,00 €	209,30 €	246,97 €	
MG	131	535	27,22 €	229,67 €	11,21 €	268,09 €	316,35 €	19,08%
MGB	131	535	45,94 €	161,20 €	9,80 €	216,94 €	255,99 €	
MG	130	285	20,70 €	209,86 €	7,39 €	237,95 €	280,78 €	24,31%
MGB	130	285	32,78 €	140,33 €	7,00 €	180,11 €	212,53 €	

MG	130	845	29,72 €	256,75 €	14,24 €	300,70 €	354,83 €	13,09%
MGB	130	845	40,10 €	207,55 €	13,70 €	261,35 €	308,40 €	
MG	131	831	31,98 €	302,26 €	14,81 €	349,05 €	411,88 €	22,06%
MGB	131	831	49,81 €	208,85 €	13,40 €	272,06 €	321,03 €	

Table 5.1: Cost comparison among replaceable products.

The main cause of this difference is due to the difference in material costs that correspond to each product type. We can observe in the following table that costs related to brass fusion (Collettore) and brazing material (Bobine Lega) of MG type are significantly higher than costs of Plates (Piastra) and sleeves (Manicotto) that have the same overall function in the MGB type of product. The rest of the materials employed are the same or very similar.

COST OF RAW MATERIALS MG 131-845				
ARTICLE	QUANTITY	UNIT COST	MEASURE UNIT	TOTAL
MINUTERIA.	1	0,10 €	NR	0,10 €
BOBINE LEGA 4576 D.0.7 MM	68	0,39 €	GR	26,43 €
BOBINE LEGA 4576 D.2 MM	76	0,38 €	GR	28,82 €
TUBO RAME 9x0.75 CRUDO	0,359	7,12 €	KG	2,56 €
TUBO RAME 7x0.6 CRUDO	14,008	7,14 €	KG	100,07 €
TUBO Fe360 130x2 TOLL. UNI EN 10305	5,15	1,02 €	KG	5,25 €
COLLETTORE DX MG 131 1 1/2"BSP D.15007C	1	33,50 €	NR	33,50 €
COLLETTORE SX MG 131 1 1/2"BSP D.15008C	1	31,72 €	NR	31,72 €
DIAFRAMMA D.15503 MG/MGB 131 OTTONE	11	0,62 €	NR	6,82 €
COPERCHIO ANT.LAVOR.MG 130-131 4	1	22,20 €	NR	22,20 €
COPERCHIO POST.LAVOR.MG 130-131	1	18,00 €	NR	18,00 €
GUARNIZIONE X MG130/131-4	2	0,48 €	NR	0,96 €
STAFFA DI FISSAGGIO D.35202C	2	0,89 €	NR	1,78 €
TAPPO 3/8"BSP	1	0,26 €	NR	0,26 €
TAPPO 1/4	1	0,20 €	NR	0,20 €
			€ 278,67	

Table 5.2: Raw material costs MG 131-845

COST OF RAW MATERIALS MGB 131-845				
ARTICLE	QUANTITY	UNIT COST	MEASURE UNIT	TOTAL
MINUTERIA.	1,00	0,10 €	NR	0,10 €
TUBO RAME 9x0.75 CRUDO	0,31	7,00 €	KG	2,17 €
TUBO RAME 7x0.6 CRUDO	13,22	6,90 €	KG	91,20 €
TUBO Fe360 130x2 TOLL. UNI EN 10305	6,20	0,87 €	KG	5,40 €
PIASTRA TUBIERA D.15127B MGB131	2,00	17,85 €	NR	35,70 €
DIAFRAMMA D.15503 MG/MGB 131 OTTONE	11,00	0,62 €	NR	6,82 €
COPERCHIO ANT.LAVOR.MG 130-131 4	1,00	22,20 €	NR	22,20 €
COPERCHIO POST.LAVOR.MG 130-131 4 V	1,00	18,00 €	NR	18,00 €
MANICOTTO 1 1/2" FE R.65 D.16271	2,00	3,70 €	NR	7,40 €
MANICOTTO FE 1/4'GAS (NERO) H.11	1,00	0,75 €	NR	0,75 €
GUARNIZIONE X MG130/131-4 DIS.17042	2,00	0,50 €	NR	1,00 €
STAFFA DI FISSAGGIO D.35202C MG130-131	2,00	0,89 €	NR	1,78 €
TAPPO 3/8"BSP	1,00	0,26 €	NR	0,26 €
TAPPO 1/4	1,00	0,20 €	NR	0,20 €
			192€	

Table 5.3: Raw material costs MGB 131-845

Profit comparison between replaceable products is similar due to the Emmegi strategy of selling products at different prices as if quality of MG products was higher. Therefore, if MG products are replaced with MGB products, Emmegi will be capable of offering a product with the same performance and a lower cost and modifying prices up to a suitable one. **Table 6.4** contains a present profit comparison on between replaceable products.

COMPARISON OF PROFITS AND MARGINS BETWEEN REPLACEABLE PRODUCTS								
TYPE	D [mm]	L [mm]	OPERATIVE COST	TOTAL COST	PRICE	PROFITS	Δ COST	PROFIT MARGIN
MG	130	535	274,35 €	323,73 €	768,38 €	444,65 €	23,71%	57,87%
MGB	130	535	209,30 €	246,97 €	663,32 €	416,35 €		62,77%
MG	131	535	268,09 €	316,35 €	819,88 €	503,53 €	19,08%	61,42%
MGB	131	535	216,94 €	255,99 €	732,33 €	476,34 €		65,04%
MG	130	285	237,95 €	280,78 €	676,71 €	395,93 €	24,31%	58,51%
MGB	130	285	180,11 €	212,53 €	556,20 €	343,67 €		61,79%
MG	130	845	300,70 €	354,83 €	911,55 €	556,72 €	13,09%	61,07%
MGB	130	845	261,35 €	308,40 €	827,09 €	518,69 €		62,71%
MG	131	831	349,05 €	411,88 €	1.236,00 €	824,12 €	22,06%	66,68%
MGB	131	831	272,06 €	321,03 €	901,25 €	580,22 €		64,38%

Table 5.4: Profit and Margin comparison between replaceable products.

Eliminating the MG class, production is standardized, unifying the productive process of more than the 85% of the products 'catalogue and reducing drastically the amount of defects.

6.2 REDESIGNING LAYOUT

With the change of MG to MGB class, a brainstorming of ideas, technological changes in the process and a Lean system of production that avoids creation of inventories of intermediate products, the opportunity of creating a new efficient layout of the plant is now possible. The objective of it is reducing distances among stations, prioritizing the optimization of distances with a huge flow of materials, heavy materials, materials that are difficult to manage or fragile. All the internal transport around the company is an activity that adds no value from the clients' perspective; therefore Lean philosophy tries to reduce manipulation as much as possible.

It is important to mention, that in this case Layout optimization must be done not from zero, but taking into account the actual layout, considering only changes that imply important advantages to the productive process, with low cost and low realization times. This is a major issue due to the fact that Emmegi is now on a secure position but does not encourage big investments as the actual Economic situation in Europe is not very promising. An example of this is the gas extraction systems located on the Northern part of the plant. Changing the location of them will imply huge costs that lead to higher risks that can be avoided.

6.2.1 Layout changes

<u>Selling or disbanding the automatic Robot machine for brazing:</u>

This machine is only useful in cases in which batches of production are bigger than 50 units, due to the high set-up times. By eliminating the MG gamma, this machine will be no longer useful, bringing an increase in available space.

<u>Moving shelves for stocking final products to the East Section:</u>

By applying this modification a central space in the plant could be used more efficiently. At the same time, the South East entrance of the plant could be now reopened taking products in the firm after the painting takes places, avoiding a messy flow of materials.

<u>Moving machines for bending tubes, AISI cut, and AISI storage shelves to the East section:</u>

Based on the low amount of products that are produced with AISI steal and the low quantity of products that use U tubes, it turns out to be beneficial to move all those machines and shelves that are used no more than once or twice a month, to leave space in the core part of the plant to processes with more usage

<u>Eliminating brass fusions from the inventories:</u>

The quantity and dimension of brass fusion is nowadays quite significant as implies a lot of space occupation. With the change in MG to MGB class that implies that brass fusions will be no longer needed, Emmegi inventories will have fewer items in consideration and more space will be created in the plant.

<u>Reduction of the Work in progress:</u>

With batch production, before and after each working station, intermediate stocks were created. These forced inventories can be avoided with Lean philosophies, leading to smaller stations and less space between them.

Taking into account all the proposed changes, the Layout can now be designed in the following way:

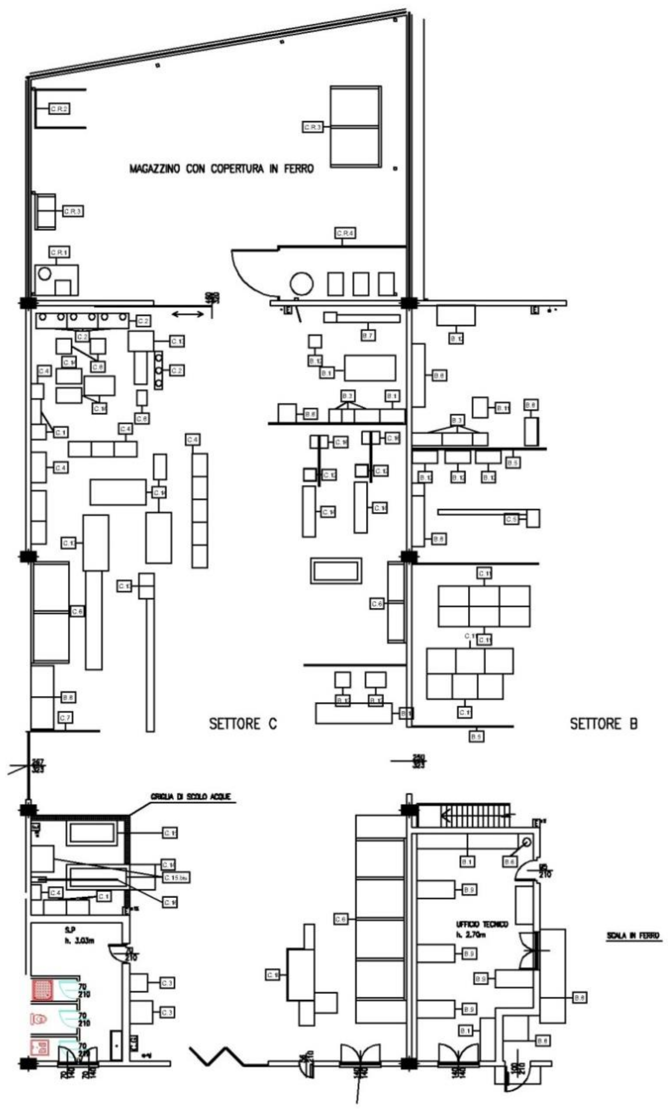


Figure 5.5: New proposed layout.

5.2.2 Modification on working stations.

Maintaining Shell cut station:

Being placed near to the entrance allowing easy access to suppliers, the actual position is now considered to be optimal. In order to reduce space between shell cut and drilling, the machine can rotate 180 degrees, allowing products to be nearer from one station to the next one.

Move Drilling machines:

With the reduction of WIP, it is possible to place drilling machines next to the Shell cut station, reducing distance between them.

Maintaining internal tube cut, spacers and assembly station:

The placement of machines in this ways allows the optimal movement of the worker and no modification should be done.

Maintaining semi-automatic and manual brazing stations:

With the objective of reducing risks to create a smooth transition of MG to MGB and reducing risks, it is convenient to maintain these working stations as a first step of a radical change in Emmegi productive process.

Moving TIG welding station:

By taking advantage of the space left by the automatic robot brass station, TIG welding station can be moved to that position. With this changes there is no need for modifying gas extraction bells and also shortens distance with the previous and next working stations.

Placing two boring machines in parallel positions next to the TIG welding stations:

Reducing distance between two critical working stations is essential. Moreover, keeping both machines active will allow Emmegi to have excess productive capacity by relocating a worker on a boring station. This will allow responding to strong raises in demand in an effective and simple way as the boring station does not require a huge previous capacitation.

Placing a belt conveyor between welding and boring stations:

As they are almost finished products, this means that they are heavy products, complex to move and due to the fact that the saturation of both stations is high, it can be beneficial to create a belt conveyor to reduce to the minimum the time spent by workers on moving the units from one station to the other and assuring there is no problem with fulfilling Takt time established.

Placing a new Quality control station and final assembly:

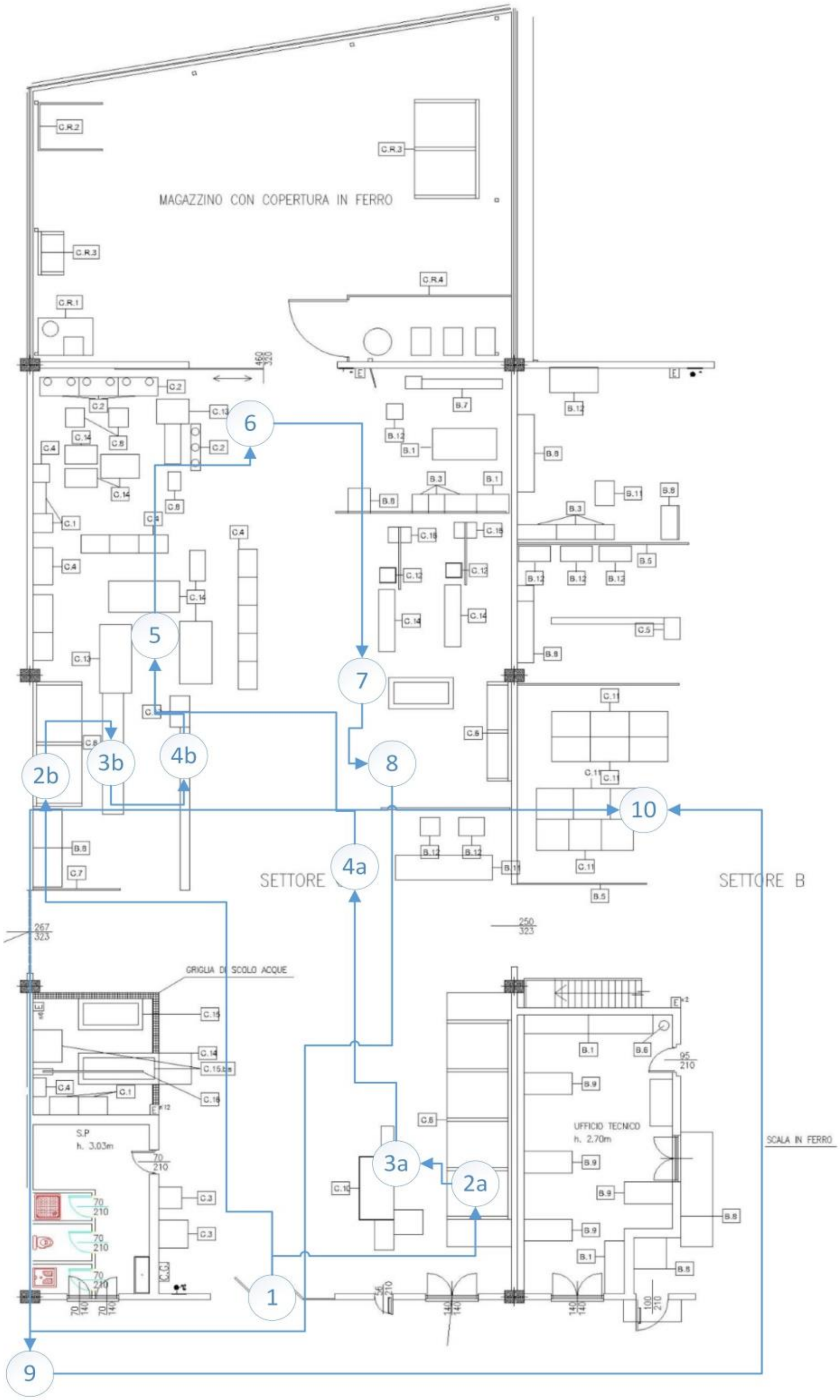
Applying a new quality control station with a pneumatic system instead of a hydraulic one next to the boring station will permit reducing to the minimum distances where the unit is being moved is heavy and almost finished.

Keeping the old Quality control station:

It is still necessary to use in case losses or defects are found in the product. Relocating the station to optimize distances is not enough beneficial because, with the changes implemented in the productive process, the percentage of products that will have defects will be extremely low. Therefore the flow of products that will pass through this station won’t be important to make changes. Moreover, water pumps, pools and machines relocation will imply high costs that are unnecessary for the project.

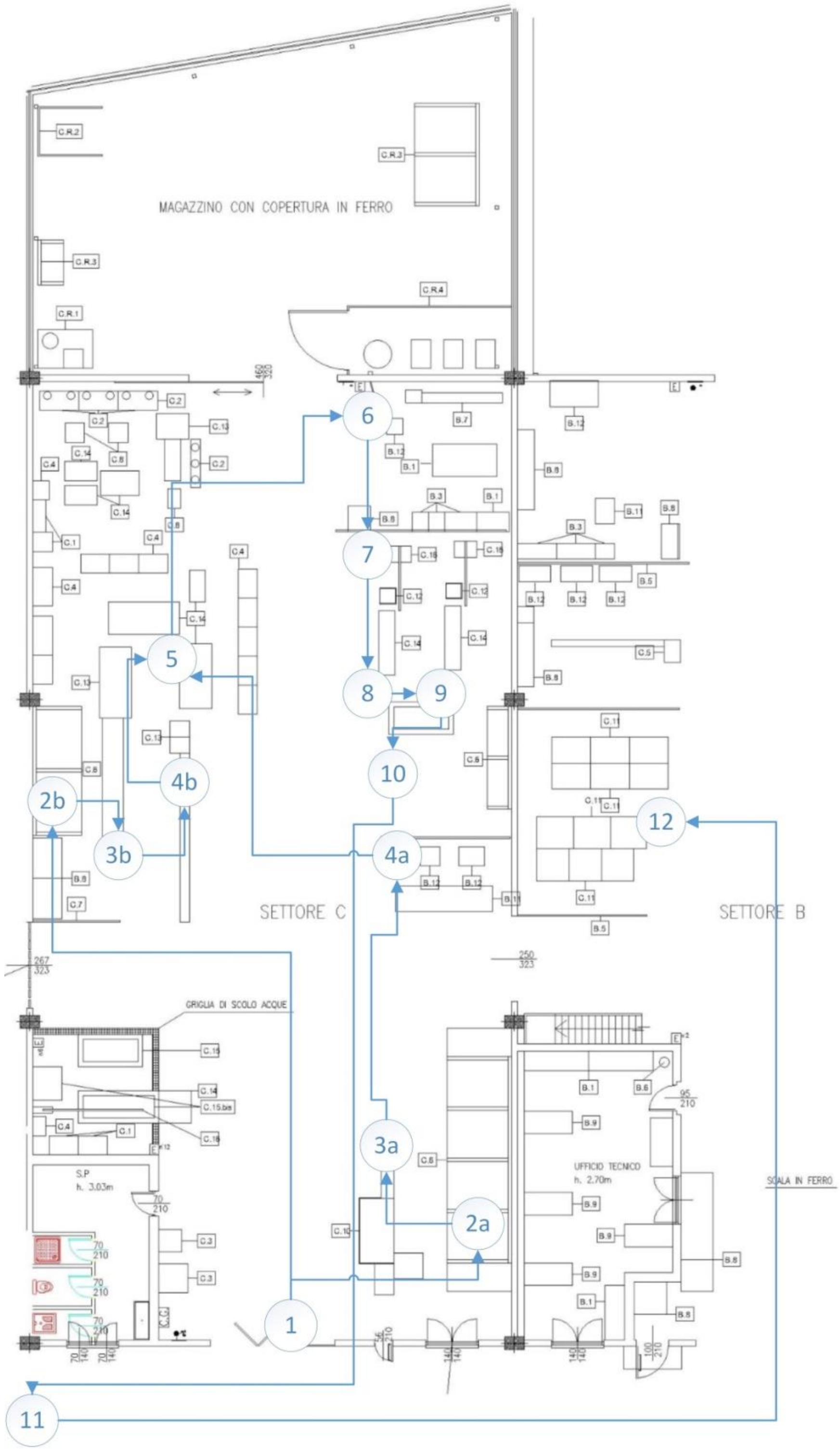
5.2.3 New Layout

As a consequence of the changes implemented, it is interesting to see the new flow diagram of the different product families (**Figures 5.6, 5.7 y 5.8**). This is a clear way to understand how distances between stations have been reduced and now are in an optimal disposition.



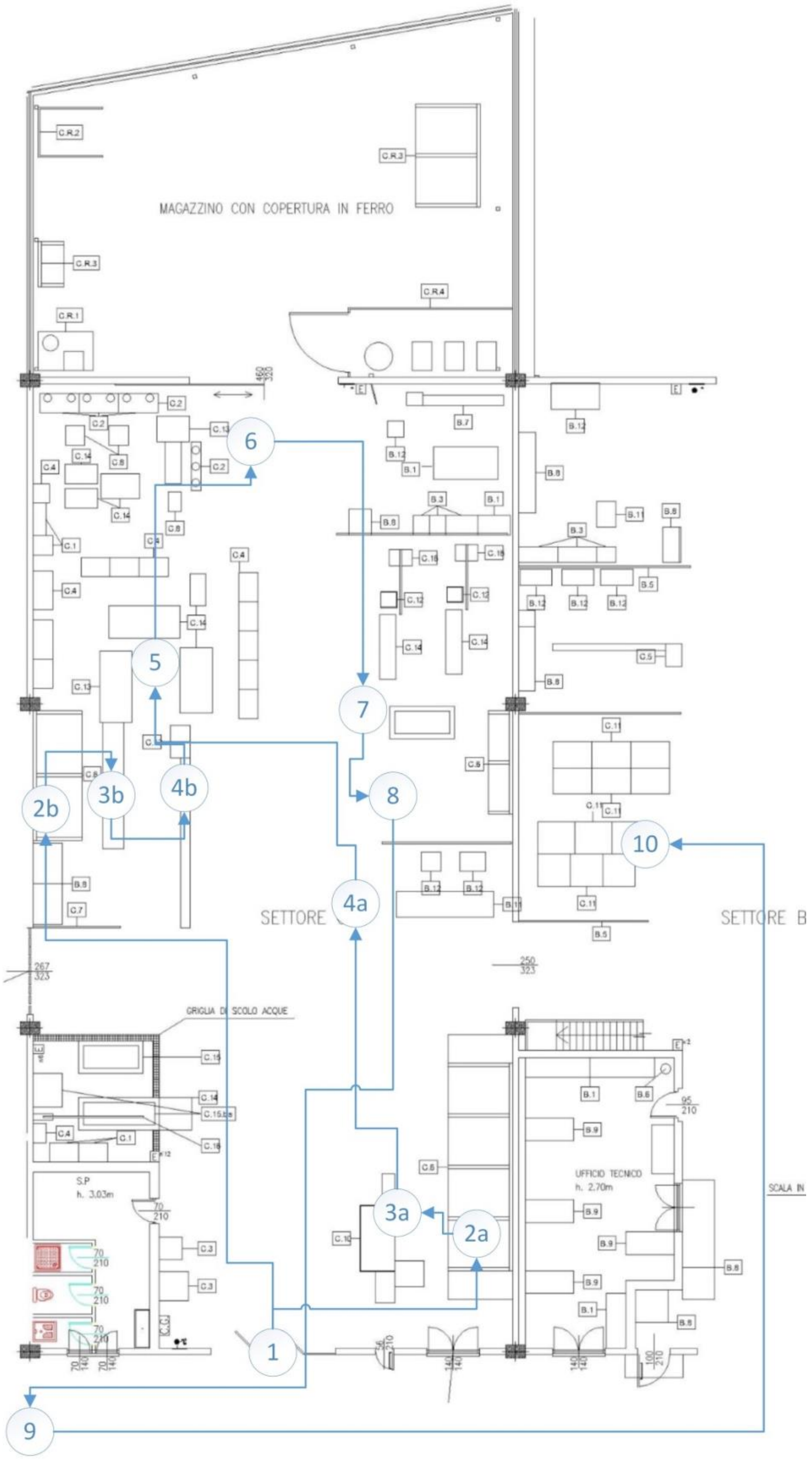
1. Material Reception
2a. Storage of external tubes
3a. Cutting of external tubes
4a. Drilling of external tubes
2b. Storage of internal tubes
3b. Cutting of internal tubes
4b. Cutting of spacers
5. Assembly
6. Brazing
7. Cover assembly
8. Quality control
9. Painting shipment
10. Reception of painted units
11. Final storage

Figure 5.6: New flow diagram for MG products.



1. Material Reception
2a. Storage of external tubes
3a. Cutting of external tubes
4a. Drilling of external tubes
2b. Storage of internal tubes
3b. Cutting of internal tubes
4b. Cutting of spacers
5. Assembly
6. TIG welding
7. Boring
8. Covers assembly
9. Quality control
10. Painting shipment
11. Reception of painted units
12. Final storage

Figure 5.7: New flow diagram for MGB products.



1. Material Reception
2a. Storage of external tubes
3a. Cutting of external tubes
4a. Drilling of external tubes
2b. Storage of internal tubes
3b. Cutting of internal tubes
4b. Cutting of spacers
5. Assembly
6. Brazing
7. Cover assembly
8. Quality control
9. Painting shipment
10. Reception of painted units
11. Final storage

Figure 5.8: New flow diagram for MG 54-60 products.

5.3 ELIMINATING BATCH PRODUCTION

Nowadays, Emmegi has a batch productive system due to the washing process. As the washing machine is placed on another building, huge batches are created after the shell cutting station waiting to be sent to the washing building.

One of the consequences of working in batches is the time employed for a product to pass through the entire productive process. In a batch of N units with a fabricating time T, the first product has a fabricating time T, but the last must wait N-1 units that must be processed in a time NxT. The chief of production organization tends to put together orders of the same products but different dates, leading to a delay in the delivery of products in a significant amount of cases.

Based on data obtained over the last two years, the average delay time is of 7 days more than the 3 or 4 week Lead Time offered by the commercial department for delivering the product. Taking into account that the average time for producing each unit is less than 2 hours and not more than 3 days taking into account the outsourcing stage of painting, it shows that batches represent a problem as they increase heavily the time to market in an average of more than 4 weeks.

Another consequence of batch production is the amount of intermediate products waiting to be manufactured between each station (WIP). The average amount of units circulating is of 400 units, while the monthly demand is of approximately 600. In addition to the WIP, the high levels of inventories needed to cover lack of raw materials represent a huge financial cost associated to frozen capital.

The following possibilities have been analyzed to eliminate batch production:

5.3.1 Buying shorter external tubes

Due to the fact that the washing machine has a maximum length capacity of 1350 mm, tubes that arrive from suppliers cannot be washed directly before being cut to its final length. One possible solution is buying tubes of 1350 mm. By applying this idea they can be washed before being stored beside the external tube shelves, avoiding unnecessary manipulation from the storage shelves back and forth, avoiding more than 80 meters manipulation. In this case the stored tube can be sent directly to the next working station with no need for working in batches. On the other hand, the cost of external tube will increase as Emmegi will be asking out of standard measures and also the amount of scrap and waste will be also increased. **Table 5.9** shows the influence on external tube on the total cost for the products that are sold more frequently.

INFLUENCE OF EXTERNAL TUBE ON COSTS		
MG/MGB 80	INFLUENCE OF EXTERNAL TUBE ON MATERIAL COSTS	0,93%
	INFLUENCE OF EXTERNAL TUBE ON TOTAL COSTS	0,65%
MG/MGB 130	INFLUENCE OF EXTERNAL TUBE ON MATERIAL COSTS	1,40%
	INFLUENCE OF EXTERNAL TUBE ON TOTAL COSTS	0,99%

Table 5.9: Influence of external tube on costs

As seen in **Table 5.9**, the shell tube represents less than 1% of the total cost. Therefore this option tends to be an acceptable measure that can be taken into consideration.

Tables 5.10 and 5.11 contain the offers of suppliers of external tubes for the most usual measures (80 mm y 130 mm).

Fe EXTERNAL TUBE 80x1,5 (2,94 kg/m)							
BY QUANTITY							
COMPANY	L	eu/kg	Minimum Q (kg)	Minimum Q (nº)	Δ PRICE	ΔMATERIAL COST	ΔTOT COST
EUROTUBI	6000	0,878	687,96				
BIDUE	1350	1,615	2381,4	600	83,95%	0,78%	0,55%
BIDUE	3000	1,397	2354,94	267	59,10%	0,55%	0,39%
EUROTUBI	3000	0,930	5997,6	680	5,89%	0,05%	0,04%
EUROTUBI(*)	1200	1,732	1919,232	544	97,26%	0,90%	0,64%
EUROTUBI(*)	1350	1,746	2159,136	544	98,87%	0,92%	0,65%
BY LENGHT							
COMPANY	L	eu/kg	Minimum Q (kg)	Minimum Q (nº)	Δ PRICE	ΔMATERIAL COST	ΔTOT COST
EUROTUBI	6000	2,581	234				
BIDUE	1350	4,748	810	600	83,95%	0,78%	0,55%
BIDUE	3000	4,107	801	267	59,10%	0,55%	0,39%
EUROTUBI	3000	2,733	2040	680	5,89%	0,05%	0,04%
EUROTUBI(*)	1200	5,092	652,8	544	97,26%	0,90%	0,64%
EUROTUBI(*)	1350	5,133	734,4	544	98,87%	0,92%	0,65%

Table 5.10: Budgeted cost for 80 mm diameter external tubes.

Fe EXTERNAL TUBE 130x2 (6,37 kg/m)							
BY QUANTITY							
COMPANY	L	eu/kg	Minimum Q (kg)	Minimum Q (nº)	Δ PRICE	ΔMATERIAL COST	ΔTOT COST
BIDUE	6000	1,020	1070,16				
BIDUE	1350	1,423	3869,775	450	39,54%	0,55%	0,39%
BIDUE	3000	1,229	3822	200	20,51%	0,29%	0,20%
EUROTUBI	3000	0,911	11981,97	627	-10,73%	-0,15%	-0,11%
EUROTUBI(*)	1200	1,565	4540,536	594	53,39%	0,75%	0,53%
EUROTUBI(*)	1350	1,581	5108,103	594	55,05%	0,77%	0,54%
BY LENGHT							
COMPANY	L	eu/kg	Minimum Q (kg)	Minimum Q (nº)	Δ PRICE	ΔMATERIAL COST	ΔTOT COST
BIDUE	6000	6,497	168				
BIDUE	1350	9,067	607,5	450	39,54%	0,55%	0,39%
BIDUE	3000	7,830	600	200	20,51%	0,29%	0,20%
EUROTUBI	3000	5,800	1881	627	-10,73%	-0,15%	-0,11%
EUROTUBI(*)	1200	9,967	712,8	594	53,39%	0,75%	0,53%
EUROTUBI(*)	1350	10,074	801,9	594	55,05%	0,77%	0,54%

Table 5.11: Budgeted cost for 130 mm diameter external tubes.

As seen in offers shown by actual suppliers, the variation in total costs for buying tubes of 1350 mm is of 0, 55% for 80 mm external tubes and 0, 39% in the case of 130 mm. As a consequence of buying tubes that are different from market standards, suppliers increase the minimum quantity that must be ordered, forcing Emmegi to create a huge stock of external tubes.

All in all, not only the rise in price and the financial costs of stocking more raw materials should be considered, but also the increase in scrap produced. As Emmegi will now work with tubes 4 times shorter, scrap will increase 4 times at least.

5.3.2 Cutting external tubes in 1, 2 meters long.

Another alternative for eliminating batches is buying tubes of 6 meters as it is done nowadays. But this are directly cut in 1, 2 meters long allowing them to be washed as soon as they are received and then stocked, ready to be cut and sent to the next station with no need of further washing. In comparison to the previous proposal, this alternative implies using twice the cutting machine, adding saturation to the cutting semi-automatic machine but avoiding extra costs due to increase in price of raw materials.

As the cutting machine is a semi-automatic machine with low saturation, the extra costs of the proposed alternative are low, but it should be taken into consideration that while reducing the length of tubes 5 times, the amount of scrap will increase approximately five times too.

5.3.3 Buying galvanized external tubes.

Another alternative is buying galvanized tubes. These tubes do not have to be washed as they do not have an oil protective surface. Through this proposal the washing activity will be eliminated, avoiding not only transportation costs and time but also costs of water treatment and solvents used in the machine. According to suppliers, the increase in cost of galvanized tubes will be of a 23% more than the tubes that are bought nowadays with an oil protective surface. The drawbacks of galvanized tubes is that they cannot be welded directly due to its toxic gases and welding complexity. To solve this problem Zinc can be removed in a mechanical way with a very simple existing machine in no more than 10 seconds. Another aspect that must be considered is the difference in electrical potentials that can form a galvanic cell as it will be in contact with spacers and internal tubes of different electric potentials. Nevertheless, as zinc is the material with less electronegativity, the effect of the galvanic cell will be slowly dissolving the zinc inner cover leaving finally no galvanized as it works nowadays, therefore this won't represent a problem regarding its performance.

According to the offers received by the acquisition department, the increase in costs will be of 200 Euros/ton. At the same time, as there is no variation on the length of tubes there will be no increase in frozen capital costs and there will not be an extra amount of scrap.

BUDGETED COSTS FOR GALVANIZED TUBES						
80x1,5 (2,94 kg/m)						
COMPANY	L	Eu/m	Eu/kg	Δ PRICE	ΔMAT COST	ΔTOT COST
EUROTUBI	6000	0,87797	2,5812318			
BIDUE	6000	1,07797	3,1692318	22,78%	0,46%	0,32%
130x2 (6,37 kg/m)						
COMPANY	L	Eu/m	Eu/kg	Δ PRICE	ΔMAT COST	ΔTOT COST
BIDUE	6000	1,02	6,4974			
BIDUE	6000	1,22	7,7714	19,61%	0,39%	0,27%

Table 5.12: Budgeted cost for galvanized tubes.

5.4 INVENTORIES REDUCTION

By modifying MG to MGB type, the variability of raw materials required decreases. The variation of the models from the catalogue is now not established since the beginning by buying different raw materials, it will be now satisfied with variations on the productive process. For this reason, the variability of models and requirements on demand that vary highly from month to month will no longer be a difficult problem. The quantities ordered of plates and sleeves will tend to stabilize every month. At the same time, provisioning of materials will be easier and there will be an overall reduction of inventory costs.

To establish future value of inventories, it was established as a first step to maintain reorder times to understand clearly the effects on changes from MG to MGB.

Therefore inventory costs will stay equal in:

- AISI sleeves
- Internal tubes
- External shell
- Covers
- AISI plates and other minor products.

Inventory costs will be reduced:

- Plate rings for brazing (0)
- Brazing materials (only costs of MG 60 and MGE 80 will continue)

ACTUAL CONSUME OF BRAZING MATERIAL PER FAMILY							
Family	Sales	Gr/U	Cost/Gr	Cost/ U	Weighted cost	Percentage cost	Cost per Family
MGE 60-80	14,29%	60	0,29 €	17,40 €	2,48	11,14%	1.791,52 €
MG 80	62,64%	70	0,29 €	20,30 €	12,71	56,96%	9.164,33 €
MG 131	23,08%	106	0,29 €	30,86 €	7,12	31,90%	5.132,03 €

Table 5.13: Actual consume of brazing material per family.

- Brass fusions for MG class (0)

On the other hand, inventory levels of the following items will increase:

- Plates (87/130/131)
- Sleeves (87/130/131)

In order to analyse the future inventory costs, the following hypothesis were established:

- Reordering time for plates and sleeves will be kept in a pessimistic perspective as 45 days. This is not completely real because when talking of standard products it’s simpler to make orders for shorter periods of time. Nowadays, the reordering time is so high because of the very low existent demand; this makes costs of making orders and receiving raw materials quite significant.
- Safety stock established by the ERP of Emmegi (demand for 5 working days).
- Unit cost of plates and sleeves will maintain the same. This hypothesis is pessimistic because according to the acquisition department, the future increase in units bought per order will have an important effect on unit costs.
- Monthly demand will be the same as the average demand of 2014

INCREASE IN FUTURE INVENTORY COSTS					
SLEEVES		MONTHLY DEMAND (products)	UNIT COST	UNITS PER PRODUCT	AVERAGE INVENTORY
MGB	87	232	3,80 €	X2	2.424,40 €
MGB	87	69	5,64 €	X2	1.070,19 €
MG	130	75	3,80 €	X2	783,75 €
MG	131	79	5,64 €	X2	1.225,29 €
TODOS		455	0,75 €	X1	938,44 €
				TOTAL	6.442,07 €
PLATES		MONTHLY DEMAND (products)	UNIT COST	UNITS PER PRODUCT	AVERAGE INVENTORY
MGB	87	232	6,1	X2	3.891,80 €
MGB	87	69	6,1	X2	1.157,48 €
MGB	130	75	17,85	X2	3.681,56 €
MGB	131	79	14,85	X2	3.226,16 €
				TOTAL	11.957,00 €

Table 5.14: Increase in future inventory costs.

ACTUAL VS FUTURE INVENTORY LEVELS			
COMPONENT TYPE	ACTUAL VALUE	FUTURE VALUE	Δ VALUE
BRASS RINGS	7.887,0 €	0,0 €	-7.887,0 €
BRASS SUPPORT MATERIAL	16.087,9 €	1.791,0 €	-14.296,9 €
BRASS FUSION	100.070,1 €	0,0 €	-100.070,1 €
COVERS	84.544,2 €	84.544,2 €	0,0 €
SPECIAL SLEEVES+ AISI	8.219,5 €	8.219,5 €	0,0 €
SLEEVES(80/81/130/131)	1.867,8 €	6.442,1 €	4.574,2 €
PLATES FROM OTHER PRODUCTS + AISI	17.732,2 €	17.732,2 €	0,0 €
PLATES(87+130+131)	3.432,0 €	11.957,0 €	8.525,0 €
SHELL TUBES	14.403,6 €	14.403,6 €	0,0 €
INTERNAL TUBES	41.135,3 €	41.135,3 €	0,0 €
TOTAL	295.379,6 €	186.224,9 €	-109.154,7 €

Table 5.15: Comparison between actual and future inventory levels.

The results of this analysis clearly show how a change in MG to MGB type represents a huge reduction in inventory levels, shown by a decrease in 40% of total inventory costs.

This decrease is caused by the future expected low variability in the type and designs of raw materials required. With the changes proposed, raw material provisioning acquires a higher degree of standardization without reducing a huge catalogue offer to the client. This huge catalogue can be offered by offering diversification in materials with lower unit costs such as sleeves and also with a flexible productive process related to its low automation, capable of adjusting easily to clients' demands.

The advantages of this decline in inventory costs will also lead to lower financial costs, reducing frozen capital. Taking into account that these changes imply investments that will be thoroughly analyzed later, this greater liquidity allows Emmegi to auto-finance the investments with no need for loans.

Last but not least, this reduction in inventories also implies an increase in available space due to the fact that plates and sleeves occupy much less space than fusions due to its shape and minimum order quantity established.

5.4.1 How could a more effective acquisition policy be applied?

Inefficiencies in the acquisitions department are clearly confirmed by seeing the delay in orders that are due to the lack of materials and the high costs of inventories. Therefore it is important to analyze methods that can improve this functioning.

Taking into account that there is a significant variability on the demand for each category of products but it is also important to respond effectively to these changes, the following policies could be suggested:

5.4.2.1 Reduction of ordering time between each order.

As tubular plates and sleeves demand will be bigger than the actual situation and taking into account that these are standard products which suppliers have low delivering and producing Lead Times, it is possible of making orders weekly or for shorter periods. In case it is weekly, monthly demand forecast will be divided into 4 and this will represent the weekly demand and order size required. Moreover, in order to cover variability in demand two policies may be held even simultaneously if necessary: One option will be establishing a security stock of 5 days of demand to cover eventual drastic demand changes effectively. Another possibility, as higher amounts will be now bought to our suppliers; more commitment can be required by the supplier. A "framework agreement" obliges supplier to have a certain percentage (20% was fixed) of weekly demand in stock. In this way, Emmegi assures that with a fast shipment of raw materials they will be able of covering occasional demand changes.

This model of stock handling continues with Emmegi actual line of thinking, but offering a simple but inefficient way of improving stock management.

5.4.2.2 Continuous Review System + ERP

The most reliable option comes together with taking advantage of the system SAM-ERP available in Emmegi nowadays. A couple of years ago, every time that raw materials are placed or taken from its shelves the worker must indicate this activity with a bar-code system. This implementation implies great advantages that are not being efficiently exploited. The daily knowledge brings a great advantage over fixed ordering times as permits a continuous review System with no additional costs.

With the previous system a security stock must cover the demand variation in the time between orders and the delivering time of suppliers. If orders were done by a continuous review system, orders are done in variable periods, each time the system registers the level of inventories reaches a certain limit. In this way security stock will only need to cover demand variation during the time in which Emmegi makes the supply order and time that the order arrives to Emmegi.

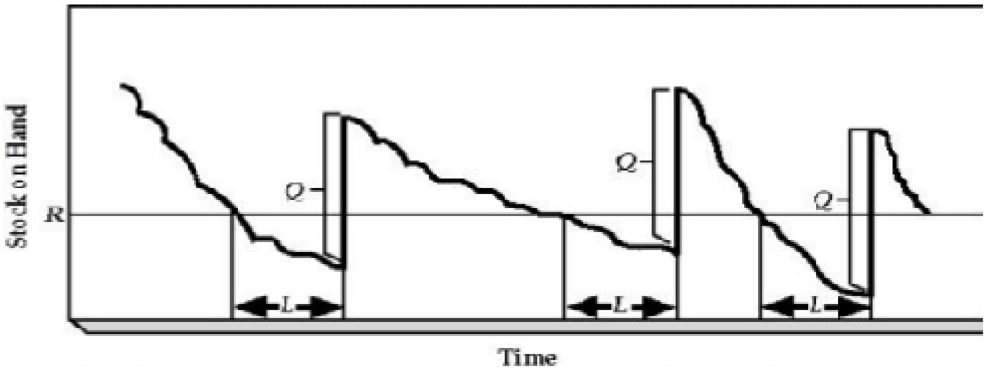


Figure 5.16: Continuous review system.

To establish the amount that will be ordered, a fixed quantity Q will be obtained. This quantity will be ordered each time my inventories level reaches the reorder level R. To calculate Q the following estimations must be done:

- D = Annual Average demand (Considered constant)
- C_P= Cost of submitting the order (It can be established in an approximate way as the annual cost of the acquisition department divided by the amount of orders done annually)
- C_{mi}= Anual cost of mantaining Inventories (Calculated as the annual financial costs of money added to the annual cost of managing inventories and the opportunity cost of the space they occupy)

$$Q^* = \sqrt{\frac{2 * D * C_P}{C_{mi}}}$$

To estimate the security stock:

- σ_{anual}= Annual standard deviation of each product
- LT= The average Lead time of each main supplier for every item.
- $1 - \alpha$= The service level desired
- σ_{LT}= Annual standard deviation of each product during the Lead Time. It must be calculated with the variance.

$$SS = \sigma_{LT} * Z_{1-\alpha}$$

The application of this methodology will permit covering demand changes in a precise way. Establishing orders that minimize costs of submitting the order and managing inventories, together with establishing an adequate security stock for each raw material based on real variations in demand, will reduce significantly inventory costs.

5.5 PLACING A SUPERMARKET OF EXTERNAL TUBES

In order to place a supermarket it is first important to understand how the future projected demand will work.

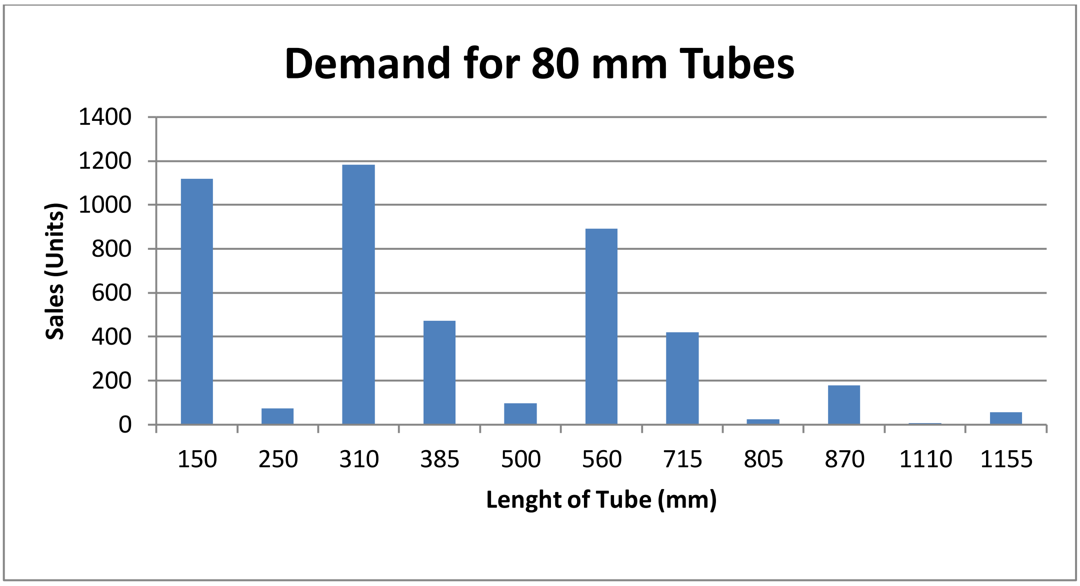


Figure 5.17: Demand for 80 mm tubes according to length

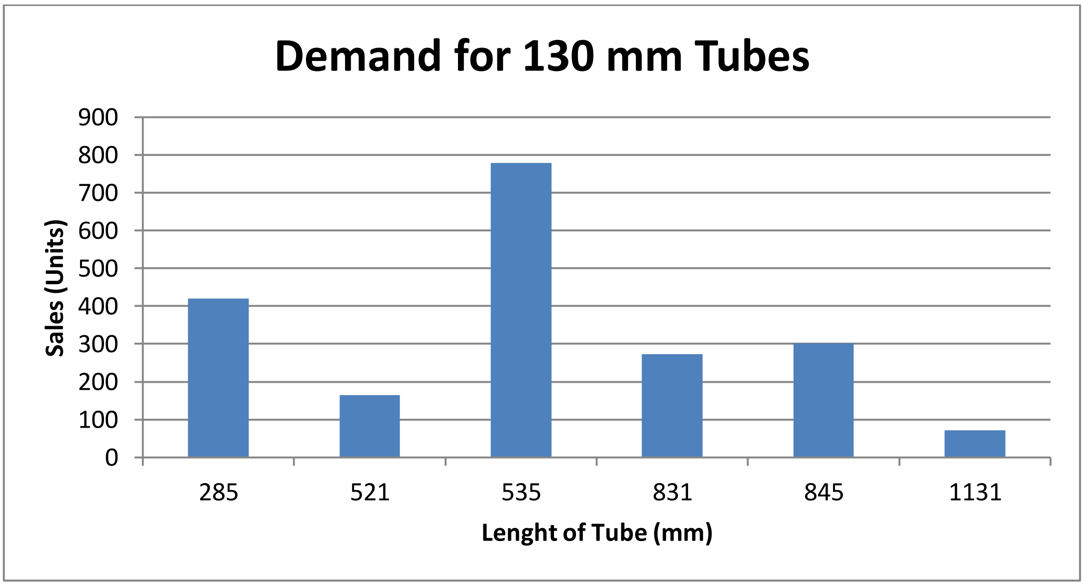


Figure 5.18: Demand for 130mm tubes according to length.

Based on this graphs we can understand that the demand of each product is very despair so if a supermarket is done it must be dimensioned accordingly. A well dimensioned supermarket will permit a greater efficiency in the shell tube handling and greater access to already cut tubes by the worker from the following station. Nevertheless, the great coefficient of variation, amount of different diameters (54-60-114-130-155-219) and the more than 30 different lengths offered, it will be very hard to establish a supermarket that covers all the necessities of the following stations and a huge space will be required. Therefore, applying a supermarket with diameters that have only occasional requests will imply occupying lots of space with low rotation products. For example, a supermarket for Diameter 114mm which has an average monthly demand of 4,8 products and has in catalogue 5 different lengths offered, a very big supermarket must be created and won't even assure covering demand as the variation coefficient of this product type is 82%.

5.6 ORDERING DAILY PRODUCTION BY DIAMETERS

According to estimations, 30 shell and tube heat exchangers will be produced in Emmegi daily. A 6 meter long external tube can create tubes for 10-12 units. In this way, based on the fact that more than 80% of production is of 80mm and 130mm and the other 12% of small tubes 54/60mm that are easily handled, manipulation and handling problem of shells can be solved by simply ordering daily production by diameter. With this simple organizational measure, there will be less handling and re-stocking of long heavy external tubes. Only considerable efforts will be required when products with occasional demand are requested such as 114mm, 155mm or 219mm.

5.7 CHANGES IN WORKING STATIONS

External tube cutting:

External tubes have no longer need for washing and batches will be eliminated. To avoid unnecessary efforts, the tube daily orders can be ordered by diameter allowing less manipulation. The procedure for scrap will be the same as the previous one.

Drilling:

External tubes and shells arrive by single units or very low quantities already washed, allowing the working station to drill the tube and sending it directly to the assembly station. As there are two unused drilling machines in the plant, each can be calibrated with the main two different drilling diameters to avoid changing them.

Internal tube cut:

No modifications.

Washing:

As tubes have no need of being washed anymore as explained in chapter 5.3, washing station and manipulation will be completely avoided

Brazing:

As explained in Chapter 5.1, MG 80 or superior diameters are replaced by MGB type of heat exchangers. Therefore, brazing will be only use in MG 54-60 products. As a consequence of this, Robot automatic brazing machine can be disbanded instantly as there will be no batches of more than 50 units. Secondly, the semi-automatic machine can also be eliminated as only manual brazing machine can be used for the expected necessities. The explanation why MG 54-60 products are not replaced by an alternative MGB product it that these products' external shell is of another material, which has no need of being washed. In these cases, it is impossible to use Iron plates because of the difference in electronegativity that will have severe effects on the products performance.

<u>TIG welding</u>:

The station will be divided into two sub-stations that will work in series: orbital welding and sleeves welding. With this modification, two specialized welders may be welding simultaneously reducing welding time in a 40%. Furthermore, a tool can be designed to facilitate the sleeves calibration and positioning. For future considerations, in case demand rises drastically for long periods of time, a numerical control machine (CNC) can be taken into consideration, but is not profitable at all with the existent levels of demand.

<u>Boring</u>:

By replacing MG with MGB products, boring time per internal tube must be reduced from 10 seconds to 7, 5 seconds. This boring cycle times can be achieved by buying a new boring machine because the actual one has an engine that has been created 25 years ago and software that has been actualized in 1994. With the acquisition of the new machine there will be two boring machines in parallel that will allow extra productive capacity in case demand rises in a constant way or there is any worker inefficiency.

<u>Quality Control</u>:

Taking into account the actual high level of defectiveness of brazing, the quality control is held in a hydraulic way that allows the worker to locate where the loss or defect is. This quality control must be held in two stages and the cover assembly between both of them. When replacing MG with MGB class, we can now have a much higher certainty that there will be no loss in the unit. Therefore, a pneumatic quality control system can be applied, where the worker first assemblies the covers and then does the quality control of internal tubes and plates in simultaneous reducing drastically quality control times. In this way, instead of employing two workers for the job, one will be enough.

We can also consider in a future even avoiding this working station. In order to do this we must assure that workers have bored each internal tube hole and that covers have no defects. In order to achieve this, a good relationship with the covers supplier must be achieved that guarantees no defects on the products delivered. To avoid mistakes made by workers, they must be included on the continuous search for quality throughout the Jidoka philosophies, one of the main pillars of Lean Production; Searching for monetary incentives in case there are no defects in each daily production or assuring the worker saturation is not too complex to achieve can also be interesting alternatives.

5.8 TAKT TIME

In order to maintain Lean Manufacturing principles, a pace of production that does not generate queues and intermediate stocks, but at the same time fulfills existent demand, must be achieved. In order to do so, each working station must produce what the market requires and not as much as possible in an uncertain way. The way of calculating this Takt time is the following:

Takt time = Available time/demand

The problem arises when there are different products with different manufacturing cycle times and Takt time becomes an average of these times. This means that if a piece is produced in a longer time than the takt time, the immediate next must be produced in a way that the product covers the delay in time reached. In case a piece is produced in a lower time, this time is employed to recover time used by pieces of higher time demand, or , in case there is no delay, production can stop for the excess time available.

The Takt Time for Emmegi shell and tube heat exchangers production based on the future state map is:

TAKT TIME	
MGE 60/MG 54	9357,80 s
MGB	1405,17 s

Table 6.19: Takt time based on Future State

The concept of Takt time is an essential concept in Lean philosophies permitting the establishment of an efficient pace of production without generating additional costs due to inefficiencies and also having tight control of the development on each working station throughout each day, assuring a certain rhythm that fulfills clients 'needs

6. INVESTMENT PROJECT EVALUATION

In order to implement the proposed changes described previously, it is necessary an investment in machinery, installations and worker capacitation. It is first essential to analyze the convenience of the investment; Emmegi should analyze the increase in capacity of each working station and mainly critical activities.

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6.1 ADQUIRING NEW BORING MACHINE

Actual welding machine has an average capacity of 10, 9 seconds per internal tube hole. If MG is replaced by MGB, it is necessary to buy a Boring machine capable of boring a hole every 8 seconds as shown in **Table 7.1**:

BORING CAPACITY		
BORING TAKT TIME (S)		1092,52
TIME PER HOLE(s)	AVERAGE NUMBER OF HOLES	AVERAGE NUMBER OF TUBES
10,9	100,23	50,12
10	109,25	54,63
8	136,57	68,28
6	182,09	91,04
4	273,13	136,57
NOWADAYS 65 TUBES ON AVERAGE		

Table 6.1: Analysis of productive capacity of boring machine.

With the acquisition of a new manual boring machine with a budgeted list price of 32500€, it will be capable of reaching an average of 7 to 8 seconds per tube that will allow us to reach the capacity required to fulfill market needs. The actual boring machine will be installed in parallel as mentioned previously, allowing excess capacity in case there are huge increases in demand. MAUS manufacturing company sent also the list price of a numeric control automatic machine for 350000€, but it is completely irrational to do this investment with the actual level of demand.

6.2 ACQUISITION OF A NEW QUALITY CONTROL SYSTEM

The actual process of quality control is based in the high probability of finding defects and is consists on the following steps:

1. Hydraulic control at low pressure.
2. Assembling of covers.
3. Hydraulic control at high pressure.

Each time a quality control is done, plugs must be installed and removed together with the time the hydraulic pump needs to make the control and empty the water inserted. The quality control is done in a hydraulic way as it allows to understand where does the loss comes from due to bubbles.

When changing MG to MGB, it must be considered that the probability of finding losses will be much lower because boring and TIG welding are much more efficient processes and losses will not appear unless the worker makes huge mistakes. Together with this premise, the sequence of quality control can change into:

1. Assembling of covers.
2. Low and high pressure pneumatic control in simultaneous.

With this new sequence only one worker will be needed instead of two to carry on the job.

The budgeted Price for the new quality control system is of 32000€ and allows the worker to assemble the covers of the next piece while the machine is working because once the hosepipes have been connected, the machine works automatically.

This application won't have sense for the actual situation due to the fact that in case losses were found, it will not be possible of distinguishing where do these losses come from so they must be sent again to the hydraulic control spending nearly twice as much time with a high probability of occurrence. With the MGB situation, the percentage of defectiveness and therefore the probability of passing through the hydraulic control is much lower.

We can also consider in a future even avoiding this working station. In order to do this we must assure that workers have bored each internal tube hole and that covers have no defects. In order to achieve this, a good relationship with the covers supplier must be achieved that guarantees no defects on the products delivered. To avoid mistakes made by workers, they must be included on the continuous search for quality throughout the Jidoka philosophies, one of the main pillars of Lean Production; Searching for monetary incentives in case there are no defects in each daily production or assuring the worker saturation is not too complex to achieve can also be interesting alternatives.

6.3 PROFITS BY REPLACING MG WITH MGB

When replacing MG with MGB products, a price actualization must be held. The proposal f of the new catalogue prices is the following:

Products of diameter 80mm will maintain the price of the MG class due to the fact that these new MGB products will be added specially to the catalogue. The client will not perceive differences in quality and performance and in exchange receives products in lower times. Moreover, Emmegi is benefited because sells a product with lower total costs at the same price.

Products of diameter 130mm can fix a price within the range formed by the actual price of MG class and the actual price of the MGB price. The following table shows the increase in profits fixing different prices based on the percentage increase of this difference among the two prices:

PROFIT VARIATION OF 130mm PRODUCTS ADDING A PERCENTUAL DIFFERENCE OF THE ACTUAL MG PRICE AND ACTUAL MGB PRICE	
Percentage increase	Δ Profits
20%	€ 69,91
30%	€ 981,31
40%	€ 1.892,72
50%	€ 2.804,12
60%	€ 3.715,52
70%	€ 4.626,93
80%	€ 5.538,33
90%	€ 6.449,74
100%	€ 7.361,14

Table 6.2: Variation in profits of 130mm products varying the percentual difference in prices between MG and MGB in 130mm tubes.

With the indicated values on **Table 7.3**, taking an approximate increase in 50% for MGB products, the profits are the following:

AVERAGE MONTHLY DELTA PROFITS	
AVERAGE MONTHLY DELTA PROFITS (DIAMETER 80mm)	€ 4.049,20
AVERAGE MONTHLY DELTA PROFITS (DIAMETER 130mm)	€ 2.804,12
AVERAGE MONTHLY DELTA PROFITS (ALL PRODUCTS)	€ 6.853,32

Table 6.3: Average monthly increase in profits with the increase in prices established.

Table 6.4 appendix: Contains in detail the increase in profits for every product, without grouping it into different product families.

6.4 PROFITS FOR DECREASE IN INVENTORY LEVELS

Based on the inventory reduction described in chapter 5.4, the level of average inventories can be decreased by 109.154€ in approximately 5 months' time in a progressive way. This reduction brings also an increase in profit associated to less frozen capital, risk and opportunity cost of money. With the change in MG to MGB only, when production and transitional demand reaches stability and inventories of brass fusions empty, annual increase in earnings will be of 16.400€, 1.350€ monthly. These earnings were established in an approximate way as a 15% of the reduction in the cost of inventories based on the value of money, that is to say, opportunity cost, financial cost and risk.

6.5 PROJECT EVALUATION

Considering the investment mentioned and the expected increase in profits obtained by fixing product prices by the criteria established in chapter 6.4, a temporal horizon must be established to calculate the Net present value NPV of the project. **Tables 7.5, 7.6 y 7.7** show the calculations of the van depending on three variables: actualization rates, Price established and time horizon.

NET PRESENT VALUE FOR DIFFERENT TIME HORIZONS BASED ON PROFIT EARNINGS OF 6853, 32€ (50%)			
MONTH	NPV	NPV	NPV
	10%	12%	15%
0	-70.000 €	-70.000 €	-70.000 €
1	-62.791 €	-62.788 €	-62.783 €
2	-55.641 €	-55.647 €	-55.655 €
3	-48.551 €	-48.577 €	-48.616 €
4	-41.519 €	-41.577 €	-41.663 €
5	-34.545 €	-34.646 €	-34.796 €
6	-27.629 €	-27.784 €	-28.013 €
7	-20.770 €	-20.989 €	-21.315 €
8	-13.968 €	-14.262 €	-14.699 €
9	-7.222 €	-7.602 €	-8.165 €
10	-532 €	-1.008 €	-1.711 €
11	6.103 €	5.522 €	4.663 €
12	12.684 €	11.986 €	10.958 €

Table 6.5: NPV calculated for an increase in prices of 50% of the difference in prices between MG and MGB and a Required Rate of Return of 10%, 12% y 15%.

NET PRESENT VALUE FOR DIFFERENT TIME HORIZONS BASED ON PROFIT EARNINGS OF 14648, 79€ (55%)			
MONTH	NPV	NPV	NPV
	10%	12%	15%
0	-70.000 €	-70.000 €	-70.000 €
1	-62.339 €	-62.337 €	-62.333 €
2	-54.741 €	-54.749 €	-54.761 €
3	-47.206 €	-47.237 €	-47.282 €
4	-39.734 €	-39.799 €	-39.895 €
5	-32.323 €	-32.434 €	-32.600 €
6	-24.973 €	-25.143 €	-25.395 €
7	-17.684 €	-17.923 €	-18.279 €
8	-10.455 €	-10.775 €	-11.250 €
9	-3.286 €	-3.698 €	-4.308 €
10	3.823 €	3.309 €	2.548 €
11	10.874 €	10.246 €	9.319 €
12	17.867 €	17.115 €	16.007 €

Table 6.6: NPV calculated for an increase in prices of 55% of the difference in prices between MG and MGB and a Required Rate of Return of 10%, 12% y 15%.

NET PRESENT VALUE FOR DIFFERENT TIME HORIZONS BASED ON PROFIT EARNINGS OF 22444, 25€ (60%)			
MONTH	NPV	NPV	NPV
	10%	12%	15%
0	-70.000 €	-70.000 €	-70.000 €
1	-61.887 €	-61.885 €	-61.883 €
2	-53.841 €	-53.851 €	-53.866 €
3	-45.862 €	-45.896 €	-45.948 €
4	-37.948 €	-38.020 €	-38.128 €
5	-30.100 €	-30.222 €	-30.405 €
6	-22.317 €	-22.502 €	-22.776 €
7	-14.598 €	-14.857 €	-15.242 €
8	-6.943 €	-7.289 €	-7.801 €
9	649 €	205 €	-452 €
10	8.178 €	7.625 €	6.806 €
11	15.645 €	14.971 €	13.975 €
12	23.050 €	22.244 €	21.055 €

Table 6.7: NPV calculated for an increase in prices of 60% of the difference in prices between MG and MGB and a Required Rate of Return of 10%, 12% y 15%.

We can observe from **Tables 6.5, 6.6 y 6.7** that the main factor that influences the results obtained is the price fixed for MGB new products. In case of fixing price increase in 50% of the difference, the payback of the project will be 11 months. In case the increase is of 55% 10 months and lastly if the increase is of 60%, only 9 months. These results were established in an approximate way.

7. IMPLEMENTATION

When talking about a Project that implies changes in different areas and departments among the business, the implementation of it must be held in a smooth way. A modification of more than 70% of the productive process implies huge changes for workers, production managers, acquisition managers, clients, etc. This is why we consider that a stepped modification of the productive system must be held in order to reduce change resistance from an internal and external perspective.

Firstly, the main step will be converting the MG gamma of products to MGB but prioritizing using all the raw materials that are specific from MG products as they will not be useful in a short future. To begin with changes, it is essential to change first MG 130/131 to MGB 130/131 that represents a minor part of the production. Followed by other diameters that represent also a minor percentage of production in order to analyze how clients respond to changes. Finally, the most representative part of production will be changed from MG 80/81 to MGB 87.

It is necessary to be in constant contact with clients to be able to evaluate the response to the new product being offered and conformity with established Price. In case the client is not capable of adapting to the new product due to its slight increase in dimensions or inter-axis distance, the technical department can also create new designs for products with a slight lower performance but the same dimensions than MG in order to avoid losing any client.

In order to satisfy the future demand of MGB products entirely, it is necessary to have a dedicated TIG welder, therefore capacitation to one of the brazing workers must be done, doing this training with anticipation to avoid future productive problems and delays.

In order to work under Lean philosophies efficiently, it is necessary to make changes regarding the new Layout previously described. In order to avoid delays in orders, production manager must over produce to cover the demand while the production stops due to layout changes and installations. Another alternative is making Layout changes during weekends in a gradual way. This will imply extra costs for the business but will not be very significant.

With the improvements already implemented and the desired layout, techniques that encourage workers to work at Takt Time avoiding over production and intermediate stocks can be now applied. Some visual elements such as lights in green and red colors can be installed that permits the worker to know if he is working at a regular rhythm of production or should speed up.

Once product transformation has been established and transition problems have been overcame, improving stock policies continues. It is essential to negotiate with providers to change the actual prices of raw materials and Continuous Review Systems thanks to the ERP system with orders oriented to the optimal quantity and not in a random way. This implies a huge change in the production planning department and acquisition department that can also synchronize with suppliers throughout Information and technology to optimize inventory planning. To carry on these measures it is also important to train workers on the importance of using bar code systems.

Last but not least, Jidoka philosophies and continuous improvement can be achieved, having a productive system that aims to improve quality, efficiency and constant evolution of the productive process.

8. FUTURE STATE

Taking into account the introduced changes in the productive process, an analysis of the future state of the productive process must be held to have an idea of new production times and availability to respond to demand.

To calculate the future state, production time of each product can be estimated by approximating new cycle times for the new boring machine and quality control system. Also, changes in layout imply reduction of distances between working stations which contribute to an increase in workers efficiency. Once the production time estimated for each product is obtained, a weighted average is obtained based on the demand expected in Chapter 3.1.

Table 8.1 contains the production time values for the actual and future state.

COMPARISON BETWEEN ACTUAL STATE AND FUTURE STATE					
	ACTUAL STATE			FUTURE STATE	
	MG 54/6	MG	MGB	MG	MGB
CUT1 [s]	103,30	217,43	351,18	103,30	271,03
DRILL [s]	48,36	0,00	160,60	48,36	151,99
CUT2 [s]	131,99	368,68	536,28	131,99	384,15
WASH [s]	20,66	112,45	187,95	0,00	0,00
ASSEMBLY [s]	237,27	299,78	342,47	237,27	303,72
BRASS [s]	902,52	987,46	0,00	902,52	0,00
TIG WELDING [s]	0,00	0,00	1641,81	0,00	1581,11
BORE [s]	0,00	0,00	1595,27	0,00	1336,26
QUALITY CONTROL (20 BAR) [s]	100,75	239,67	293,64	115,35	272,10
COVER ASSEMBLY[s]	9,95	333,97	392,51	9,95	339,37
QUALITY CONTROL (8 BAR) [s]	115,35	267,86	313,71	0,00	0,00
TOTAL [s]	**1670,15**	**2827,30**	**5815,43**	**1548,74**	**4639,72**

Table 8.1: Comparison of production times between actual state and future state.

Figure 8.2 and 8.3 contain the Value Stream Maps for the future state for MG and MGB class based on times recorded on **Table 8.1.**

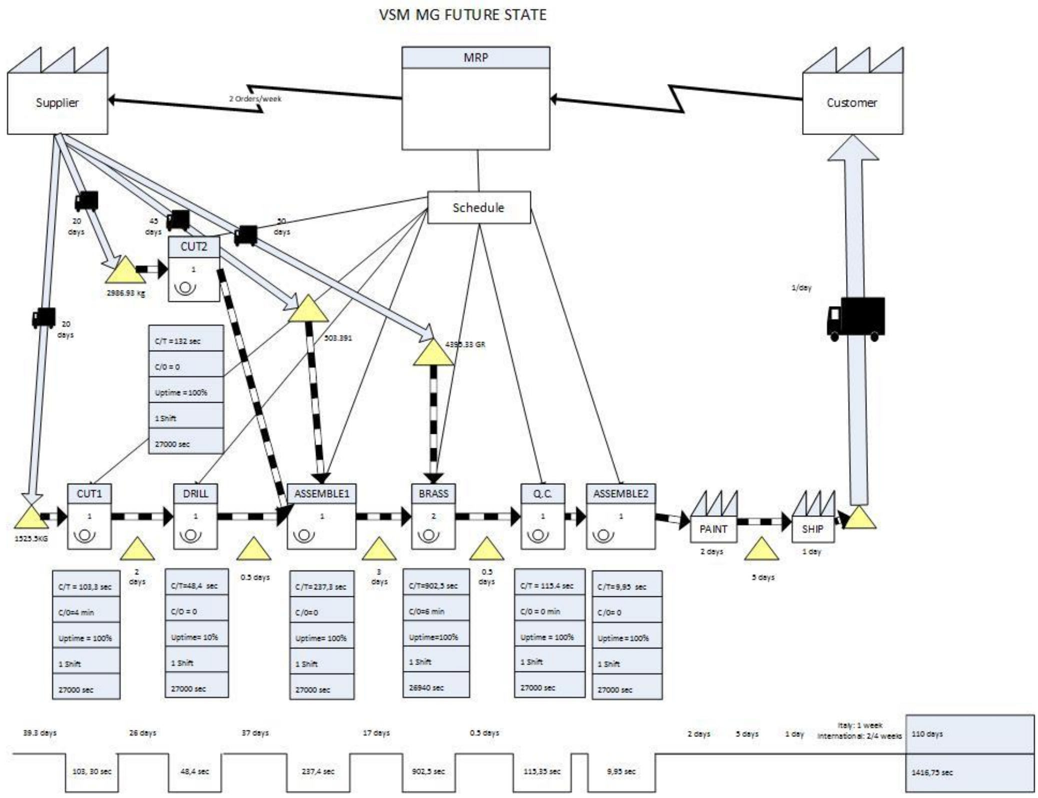

Figure 8.2: MG class Value Stream Map for Future State

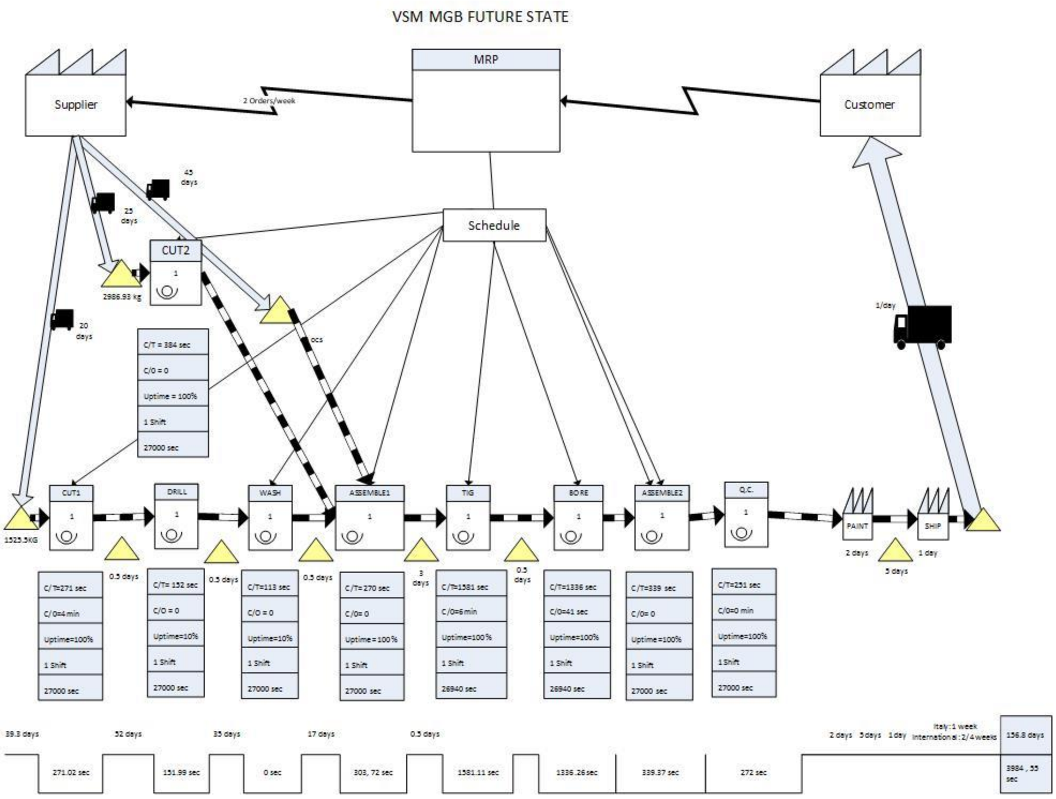

Figure 8.3: MGB class Value Stream Map for Future State

Once the future state has been calculated, EPE allows the business to know what is the time interval in which the new productive line can produce any product. Lean philosophies strive to reduce EPE throughout SMED techniques that allow reducing set-up times or reducing the variety of products by standardization. As it can be observed in the EPE formula, the main variables that play a role are the amount of products that are manufactured, the variability of its demand and the set up times:

$D \times T_p + n_P \times T_{set\ up} > EPE \times T_d$

D = Demand

T_p = Producing time

n_P = Number of products in catalogue

$T_{set\ up}$ = Set up time

T_d = Available time

Table 8.4 contains the EPE for every working station and the total EPE of the productive line.

EPE INDEX					
	FUTURE STATE		**STATION DEMAND**	**EPE**	
	MG	MGB	FUTURE STATE	SET UP	FUTURE STATE
CUT1 [s]	103,30	271,03	249,13	240,00	0,40
DRILL [s]	48,36	151,99	138,46	0,00	0,16
CUT2 [s]	131,99	384,15	351,23	0,00	0,39
WASH [s]	0,00	0,00	0,00	0,00	0,00
ASSEMBLY [s]	237,27	303,72	295,04	0,00	0,33
BRASS [s]	902,52	0,00	117,83	360,00	0,31
TIG WELDING [s]	0,00	1581,11	1374,69	360,00	1,72
BORE [s]	0,00	1336,26	1161,80	41,00	1,32
QUALITY CONTROL (20 BAR) [s]	115,35	272,10	251,63	0,00	0,28
COVER ASSEMBLY[s]	9,95	339,37	296,36	0,00	0,33
QUALITY CONTROL (8 BAR) [s]	0,00	0,00	0,00	0,00	0,00
TOTAL [s]	**1548,74**	**4639,72**	**4236,18**		**5,24**

Table 8.4: Calculus of the EPE index.

Table 8.4 shows that in case investment is done, EPE will be of approximately 5, 24 days plus 3 days of painting at maximum which sums a total of 8 days. This means that the Lead Time for any client can be reduced from a minimum of 3 or 4 weeks into one week in average reducing drastically the amount of Work in Progress and inefficiencies.

9. CONCLUSIONS

Due to the continuous research of optimization based on Lean thinking, new interesting proposals have been created but with a complex implementation that must be held smoothly to avoid organizational problems and reduce risks.

The proposal is based in the change of the MG category into the MGB category in almost the totality of products that represent nowadays more than 85% of the production, excepting those of the MG 54 and MG 60 family that represent the 15% missing. The reasons that justify the impossibility of transforming 100% of the production to MGB stands on the fact that the MG 54/60 families are not replaceable as they have different raw materials that do not allow iron plates and TIG welding to be done.

Based on this change in product catalogue, a new window of possible improvement opens to improve the entire process and carry on Lean Manufacturing which implies:

- Redesigning layout and modifying working stations.
- Eliminating Batch production throughout the buying of galvanized Shell tubes.
- Acquisition of a new boring machine.
- Acquisition of a pneumatic Quality control machine.
- New inventory managing policies.

It is important to understand that all measures applied are caused by the change from MG to MGB but cannot be analyzed separately because most of them are correlated among them or are essential to the development of the Project.

- If batches weren't eliminated and the change in product category held, the new layout could not be done and the space for new machines will be limited.
- If changes in MG and MGB categories weren't held, then a new inventory policy would not be held due to the minimum order quantities established by suppliers for Brass fusions.
- If the new boring machine is wasn't bought, it will be impossible to produce at the Takt Time.
- If the quality control system was not applied, Emmegi will be obliged to hiring another employee to cover their producing requirements.

This is why the proposal must be analyzed entirely as one project and not separately.

As a first analysis, the NPV (net present value) and IRR (internal rate of return) show encouraging results that justify the proposed investment. These indexes indicate that the money invested will be recovered in less than one year based on a pessimistically perspective saying that demand will continue low as recession goes on.

To analyze clearly the benefits and risks of the Project, it is useful to create a chart of Strengths, weaknesses, opportunities and threats of it.

SWOT ANALYSIS	
Strengths	Weaknesses
• Offering the client a product of the same performance with a lower cost. • Reducing Lead Time to clients. • Reducing inventory levels and variety of raw materials required. • Less frozen capital. • Less defect rate. • Reduction of waste (activities that do not add value from the client's perspective).	• Commercial policies that offer two products at different prices will be eliminated. • Employees must be trained to carry on new activities. • Rise in the cost of Shell tubes • More time is required to produce each piece.
Opportunities	Threats
• Fabricating plates inside Emmegi is possible. • In case demand increases heavily, there will be excess capacity in the plant by hiring an extra worker due to the existence of two boring machines.	• Possibility of client rejection of the new product due to customs, distrust or simply as a price negotiating weapon. • Possibility of resistance to change inside the firm caused by production managers, acquisition managers or workers.

Table 9.1: SWOT analysis.

This chart shows clearly how the vast majority of Lean principles mentioned in Chapter 1 were taken into consideration, contributing positively to the business.

9.1 STRENGHTS AND OPPORTUNITIES

Apart from the strengths analyzed in the Project, it is also important to consider all the opportunities of it.

First of all, manufacturing Iron Plates in Emmegi is presented as an interesting opportunity for reducing costs and covering needs for extra components in urgent situations. Technology required and know how already exist inside the business on account on the fact that a couple of years ago they were produced in the plant. Managers decided to outsource this activity to give priority to the production of other components required in the firm in other sectors. However, with the increase in levels of requirement of iron plates it may result profitable to add a shift of production to do the plates. This has not been analyzed with detail in terms of costs, but will be analyzed in a second step when levels of production and demand start stabilizing.

Secondly, the actual bottleneck is present on the brass working stations which work at a high saturation level. Therefore it is complex to cover increases in demand. With this new project, in the Boring working station, which is the most saturated one, there will be two boring machines. This implies that in case there are huge increases in demand, delay in orders or urgent orders, this could be solved by hiring an extra worker temporarily or relocating another worker from an unused sector. This will be very simple as the Boring activity is monotonous and easy to develop with almost none previous training.

9.2 WEAKNESSES AND THREATS

The weaknesses and threats of the Project must be analyzed even with more depth than strength and opportunities. In this case anyway, there is no huge relevance and complications that may arise.

The rise in the cost of Shell tubes loses importance when analyzing the fact that the cost of external tubes represents less than 1% of the total cost of the product. Furthermore, the need for increasing the time required by workers to manufacture a product can be counter posed with the fact that only 15% of the product cost is due to worker wages, while the missing 85% is due to raw material costs. All in all, the total cost of the MGB product is much lower than the MG one.

Threats of the project are mainly related to the resistance to change. In order to carry on an organized change, it is necessary to do it gradually, defining the different steps of the project and reducing the impact of these threats.

First of all, clients must be aware of the changes that will be held with anticipation and be informed of the reasons why this changes has been implemented, explaining the advantages that brings to the clients. In case there is any problem related to clients requirements, extra designs can be created that adjust to the necessities of each client without representing extra costs for the business.

Internally it is important to communicate every Emmegi member the changes that will be carried, from workers up to the top of the hierarchical pyramid, specifying the new functions and roles of each member in this new scenario. It is also essential to explain the reasons why these changes are taking place. Every employee will tend to be more helpful towards changing if they understand the benefits this new measures will have on the firm.

10. PROJECT STEPS

PROJECT STEPS	
28-oct	Meeting with Arturo Sergio, human resource responsible and Eng. Davide Franchino for Project approval.
12-nov	Meeting with Marco Giuliani, IT manager, to obtain access to ERP SAM software.
20-nov	Meeting with Leonardo de Palma, technical and Project manager to understand the technical characteristics of the product.
25-nov	Detailed analysis of working stations and timing planification.
27-nov	Meeting with MassimoStarone, timing responsible. Meeting with Leonardo Signorile, commercial manager.
28-nov	Timing of welding, brazing and cut stations
02-dic	Timing of quality control, boring and internal tube cut.
03- Dec	Timing other activities. Meeting with Enrico Cara, acquisition manager. Design of VSM.
04- Dec	Time interpolation to analyze each cycle times per family. Subdivisión of product families.
05- Dec	Time study and comparison with historical and standard times.
08- Dec	Adjustment of times obtained based on global standards and inefficiencies.
10- Dec	Inventory analysis and acquisition policies.
11- Dec	Costs, profit and margin study for each product family.
16- Dec	Current state analysis and layout analysis. Termination of VSM.
17- Dec	VOC (Voice of customers) with Leonardo Signorile.
19- Dec	Presentation of initial analysis with Davide Franchino, engineer responsible for the Project.
22-dec	Presentation of initial analysis with Matteo Rossini, Polimi tutor.
07-jan	Meeting with Enrico Cara looking for new suppliers of external tubes.
08- Jan	Meeting with Adelio, production chief, to discuss ideas regarding new layout.
09- Jan	Request of Budget for external tubes of different characteristics and lengths to suppliers.
13- Jan	Meeting with Enrico Cara to discuss possibilities of changing inventory policies.
14- Jan	Meeting with MRP responsible, to discuss a new policy of production management.
16- Jan	Analysis of improvements in each working station.
20- Jan	Meeting with Ing. Davide Franchino to discuss suggested improvements
21- Jan	Meeting with MAUS ITALIA to ask for prices and cycle time for new boring machine.
23- Jan	Meeting with Matteo Rossini to talk about Project advance
26- Jan	Analysis of boring working station based on MAUS offer.
27- Jan	Meeting with Quality Control techniques and Marco Giuliani to ask for budgets for a new pneumatic control system.
29- Jan	Meeting with Leonardo de Palma y Giuseppe Lavorante to design the new catalogue.
03-feb	Meeting with Leonardo Signorile to discuss new catalogue changes.
04-feb	Meeting with Leonardo de Palma to analyze feasibility of applying galvanized tubes.
06-feb	Meeting with Davide Franchino to discuss the Project.
09-feb	Meeting with Matteo Rossini to discuss the project.
13-feb	Design of new layout and new flow diagrams.
17-feb	Calculus of profits created by the Project
20-feb	NPV analysis and payback time
23-feb	Calculus of Future State
24-feb	EPE analysis
27-feb	Final presentation to directors and managers of each department together with Matteo Rossini.

APPENDIX

APPENDIX Chapter 3

DEMAND FROM 01/01/2013 TO 31/08/2014				
ARTICLE CODE	ARTICLE DESCRIPTION	AVERAGE DAILY DEMAND	01/01/2013-31/08/2014 515	AVERAGE MONTHLY DEMAND 17
102404004	MG 80-310-4	1,834	945	56
102402004	MG 80-150-4	1,76	906	53
102408004	MG 80-560-4	1,037	534	31
104406008	MG 130-535-4	0,666	343	20
100804002	MGE 60-260-2	0,661	340	20
102406004	MG 80-385-4	0,594	306	18
103408004	MG 81-560-4	0,532	274	16
103410004	MG 81-715-4	0,452	233	14
105406008	MG 131-535-4	0,447	230	14
100802002	MGE 60-140-2	0,339	175	10
104402008	MG 130-285-4	0,334	172	10
102412004	MG 80-870-4	0,288	148	9
104410008	MG 130-845-4	0,279	144	8
103404004	MG 81-310-4	0,276	142	8
101004012	MGE 80-280-1	0,272	140	8
105404008	MG 131-521-4	0,26	134	8
100604002	MGE 60-260-1	0,249	128	8
102410004	MG 80-715-4	0,24	124	7
105408008	MG 131-831-4	0,228	117	7
104102008	MG 130-285-1	0,194	100	6
102102050	MG 80-150-1 S.W.	0,187	96	6
112406046	MGB 130-535-4	0,18	93	5
105108050	MG 131-831-1 S.W.	0,177	91	5
101603052	MG 54-255-1 S.W.	0,173	89	5
123404012	MGF 131-453-4	0,166	85	5
103108050	MG 81-560-1 S.W.	0,164	84	5
101404012	MGF 80-340-2	0,157	81	5
105410008	MG 131-845-4	0,15	77	5
108404042	MGB 80-500-4	0,147	76	4
100204002	MGC 60-190-2	0,136	70	4
103406004	MG 81-385-4	0,136	70	4
102104050	MG 80-310-1 S.W.	0,131	67	4
101204012	MGE 80-280-2	0,129	66	4
101206012	MGE 80-530-2	0,127	65	4
113408046	MGB 131-831-4	0,127	65	4
102202004	MG 80-150-2	0,124	64	4
102210004	MG 80-715-2	0,12	62	4

108402042	MGB 80-250-4	0,118	61	4
113406046	MGB 131-535-4	0,111	57	3
102414004	MG 80-1155-4	0,108	56	3
104106050	MG 130-535-1 S.W.	0,108	56	3
102102004	MG 80-150-1	0,101	52	3
105402008	MG 131-285-4	0,101	52	3
123406012	MGF 131-623-4	0,101	52	3
112402046	MGB 130-285-4	0,099	51	3
100606002	MGE 60-440-1	0,097	50	3
123202012	MGF 131-310-2	0,097	50	3
100602002	MGE 60-140-1	0,094	48	3
105412008	MG 131-1131-4	0,094	48	3
100202002	MGC 60-90-2	0,092	47	3
101002012	MGE 80-120-1	0,09	46	3
106404010	MG 155-830-4	0,09	46	3
101602052	MG 54-150-1 S.W	0,088	45	3
112410046	MGB 130-845-4	0,088	45	3
105202008	MG 131-285-2	0,081	42	2
105406050	MG 131-535-4 S.W.	0,078	40	2
113410046	MGB 131-845-4	0,078	40	2
102106050	MG 80-385-1 S.W.	0,076	39	2
105104050	MG 131-521-1 S.W.	0,076	39	2
111406040	MGB 168-1080-4	0,076	39	2
320702002	C-350-997 RAME D.20458	0,076	39	2
100806002	MGE 60-440-2	0,071	37	2
104110050	MG 130-845-1 S.W.	0,069	36	2
106406010	MG 155-1130-4	0,069	36	2
100404012	MGC 80-180-2	0,065	33	2
107408020	MGW 135-375-2	0,065	33	2
103412004	MG 81-870-4	0,062	32	2
104410050	MG 130-845-4 S.W.	0,06	31	2
113404046	MGB 131-521-4	0,06	31	2
318202060	SCAMB.INOX 30000 KCAL/H 20006	0,06	31	2
320102002	FASCIO TUBIERO D.20408 C-400-995 RAME	0,06	31	2
103104050	MG 81-310-1 S.W.	0,058	30	2
103106050	MG 81-385-1 S.W.	0,058	30	2
109404040	MGB 114-805-4	0,058	30	2
102206004	MG 80-385-2	0,053	27	2
317202060	SCAMB.INOX 18000 KCAL/H 20005	0,053	27	2
105404050	MG 131-521-4 S.W.	0,051	26	2
109402040	MGB 114-500-4	0,051	26	2
104406050	MG 130-535-4 S.W.	0,048	25	1
109406040	MGB 114-1110-4	0,048	25	1
123408012	MGF 131-805-4	0,048	25	1

104102050	MG 130-285-1 S.W.	0,046	24	1
108406042	MGB 80-805-4	0,046	24	1
111402040	MGB 168-470-4	0,046	24	1
113412046	MGB 131-1131-4	0,046	24	1
103208004	MG 81-560-2	0,044	23	1
104206008	MG 130-535-2	0,044	23	1
111404040	MGB 168-775-4	0,044	23	1
320402002A	FASCIO TUBIERO D.20411A C-90-998	0,044	23	1
105414008	MG 131-1145-4	0,041	21	1
111408040	MGB 168-1385-4	0,041	21	1
311402064	MGB 168-470-4 AISI 304	0,039	20	1
104413008	MG 130-1105-4	0,037	19	1
105102050	MG 131-285-1 S.W.	0,037	19	1
105106050	MG 131-535-1 S.W.	0,037	19	1
103408050	MG 81-560-4 S.W.	0,035	18	1
102108004	MG 80-560-1	0,032	16	1
106402010	MG 155-520-4	0,032	16	1
106406050	MG 155-1130-4 SW	0,032	16	1
113402046	MGB 131-285-4	0,032	16	1
123402012	MGF 131-310-4	0,032	16	1
308404066	MGB 80-500-4 AISI 304	0,032	16	1
100402012	MGC 80-80-2	0,03	15	1
101406012	MGF 80-440-2	0,03	15	1
105206008	MG 131-535-2	0,03	15	1
105212050	MG 131-1131-2 S.W.	0,03	15	1
106402050	MG 155-520-4 SW	0,03	15	1
101202012	MGE 80-120-2	0,028	14	1
101402012	MGF 80-240-2	0,028	14	1
102206050	MG 80-385-2 S.W.	0,028	14	1
102404050	MG 80-310-4 S.W.	0,028	14	1
105206050	MG 131-535-2 S.W.	0,028	14	1
102402050	MG 80-150-4 S.W.	0,025	13	1
107202020	MGW 130-155-2	0,025	13	1
308402066	MGB 80-250-4 AISI 304	0,025	13	1
102108050	MG 80-560-1 S.W.	0,023	12	1
102210050	MG 80-715-2 S.W.	0,023	12	1
105208050	MG 131-831-2 S.W.	0,023	12	1
116410010	MG 157-1730-4	0,023	12	1
313410064	MGB 131-845-4 AISI 304	0,023	12	1
102112050	MG 80-870-1 S.W.	0,021	11	1
102208050	MG 80-560-2 S.W.	0,021	11	1
103210004	MG 81-715-2	0,021	11	1
104402050	MG 130-285-4 S.W.	0,021	11	1
105408050	MG 131-831-4 S.W.	0,021	11	1
110404040	MGB 140-795-4	0,021	11	1

115410044	MGB 220-1660-4	0,021	11	1
116408010	MG 157-1435-4	0,021	11	1
101006012	MGE 80-530-1	0,018	9	1
102110004	MG 80-715-1	0,018	9	1
102406050	MG 80-385-4 S.W.	0,018	9	1
104110008	MG 130-845-1	0,018	9	1
106404050	MG 155-830-4 SW	0,018	9	1
106408010	MG 155-1435-4	0,018	9	1
114406044	MGB 219-1045-4	0,018	9	1
103106004	MG 81-385-1	0,016	8	0
103208050	MG 81-560-2 S.W.	0,016	8	0
103212004	MG 81-870-2	0,016	8	0
104106008	MG 130-535-1	0,016	8	0
105414050	MG 131-1145-4 SW	0,016	8	0
113414046	MGB 131-1145-4	0,016	8	0
102202050	MG 80-150-2 S.W.	0,014	7	0
102204050	MG 80-310-2 SW	0,014	7	0
104411008	MG 130-995-4	0,014	7	0
105410050	MG 131-845-4 S.W.	0,014	7	0
105412050	MG 131-1131-4 S.W.	0,014	7	0
112411046	MGB 130-995-4	0,014	7	0
114404044	MGB 219-740-4	0,014	7	0
115408044	MGB 220-1350-4	0,014	7	0
116404050	MG 157-830-4 SW	0,014	7	0
302304050	FASCIO TUBIERO D.20414 AIFO 80 (8113782)	0,014	7	0
310406064	MGB 140-1110-4 AISI 304	0,014	7	0
312206064	MGB 130-535-2 AISI 304	0,014	7	0
312406064	MGB 130-535-4 AISI 304	0,014	7	0
320302002	C-90-996 RAME D.20406	0,014	7	0
102106004	MG 80-385-1	0,012	6	0
102408050	MG 80-560-4 S.W.	0,012	6	0
103204050	MG 81-310-2 S.W.	0,012	6	0
105110050	MG 131-845-1 S.W.	0,012	6	0
105214050	MG 131-1145-2 S.W.	0,012	6	0
107204020	MGW 130-210-2	0,012	6	0
107208020	MGW 130-375-2	0,012	6	0
108408042	MGB 80-1110-4	0,012	6	0
112106046	MGB 130-535-1	0,012	6	0
112206046	MGB 130-535-2	0,012	6	0
114402044	MGB 219-435-4	0,012	6	0
116406010	MG 157-1130-4	0,012	6	0
308104066	MGB 80-500-1 AISI 304	0,012	6	0
313406064	MGB 131-535-4 AISI 304	0,012	6	0
MGB08701002ST	MGB 87-100-2PASS	0,012	6	0

020351B0000ST	MG 131-285-1131-1F D.20351B	0,009	5	0
02044100000ST	MG 80-1155-4 ID 40 D.20441	0,009	5	0
101607052	MG 54-455-1 S.W.	0,009	5	0
102112004	MG 80-870-1	0,009	5	0
102212050	MG 80-870-2 S.W.	0,009	5	0
102214004	MG 80-1155-2	0,009	5	0
105208008	MG 131-831-2	0,009	5	0
105210008	MG 131-845-2	0,009	5	0
108202042	MGB 80-250-2	0,009	5	0
110402040	MGB 140-490-4	0,009	5	0
110406040	MGB 140-1110-4	0,009	5	0
114204044	MGB 219-740-2	0,009	5	0
115406044	MGB 220-1045-4	0,009	5	0
116410050	MG 157-1730-4 SW	0,009	5	0
315402064	MGB 220-435-4 AISI 304	0,009	5	0
0204180A000ST	MGB 140-1660-4 D.20418A	0,007	4	0
101605052	MG 54-355-1 S.W.	0,007	4	0
102110050	MG 80-715-1 S.W.	0,007	4	0
102212004	MG 80-870-2	0,007	4	0
103108004	MG 81-560-1	0,007	4	0
103412050	MG 81-870-4 S.W.	0,007	4	0
103414050	MG 81-1155-4 S.W.	0,007	4	0
104202008	MG 130-285-2	0,007	4	0
104202050	MG 130-285-2 S.W.	0,007	4	0
104206050	MG 130-535-2 S.W.	0,007	4	0
105204050	MG 131-521-2 S.W.	0,007	4	0
105214008	MG 131-1145-2	0,007	4	0
107206020	MGW 130-280-2	0,007	4	0
107606024	MGW 168-370-2	0,007	4	0
113204046	MGB 131-521-2	0,007	4	0
114206044	MGB 219-1045-2	0,007	4	0
115404044	MGB 220-740-4	0,007	4	0
301902052	SCAM.RE AIFO 65 1V(8102001)L=320 D.20420	0,007	4	0
313408064	MGB 131-831-4 AISI 304	0,007	4	0
320202002	FASCIO TUBIERO D.20423 C-600-996 RAME	0,007	4	0
02021300000ST	MGF 80-340-2S D.20213	0,005	3	0
020450B0000ST	FASCIO TUBIERO D.20450B MGB 130-100-1	0,005	3	0
020471A0000ST	MGW 130-155-2 D.20471A	0,005	3	0
02053800000ST	MG 81-310-2 S 20538	0,005	3	0
020720000SWNV	MG 130-535-2 SEA WATER NON VERNICIATO	0,005	3	0
103112004	MG 81-870-1	0,005	3	0
103214050	MG 81-1155-2 S.W.	0,005	3	0
103414004	MG 81-1155-4	0,005	3	0

105112008	MG 131-1131-1	0,005	3	0
105112050	MG 131-1131-1 S.W.	0,005	3	0
105114050	MG 131-1145-1 S.W.	0,005	3	0
105204008	MG 131-521-2	0,005	3	0
105402050	MG 131-285-4 S.W.	0,005	3	0
106410010	MG 155-1730-4	0,005	3	0
107404020	MGW 135-210-2	0,005	3	0
107406020	MGW 135-280-2	0,005	3	0
107410020	MGW 135-515-2	0,005	3	0
107612024	MGW 168-710-2	0,005	3	0
107814024	MGW 170-820-2	0,005	3	0
108104042	MGB 80-500-1	0,005	3	0
112102046	MGB 130-285-1	0,005	3	0
112210046	MGB 130-845-2	0,005	3	0
113112046	MGB 131-1131-1	0,005	3	0
113202046	MGB 131-285-2	0,005	3	0
114108044	MGB 219-1350-1	0,005	3	0
116402010	MG 157-520-4	0,005	3	0
311406064	MGB 168-1080-4 AISI 304	0,005	3	0
312402064	MGB 130-285-4 AISI 304	0,005	3	0
313106064	MGB 131-535-1 AISI 304	0,005	3	0
313404064	MGB 131-521-4 AISI 304	0,005	3	0
313414064	MGB 131-1145-4 AISI 304	0,005	3	0
315106064	MGB 220-1045-1 AISI 304	0,005	3	0
321002062	FASCIO TUBIERO D.20410 C-90-983 INOX	0,005	3	0
02021000000ST	FASCIO TUBIERO D.20210 MGC60-440-2F ID25	0,002	1	0
02035300000ST	MG 131-845-4 ID30 D.20353	0,002	1	0
020355C0000A4	MGB 80-200-4 D.20355C INOX T.D.25% N.D.5	0,002	1	0
02044900000A4	SERBATOIO AISI304 dis. 20449 L=1070	0,002	1	0
02046100000ST	MG 81-560-4 I.D.25 D.20461	0,002	1	0
02050800000ST	MG 131-480-1 SP ID=34.5 D.20508	0,002	1	0
02052600000ST	FASCIO TUBIERO D.20526	0,002	1	0
02078000000ST	MGB 220-1660-4 ID.85 D.20780 SPECIALE	0,002	1	0
103110050	MG 81-715-1 S.W.	0,002	1	0
103112050	MG 81-870-1 S.W.	0,002	1	0
103114050	MG 81-1155-1 S.W.	0,002	1	0
103206050	MG 81-385-2 S.W.	0,002	1	0
103214004	MG 81-1155-2	0,002	1	0
104111008	MG 130-995-1	0,002	1	0
104210050	MG 130-845-2 S.W.	0,002	1	0
104211008	MG 130-995-2	0,002	1	0
104213008	MG 130-1105-2	0,002	1	0
105104008	MG 131-521-1	0,002	1	0

105212008	MG 131-1131-2	0,002	1	0
107614024	MGW 168-820-2	0,002	1	0
107806024	MGW 170-370-2	0,002	1	0
107810024	MGW 170-620-2	0,002	1	0
110408040	MGB 140-1405-4	0,002	1	0
112202046	MGB 130-285-2	0,002	1	0
113104046	MGB 131-521-1	0,002	1	0
113206046	MGB 131-535-2	0,002	1	0
114102044	MGB 219-435-1	0,002	1	0
114210044	MGB 219-1660-2	0,002	1	0
114408044	MGB 219-1350-4	0,002	1	0
114410044	MGB 219-1660-4	0,002	1	0
115102044	MGB 220-435-1	0,002	1	0
115202044	MGB 220-435-2	0,002	1	0
115210044	MGB 220-1660-2	0,002	1	0
123204012	MGF 131-453-2	0,002	1	0
123410012	MGF 131-1124-4	0,002	1	0
309402064	MGB 114-500-4 AISI 304	0,002	1	0
313204064	MGB 131-521-2 AISI 304	0,002	1	0
313402064	MGB 131-285-4 AISI 304	0,002	1	0
314410064	MGB 219-1660-4 AISI 304	0,002	1	0
315210064	MGB 220-1660-2 AISI 304	0,002	1	0
316202060	SCAMB.INOX 6000KCAL/H	0,002	1	0
MGT13103001ST	SCAMBIATORE 131-300-1 D.20672	0,002	1	0

Table 3.1: Demand from 01/01/2013 to 31/08/2014

HISTORICAL TIMES								
TYPE	D [mm]	L [mm]	CUT [s]	WASH [s]	ASSEMBLY [s]	BRASS [s]	BORE [s]	QUALITY CONTROL [s]
MGE	60	260	198	34	234	964	0	103
MGE	60	140	126	34	228	964	0	103
MGE	60	260	198	34	234	964	0	103
MGE	54	255	60	34	234	964	0	103
MGC	60	190	140	34	228	850	0	103
MGE	60	440	309	34	240	964	0	103
MGC	60	90	85	34	222	850	0	103
MG	54	150	40	34	228	964	0	103
MGE	60	440	309	34	240	964	0	103
			166	34	232	950	0	103
MG	80	310	254	30	282	443	0	311
MG	80	150	135	34	276	443	0	311
MG	80	560	440	34	300	443	0	311
MG	80	385	310	34	282	443	0	311
MG	81	560	447	34	282	443	0	311
MG	81	715	563	30	288	443	0	311
MG	80	870	672	34	306	503	0	404
MG	81	310	260	30	282	443	0	311
MG	80	715	554	34	300	443	0	311
MG	80	150	135	34	276	443	0	311

MG	81	560	447	34	282	443	0	311
MG	81	385	316	34	282	443	0	311
MG	80	310	254	34	282	443	0	311
MG	80	150	135	34	276	443	0	311
MG	80	715	554	34	300	443	0	311
MG	80	1155	881	34	312	513	0	404
MG	80	150	135	34	276	443	0	311
MG	80	385	310	34	282	443	0	311
MG	81	870	679	34	288	513	0	404
MG	81	310	260	34	282	443	0	311
MG	81	385	316	34	282	443	0	311
MG	80	385	310	34	282	443	0	311
			324	33	285	446	0	316
MGB	80	500	223	34	276	949	474	404
MGB	80	250	133	34	264	949	474	404
MGB	80	805	336	34	282	949	474	404
MGB	80	500	336	34	282	949	474	404
MGB	80	250	446	34	288	949	474	268
MGB	80	1110	446	34	288	949	474	268
MGB	80	500	446	34	288	949	474	268
			246	34	275	949	474	387
MG	130	535	677	34	300	691	0	416
MG	131	535	1112	34	318	868	0	540
MG	130	285	382	34	294	691	0	540
MG	130	845	1042	34	312	794	0	540
MG	131	521	1112	34	306	868	0	540
MG	131	831	1701	34	318	868	0	416
MG	130	285	382	34	294	691	0	540
MG	131	831	1701	34	318	868	0	540
MG	131	845	1701	34	330	794	0	540
MG	130	535	677	34	300	691	0	540
MG	131	285	637	34	306	868	0	540
MG	131	1131	2270	34	324	794	0	540
MG	131	285	637	34	306	868	0	540
			985	34	308	782	0	505
MGB	130	535	783	34	300	875	2252	540
MGB	131	831	1839	34	324	947	4031	540
MGB	131	535	1759	34	318	875	4031	540
MGB	130	285	494	34	294	1000	2252	540
MGB	130	845	1136	34	312	875	2252	540
MGB	131	845	1835	34	324	875	4031	540
MGB	131	521	802	34	306	1071	4031	540
MGB	131	1131	1835	34	324	875	4031	540
			1261	34	311	918	3215	540

Table 3.13: Historical times.

EXTERNAL TUBE CUT (60mm)[s]			
140mm			
75,0	74,8	74,9	74,8
74,8	74,8	74,7	75,0
74,7	75,1	75,0	74,7
75,3	75,0	74,9	74,8
75,6	75,6	74,8	75,0

EXTERNAL TUBE CUT (80mm)[s]			
98mm			
79,0	78,1	78,5	78,3
78,1	78,0	78,1	77,9
78,2	77,9	78,0	78,1
78,4	78,6	78,3	78,3
77,9	78,2	78,2	77,9

EXTERNAL TUBE CUT (130mm)[s]			
285mm			
262,6	262,4	262,5	262,0
262,3	262,6	262,3	262,3
261,9	262,0	262,3	262,4
262,6	262,4	262,2	262,6
262,2	262,0	262,2	262,3

75,2	75,0	74,7	75,2
AVERAGE:			74,97
260mm			
88,0	88,2	88,1	88,4
88,3	88,3	88,0	88,0
88,4	88,0	87,9	87,9
88,0	88,4	87,9	87,8
87,9	87,9	88,1	88,2
87,9	87,8	88,0	88,3
AVERAGE:			88,07

78,1	78,1	78,5	78,2
AVERAGE:			78,20
239mm			
97,0	95,2	95,2	95,3
96,0	95,6	95,1	95,1
95,9	95,4	95,6	94,9
96,1	95,3	94,9	95,6
94,7	95,1	95,8	95,1
92,4	95,0	95,7	95,3
AVERAGE:			95,30

262,3	262,3	262,0	262,5
AVERAGE:			262,30
535mm			
340,0	341,0	341,6	341,4
341,6	341,2	341,5	341,6
339,8	341,4	341,3	341,0
341,2	339,9	341,6	341,2
341,5	341,1	341,5	341,2
341,2	341,3	341,1	341,0
AVERAGE:			341,13

Table 3.14: Taken times for external tube cut station.

INTERNAL TUBE CUT[s]			
DIAMETER OF EXTERNAL TUBE	QUANTITY CUT	TIME	TIME PER TUBE
60mm	400	1447,5	3,62
80mm	400	1769,17	4,42
130mm	400	2509,00	6,27

Table 3.15: Taken times for Internal tube cut station.

ASSEMBLY (60mm)[s]			
140mm			
190,9	192,4	191,5	195,1
192,0	186,8	188,2	193,2
191,0	194,7	194,3	192,9
190,9	186,9	188,1	189,4
188,5	186,9	187,5	189,8
192,4	196,4	195,5	190,8
190,3	193,6	191,9	195,3
183,6	192,9	190,8	192,1
190,1	195,9	195,0	190,1
188,4	195,4	190,4	191,4
187,8	193,2	189,9	195,4
195,1	189,9	195,4	192,0
AVERAGE:			191,5006

ASSEMBLY (80mm)[s]			
310mm			
202,5	203,1	193,5	191,7
206,3	192,6	190,8	190,7
194,2	208,9	211,8	204,6
189,4	209,5	212,0	210,3
208,4	202,4	206,7	188,2
205,1	208,7	196,2	188,8
AVERAGE:			200,69
560mm			
214,2	207,4	224,2	226,9
206,8	212,7	211,8	227,2
207,8	223,2	212,0	227,1
227,2	221,5	220,0	215,6
215,1	229,6	221,3	205,3
229,0	216,3	214,9	230,6
AVERAGE:			218,65

ASSEMBLY (130mm)[s]			
285mm			
305,3	294,1	307,1	288,7
305,6	297,6	310,3	295,4
302,5	311,3	306,5	294,7
293,3	308,4	308,9	311,6
295,9	309,3	292,0	307,4
300,3	288,4	306,7	307,0
AVERAGE:			302,0157
535mm			
325,6	331,3	338,5	339,0
321,8	340,1	320,3	329,4
335,3	320,1	320,5	330,2
325,3	329,5	339,2	324,1
337,3	320,3	328,4	337,0
337,5	325,5	342,7	331,6
AVERAGE:			330,44

Table 3.16: Taken times for Assembly station.

BRASS (60mm)[s]
140mm

BRASS (80mm)[s]
310mm

BRASS (130mm)[s]
285mm

668,9	675,1	691,7	686,4
670,2	696,3	683,0	689,1
670,8	692,3	669,5	681,4
697,1	674,9	676,9	698,3
672,1	694,3	679,1	674,5
681,8	694,5	670,8	679,6
694,7	696,7	678,2	686,4
677,7	670,0	670,2	692,5
671,8	671,9	678,3	689,8
691,6	682,6	696,2	677,6
686,8	678,2	685,5	692,3
690,6	696,9	694,8	678,9
AVERAGE:			683,3028

623,3	630,4	628,8	628,9
618,7	623,6	626,1	627,3
623,3	619,5	637,9	642,1
621,3	633,8	645,0	640,6
639,6	636,5	624,6	626,7
637,9	640,8	640,6	620,6
AVERAGE:			630,75
870mm			
654,5	637,1	642,9	655,9
642,2	657,1	651,7	652,6
641,1	647,9	647,8	639,8
631,6	636,2	650,9	636,7
639,1	638,5	658,7	648,1
652,1	632,7	656,2	633,3
AVERAGE:			645,20

996,3	998,2	968,9	979,4
1001,2	985,6	979,1	990,4
982,9	966,4	990,2	985,1
963,3	971,8	969,7	989,9
993,4	985,2	999,7	972,0
998,0	968,1	973,9	978,6
AVERAGE:			982,80
845mm			
1133,4	1111,2	1132,3	1111,6
1103,9	1129,4	1116,6	1113,2
1116,5	1114,4	1139,0	1116,8
1142,2	1134,6	1136,9	1133,2
1109,4	1123,0	1118,2	1134,2
1109,8	1110,3	1134,1	1110,7
AVERAGE:			1122,29

Table 3.17: Taken times for Brass working station.

TIG WELDING 80mm[s]			
1200,00	1202,08	1216,96	1228,35
1199,16	1165,36	1194,66	1151,37
1229,87	1208,91	1227,56	1194,59
1228,86	1185,82	1192,55	1155,22
1200,86	1178,85	1187,14	1202,90
1145,58	1175,88	1213,67	1146,32
1191,75	1151,22	1209,15	1205,37
AVERAGE:			1192,50069

TIG WELDING 130mm[s]			
1356,01	1352,41	1339,78	1313,93
1304,58	1364,09	1349,32	1324,98
1359,48	1316,22	1281,29	1302,53
1336,14	1326,63	1270,58	1338,00
1318,22	1293,57	1312,27	1287,29
1324,09	1340,45	1325,32	1363,05
1296,36	1349,54	1292,30	1361,57
AVERAGE:			1325,00041

TIG WELDING 80mm[s]	
AVERAGE:	1192,50

TIG WELDING 130mm[s]	
AVERAGE:	1325,00

Table 3.18: Taken times for TIG welding station.

BORING [s]				
7,44	7,78	7,46	9,48	8,48
7,97	8,03	7,49	7,80	8,62
9,06	8,18	7,61	7,67	7,62
7,27	7,62	7,57	7,13	7,52
7,87	8,51	7,43	7,68	7,78
7,22	8,31	7,79	8,05	8,16
7,33	8,45	7,49	9,33	7,25
7,76	7,81	7,80	7,62	7,64
7,61	8,61	7,77	7,92	7,76

7,82	8,85	7,71	8,13	8,27
AVERAGE BORING TIME			7,91	sec/internal tube
LUBRICATING AND FIXING PLATE			58,00	sec/unit
CHANGING BORING TYPE			30,00	sec/unit
ROTATING UNIT			21,00	sec/unit
AVERAGE TIME FOR BORING A TUBE			8,75	sec/internal tube

Table 3.19: Taken time for boring working station

TUBE 60mm x 140mm[s]			
QUALITY CONTROL 8bar			
70,40	77,18	69,93	66,79
72,43	70,40	65,40	61,17
78,23	62,16	66,54	68,76
78,22	61,01	71,90	68,90
59,49	71,24	64,41	76,89
66,54	61,24	78,74	73,91
71,74	76,02	72,74	76,69
AVERAGE TIME		69,97	sec/unit
QUALITY CONTROL 20bar			
88,61	87,09	93,31	83,26
81,46	78,74	81,60	81,05
88,20	80,08	82,40	93,10
81,42	82,84	80,65	92,50
80,29	85,80	88,03	84,41
74,68	78,97	81,75	80,40
76,65	85,88	85,53	92,38
AVERAGE TIME		83,97	sec/unit

TUBE 80mm x 310mm[s]			
QUALITY CONTROL 8bar			
304,83	314,43	303,80	313,92
304,53	317,03	317,48	316,93
308,92	306,83	315,77	312,25
312,09	312,04	309,09	314,35
302,93	312,88	319,48	313,65
303,19	310,32	317,79	314,48
312,94	304,51	313,78	311,31
AVERAGE TIME		311,48	sec/unit
QUALITY CONTROL 20bar			
344,06	325,98	326,16	339,83
334,61	332,34	325,61	338,97
341,52	331,79	330,10	330,22
333,76	342,74	341,60	334,51
330,67	330,23	337,84	333,18
328,21	329,43	338,45	329,48
326,84	333,14	335,44	331,19
AVERAGE TIME		333,50	sec/unit

TUBE 130mm x 285mm[s]			
QUALITY CONTROL 8bar			
477,43	471,33	478,56	465,01
482,89	481,49	472,95	467,23
464,92	471,60	472,41	473,31
476,26	476,80	481,45	471,03
465,12	479,55	470,10	467,24
474,06	473,76	473,36	477,40
468,20	471,16	472,87	473,55
AVERAGE TIME		473,25	sec/unit
QUALITY CONTROL 20bar			
506,12	491,13	495,38	499,58
497,88	495,18	504,17	488,51
503,16	498,13	501,19	492,74
491,62	500,10	501,58	491,68
506,50	500,58	498,65	497,99
493,24	488,12	500,07	496,59
501,68	492,79	500,71	487,92
AVERAGE TIME		497,25	sec/unit

TUBE 60mm x 260mm[s]			
QUALITY CONTROL 8bar			
85,80	78,01	74,22	75,93
80,40	74,75	83,27	83,89
81,84	69,60	71,30	86,66
83,21	87,68	69,06	80,49
75,69	83,53	79,46	80,88
77,69	77,51	74,77	78,62
68,70	81,94	70,51	80,73
AVERAGE TIME		78,43	sec/unit
QUALITY CONTROL 20bar			
96,81	84,33	95,78	101,98
99,46	91,47	100,96	92,10
85,82	94,23	89,32	90,39

TUBE 80mm x 870mm[s]			
QUALITY CONTROL 8bar			
456,65	458,55	456,49	456,35
454,51	452,67	454,48	456,68
463,09	458,51	452,02	458,54
453,93	455,46	443,63	449,73
450,19	460,80	443,97	460,68
448,54	456,89	464,01	450,07
457,20	458,87	455,26	458,60
AVERAGE TIME		455,23	sec/unit
QUALITY CONTROL 20bar			
472,86	483,02	482,21	485,61
470,63	478,23	471,37	470,38
483,37	486,29	480,41	474,20

TUBE 130mm x 535mm[s]			
QUALITY CONTROL 8bar			
680,27	696,03	687,50	680,98
693,89	686,52	687,57	692,94
688,82	691,46	681,85	689,35
686,25	680,08	688,86	693,95
692,58	689,36	686,57	693,95
696,92	680,32	685,92	688,28
698,63	681,06	693,92	692,54
AVERAGE TIME		688,80	sec/unit
QUALITY CONTROL 20bar			
703,62	706,66	720,77	712,16
721,98	704,52	708,85	701,44
717,02	717,67	709,94	705,01

90,50	97,90	89,33	86,04
89,13	91,93	88,62	95,13
102,86	94,44	86,82	93,77
92,49	84,58	96,15	85,79
AVERAGE TIME		92,43	sec/unit

483,95	474,86	473,47	473,12
486,80	473,60	483,31	477,00
481,36	478,73	487,97	483,21
479,09	480,45	479,91	481,43
AVERAGE TIME		479,17	sec/unit

718,73	714,93	711,61	711,14
720,46	719,99	718,30	721,09
718,61	701,18	708,88	708,86
711,35	717,58	721,81	704,14
AVERAGE TIME		712,80	sec/unit

Table 3.20: Taken times for quality control working station.

COVER ASSEMBLY (60mm)[s]			
60mm			
6,39	6,84	7,15	7,63
6,90	8,42	6,66	6,12
5,88	6,97	5,76	8,05
7,09	5,95	6,47	7,82
7,63	6,67	7,50	7,23
6,79	6,52	5,95	5,87
AVERAGE TIME		6,90	sec/unit

COVER ASSEMBLY (80mm)[s]			
310mm			
172,30	163,11	161,30	173,97
155,65	165,94	171,51	165,62
175,23	172,06	175,66	159,87
160,04	168,27	157,35	170,00
174,97	164,38	160,45	175,10
157,68	160,28	156,07	166,21
166,72	161,54	167,92	160,56
AVERAGE TIME		165,70	sec/unit
560mm			
193,16	196,79	189,45	192,49
187,25	193,33	188,17	185,92
189,78	183,94	189,93	195,34
190,69	192,11	181,18	195,57
192,67	185,11	185,90	179,27
191,07	180,76	178,03	181,64
188,26	178,83	194,41	179,96
AVERAGE TIME		187,89	sec/unit

COVER ASSEMBLY (130mm)[s]			
285mm			
337,25	337,96	329,77	340,83
324,96	337,46	336,69	323,84
334,72	323,09	340,77	332,91
334,86	340,71	338,61	328,88
334,52	340,56	329,01	331,17
323,62	334,06	336,68	325,32
335,64	334,39	334,02	327,47
AVERAGE TIME		333,21	sec/unit
535mm			
371,19	369,72	376,34	374,88
374,65	386,31	380,11	382,92
372,12	387,79	371,39	383,18
387,39	388,05	377,04	379,32
384,32	379,80	377,02	378,93
376,53	384,10	373,98	374,95
377,16	382,26	383,25	376,43
AVERAGE TIME		378,97	sec/unit

Table 3.21: Taken times for cover assembly working station.

EXTERNAL TUBE CUT (60mm)[s]	
M	0,109

EXTERNAL TUBE CUT (80mm)[s]	
M	0,121

EXTERNAL TUBE CUT (130mm)[s]	
M	0,315

B	59,693		B	66,319		B	172,430

Table 3.22: Linear interpolation for external tube cut station.

ASSEMBLY (60mm)[s]	
AVERAGE	191,501

ASSEMBLY (80mm)[s]	
M	0,072
B	178,41

ASSEMBLY (130mm)[s]	
M	0,114
B	269,609

Table 3.23: Linear interpolation for assembly station.

BRASS (60mm)[s]	
AVRG	683,303

BRASS (80mm)[s]	
M	0,026
B	622,75

BRASS (130mm)[s]	
M	0,249
B	911,803

Table 3.24: Linear interpolation for brass station.

QUALITY CONTROL 8bar (60mm)[s]		QUALITY CONTROL 8bar (80mm)[s]		QUALITY CONTROL 8bar (130mm)[s]	
M	0,071	M	0,257	M	0,862
B	60,09	B	231,912	B	227,53
QUALITY CONTROL 20bar (60mm)[s]		**QUALITY CONTROL 20bar (80mm)[s]**		**QUALITY CONTROL 20bar (130mm)[s]**	
M	0,071	M	0,260	M	0,862
B	74,09	B	252,85	B	251,53

Table 3.25: Linear interpolation for quality control station.

COVER ASSEMBLY (60mm)[s]		
AVERAGE	6,9016	Sec/unit

COVER ASSEMBLY (80mm)[s]	
M	0,0888
B	138,192 0

COVER ASSEMBLY (130mm)[s]	
M	0,18305
B	281,0368

Table 3.26: Linear interpolation for cover assembly working station.

ESTIMATED TIMES												
TYPE	D [mm]	L [mm]	CUT 1[s]	DRILL. [s]	CUT2 [s]	WASH [s]	ASSEMB [s]	BRASS [s]	BORE[s]	QUALITY CONTROL (20bar) [s]	COVERS [s]	QUALITY CONTROL (8bar) [s]
MGE	60	260	88	40	109	19	192	683	0	78	7	92
MGE	60	140	75	40	109	10	192	683	0	70	7	84
MGE	60	260	88	40	109	19	192	683	0	78	7	92
MGE	54	255	88	40	101	15	192	683	0	78	7	92
MGC	60	190	80	40	109	14	192	683	0	73	7	87
MGE	60	440	108	40	109	33	192	683	0	91	7	105

MGC	60	90	70	40	109	7	192	683	0	66	7	80
MG	54	150	76	40	101	9	192	683	0	71	7	85
MGE	60	440	108	40	109	33	192	683	0	91	7	105
			85	40	108	17	192	683	0	77	7	91
MG	80	310	104	0	212	41	201	631	0	150	166	174
MG	80	150	85	0	212	20	189	627	0	129	151	153
MG	80	560	134	0	212	74	219	637	0	182	188	206
MG	80	385	113	0	212	51	206	633	0	159	172	183
MG	81	560	134	0	212	74	219	637	0	182	188	206
MG	81	715	153	0	212	94	230	641	0	202	202	226
MG	80	870	172	0	212	115	241	645	0	222	215	246
MG	81	310	104	0	212	41	201	631	0	150	166	174
MG	80	715	153	0	212	94	230	641	0	202	202	226
MG	80	150	85	0	212	20	189	627	0	129	151	153
MG	81	560	134	0	212	74	219	637	0	182	188	206
MG	81	385	113	0	212	51	206	633	0	159	172	183
MG	80	310	104	0	212	41	201	631	0	150	166	174
MG	80	150	85	0	212	20	189	627	0	129	151	153
MG	80	715	153	0	212	94	230	641	0	202	202	226
MG	80	1155	206	0	212	152	261	653	0	258	241	282
MG	80	150	85	0	212	20	189	627	0	129	151	153
MG	80	385	113	0	212	51	206	633	0	159	172	183
MG	81	870	172	0	212	115	241	645	0	222	215	246
MG	81	310	104	0	212	41	201	631	0	150	166	174
MG	81	385	113	0	212	51	206	633	0	159	172	183
MG	80	385	113	0	212	51	206	633	0	159	172	183
			115	0	212	53	207	633	0	162	174	186
MGB	80	500	127	120	106	66	149	1193	280	174	183	198
MGB	80	250	97	120	106	33	131	1193	280	142	160	166
MGB	80	805	164	120	106	106	171	1193	280	213	210	237
MGB	80	500	127	120	106	66	149	1193	280	174	183	198
MGB	80	250	97	120	106	33	131	1193	280	142	160	166
MGB	80	1110	201	120	106	146	193	1193	280	252	237	276
MGB	80	500	127	120	106	66	149	1193	280	174	183	198
			122	120	106	61	147	1193	280	169	179	193
MG	130	535	341	0	477	186	330	1045	0	222	379	246
MG	131	535	341	0	853	186	330	1045	0	222	379	246
MG	130	285	262	0	477	99	302	983	0	114	333	138
MG	130	845	439	0	477	294	366	1122	0	355	436	379
MG	131	521	337	0	853	182	329	1042	0	216	376	240
MG	131	831	434	0	853	290	364	1119	0	349	433	373
MG	130	285	262	0	477	99	302	983	0	114	333	138
MG	131	831	434	0	853	290	364	1119	0	349	433	373
MG	131	845	439	0	853	294	366	1122	0	355	436	379
MG	130	535	341	0	477	186	330	1045	0	222	379	246
MG	131	285	262	0	853	99	302	983	0	114	333	138
MG	131	1131	529	0	853	394	398	1194	0	479	488	503
MG	131	285	262	0	853	99	302	983	0	114	333	138
			354	0	662	200	335	1055	0	239	386	263
MGB	130	535	341	140	477	186	330	1325	1330	222	379	246
MGB	131	831	434	140	853	290	364	1325	2380	349	433	373
MGB	131	535	341	140	853	186	330	1325	2380	222	379	246
MGB	130	285	262	140	477	99	302	1325	1330	114	333	138
MGB	130	845	439	140	477	294	366	1325	1330	355	436	379
MGB	131	845	439	140	853	294	366	1325	2380	355	436	379
MGB	131	521	337	140	853	182	329	1325	2380	216	376	240
MGB	131	1131	529	140	853	394	398	1325	2380	479	488	503
			377	140	680	226	343	1325	1898	270	400	294

Table 3.27: Calculated times based on timing and interpolation.

ADJUSTED TIME												
TYPE	D [mm]	L [mm]	CUT 1[s]	DRILL. [s]	CUT2 [s]	WASH [s]	ASSEMB [s]	BRASS [s]	BORE[s]	QUALITY CONTROL (20bar) [s]	COVERS [s]	QUALITY CONTROL (8bar) [s]
MGE	60	260	106	48	135	23	237	903	0	103	10	118
MGE	60	140	91	48	135	13	237	903	0	92	10	107
MGE	60	260	106	48	131	23	237	903	0	103	10	118
MGE	54	255	106	48	134	19	237	903	0	103	10	117
MGC	60	190	97	48	120	17	237	903	0	97	10	111
MGE	60	440	130	48	131	39	237	903	0	120	10	134
MGC	60	90	84	48	131	8	237	903	0	87	10	102
MG	54	150	92	48	123	11	237	903	0	93	10	108
MGE	60	440	130	48	132	39	237	903	0	120	10	134
			103	48	132	21	237	903	0	101	10	115
MG	80	310	126	0	234	49	249	833	0	197	239	221
MG	80	150	102	0	234	24	234	828	0	170	219	195
MG	80	560	162	0	234	89	271	842	0	239	271	262
MG	80	385	137	0	234	61	255	836	0	209	249	233
MG	81	560	162	0	234	89	271	842	0	239	271	262
MG	81	715	185	0	234	114	285	847	0	265	291	287
MG	80	870	208	0	234	139	299	852	0	291	311	312
MG	81	310	126	0	234	49	249	833	0	197	239	221
MG	80	715	185	0	234	114	285	847	0	265	291	287
MG	80	150	102	0	234	24	234	828	0	170	219	195
MG	81	560	162	0	234	89	271	842	0	239	271	262
MG	81	385	137	0	234	61	255	836	0	209	249	233
MG	80	310	126	0	234	49	249	833	0	197	239	221
MG	80	150	102	0	234	24	234	828	0	170	219	195
MG	80	715	185	0	234	114	285	847	0	265	291	287
MG	80	1155	250	0	234	184	324	862	0	339	347	359
MG	80	150	102	0	234	24	234	828	0	170	219	195
MG	80	385	137	0	234	61	255	836	0	209	249	233
MG	81	870	208	0	234	139	299	852	0	291	311	312
MG	81	310	126	0	234	49	249	833	0	197	239	221
MG	81	385	137	0	234	61	255	836	0	209	249	233
MG	80	385	137	0	234	61	255	836	0	209	249	233
			148	0	117	67	181	1529	329	210	216	236
MGB	80	500	153	145	117	73	184	1529	329	216	220	239
MGB	80	250	116	145	117	36	162	1529	329	176	193	200
MGB	80	805	198	145	117	117	211	1529	329	265	253	286
MGB	80	500	153	145	117	73	184	1529	329	216	220	239
MGB	80	250	116	145	117	36	162	1529	329	176	193	200
MGB	80	1110	242	145	117	161	238	1529	329	314	285	333
MGB	80	500	153	145	117	73	184	1529	329	216	220	239
			148	145	117	67	181	1529	329	210	216	233
MG	130	535	412	0	526	225	409	1380	0	291	547	330
MG	131	535	412	0	940	225	409	1380	0	291	547	330
MG	130	285	317	0	526	120	374	1298	0	149	481	185
MG	130	845	531	0	526	356	453	1482	0	466	629	510
MG	131	521	407	0	940	219	407	1376	0	283	543	322
MG	131	831	525	0	940	350	451	1478	0	459	625	502
MG	130	285	317	0	526	120	374	1298	0	149	481	185
MG	131	831	525	0	940	350	451	1478	0	459	625	502
MG	131	845	531	0	940	356	453	1482	0	466	629	510
MG	130	535	412	0	526	225	409	1380	0	291	547	330
MG	131	285	317	0	940	120	374	1298	0	149	481	185
MG	131	1131	640	0	940	476	493	1576	0	628	704	676
MG	131	285	317	0	940	120	374	1298	0	149	481	185
			428	0	730	242	415	1394	0	314	557	354

MGB	130	535	411	169	524	205	408	1699	1565	275	457	296
MGB	131	831	523	169	937	319	450	1699	2800	434	522	450
MGB	131	535	411	169	937	205	408	1699	2800	275	457	296
MGB	130	285	316	169	524	109	373	1699	1565	141	401	166
MGB	130	845	529	169	524	325	451	1699	1565	441	525	457
MGB	131	845	529	169	937	325	451	1699	2800	441	525	457
MGB	131	521	406	169	937	200	406	1699	2800	268	454	289
MGB	131	1131	637	169	937	434	492	1699	2800	594	588	605
			454	169	748	249	424	1699	2233	336	481	354

Table 3.33: Adjusted times for inefficiencies.

COSTS BASED ON HISTORICAL TIMES								
TYPE	D [mm]	L [mm]	CUT [s]	WASH [s]	ASSEMBLY [s]	BRASS-WELD [s]	BORE [s]	QUALITY CONTROL [s]
MGE	60	260	2	€ 9,17	€ 36,30	€ 2,00	€ 47,47	€ 56,02
MGE	60	140	2	€ 8,70	€ 45,47	€ 2,00	€ 56,17	€ 66,29
MGE	60	260	1	€ 10,15	€ 51,96	€ 2,00	€ 64,10	€ 75,64
MGE	54	255	1	€ 8,35	€ 47,37	€ 2,00	€ 57,72	€ 68,11
MGC	60	190	2	€ 8,10	€ 48,01	€ 2,00	€ 58,11	€ 68,57
MGE	60	440	1	€ 9,86	€ 56,79	€ 3,00	€ 69,66	€ 82,19
MGC	60	90	2	€ 7,74	€ 40,60	€ 2,00	€ 50,34	€ 59,40
MG	54	150	1	€ 8,19	€ 43,72	€ 1,50	€ 53,41	€ 63,02
MGE	60	440	2	€ 9,86	€ 57,09	€ 3,00	€ 69,95	€ 82,54
MG	80	310	4	€ 7,89	€ 85,08	€ 4,20	€ 97,17	€ 114,66
MG	80	150	4	€ 7,18	€ 77,83	€ 3,00	€ 88,00	€ 103,84
MG	80	560	4	€ 9,13	€ 96,83	€ 6,10	€ 112,05	€ 132,22
MG	80	385	4	€ 8,25	€ 86,47	€ 4,80	€ 99,51	€ 117,43
MG	81	560	4	€ 9,07	€ 112,15	€ 6,20	€ 127,42	€ 150,36
MG	81	715	4	€ 9,77	€ 120,17	€ 7,40	€ 137,34	€ 162,06
MG	80	870	4	€ 11,53	€ 110,54	€ 8,40	€ 130,46	€ 153,95
MG	81	310	4	€ 7,93	€ 101,10	€ 4,30	€ 113,32	€ 133,72
MG	80	715	4	€ 9,82	€ 103,30	€ 7,20	€ 120,32	€ 141,97
MG	80	150	1	€ 7,23	€ 90,04	€ 7,00	€ 104,27	€ 123,04
MG	81	560	1	€ 9,13	€ 119,16	€ 6,20	€ 134,49	€ 158,70
MG	81	385	4	€ 8,29	€ 105,95	€ 4,90	€ 119,13	€ 140,58
MG	80	310	1	€ 7,98	€ 97,62	€ 8,20	€ 113,79	€ 134,27
MG	80	150	2	€ 7,18	€ 81,31	€ 3,00	€ 91,48	€ 107,95
MG	80	715	2	€ 9,82	€ 106,51	€ 7,20	€ 123,53	€ 145,77
MG	80	1155	4	€ 12,81	€ 124,87	€ 10,50	€ 148,18	€ 174,85
MG	80	150	1	€ 7,18	€ 84,93	€ 3,00	€ 95,10	€ 112,22
MG	80	385	1	€ 8,31	€ 99,61	€ 8,80	€ 116,72	€ 137,73
MG	81	870	4	€ 11,47	€ 123,16	€ 8,50	€ 143,12	€ 168,88
MG	81	310	1	€ 8,02	€ 107,40	€ 4,30	€ 119,71	€ 141,26
MG	81	385	1	€ 8,35	€ 111,76	€ 4,90	€ 125,01	€ 147,51
MG	80	385	2	€ 8,25	€ 91,05	€ 4,80	€ 104,10	€ 122,84
MGB	80	500	4	€ 14,11	€ 72,47	€ 5,60	€ 92,18	€ 108,77
MGB	80	250	4	€ 13,50	€ 60,36	€ 3,70	€ 77,56	€ 91,52
MGB	80	805	4	€ 14,82	€ 89,78	€ 7,80	€ 112,40	€ 132,63
MGB	80	500	4	€ 14,82	€ 139,62	€ 0,00	€ 154,43	€ 182,23
MGB	80	250	4	€ 14,70	€ 123,67	€ 0,00	€ 138,37	€ 163,28
MGB	80	1110	4	€ 14,70	€ 99,53	€ 0,00	€ 114,23	€ 134,79
MGB	80	500	1	€ 14,70	€ 146,35	€ 0,00	€ 161,05	€ 190,04
MG	130	535	4	€ 12,66	€ 237,81	€ 10,49	€ 260,95	€ 307,92
MG	131	535	4	€ 17,16	€ 228,39	€ 11,21	€ 256,76	€ 302,98

MG	130	285	4	€ 11,60	€ 208,69	€ 7,39	€ 227,68	€ 268,66
MG	130	845	4	€ 16,27	€ 255,32	€ 14,24	€ 285,82	€ 337,27
MG	131	521	4	€ 17,08	€ 241,97	€ 10,41	€ 269,46	€ 317,96
MG	131	831	4	€ 19,93	€ 270,21	€ 14,81	€ 304,94	€ 359,83
MG	130	285	1	€ 11,60	€ 192,01	€ 7,39	€ 210,99	€ 248,97
MG	131	831	1	€ 20,74	€ 300,58	€ 14,81	€ 336,12	€ 396,63
MG	131	845	4	€ 20,31	€ 262,32	€ 15,01	€ 297,64	€ 351,21
MG	130	535	1	€ 13,46	€ 228,25	€ 10,79	€ 252,49	€ 297,94
MG	131	285	4	€ 14,25	€ 190,13	€ 8,11	€ 212,49	€ 250,73
MG	131	1131	4	€ 23,67	€ 302,15	€ 18,56	€ 344,37	€ 406,36
MG	131	285	2	€ 14,25	€ 189,13	€ 8,11	€ 211,49	€ 249,55
MGB	130	535	4	€ 28,58	€ 162,34	€ 10,00	€ 200,93	€ 237,09
MGB	131	831	4	€ 46,07	€ 207,69	€ 13,40	€ 267,15	€ 315,24
MGB	131	535	4	€ 45,13	€ 160,30	€ 9,80	€ 215,23	€ 253,98
MGB	130	285	4	€ 27,56	€ 139,55	€ 7,00	€ 174,11	€ 205,45
MGB	130	845	4	€ 30,76	€ 206,40	€ 13,70	€ 250,86	€ 296,01
MGB	131	845	4	€ 45,62	€ 192,98	€ 13,60	€ 252,20	€ 297,59
MGB	131	521	4	€ 40,51	€ 159,47	€ 9,60	€ 209,58	€ 247,30
MGB	131	1131	4	€ 45,62	€ 223,71	€ 17,00	€ 286,33	€ 337,87

Table 3.44: Costs and profits based on historical data.

COSTS BASED ON ESTIMATED TIMES								
TYPE	D [mm]	L [mm]	CUT [s]	WASH [s]	ASSEMBLY [s]	BRASS-WELD [s]	BORE [s]	QUALITY CONTROL [s]
MGE	60	260	2	€ 7,81	€ 36,30	€ 2,00	€ 46,11	€ 54,41
MGE	60	140	2	€ 7,58	€ 45,47	€ 2,00	€ 55,05	€ 64,96
MGE	60	260	1	€ 7,81	€ 51,96	€ 2,00	€ 61,77	€ 72,89
MGE	54	255	1	€ 7,74	€ 47,37	€ 2,00	€ 57,11	€ 67,39
MGC	60	190	2	€ 7,68	€ 48,01	€ 2,00	€ 57,68	€ 68,07
MGE	60	440	1	€ 8,16	€ 56,79	€ 3,00	€ 67,95	€ 80,19
MGC	60	90	2	€ 7,48	€ 40,60	€ 2,00	€ 50,08	€ 59,10
MG	54	150	1	€ 7,54	€ 43,72	€ 1,50	€ 52,76	€ 62,26
MGE	60	440	2	€ 8,16	€ 57,09	€ 3,00	€ 68,25	€ 80,53
MG	80	310	4	€ 10,02	€ 85,08	€ 4,20	€ 99,29	€ 117,17
MG	80	150	4	€ 9,35	€ 77,83	€ 3,00	€ 90,18	€ 106,41
MG	80	560	4	€ 11,05	€ 96,83	€ 6,10	€ 113,98	€ 134,49
MG	80	385	4	€ 10,33	€ 86,47	€ 4,80	€ 101,59	€ 119,88
MG	81	560	4	€ 11,05	€ 112,15	€ 6,20	€ 129,40	€ 152,70
MG	81	715	4	€ 11,70	€ 120,17	€ 7,40	€ 139,27	€ 164,33
MG	80	870	4	€ 12,34	€ 110,54	€ 8,40	€ 131,28	€ 154,91
MG	81	310	4	€ 10,02	€ 101,10	€ 4,30	€ 115,41	€ 136,19
MG	80	715	4	€ 11,70	€ 103,30	€ 7,20	€ 122,19	€ 144,19
MG	80	150	1	€ 9,35	€ 90,04	€ 7,00	€ 106,39	€ 125,54
MG	81	560	1	€ 11,05	€ 119,16	€ 6,20	€ 136,41	€ 160,96
MG	81	385	4	€ 10,33	€ 105,95	€ 4,90	€ 121,17	€ 142,98
MG	80	310	1	€ 10,02	€ 97,62	€ 8,20	€ 115,83	€ 136,68
MG	80	150	2	€ 9,35	€ 81,31	€ 3,00	€ 93,66	€ 110,52
MG	80	715	2	€ 11,70	€ 106,51	€ 7,20	€ 125,41	€ 147,98
MG	80	1155	4	€ 13,53	€ 124,87	€ 10,50	€ 148,90	€ 175,70
MG	80	150	1	€ 9,35	€ 84,93	€ 3,00	€ 97,28	€ 114,79
MG	80	385	1	€ 10,33	€ 99,61	€ 8,80	€ 118,74	€ 140,11
MG	81	870	4	€ 12,34	€ 123,16	€ 8,50	€ 143,99	€ 169,91
MG	81	310	1	€ 10,02	€ 107,40	€ 4,30	€ 121,71	€ 143,62
MG	81	385	1	€ 10,33	€ 111,76	€ 4,90	€ 126,98	€ 149,84
MG	80	385	2	€ 10,33	€ 91,05	€ 4,80	€ 106,18	€ 125,29
MGB	80	500	4	€ 15,49	€ 72,47	€ 5,60	€ 93,57	€ 110,41

MGB	80	250	4	€ 14,49	€ 60,36	€ 3,70	€ 78,56	€ 92,70
MGB	80	805	4	€ 16,72	€ 89,78	€ 7,80	€ 114,30	€ 134,87
MGB	80	500	4	€ 15,49	€ 139,62	€ 0,00	€ 155,11	€ 183,03
MGB	80	250	4	€ 14,49	€ 123,67	€ 0,00	€ 138,16	€ 163,03
MGB	80	1110	4	€ 17,94	€ 99,53	€ 0,00	€ 117,47	€ 138,61
MGB	80	500	1	€ 15,49	€ 146,35	€ 0,00	€ 161,85	€ 190,98
MG	130	535	4	€ 19,26	€ 237,81	€ 10,49	€ 267,55	€ 315,71
MG	131	535	4	€ 21,50	€ 228,39	€ 11,21	€ 261,10	€ 308,10
MG	130	285	4	€ 16,16	€ 208,69	€ 7,39	€ 232,24	€ 274,04
MG	130	845	4	€ 23,09	€ 255,32	€ 14,24	€ 292,65	€ 345,32
MG	131	521	4	€ 21,33	€ 241,97	€ 10,41	€ 273,71	€ 322,97
MG	131	831	4	€ 25,16	€ 270,21	€ 14,81	€ 310,18	€ 366,01
MG	130	285	1	€ 16,16	€ 192,01	€ 7,39	€ 215,56	€ 254,36
MG	131	831	1	€ 25,16	€ 300,58	€ 14,81	€ 340,55	€ 401,85
MG	131	845	4	€ 25,34	€ 262,32	€ 15,01	€ 302,67	€ 357,15
MG	130	535	1	€ 19,26	€ 228,25	€ 10,79	€ 258,29	€ 304,79
MG	131	285	4	€ 18,41	€ 190,13	€ 8,11	€ 216,65	€ 255,65
MG	131	1131	4	€ 28,87	€ 302,15	€ 18,56	€ 349,58	€ 412,50
MG	131	285	2	€ 18,41	€ 189,13	€ 8,11	€ 215,65	€ 254,47
MGB	130	535	4	€ 29,70	€ 162,34	€ 10,00	€ 202,05	€ 238,41
MGB	131	831	4	€ 41,44	€ 207,69	€ 13,40	€ 262,52	€ 309,78
MGB	131	535	4	€ 38,22	€ 160,30	€ 9,80	€ 208,32	€ 245,82
MGB	130	285	4	€ 26,98	€ 139,55	€ 7,00	€ 173,53	€ 204,77
MGB	130	845	4	€ 33,08	€ 206,40	€ 13,70	€ 253,17	€ 298,74
MGB	131	845	4	€ 41,59	€ 192,98	€ 13,60	€ 248,17	€ 292,84
MGB	131	521	4	€ 38,06	€ 159,47	€ 9,60	€ 207,14	€ 244,42
MGB	131	1131	4	€ 44,70	€ 223,71	€ 17,00	€ 285,41	€ 336,79

Table 3.45: Costs and profits based on calculated and interpolated times.

COSTS BASED ON ADJUSTED TIMES								
TYPE	D [mm]	L [mm]	Nr PAS.	WORKER COSTS	RAW MATERIAL COST	PAINT	OPERATIVE COST	TOTAL COST
MGE	60	260	2	€ 10,10	€ 36,51	€ 2,00	€ 48,60	€ 57,35
MGE	60	140	2	€ 9,81	€ 45,73	€ 2,00	€ 57,53	€ 67,89
MGE	60	260	1	€ 10,08	€ 52,25	€ 2,00	€ 64,32	€ 75,90
MGE	54	255	1	€ 10,06	€ 47,64	€ 2,00	€ 59,69	€ 70,44
MGC	60	190	2	€ 9,84	€ 48,28	€ 2,00	€ 60,12	€ 70,94
MGE	60	440	1	€ 10,51	€ 57,11	€ 3,00	€ 70,63	€ 83,34
MGC	60	90	2	€ 9,67	€ 40,83	€ 2,00	€ 52,50	€ 61,95
MG	54	150	1	€ 9,74	€ 43,97	€ 1,50	€ 55,21	€ 65,15
MGE	60	440	2	€ 10,52	€ 57,41	€ 3,00	€ 70,93	€ 83,69
MG	80	310	4	€ 12,88	€ 85,56	€ 4,20	€ 102,64	€ 121,11
MG	80	150	4	€ 12,03	€ 78,27	€ 3,00	€ 93,29	€ 110,09
MG	80	560	4	€ 14,22	€ 97,37	€ 6,10	€ 117,68	€ 138,86
MG	80	385	4	€ 13,28	€ 86,95	€ 4,80	€ 105,03	€ 123,94
MG	81	560	4	€ 14,22	€ 112,78	€ 6,20	€ 133,20	€ 157,17
MG	81	715	4	€ 15,04	€ 120,84	€ 7,40	€ 143,28	€ 169,08
MG	80	870	4	€ 15,87	€ 111,16	€ 8,40	€ 135,43	€ 159,80
MG	81	310	4	€ 12,88	€ 101,67	€ 4,30	€ 118,85	€ 140,24
MG	80	715	4	€ 15,04	€ 103,88	€ 7,20	€ 126,12	€ 148,82
MG	80	150	1	€ 12,03	€ 90,54	€ 7,00	€ 109,57	€ 129,29
MG	81	560	1	€ 14,22	€ 119,83	€ 6,20	€ 140,24	€ 165,48
MG	81	385	4	€ 13,28	€ 106,54	€ 4,90	€ 124,72	€ 147,17
MG	80	310	1	€ 12,88	€ 98,16	€ 8,20	€ 119,25	€ 140,71
MG	80	150	2	€ 12,03	€ 81,77	€ 3,00	€ 96,79	€ 114,22
MG	80	715	2	€ 15,04	€ 107,11	€ 7,20	€ 129,35	€ 152,63

MG	80	1155	4	€ 17,39	€ 125,57	€ 10,50	€ 153,46	€ 181,08
MG	80	150	1	€ 12,03	€ 85,41	€ 3,00	€ 100,43	€ 118,51
MG	80	385	1	€ 13,28	€ 100,17	€ 8,80	€ 122,25	€ 144,26
MG	81	870	4	€ 15,87	€ 123,84	€ 8,50	€ 148,21	€ 174,89
MG	81	310	1	€ 12,88	€ 108,00	€ 4,30	€ 125,18	€ 147,72
MG	81	385	1	€ 13,28	€ 112,39	€ 4,90	€ 130,57	€ 154,07
MG	80	385	2	€ 13,28	€ 91,56	€ 4,80	€ 109,64	€ 129,38
MGB	80	500	4	€ 19,23	€ 72,88	€ 5,60	€ 97,70	€ 115,29
MGB	80	250	4	€ 18,03	€ 60,70	€ 3,70	€ 82,42	€ 97,26
MGB	80	805	4	€ 20,69	€ 90,28	€ 7,80	€ 118,78	€ 140,16
MGB	80	500	4	€ 19,23	€ 140,40	€ 0,00	€ 159,62	€ 188,36
MGB	80	250	4	€ 18,03	€ 124,36	€ 0,00	€ 142,38	€ 168,01
MGB	80	1110	4	€ 22,16	€ 100,09	€ 0,00	€ 122,25	€ 144,25
MGB	80	500	1	€ 19,23	€ 147,17	€ 0,00	€ 166,40	€ 196,35
MG	130	535	4	€ 24,73	€ 239,14	€ 10,49	€ 274,35	€ 323,73
MG	131	535	4	€ 27,22	€ 229,67	€ 11,21	€ 268,09	€ 316,35
MG	130	285	4	€ 20,70	€ 209,86	€ 7,39	€ 237,95	€ 280,78
MG	130	845	4	€ 29,72	€ 256,75	€ 14,24	€ 300,70	€ 354,83
MG	131	521	4	€ 26,99	€ 243,32	€ 10,41	€ 280,72	€ 331,25
MG	131	831	4	€ 31,98	€ 271,72	€ 14,81	€ 318,50	€ 375,83
MG	130	285	1	€ 20,70	€ 193,08	€ 7,39	€ 221,17	€ 260,98
MG	131	831	1	€ 31,98	€ 302,26	€ 14,81	€ 349,05	€ 411,88
MG	131	845	4	€ 32,21	€ 263,79	€ 15,01	€ 311,00	€ 366,98
MG	130	535	1	€ 24,73	€ 229,53	€ 10,79	€ 265,04	€ 312,75
MG	131	285	4	€ 23,19	€ 191,19	€ 8,11	€ 222,49	€ 262,54
MG	131	1131	4	€ 36,81	€ 303,84	€ 18,56	€ 359,20	€ 423,86
MG	131	285	2	€ 23,19	€ 190,19	€ 8,11	€ 221,49	€ 261,36
MGB	130	535	4	€ 36,05	€ 163,25	€ 10,00	€ 209,30	€ 246,97
MGB	131	831	4	€ 49,81	€ 208,85	€ 13,40	€ 272,06	€ 321,03
MGB	131	535	4	€ 45,94	€ 161,20	€ 9,80	€ 216,94	€ 255,99
MGB	130	285	4	€ 32,78	€ 140,33	€ 7,00	€ 180,11	€ 212,53
MGB	130	845	4	€ 40,10	€ 207,55	€ 13,70	€ 261,35	€ 308,40
MGB	131	845	4	€ 50,00	€ 194,06	€ 13,60	€ 257,65	€ 304,03
MGB	131	521	4	€ 45,76	€ 160,36	€ 9,60	€ 215,72	€ 254,55
MGB	131	1131	4	€ 53,74	€ 224,96	€ 17,00	€ 295,70	€ 348,93

Table 3.46: Costs and profits based on adjusted times.

PROFITS AND MARGINS BASED ON HISTORICAL TIMES							
TYPE	D [mm]	L [mm]	OPERATIVE COST	TOTAL COST	PRICE	PROFIT	MARGIN
MGE	60	260	€ 47,47	€ 56,02	€ 148,32	€ 92,30	62,23%
MGE	60	140	€ 56,17	€ 66,29	€ 127,72	€ 61,43	48,10%
MGE	60	260	€ 64,10	€ 75,64	€ 153,47	€ 77,83	50,71%
MGE	54	255	€ 57,72	€ 68,11	€ 226,60	€ 158,49	69,94%
MGC	60	190	€ 58,11	€ 68,57	€ 135,96	€ 67,39	49,57%
MGE	60	440	€ 69,66	€ 82,19	€ 193,64	€ 111,45	57,55%
MGC	60	90	€ 50,34	€ 59,40	€ 115,36	€ 55,96	48,51%
MG	54	150	€ 53,41	€ 63,02	€ 196,73	€ 133,71	67,96%
MGE	60	440	€ 69,95	€ 82,54	€ 182,31	€ 99,77	54,72%
MG	80	310	€ 97,17	€ 114,66	€ 323,42	€ 208,76	64,55%
MG	80	150	€ 88,00	€ 103,84	€ 298,70	€ 194,86	65,23%
MG	80	560	€ 112,05	€ 132,22	€ 376,98	€ 244,76	64,93%
MG	80	385	€ 99,51	€ 117,43	€ 339,90	€ 222,47	65,45%
MG	81	560	€ 127,42	€ 150,36	€ 396,55	€ 246,19	62,08%
MG	81	715	€ 137,34	€ 162,06	€ 430,54	€ 268,48	62,36%
MG	80	870	€ 130,46	€ 153,95	€ 428,48	€ 274,53	64,07%

MG	81	310	€ 113,32	€ 133,72	€ 349,17	€ 215,45	61,70%
MG	80	715	€ 120,32	€ 141,97	€ 394,49	€ 252,52	64,01%
MG	80	150	€ 104,27	€ 123,04	€ 356,38	€ 233,34	65,48%
MG	81	560	€ 134,49	€ 158,70	€ 510,88	€ 352,18	68,94%
MG	81	385	€ 119,13	€ 140,58	€ 361,53	€ 220,95	61,12%
MG	80	310	€ 113,79	€ 134,27	€ 410,97	€ 276,70	67,33%
MG	80	150	€ 91,48	€ 107,95	€ 298,70	€ 190,75	63,86%
MG	80	715	€ 123,53	€ 145,77	€ 394,49	€ 248,72	63,05%
MG	80	1155	€ 148,18	€ 174,85	€ 499,55	€ 324,70	65,00%
MG	80	150	€ 95,10	€ 112,22	€ 298,70	€ 186,48	62,43%
MG	80	385	€ 116,72	€ 137,73	€ 439,81	€ 302,08	68,68%
MG	81	870	€ 143,12	€ 168,88	€ 451,14	€ 282,26	62,57%
MG	81	310	€ 119,71	€ 141,26	€ 410,97	€ 269,71	65,63%
MG	81	385	€ 125,01	€ 147,51	€ 439,81	€ 292,30	66,46%
MG	80	385	€ 104,10	€ 122,84	€ 339,90	€ 217,06	63,86%
MGB	80	500	€ 92,18	€ 108,77	€ 303,85	€ 195,08	64,20%
MGB	80	250	€ 77,56	€ 91,52	€ 259,56	€ 168,04	64,74%
MGB	80	805	€ 112,40	€ 132,63	€ 636,59	€ 503,96	79,17%
MGB	80	500	€ 154,43	€ 182,23	€ 641,69	€ 459,46	71,60%
MGB	80	250	€ 138,37	€ 163,28	€ 551,05	€ 387,77	70,37%
MGB	80	1110	€ 114,23	€ 134,79	€ 414,06	€ 279,27	67,45%
MGB	80	500	€ 161,05	€ 190,04	€ 641,69	€ 451,65	70,38%
MG	130	535	€ 260,95	€ 307,92	€ 768,38	€ 460,46	59,93%
MG	131	535	€ 256,76	€ 302,98	€ 819,88	€ 516,90	63,05%
MG	130	285	€ 227,68	€ 268,66	€ 676,71	€ 408,05	60,30%
MG	130	845	€ 285,82	€ 337,27	€ 911,55	€ 574,28	63,00%
MG	131	521	€ 269,46	€ 317,96	€ 819,88	€ 501,92	61,22%
MG	131	831	€ 304,94	€ 359,83	€ 939,36	€ 579,53	61,69%
MG	130	285	€ 210,99	€ 248,97	€ 676,71	€ 427,74	63,21%
MG	131	831	€ 336,12	€ 396,63	€ 1.236,00	€ 839,37	67,91%
MG	131	845	€ 297,64	€ 351,21	€ 939,36	€ 588,15	62,61%
MG	130	535	€ 252,49	€ 297,94	€ 844,60	€ 546,66	64,72%
MG	131	285	€ 212,49	€ 250,73	€ 646,84	€ 396,11	61,24%
MG	131	1131	€ 344,37	€ 406,36	€ 1.452,30	€ 1.045,94	72,02%
MG	131	285	€ 211,49	€ 249,55	€ 646,84	€ 397,29	61,42%
MGB	130	535	€ 200,93	€ 237,09	€ 663,32	€ 426,23	64,26%
MGB	131	831	€ 267,15	€ 315,24	€ 901,25	€ 586,01	65,02%
MGB	131	535	€ 215,23	€ 253,98	€ 732,33	€ 478,35	65,32%
MGB	130	285	€ 174,11	€ 205,45	€ 556,20	€ 350,75	63,06%
MGB	130	845	€ 250,86	€ 296,01	€ 827,09	€ 531,08	64,21%
MGB	131	845	€ 252,20	€ 297,59	€ 949,66	€ 652,07	68,66%
MGB	131	521	€ 209,58	€ 247,30	€ 721,00	€ 473,70	65,70%
MGB	131	1131	€ 286,33	€ 337,87	€ 1.004,25	€ 666,38	66,36%

Table 3.48: Profits and margins based on historical times.

PROFIT AND MARGINS BASED ON ESTIMATED TIMES							
TYPE	D [mm]	L [mm]	OPERATIVE COST	TOTAL COST	PRICE	PROFIT	MARGIN
MGE	60	260	€ 46,11	€ 54,41	€ 148,32	€ 93,91	63,31%
MGE	60	140	€ 55,05	€ 64,96	€ 127,72	€ 62,76	49,14%
MGE	60	260	€ 61,77	€ 72,89	€ 153,47	€ 80,58	52,51%
MGE	54	255	€ 57,11	€ 67,39	€ 226,60	€ 159,21	70,26%
MGC	60	190	€ 57,68	€ 68,07	€ 135,96	€ 67,89	49,94%
MGE	60	440	€ 67,95	€ 80,19	€ 193,64	€ 113,45	58,59%
MGC	60	90	€ 50,08	€ 59,10	€ 115,36	€ 56,26	48,77%

MG	54	150	€ 52,76	€ 62,26	€ 196,73	€ 134,47	68,35%
MGE	60	440	€ 68,25	€ 80,53	€ 182,31	€ 101,78	55,83%
MG	80	310	€ 99,29	€ 117,17	€ 323,42	€ 206,25	63,77%
MG	80	150	€ 90,18	€ 106,41	€ 298,70	€ 192,29	64,38%
MG	80	560	€ 113,98	€ 134,49	€ 376,98	€ 242,49	64,32%
MG	80	385	€ 101,59	€ 119,88	€ 339,90	€ 220,02	64,73%
MG	81	560	€ 129,40	€ 152,70	€ 396,55	€ 243,85	61,49%
MG	81	715	€ 139,27	€ 164,33	€ 430,54	€ 266,21	61,83%
MG	80	870	€ 131,28	€ 154,91	€ 428,48	€ 273,57	63,85%
MG	81	310	€ 115,41	€ 136,19	€ 349,17	€ 212,98	61,00%
MG	80	715	€ 122,19	€ 144,19	€ 394,49	€ 250,30	63,45%
MG	80	150	€ 106,39	€ 125,54	€ 356,38	€ 230,84	64,77%
MG	81	560	€ 136,41	€ 160,96	€ 510,88	€ 349,92	68,49%
MG	81	385	€ 121,17	€ 142,98	€ 361,53	€ 218,55	60,45%
MG	80	310	€ 115,83	€ 136,68	€ 410,97	€ 274,29	66,74%
MG	80	150	€ 93,66	€ 110,52	€ 298,70	€ 188,18	63,00%
MG	80	715	€ 125,41	€ 147,98	€ 394,49	€ 246,51	62,49%
MG	80	1155	€ 148,90	€ 175,70	€ 499,55	€ 323,85	64,83%
MG	80	150	€ 97,28	€ 114,79	€ 298,70	€ 183,91	61,57%
MG	80	385	€ 118,74	€ 140,11	€ 439,81	€ 299,70	68,14%
MG	81	870	€ 143,99	€ 169,91	€ 451,14	€ 281,23	62,34%
MG	81	310	€ 121,71	€ 143,62	€ 410,97	€ 267,35	65,05%
MG	81	385	€ 126,98	€ 149,84	€ 439,81	€ 289,97	65,93%
MG	80	385	€ 106,18	€ 125,29	€ 339,90	€ 214,61	63,14%
MGB	80	500	€ 93,57	€ 110,41	€ 303,85	€ 193,44	63,66%
MGB	80	250	€ 78,56	€ 92,70	€ 259,56	€ 166,86	64,29%
MGB	80	805	€ 114,30	€ 134,87	€ 636,59	€ 501,72	78,81%
MGB	80	500	€ 155,11	€ 183,03	€ 641,69	€ 458,66	71,48%
MGB	80	250	€ 138,16	€ 163,03	€ 551,05	€ 388,02	70,41%
MGB	80	1110	€ 117,47	€ 138,61	€ 414,06	€ 275,45	66,52%
MGB	80	500	€ 161,85	€ 190,98	€ 641,69	€ 450,71	70,24%
MG	130	535	€ 267,55	€ 315,71	€ 768,38	€ 452,67	58,91%
MG	131	535	€ 261,10	€ 308,10	€ 819,88	€ 511,78	62,42%
MG	130	285	€ 232,24	€ 274,04	€ 676,71	€ 402,67	59,50%
MG	130	845	€ 292,65	€ 345,32	€ 911,55	€ 566,23	62,12%
MG	131	521	€ 273,71	€ 322,97	€ 819,88	€ 496,91	60,61%
MG	131	831	€ 310,18	€ 366,01	€ 939,36	€ 573,35	61,04%
MG	130	285	€ 215,56	€ 254,36	€ 676,71	€ 422,35	62,41%
MG	131	831	€ 340,55	€ 401,85	€ 1.236,00	€ 834,15	67,49%
MG	131	845	€ 302,67	€ 357,15	€ 939,36	€ 582,21	61,98%
MG	130	535	€ 258,29	€ 304,79	€ 844,60	€ 539,81	63,91%
MG	131	285	€ 216,65	€ 255,65	€ 646,84	€ 391,19	60,48%
MG	131	1131	€ 349,58	€ 412,50	€ 1.452,30	€ 1.039,80	71,60%
MG	131	285	€ 215,65	€ 254,47	€ 646,84	€ 392,37	60,66%
MGB	130	535	€ 202,05	€ 238,41	€ 663,32	€ 424,91	64,06%
MGB	131	831	€ 262,52	€ 309,78	€ 901,25	€ 591,47	65,63%
MGB	131	535	€ 208,32	€ 245,82	€ 732,33	€ 486,51	66,43%
MGB	130	285	€ 173,53	€ 204,77	€ 556,20	€ 351,43	63,18%
MGB	130	845	€ 253,17	€ 298,74	€ 827,09	€ 528,35	63,88%
MGB	131	845	€ 248,17	€ 292,84	€ 949,66	€ 656,82	69,16%
MGB	131	521	€ 207,14	€ 244,42	€ 721,00	€ 476,58	66,10%
MGB	131	1131	€ 285,41	€ 336,79	€ 1.004,25	€ 667,46	66,46%

Table 3.49: Profit and margins based on estimated times.

PROFIT AND MARGINS BASED ON ADJUSTED TIMES							
TYPE	D [mm]	L [mm]	OPERATIVE COST	TOTAL COST	PRICE	PROFIT	MARGIN
MGE	60	260	€ 48,60	€ 57,35	€ 148,32	€ 90,97	61,33%
MGE	60	140	€ 57,53	€ 67,89	€ 127,72	€ 59,83	46,85%
MGE	60	260	€ 64,32	€ 75,90	€ 153,47	€ 77,57	50,54%
MGE	54	255	€ 59,69	€ 70,44	€ 226,60	€ 156,16	68,91%
MGC	60	190	€ 60,12	€ 70,94	€ 135,96	€ 65,02	47,83%
MGE	60	440	€ 70,63	€ 83,34	€ 193,64	€ 110,30	56,96%
MGC	60	90	€ 52,50	€ 61,95	€ 115,36	€ 53,41	46,30%
MG	54	150	€ 55,21	€ 65,15	€ 196,73	€ 131,58	66,89%
MGE	60	440	€ 70,93	€ 83,69	€ 182,31	€ 98,62	54,09%
MG	80	310	€ 102,64	€ 121,11	€ 323,42	€ 202,31	62,55%
MG	80	150	€ 93,29	€ 110,09	€ 298,70	€ 188,61	63,14%
MG	80	560	€ 117,68	€ 138,86	€ 376,98	€ 238,12	63,16%
MG	80	385	€ 105,03	€ 123,94	€ 339,90	€ 215,96	63,54%
MG	81	560	€ 133,20	€ 157,17	€ 396,55	€ 239,38	60,37%
MG	81	715	€ 143,28	€ 169,08	€ 430,54	€ 261,46	60,73%
MG	80	870	€ 135,43	€ 159,80	€ 428,48	€ 268,68	62,70%
MG	81	310	€ 118,85	€ 140,24	€ 349,17	€ 208,93	59,84%
MG	80	715	€ 126,12	€ 148,82	€ 394,49	€ 245,67	62,28%
MG	80	150	€ 109,57	€ 129,29	€ 356,38	€ 227,09	63,72%
MG	81	560	€ 140,24	€ 165,48	€ 510,88	€ 345,40	67,61%
MG	81	385	€ 124,72	€ 147,17	€ 361,53	€ 214,36	59,29%
MG	80	310	€ 119,25	€ 140,71	€ 410,97	€ 270,26	65,76%
MG	80	150	€ 96,79	€ 114,22	€ 298,70	€ 184,48	61,76%
MG	80	715	€ 129,35	€ 152,63	€ 394,49	€ 241,86	61,31%
MG	80	1155	€ 153,46	€ 181,08	€ 499,55	€ 318,47	63,75%
MG	80	150	€ 100,43	€ 118,51	€ 298,70	€ 180,19	60,32%
MG	80	385	€ 122,25	€ 144,26	€ 439,81	€ 295,55	67,20%
MG	81	870	€ 148,21	€ 174,89	€ 451,14	€ 276,25	61,23%
MG	81	310	€ 125,18	€ 147,72	€ 410,97	€ 263,25	64,06%
MG	81	385	€ 130,57	€ 154,07	€ 439,81	€ 285,74	64,97%
MG	80	385	€ 109,64	€ 129,38	€ 339,90	€ 210,52	61,94%
MGB	80	500	€ 97,70	€ 115,29	€ 303,85	€ 188,56	62,06%
MGB	80	250	€ 82,42	€ 97,26	€ 259,56	€ 162,30	62,53%
MGB	80	805	€ 118,78	€ 140,16	€ 636,59	€ 496,43	77,98%
MGB	80	500	€ 159,62	€ 188,36	€ 641,69	€ 453,33	70,65%
MGB	80	250	€ 142,38	€ 168,01	€ 551,05	€ 383,04	69,51%
MGB	80	1110	€ 122,25	€ 144,25	€ 414,06	€ 269,81	65,16%
MGB	80	500	€ 166,40	€ 196,35	€ 641,69	€ 445,34	69,40%
MG	130	535	€ 274,35	€ 323,73	€ 768,38	€ 444,65	57,87%
MG	131	535	€ 268,09	€ 316,35	€ 819,88	€ 503,53	61,42%
MG	130	285	€ 237,95	€ 280,78	€ 676,71	€ 395,93	58,51%
MG	130	845	€ 300,70	€ 354,83	€ 911,55	€ 556,72	61,07%
MG	131	521	€ 280,72	€ 331,25	€ 819,88	€ 488,63	59,60%
MG	131	831	€ 318,50	€ 375,83	€ 939,36	€ 563,53	59,99%
MG	130	285	€ 221,17	€ 260,98	€ 676,71	€ 415,73	61,43%
MG	131	831	€ 349,05	€ 411,88	€ 1.236,00	€ 824,12	66,68%
MG	131	845	€ 311,00	€ 366,98	€ 939,36	€ 572,38	60,93%
MG	130	535	€ 265,04	€ 312,75	€ 844,60	€ 531,85	62,97%
MG	131	285	€ 222,49	€ 262,54	€ 646,84	€ 384,30	59,41%
MG	131	1131	€ 359,20	€ 423,86	€ 1.452,30	€ 1.028,44	70,81%
MG	131	285	€ 221,49	€ 261,36	€ 646,84	€ 385,48	59,59%
MGB	130	535	€ 209,30	€ 246,97	€ 663,32	€ 416,35	62,77%
MGB	131	831	€ 272,06	€ 321,03	€ 901,25	€ 580,22	64,38%

MGB	131	535	€ 216,94	€ 255,99	€ 732,33	€ 476,34	65,04%
MGB	130	285	€ 180,11	€ 212,53	€ 556,20	€ 343,67	61,79%
MGB	130	845	€ 261,35	€ 308,40	€ 827,09	€ 518,69	62,71%
MGB	131	845	€ 257,65	€ 304,03	€ 949,66	€ 645,63	67,99%
MGB	131	521	€ 215,72	€ 254,55	€ 721,00	€ 466,45	64,69%
MGB	131	1131	€ 295,70	€ 348,93	€ 1.004,25	€ 655,32	65,26%

Table 3.50: Profits and margins based on adjusted times due to inefficiencies.

APPENDIX Chapter 6

PROFITS DUE TO ADJUSTMENT OF 50% OF THE DIFFERENCE BETWEEN MG AND MGB PRICES								
TYPE	D [mm]	L [mm]	PROFIT	NEW PROFIT	Δ PROFIT	Δ MARGIN	MONTHLY QUANTITY	EXPECTED PROFIT
MGE	60	260	90,97 €	90,97 €	0,00 €	0,00%	20,00	€ 0,00
MGE	60	140	59,83 €	59,83 €	0,00 €	0,00%	10,29	€ 0,00
MGE	60	260	77,57 €	77,57 €	0,00 €	0,00%	7,53	€ 0,00
MGE	54	255	156,16 €	156,16 €	0,00 €	0,00%	5,24	€ 0,00
MGC	60	190	65,02 €	65,02 €	0,00 €	0,00%	4,12	€ 0,00
MGE	60	440	110,30 €	110,30 €	0,00 €	0,00%	2,94	€ 0,00
MGC	60	90	53,41 €	53,41 €	0,00 €	0,00%	2,76	€ 0,00
MG	54	150	131,58 €	131,58 €	0,00 €	0,00%	2,65	€ 0,00
MGE	60	440	98,62 €	98,62 €	0,00 €	0,00%	2,18	€ 0,00
MG	80	310	202,31 €	216,84 €	14,53 €	4,49%	55,59	€ 807,90
MG	80	150	188,61 €	201,82 €	13,21 €	4,42%	53,29	€ 704,05
MG	80	560	238,12 €	254,78 €	16,66 €	4,42%	31,41	€ 523,44
MG	80	385	215,96 €	230,83 €	14,87 €	4,38%	18,00	€ 267,71
MG	81	560	239,38 €	258,24 €	18,86 €	4,76%	16,12	€ 303,99
MG	81	715	261,46 €	281,75 €	20,29 €	4,71%	13,71	€ 278,08
MG	80	870	268,68 €	287,85 €	19,18 €	4,48%	8,71	€ 166,95
MG	81	310	208,93 €	225,76 €	16,83 €	4,82%	8,35	€ 140,57
MG	80	715	245,67 €	263,53 €	17,86 €	4,53%	7,29	€ 130,26
MG	80	150	227,09 €	242,60 €	15,52 €	4,35%	5,65	€ 87,62
MG	81	560	345,40 €	365,25 €	19,86 €	3,89%	4,94	€ 98,12
MG	81	385	214,36 €	232,02 €	17,66 €	4,88%	4,12	€ 72,72
MG	80	310	270,26 €	287,15 €	16,89 €	4,11%	3,94	€ 66,55
MG	80	150	184,48 €	198,19 €	13,71 €	4,59%	3,76	€ 51,60
MG	80	715	241,86 €	260,17 €	18,32 €	4,64%	3,65	€ 66,80
MG	80	1155	318,47 €	340,20 €	21,73 €	4,35%	3,29	€ 71,58
MG	80	150	180,19 €	194,41 €	14,22 €	4,76%	3,06	€ 43,50
MG	80	385	295,55 €	312,86 €	17,31 €	3,94%	2,29	€ 39,71
MG	81	870	276,25 €	297,24 €	20,99 €	4,65%	1,88	€ 39,50
MG	81	310	263,25 €	280,98 €	17,73 €	4,31%	1,76	€ 31,28
MG	81	385	285,74 €	304,23 €	18,49 €	4,20%	1,76	€ 32,63
MG	80	385	210,52 €	226,05 €	15,53 €	4,57%	1,59	€ 24,66

MGB	80	500	€ 188,56	€ 188,56	€ 0,00	0,00%	4,47	€ 0,00
MGB	80	250	€ 162,30	€ 162,30	€ 0,00	0,00%	3,59	€ 0,00
MGB	80	805	€ 496,43	€ 496,43	€ 0,00	0,00%	1,41	€ 0,00
MGB	80	500	€ 453,33	€ 453,33	€ 0,00	0,00%	0,94	€ 0,00
MGB	80	250	€ 383,04	€ 383,04	€ 0,00	0,00%	0,76	€ 0,00
MGB	80	1110	€ 269,81	€ 269,81	€ 0,00	0,00%	0,35	€ 0,00
MGB	80	500	€ 445,34	€ 445,34	€ 0,00	0,00%	0,35	€ 0,00
MG	130	535	€ 444,65	€ 468,88	€ 24,23	7,63%	20,18	€ 488,83
MG	131	535	€ 503,53	€ 520,11	€ 16,58	5,60%	13,53	€ 224,37
MG	130	285	€ 395,93	€ 403,93	€ 7,99	7,02%	10,12	€ 80,87
MG	130	845	€ 556,72	€ 560,92	€ 4,20	3,45%	8,47	€ 35,59
MG	131	521	€ 488,63	€ 515,89	€ 27,26	7,36%	7,88	€ 214,88
MG	131	831	€ 563,53	€ 599,27	€ 35,75	5,13%	6,88	€ 246,02
MG	130	285	€ 415,73	€ 403,93	-€ 11,80	4,09%	5,88	
MG	131	831	€ 824,12	€ 747,59	-€ 76,53	3,28%	5,35	
MG	131	845	€ 572,38	€ 640,48	€ 68,11	6,88%	4,53	€ 308,48
MG	130	535	€ 531,85	€ 506,99	-€ 24,87	4,27%	3,29	
MG	131	285	€ 384,30	€ 388,99	€ 4,69	5,26%	3,06	€ 14,35
MG	131	1131	€ 1.028,44	€ 879,35	-€ 149,09	0,78%	2,82	
MG	131	285	€ 385,48	€ 388,99	€ 3,51	5,07%	2,65	€ 9,28
MGB	130	535	€ 416,35	€ 468,88	€ 52,53	2,73%	5,47	€ 287,37
MGB	131	831	€ 580,22	€ 599,27	€ 19,06	0,74%	3,82	€ 72,86
MGB	131	535	€ 476,34	€ 520,11	€ 43,78	1,97%	3,35	€ 146,78
MGB	130	285	€ 343,67	€ 403,93	€ 60,26	3,73%	3,00	€ 180,77
MGB	130	845	€ 518,69	€ 560,92	€ 42,23	1,81%	2,35	€ 99,36
MGB	131	845	€ 645,63	€ 640,48	-€ 5,15	-0,17%	2,35	-€ 12,12
MGB	131	521	€ 466,45	€ 515,89	€ 49,44	2,27%	1,82	€ 90,16
MGB	131	1131	€ 655,32	€ 879,35	€ 224,03	6,34%	1,41	€ 316,27

Table 6.4: Earnings by product based on the plan of increase in Prices established (50% of the difference in prices).