Study and design of the factory layout:

practical example

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Diploma work

Maribor, May 2020

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Resumen

En el presente trabajo se realizarán dos tareas principales; por un lado, un breve resumen de la literatura existente en lo que se refiere a lean manufacturing y los diferentes métodos existentes para poder desarrollar la fábrica más eficiente posible. En segundo lugar, se pretende resolver un ejercico del libro "Manufacturing Facilities de Dileep R Sule", ejercicio cuya resolución conlleva el conocimiento de las diferentes técnicas de modelado de un layout así como la utilización de diversas herramientas informáticas que facilitan el diseño y simulación de dichos objetivos.

Palabras clave: lean manufacturing, layout, simulation, workflow.

Summary

In the present work, two main tasks will be carried out; on the one hand, a brief summary of the existing literature regarding lean manufacturing and the different existing methods to develop the most efficient factory possible. Secondly, the aim is to solve an exercise in the book "Manufacturing Facilities by Dileep R Sule", an exercise whose resolution involves the knowledge of the different modeling techniques of a layout as well as the use of various computer tools that facilitate the design and simulation of those goals.

Key words: lean manufacturing, layout, simulation, workflow.

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1. Introduction

Nowadays, the problems that a brand new or even a veteran manufacturing company have to face are bigger and more difficult than some years ago. Competitors could appear all over the world and not just in their home country or same region, and consumers constantly ask for new items with the highest quality and the lowest prize. Even more, consumers not only ask for quality, they also ask for highly customizable products (that must produce at a very high scale) and demand for the companies to be aware about climate change and climate care, among the most important issues. Furthermore, problems inside the companies such as the role employees (involvement, empowerment, teamwork), integration of the supply chain or the lack of productive resources become crucial to accomplish objectives.

Maintain the increasing expectations while improving the benefits is one of the principal goals for the enterprise in general and for the production management engineers in particular. There exist a wide range of tools to keep updated with the latest discoveries, which must be implemented in the production environment if chief officers want to observe improvements that would incur in an increase of the profit. To mention a couple of them, AMT "Advanced Manufacturing Technologies", ICT "Information and Communication Technologies", IoT "Internet of Things", Lean Manufacturing, Total Production Maintenance…

A competitive production manager will reduce production costs in any of the different fields he is in charge of (R+D, prevention, logistics, manufacturing quality, maintenance…) or with the application of short, medium, and long-term investments. To do so, plans and projects must be done ensuring all the best.

1.1. Aims of the diploma work

The aim of these diploma work is to solve a problem extracted from the book Manufacturing Facilities, from Dileep R. Sule. The problem was designed "copying" reality, with nearly real production process data.

To solve it, different computer programs need to be used. With the simulations done, we will be able to find and fix possible problems without wasting any money, predictions are made on the base of computer simulations.

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1.2. Used programs and methodology

As it has been above mentioned, although the problem is not real, it is complex. Six products with their own particular workflow sequence are designed. The chosen battery of programs come from the Autodesk family because I did not know how to use some of them, letting me to learn something new and because they are sufficiently powerful to solve the presented tasks.

For the 2D development of the layout, AutoCAD, AutoCAD mechanical and AutoCAD architecture will be used. For the 3d modelling, Autodesk Inventor Professional and for the simulations Autodesk Process Analysis. All of them will have integrated the package Autodesk Factory Design Utilities [5] for a better comprehension and development.

2. Production systems

The following pages will be in charge of describing a series of concepts necessary to understand the background of the work and the field in which it is going to be focused.

2.1. Evolution of the production systems

Production systems have evolved as society has evolved along history. They started with guilds, then handcrafted production, followed by mass production, and arriving to nowadays just in time.

Guilds were the set of people that worked on the same item, for example shoes gave the shoemaker guild, or on the same range of materials, bakers, or butchers. There was no work specialization, the master of the guild was in charge of all the steps and controlled the product in all the workflow. Production was localized (just for one city), very predictable and without variation. It was extremely difficult to become master, something that enhances social division.

Handcrafted production was used until the XX century (nowadays it is still used for some specific products). Factories were developed, but with handmade products, production was very low and just destined for higher social classes, manufacturing luxury objects. It has easy to get personal relational with the client as well as obtaining the monopoly of the product.

Mass production started when Henry Ford concluded that selling a car for every person would give him enormous benefits, standard product with affordable prize. To do so, car pieces should be interchangeable, the design should be simple, durable and easy to repair as well as the assembly chain. The Ford T is the emblem o this way of thinking. Assembly chain was the key, the car moved from one place to another and the worker was standing in the same position making repetitive operations in every car. Everything changed when the social conscience evolved, everybody wanted to have a car, but a car defined for his demands, not more, not less.

After WWII, Japan adapted his factories to build and construct different car models in the same workplace, not as the USA, that had a factory for each product. With the petroleum rising prices, Japanese cars were selected rather than the American ones and it was not a matter of consumption; quality was higher. And the quality was higher because they had implemented

the lean manufacturing, which cause a reduction in the lead time, standardization of the operations, fluid communication… [14]

2.2. Lean manufacturing

Lean manufacturing, as it has been mentioned, was developed by the Japanese after the Second World War. Japanese had been assembling in their factories different types of cars both coming from Europe and America; this situation made their factories very flexible and easily adaptable to changes in the product or production. Even if Toyota wanted to manufacture and design a car on his own, they built his first car as mix of Ford, Chevrolet, and Chrysler.

In the beginning, Japanese cars were not very well seen by the consumers, who preferred something coming from Europe or the USA; however, when the OPEC reduced petroleum offer, they significantly augmented their sells. At first, they thought it was due to their smaller size and so smaller consumption but, nevertheless, they discovered that quality was another important point when purchasing a new car.

Bigger productivity and quality had nothing to do with labor cost but with the way of organizing production, the just in time. It was Shiego Shingo, industrial engineer from Toyota who discovered the necessity of statistical quality control and the aim for the zero errors [6].

Lots of different procedures can be used (some of them explained in the next pages). The idea for lean manufacturing is being able to adapt to the variations of the market as fast as possible, cellular layout when possible, SMED system to reduce timing, waste reduction, operation standardization, Kanban cards, weighted production, total predictive maintenance, fluid communication between the layers of the company, good relation with the providers or leaving the customer customize the product.

"Taj and Morosan (2011) say that a multi-dimensional approach that consists of production with minimum amount of waste (just in time), continuous and uninterrupted flow

(cellular layout), well-maintained equipment (TPM), well-established quality force (HRM) that has positive impact on operations/competitive performance (quality, cost, fast response, and flexibility)" [6].

2.3. Used indicators in industry

It exists the necessity of measure in industry, thus, not existing variables have to be developed to help management operations. The created indicators are known as KPI or "Key Performance Indicators" and basically are tools used to evaluate current situation, inform and communicate whatever is happening, motivate the workers and obey the basic principle of continuous improvement. They have to be carefully designed to be SMART "Specific Measurable Achievable Relevant Timely" at the same time that simple, clear and easy to calculate. Each company can build their own KPI in specific workstations or services, nonetheless, they can be grouped in KPI referring provisioning, production, transport or service client.

The most important one, OEE "Overall Equipment Effectiveness" will be briefly explained. It measures the losses that always appear in the productive system, in a way of improving with specific procedures the productivity and efficiency of the factory. To calculate it is necessary to obtain in advance three ratios [11]:

$$D = Disponibility\ ratio = \frac{Planified\ production\ time - Stops}{Planified\ production\ time}$$

$$E = Efficiency\ ratio = \frac{Total\ unit\ numbers}{Operation\ time * Maximum\ velocity}$$

$$Q = Quality\ ratio = \frac{Number\ of\ 0\ defects\ produced\ units}{Total\ number\ of\ produced\ units}$$

With all the information given by these ratios, it can be then calculated as:

$$OEE = \frac{Real\ production}{Ideal\ production} = D * E * Q$$

It is a parameter that can be trusted, easy to be calculated, connects a lot of information around all the production system and is easy to find and fix problems in any of the parameters. Factories and companies are evaluated as a function of their OEE in 10% ranges:

Table 1:OEE Classification

OEE	Classification
OEE <65%	Unacceptable, low competitivity
65% < OEE <75%	Regular, acceptable when improving
75% < OEE <85%	Acceptable, continuous improvement
85% < OEE <95%	Good competitivity
95% < OEE	Excellent, world class values, excellent competitivity

2.4. Pull system

Pull system is used in all of the lean companies or the ones willing improve their OEE and efficiency. In the pull system, typical for lean manufacturing, the job is pulled to successive workstations instead of being pushed by its preceding workstation. In other words, in a pull system the material is only moved when the next stage requires it. The flow of parts throughout the production line can be controlled by kanban cards. The primary advantage of the pull system is the reduced inventory and therefore the associated cost of inventory reduction [12].

2.5. Kaizen systems / Wastes

Continuous improvement was introduced by Deming and Juran with the statistical quality control methods and then adapted by Ishikawa, Imai and Ohno to the Toyota production system. Kaizen system is the path that must be followed to achieve continuous improvement, involving cost reduction, decrease of the lead time or avoiding long delays [13].

Toyota engineers were really aware of what the words value and waste meant for the product and the consumer. Valuable activities were defined as operations that increased the value of the product for the customer, otherwise, they were falling to waste or muda in Japanese. Seven mudas were identified, namely:

- Overproduction

- Inventory

- Repairs and defective products

- Movement

- Process

- Waiting

- Transport

Not being aware of the importance of waste reduction can lead the company to the loss of clients, or rentability. Kaizen system has to be instilled in all of the members of the company, from chief officers to production employees.

2.6. VSM or Value Stream Mapping

Value stream mapping is the way of applying the previously mentioned ideas of value and waste. It can be described as a systematic method to identify and measure the activities that add value versus that ones that do not add value to the production process considering time, work in progress and used resources. Material and information flows will be essential to create and overview of the whole process, helping the workers to focus on where is the problem. VSM has six stages:

1. Team creation: mixed team, committed and with enough knowledge.

2. Definition of the process to analyze: clients, products, markets necessities…

3. Data collection and analysis: measure times, flows, OEE, resources,

4. Realization of the actual map: takt time, lead time, production volume, wastes graph, bottlenecks…

5. Realization of the future map: lead time reduction, reduce waste, value stream map…

6. Action plan / Implementation / Tracing / Control

2.7. Technique 5's

Many times, lean manufacturing methods are not implemented in factories or everyday utilities and is not something that cannot be implemented in a few hours, days and months have to be invested. As the process is long, the first tool that is adapted is the 5's; seiri (organization), seiton (order), seiso (cleaning); seiketsu (discipline) and sitsuke (habit). They are very easy to understand, waste is avoided in some of their variations (dirty workplaces, disorder, broken machines…) and what it is more important, they usually do not need an initial investment.

To prepare the implementation of the method, the first thing to do is prepare a group of people that will be taught in the basics of the systems, how to follow instructions and how to improve it in their own [15]. Even if it is easy to understand what they are related with:

- Seiri / Organization: detect unnecessary elements and decide whether they have to be placed in other location, repair the broken ones, or throw the useless.

- Seiton / Order: tidy up the working zone depending on the frequency with which they are used. After placing the objects, label them to facilitate the research and determine the exact quantity of objects that are needed.

- Seiso / Cleaning: identify and get rid of dirtiness and pollution sources, which will increase useful life of machines and workers motivation.

- Seiketsu / Standardization: stablish a program with easy procedures to be followed by everybody without problem that ensure the application of the three previous "s".

- Sitsuke / Habit: the objective is to transform the previously standardized operations into something that is made by inertia. Is the most complicated one, since maintain motivation is complicated, but will increase the quality of the process and customers satisfaction.

2.8. Layout types

The layout of the production zone of a factory can be described as the physical arrangements of the machines and services that the production process is going to need. Layout design is considered a strategic decision because it has enormous long-term effects over the efficiency, the flexibility, and the quality of the company. This decision is usually taken in the design phase, but it can be taken when a new product is going to be launched, if there is a variation in the competitive priorities or when the efficiency is inadequate. There are four different types of layout: fixed position, job shops, production lines and cellular.

- Fixed position: typical of very big or heavy products, workers are specialized and usually machines are hired to other companies.

- Job shop:
  - Pros: lower machine investment, high flexibility, machine breakages do not stope the hole process.
  - Cons: difficult to fix product flows, higher transportation costs, bigger lead time, bigger surface needed.

- Production lines:
  - Pros: lower lead time, lower handling time, less surface needed, lower specialization from the workers is needed.
  - Cons: high machine investment, lower flexibility, the hole production line could be stopped if one machines breaks.

- Cellular:
  - Pros: simplifies changing times, lower lead time, lower inventory, lower transportation cost, easy to automatize, teamwork spirit, flexibility.
  - Cons: equipment duplicity, higher costs, difficult to define the working cellule, bigger surface needed, higher specialization of the workers.

3. Problem solving

For the production system study that has to be solved we will take all the possible data from the book Manufacturing Facilities, from the author Dileep R Sule, in particular Appendix F: Case Studies, Case study 1: facilities planning design project [1]. The exercise is very accurate regarding reality, and so are the data. Whenever the needed data for simulations or planning design are not in the example, they will be determined trying to simulate real life. If the data from the exercise vary is because we want to improve the project and the way is explained.

Summarizing the main parts of the project:

- There are three facilities that need to be allocated in 7 possible locations.

- Six products are being manufactured with six different workflows and production volume-

- Eight functional units compose the production floor: tool-room, injection molding, assembly, machining, finishing, heat treating, forming, and testing plus the extra step of storage.

- General layout must be calculated with some criteria.

- Number of forklifts is required.

- Process simulations are asked.

3.1. Facility place selection

Three new facilities want to be placed by the enterprise. Among all the possible seven options, just 3 of them are going to be chosen. The unique two criteria to select which one among all of them are better are the transportation costs and the fixed cost per year. Table 2 shows how they are related.

Table 2:Transportation Cost Matrix

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Trips per month	Trips per year
1	64	102	58	198	224	105	90	44	528
2	12	76	94	154	166	94	74	38	456
3	168	212	88	38	66	121	68	52	624
4	112	148	124	82	20	77	55	32	384
5	94	119	111	88	49	40	210	49	588
Fixed cost per year (€)	38340	34210	39450	33940	29220	36654	32119		

*Cost is calculated in euros e.g., for distribution centre 1 Site 1 costs are 64€.

According to the presented literature in the problem [1], three sites will be assigned to the 5 distribution centers. To do so, some restrictions must be considered: distribution center 3 cannot be serviced if facility is located in 5 or 6 and that distribution center 2 cannot be serviced if the facility is located at site 7. These requirements automatically block several possible combinations.

Place selection procedure is very simple. Matrices involving key information will be built, from which information could be extracted. First of all, Table 3, in where the cost of every trip multiplied by the number of trips is shown, resulting in the demand cost of every combination, e.g. Site1 center 1 is 33792 € after multiplying 64 € times 528 trips per year... Forbidden options will have a NO.

Table 3: Demand Cost

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1	33792	53856	30624	104544	118272	55440	47520
2	5472	34656	42864	70224	75696	42864	NO
3	104832	132288	54912	23712	NO	NO	42432
4	43008	56832	47616	31488	7680	29568	21120
5	55272	69972	65268	51744	28812	23520	123480

*Demand cost unit is € because trips have no units.

Next point is to find for the smallest demand cost for the distribution centers and calculate what could be the savings of placing the facility in that spot rather than placing it in the second with smallest demand cost. With the fixed cost in negative (because is something that needs investment regardless distribution center, it is site dependent), adding the

saving plus the fixed cost the net saving will be obtained and the lowest value will be the best option. For example, in center 1, the smallest values goes with Site 3, 30624 €, and the second one is Site 1 with 33792 €, saving coming from moving from Site 1 to Site 3 are 33792 – 30624 equal to 3168€. Then, net saving would be -39450 + 3168 equal to -36282€.

Table 4: Initial Assignment Minimum Saving Table

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1			3168				
2	29184						NO
3				18720	NO	NO	
4					13440		
5						5292	
Fixed cost per year (€)	-38340	-34210	-39450	-33940	-29220	-36654	-32119
Net savings (€)	-9156	-34210	-36282	-15220	-15780	-31362	-32119

* Saving units are €, e.g., distribution center 2 Site 1 savings are 29184€.

As it can be observed in Table 4, Site 1 has the smallest net savings, then, Site 1 will be chosen, and marked with an X in Table 5.

Table 5: Demand Assignments I

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1	X						
2	X						NO
3	X				NO	NO	
4	X						
5	X						

With the first option selected, procedure varies a bit. New questions appear and need an answer to follow with the site selection; would it be worth it to change the facility location from Site 1 to another different for each of the distribution centers? To answer it, demand cost of Site 1 (Table 3) must be taken and then subtract the demand cost of the corresponding site and distribution center (the one that might be a better option). If the result is positive, means that it is worth it to flip positions, the value of the savings is placed and, in any other case, a script (-) is allocated. For example, demand cost 3 for Site 1 is 104832€ if we subtract Site 2

demand cost we get negative value, not worth it then. But for Site 3 it appear to be 49920€ then it is a good option to switch the previously made selection.

Add the result to the fixed cost (that is negative) is next step, and again, if the result is positive, it is a good idea to switch places. Finally, among all the positive values, the biggest one should be taken as the best option (biggest savings) and "move" all the chosen distribution centers. For Site 3, 49920€ -39450€ is positive and 13638 €. Tables 6 and 7 illustrate the method.

Bear in mind that some of the option are forbidden, even if the numbers say it will give bigger savings, they cannot be placed there.

Table 6: Savings Table for Moving from Location

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1	X	-	3168	-	-	-	-
2	X	-	-	-	-	-	NO
3	X	-	49920	81120	NO	NO	62400
4	X	-	-	11520	35328	13440	21888
5	X	-	-	3528	26460	31752	-
Fixed cost per year (€)	-38340	-34210	-39450	-33940	-29220	-36654	-32119
Net savings (€)	-38340	-34210	13638	62228	32568	8538	52169

* Saving units are €, e.g., distribution center 4 Site 4 savings are 11520€.

Table 7: Demand Assignments II

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1	X						
2	X						NO
3				X	NO	NO	
4				X			
5				X			

Finally, same procedure and reasoning than in previous cases has to be followed, what will take to the final site selection for all of the facilities.

Table 8: Savings Table for Moving from Site 1 to Site 4

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1	X	-	3168	-	-	-	-
2	X	-	-	-	-	-	NO
3	-	-	-	X	NO	NO	-
4	-	-	-	X	23808	1920	10368
5	-	-	-	X	22932	28224	-
Fixed cost per year (€)	-38340	-34210	-39450	-33940	-29220	-36654	-32119
Net savings (€)	-38340	-34210	-36282	-33940	17520	-6510	-21751

Table 9: Demand Assignments III

Distribution centre	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1	X						
2	X						NO
3				X	NO	NO	
4					X		
5					X		

As it is shown in Table 9, the final facility location will be: distribution center 1 and 2 to Site 1, distribution center 4 and 5 to Site 5 and distribution center 3 to Site 4. A reasonable criterion has been followed, ending up with having this distribution as the best option from the transportation cost point of view, respecting the prohibited combinations, and following the best criteria. Some other restrictions could appear, as security issues or legal prohibitions, but that would be another point of view calculation.

3.2. Layout

Space calculations were made considering all the information given in the problem. Nevertheless, some variations were made to adjust the data. Main changes are: product number 1 sequence of operations was varied to get rid of three steps (treat, store, machine). Decision was taken because "treat" step was not specified, and the resulting sequence "machine store machine" had no sense.

Table 11 specifies number and size of the machines for the machining area ,12 in total, something with no sense. The size of each machine was augmented by a 50% to approach reality and an extra 20% for walkways (inside each production area, not the whole production place) and walls was also added. Space calculation were made in the basis of these 12 machines.

Next, 1 operator per machine was assigned to each of the operations, resulting in, the need of 4 machines for machining, 3 for forming, 1 for heat treatment or 1 for injection molding. Machines are then chosen from the factory design inventor library, and real dimensions could vary a little bit. Machine surroundings were oversized in the following way: extra 60 cm in 3 out 4 sides for maintenance operations and 1m in the side where the operator is working.
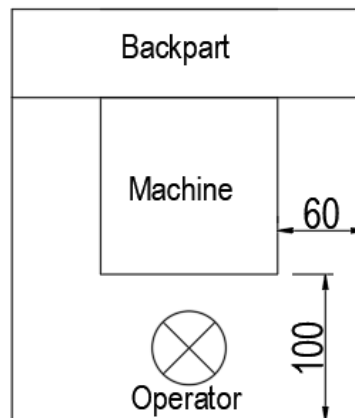

Figure 1: Enlargement of the machine

3.2.1. Area distribution

To calculate how much space are the functional units going to occupy in the total layout, approximate information on the number of workers is needed. Food and other services will need space for 200 people at the same time, design and engineering department 20 people, administrations issues 80 people, 5 production floor supervisors or extra space for meeting rooms, 2 small for 10 people and a bigger one for 40 people. All this information would be used to calculate the layout of the "office" section of the facility, but in these seminar work we are just focusing on the production floor of the facility, in which just storage, heat treating, machining or testing department areas are needed.

The calculation of the above-mentioned sections will be calculated with the machining area basis. Table 10 shows machining area already augmented a 50% with respect to the information presented in the exercise. Once the machining area is totally described, the

unknown areas can be deduced with simple relations regarding percentages, extra 50% for the

assembly section and 20% less for the rest.

Table 10: Machining area

Machine	Area (feet)		Number of machines	Space (feet²)
	Length	Width		
1	7,5	16,5	2	247,5
2	6,0	6,0	4	144,0
3	10,5	6,0	1	63,0
4	19,5	13,5	1	263,2
5	6,0	4,5	3	81,0
6	10,5	9,0	1	94,5
Subtotal				893,2
Extra-20%				178,6
Total				1071,9

*Area calculated as length x width; each dimension already augmented in a 50%.

Table 11: Production floor + Storage + Shipping + Maintenance

Production floor + Storage + Shipping + Maintenance	Relation with machining	Space (feet²)	Space (m²)*
Injection molding	-20%	858	80
Assembly	50%	1608	149
Machining	0	1072	100
Finishing	-20%	858	80
Heat treating	-20%	858	80
Forming	-20%	858	80
Testing	-20%	858	80
Subtotal production		6967	647
Warehousing/Storage	-20%	858	80
Shipping and Receiving	-20%	858	80
Maintenance	1/8 total production	871	81
Tool-room	8% total production	557	52
Total		10111	939

*1 feet² = 0,0929 m²

3.2.2. Production area needed

The most important part of the factory is going to be the production area zone.

Optimization of the layout and a straightforward method to obtain the best distribution is

needed. In the following tables, which are the different areas and the relation (in number of

trips per day) that exist between them will be exposed.

Table 12: Production Area Considerations

Department	**Area (m²)**	**Department**	**Area (m²)**
Tool-room (A)	52	Heat treating (F)	80
Injection molding (B)	80	Forming (G)	80
Assembly (C)	149	Testing (H)	80
Machining (D)	100	Storage (I)	80
Finishing (E)	80		

Each of the six different products that the factory is manufacturing has a different workflow to follow. Table 14 shows the sequence of operations, as well as presenting trips to the tool room in Table 15, or extra trips to the storage when assembly is needed in Table 16.

Table 13:Sequence of Operations

Product	**Units/Day**	**Units/Load**	**Trips/Day**	**Sequence of operation**
1	358	4	90	I, G, D, E, H, I
2	310	50	7	I, C, I
3	1120	15	75	I, D, C, D, E, I
4	18	1	18	I, G, D, C, I
5	150	12	13	I, F, G, E, I
6	3100	50	62	I, B, E, I

Table 14: Trips from each location to the tool-room

Production Area	**Trips/Day**
Forming	11
Machining	41
Heat treating	15
Finishing	19
Assembly	27
Injection molding	14
Testing	6

Table 15: Extra products needed for assembly from the storage

Product	**Units/Assembly**	**Units/Load**	**Extra units/Day**	**Trips/Day***
2	2	200	620	8
3	5	100	5600	112
4	1	20	18	2

*Go and return are counted as two times, e.g. 8 trips means 4 travels from storage to assembly

Gathered information is essential to know how important is for two functional units to be together or as together as possible. New tables need to be built to understand the interrelations. All of the trips are done by forklifts, distance to cover by the forklifts is essential, thus a big distance implies a big cost and the other way around.

The first two tables are very similar, Table 17 collects the trips from one department to another regardless if its sense is A to B or B to A and Table 18 considers that, in fact, is the same distance so they can be considered equally.

Table 16: From-to Chart. Individual Flow Per Day

Material flow	Tool-room	Injection molding	Assembly	Machining	Finishing	Heat treating	Forming	Testing	Storage
Tool-room	NO								
Injection molding	14	NO			62				
Assembly	27		NO	75					147
Machining	41		93	NO	165				
Finishing	19				NO			90	150
Heat treating	15					NO	13		
Forming	11			108	13		NO		
Testing	6							NO	90
Storage		62	7	75		13	108		NO

*All the numbers represent number of trips, dimensionless.

Table 17: From-to Chart. Total Flow Per Day

Material flow	Tool-room	Injection molding	Assembly	Machining	Finishing	Heat treating	Forming	Testing	Storage
Tool-room	NO								
Injection molding	14	NO							
Assembly	27	0	NO						
Machining	41	0	168	NO					
Finishing	19	62	0	165	NO				
Heat treating	15	0	0	0	0	NO			
Forming	11	0	0	108	13	13	NO		
Testing	6	0	0	0	90	0	0	NO	
Storage	0	62	154	75	150	13	108	90	NO

*All the numbers represent number of trips, dimensionless.

Table 18: Relation-Chart Priority Codes

Code	Priority	When?
A	Absolutely important	≥150
E	Especially important	≥90 & <150
I	Important	≥60 & <90
O	Ordinary	<60
X	Undesirable	Security

Table 19: From-to Chart. Importance

Material flow	Tool-room	Injection molding	Assembly	Machining	Finishing	Heat treating	Forming	Testing	Storage
Tool-room	NO								
Injection molding	O	NO							
Assembly	O		NO						
Machining	O		A	NO					
Finishing	O	I		A	NO				
Heat treating	O					NO			
Forming	O			E	O	O	NO		
Testing	O				E			NO	
Storage		I	A	I	A	O	E	E	NO

The letter code gives a lot of information with just a preview of the table. It is easy to deduce that storage area must be near the assembly and heat-treating zones, while machining has to be near assembly and finishing zones. With charts and pictures, a final layout is decided. To create a first approach, blocks will be used.

Table 20: Block Determination

Department	Area(m²)	Blocks	Department	Area(m²)	Blocks
Tool-room (A)	52	6	Heat treating (F)	80	9
Injection molding (B)	80	9	Forming (G)	80	9
Assembly (C)	149	17	Testing (H)	80	9
Machining (D)	100	11	Storage (I)	80	9
Finishing (E)	80	9	TOTAL		88

*Each block will have 3m x 3m dimensions.

To decide the block distribution, charts with a color code representing the importance of the relation are used [1]. The idea is very simple, each circumference represents one of the different departments and they are connected by the color lines.

The key is that as less lines cross between them, the better to the workflow, and it would be easier to have a smoother layout. The lines going out from A (tool- room) are not presented

because they are from the less important category and go for almost all of the departments converting the drawing in a mesh. Several options were though before arriving to a final decision.
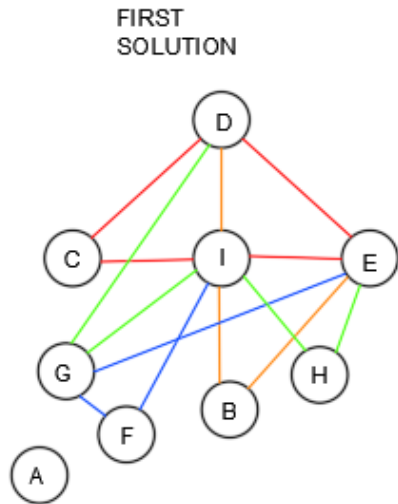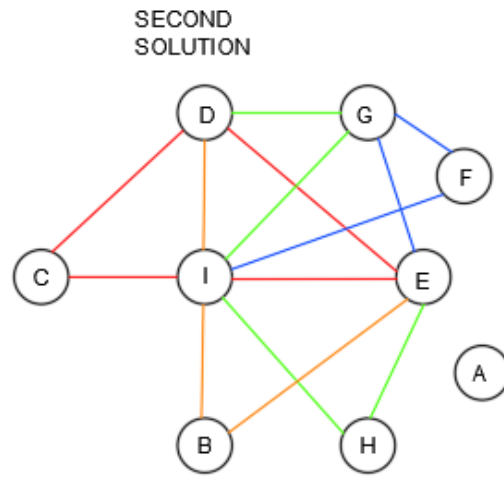

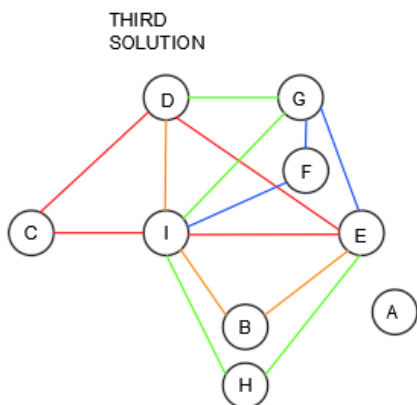*Figure 2.First Option.*

Figure 3:Second Option.

Figure 4:Third Option.

***Table 21**: Relation between colours and importance*

Color	Importance	Colour	Importance
Red	Absolutely importance	Yellow	Important
Green	Especially important	Blue	Ordinary

As it can be observed, from the first to the third sketch, the drawing evolved in a much more efficient distribution, with less crossing lines. The most important is to do not have red lines or green lines crossing between each other, while the blue meaningless. A step forward will be to distribute these ideas into a physical layout. Table 21 shows how many blocks should each of the departments have. They are going to be distribute in a firstly 8x11 rectangle. The reached option might not be as exact as the planned idea, but it will resemble.

The following figure shows a first plan, with both the block distribution one by one and a general view of how it looks like.
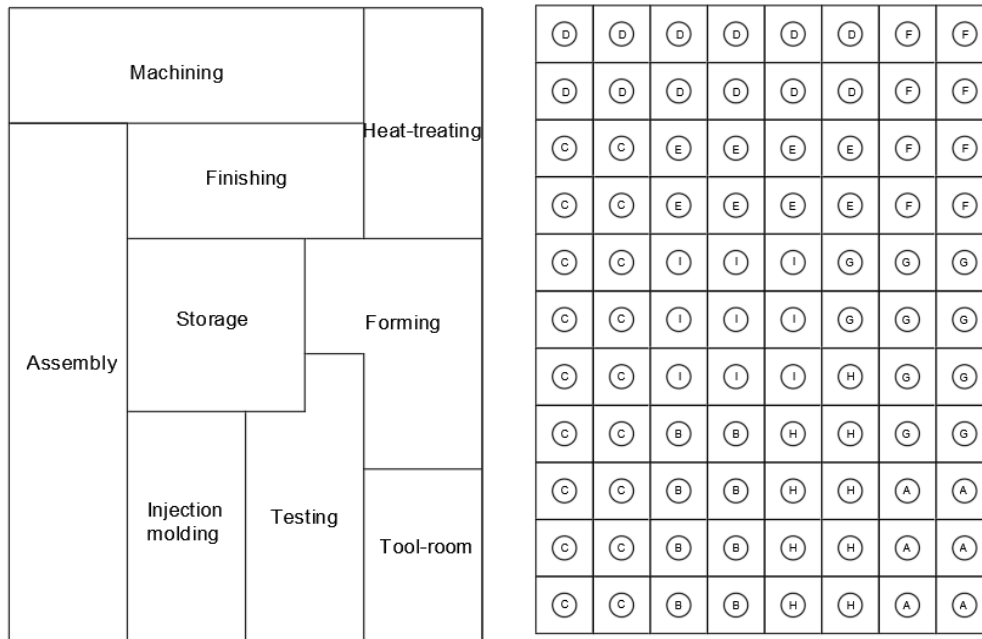

Figure 5: Block diagram and first layout.

The introduction of walkways, walls and doors forces the layout to change, machines are also introduced in the next drawing in a way of better understanding the actual plant

Figure 6:Second layout with walkways and second layout with walkways and machines.

Final distribution with all the possible measurements and the specified area of each department is the next one.
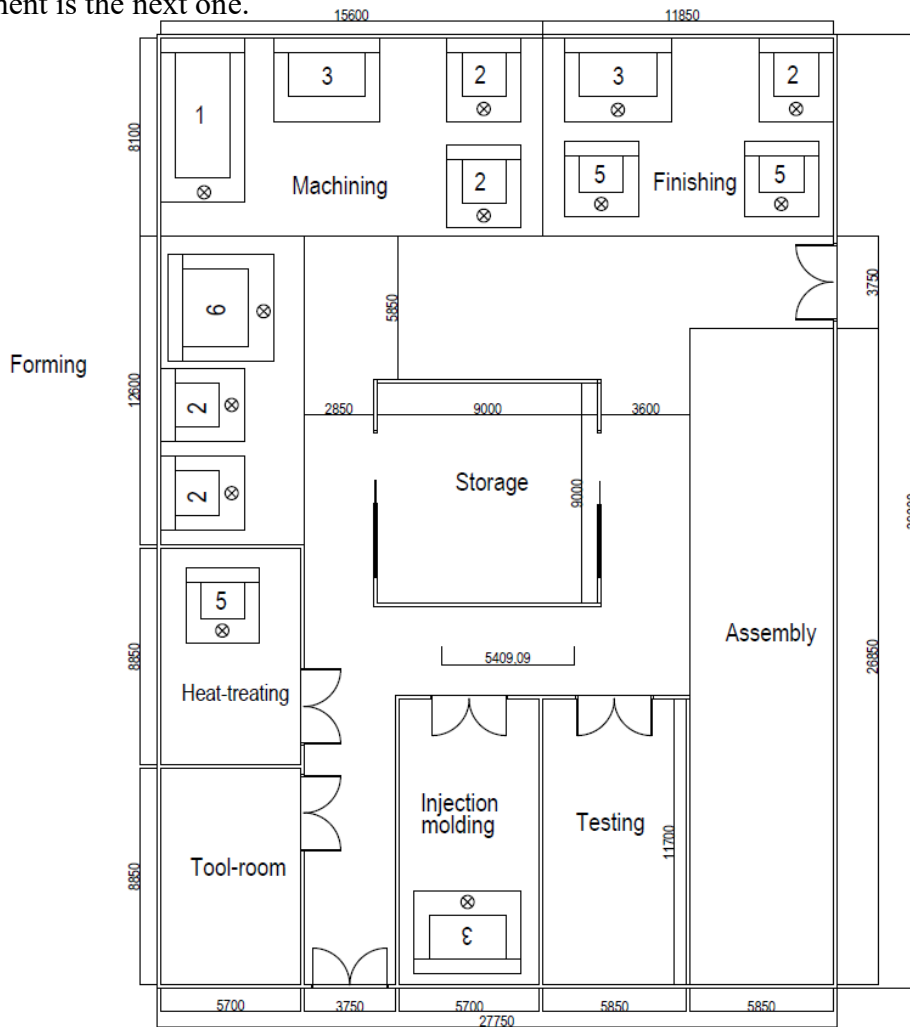
Figure 7: Layout dimensions (in mm).

3.2.3. Layout 3D Model

Allocating AutoCAD designs into the Inventor program gives the following 3D models.

Figure 8: Layout 3D model.
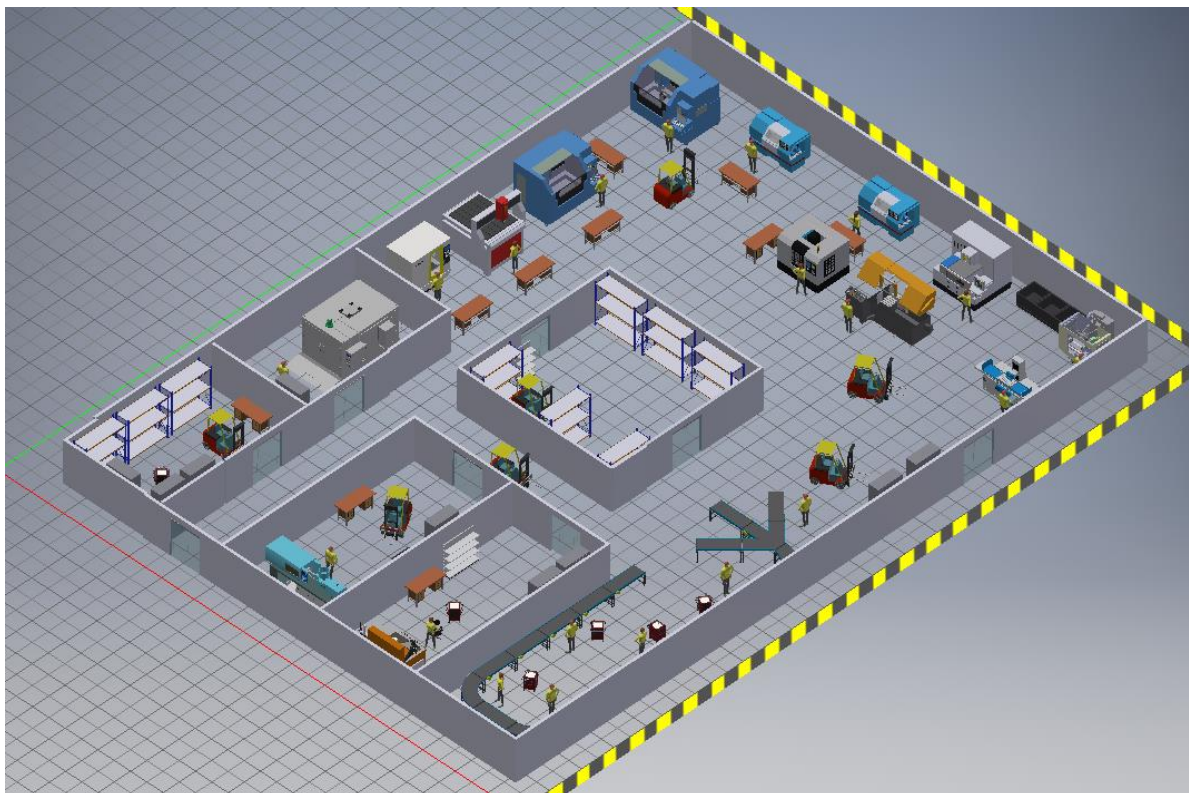
Figure 9: Layout 3D model 2.

3.2.4. Product workflows

   AutoCAD mechanical has the necessary tools to determine the individual workflows of each product. All of the paths start and finish in the same place the storage, while following their corresponding operations. A figure for each path is going to be shown.
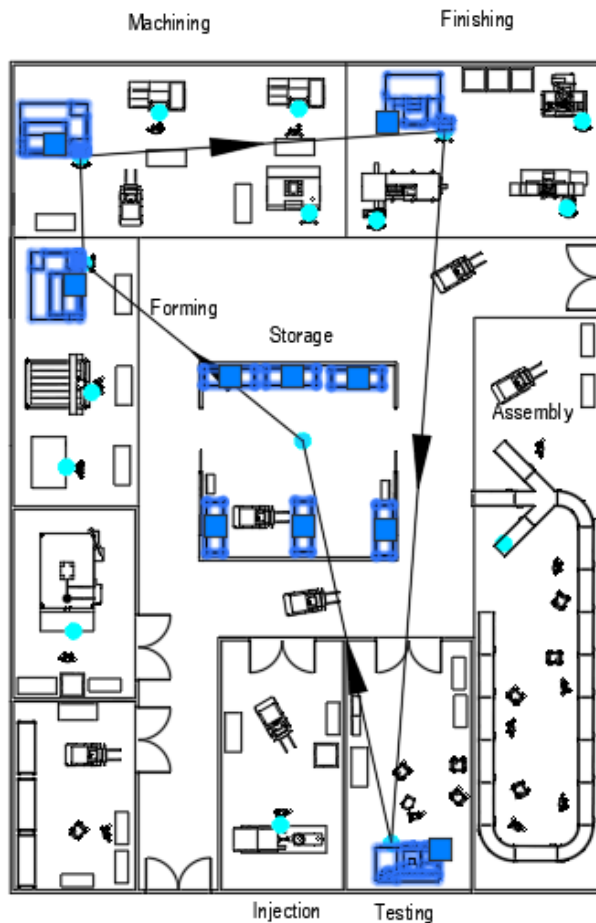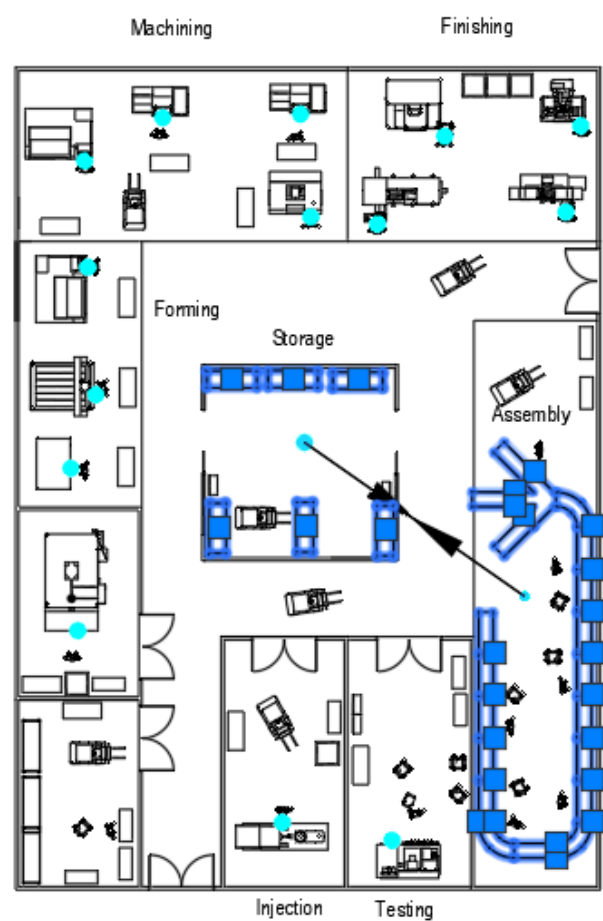

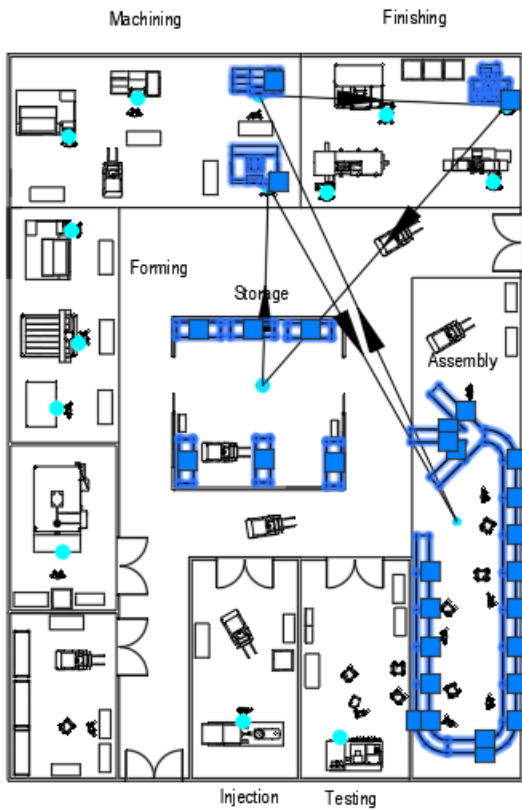*Figure 10: Workflow product 1*   *Figure 11: Workflow product 2*
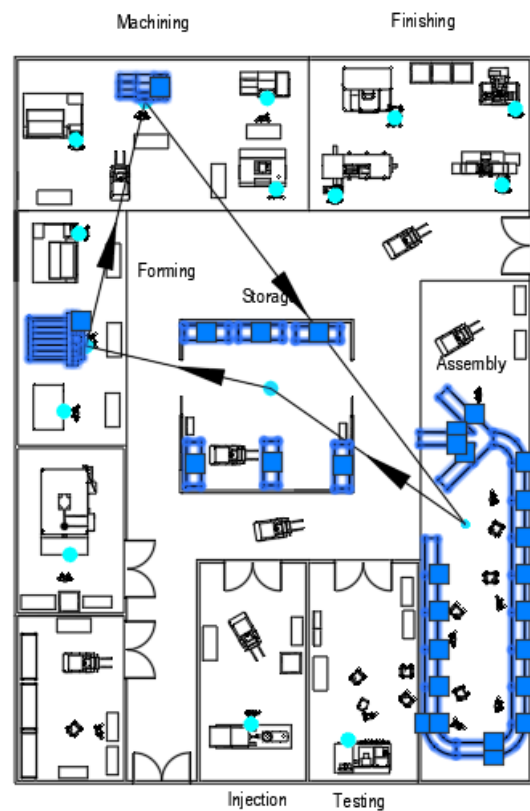
Figure 12: Workflow product 3

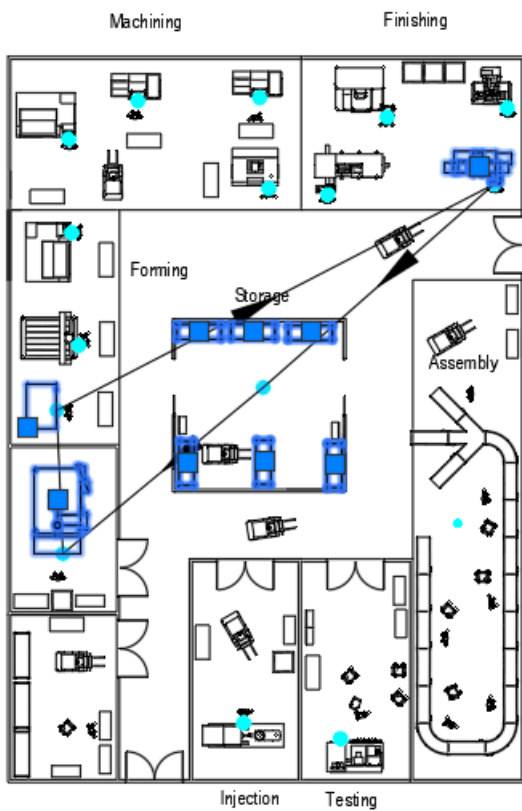*Figure 13: Workflow product 4*

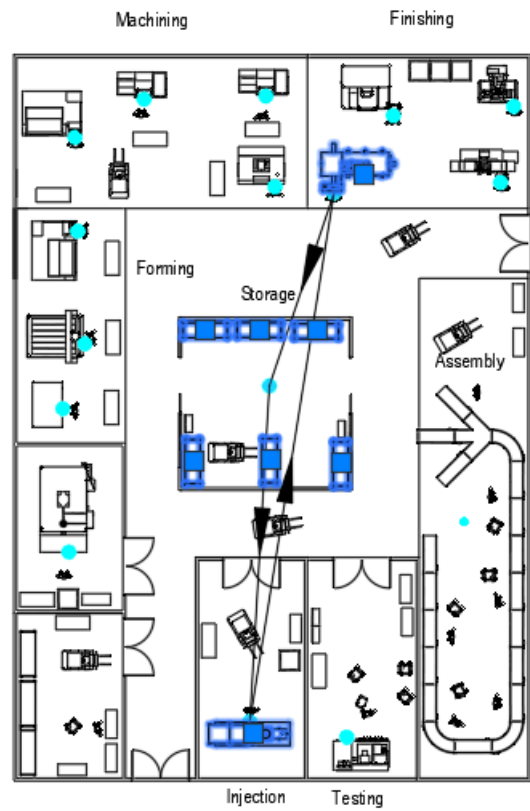
Figure 14: Workflow product 5

Figure 15: Workflow product 6

3.3. Forklift calculation

The following tables have been set up to solve all the questions related to forklifts, which specify all the necessary information in a schematic way. First of all, highlight that 8 forklifts are going to be necessary, 6 of them will take care of the 6 different products with their corresponding trips while another two more are going to be used for trips related to the tool room and carrying out the trips between the storage and the assembly respectively.

For building Table 23 it is necessary to mention that calculations are made taking into consideration that the forklift has a speed of 150 feet/minute or 0,762 m/s.

Table 22: Forklift information per product

PRODUCT 1				PRODUCT 4			
From	**To**	**Distance (m)**	**Time (s)**	**From**	**To**	**Distance (m)**	**Time (s)**
Storage	1-1:Forming	13,2	17,3	Storage	4-1:Forming	10,4	13,6
1-1:Forming	1-2:Machining	5,3	7,0	4-1:Forming	4-2:Machining	13,4	17,6
1-2:Machining	1-3:Finishing	16,9	22,2	4-2:Machining	4-3:Assembly	28,5	37,4
1-3:Finishing	1-4:Testing	33,6	44,1	4-3:Assembly	Storage	12,7	16,7
1-4:Testing	Storage	19,44	25,5				

PRODUCT 2				PRODUCT 5			
From	**To**	**Distance (m)**	**Time (s)**	**From**	**To**	**Distance (m)**	**Time (s)**
Storage	2-1: Assembly	12,8	16,8	Storage	5-1:Heat treating	13,8	18,1
2-1: Assembly	Storage	12,8	16,8	5-1:Heat treating	5-2:Forming	7,7	10,1
				5-2:Forming	5-3: Finishing	27,1	35,6
				5-3: Finishing	Storage	16,6	21,8

PRODUCT 3				PRODUCT 6			
From	**To**	**Distance (m)**	**Time (s)**	**From**	**To**	**Distance (m)**	**Time (s)**
Storage	3-1:Machining	10,7	14,0	Storage	6-1:Injection molding	18,1	23,8
3-1:Machining	3-2:Assembly	20,8	27,3	6-1:Injection molding	6-2:Finishing	28,9	37,9
3-2:Assembly	3-3:Machinig	25,3	33,2	6-2:Finishing	Storage	11	14,4
3-3:Machinig	3-4:Finishing	13,5	17,7				
3-4:Finishing	Storage	20,3	26,6				

Table 23:*Forklift information*

Forklift 1			Forklift 4		
Trips / day		90	Trips / day		18
Total distance (m) / day		7959,6	Total distance (m) / day		1170,0
Total time (min)/ day		174,1	Total time (min)/ day		25,6
Forklift 2			Forklift 5		
Trips / day		7	Trips / day		13
Total distance (m) / day		179,2	Total distance (m) / day		847,6
Total time / day		3,9	Total time (min)/ day		18,5
Forklift 3			Forklift 6		
Trips / day		75	Trips / day		62
Total distance (m) / day		6795,0	Total distance (m) / day		58,0
Total time (min)/ day		148,6	Total time (min)/ day		78,7
Forklift TR			Forklift ASS		
Trips / day		133	Trips / day		122
Total distance (m) / day		19165,8	Total distance (m) / day		1561,6
Total time (min)/ day		419,2	Total time (min)/ day		34,2

3.4. Process analysis

Finally, simulations are going to be held by the program Autodesk Process Analysis; there is a lot of information to be introduced into the system to carry out the simulations, of course some of it is taken from the literature while other has to be invented, always having in mind that they must simulate real life in the best possible way.

Some features are common to all of the simulations, and will be briefly explained now:

- Simulation time was limited to 780 min, calculated from two 8 hours production shifts minus an hour and a half lost of time due to eating breaks and briefings.

- Transportation time from one department to another was taken from Table 23.

- Transportation time adds 20 extra seconds in each displacement, 10 seconds for loading and unloading the lots.

- Material sources needs an output rate for the material coming out of the storage. This output cannot be the number of products to make divided by the number of producing hours, it has to be bigger to adapt the lost of time due to production and transportation issues.

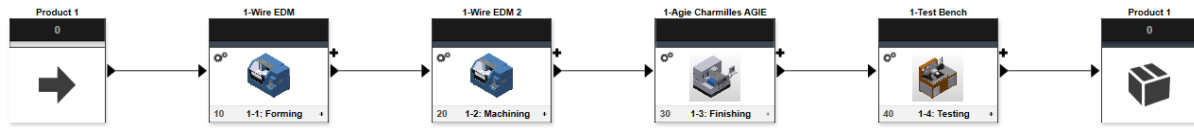### 3.4.1. Simulation process product 1

Figure 16:Workflow product 1

Product 1 workflow can be observed in Figure 16 in a schematic way while in Figure 10 is clearly defined with the spatial dimensions. It starts in the storage followed by the sequence forming, machining, finishing, testing and finally storage again. Each load carries 4 units and processing time was set for all the machines as follows:

- 1-1 Forming, 1-3 Finishing, 1-4 Testing: 1 pc / 70 s
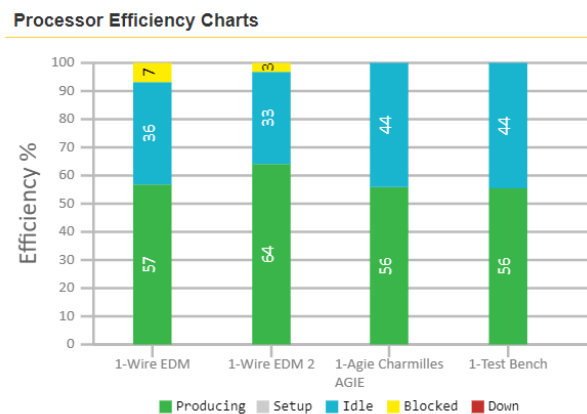
- 1-2: Machining: 1 pc / 80 s

Figure 17: Machine efficiency product 1

After making the simulation 368 pieces were made, 10 extras than the required by the literature. Machine with the highest productivity is Wire EDM 2 with a 64%. Workflow is really fluid and smooth in the simulation, there is not a machine that has to be waiting for a previous department a lot of time, they are very well placed and waiting time is mainly due to the only fact of distance between zones, having similar processing times helps the simulation to be easier.
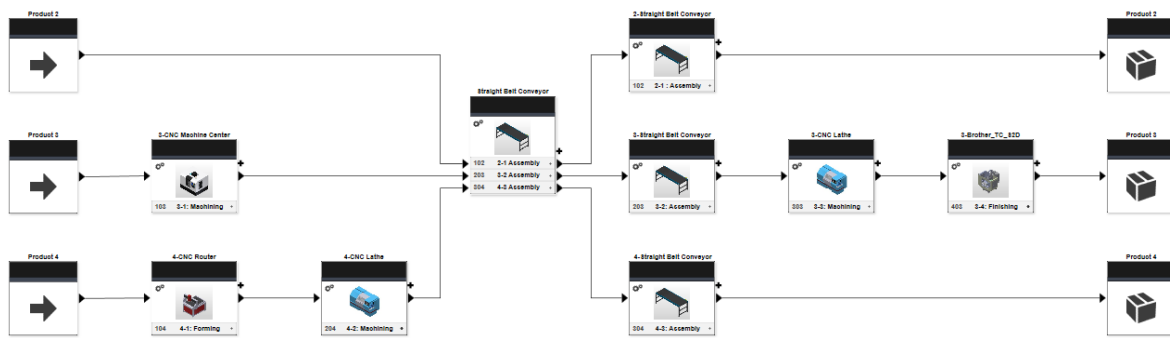
3.4.2. Simulation process products 2 3 4

Figure 18: Workflow products 2 3 4

Product 2 3 4 workflows can be observed in Figure 18 in a schematic way while in Figures 11, 12 and 13 respectively, is clearly defined with the spatial dimensions. Product 2 is composed just by the assembly part. Product 3 path is storage, machining assembly, machining, finishing and finally storage. Product 4 begins in storage, followed by forming, machining, assembly and storage to finish.

The three products have the straight belt conveyor in common, this step was set with processing time 0, in a way of representing the entrance on the belt. Conveyor belt covers approximately 32 m, at a velocity of 2 m / minute, it lasts 16 minutes to cover the total path. But none of the product is going to do it completely, they will enter in the separated belts and after 5 minutes (approximately 10m, one third of total distance) in the belt, they will be removed and carried to the next step. During their way in the belt, they will have different assembly times. Lot sizes vary for the products: 2 is 50 units/load, 3 is 15 units/load and 4 is 1 unit/load.

- 2-1 Assembly: 1 pc / 85 s

- 3-1 Machining, 3-3 Machining, 3-4 Finishing: 1 pc / 10 s

- 3-2 Assembly: 1 pc / 20 s

- 4-1 Forming, 4-2 Machining, 4-3 Assembly: 1 pc / 1200 s
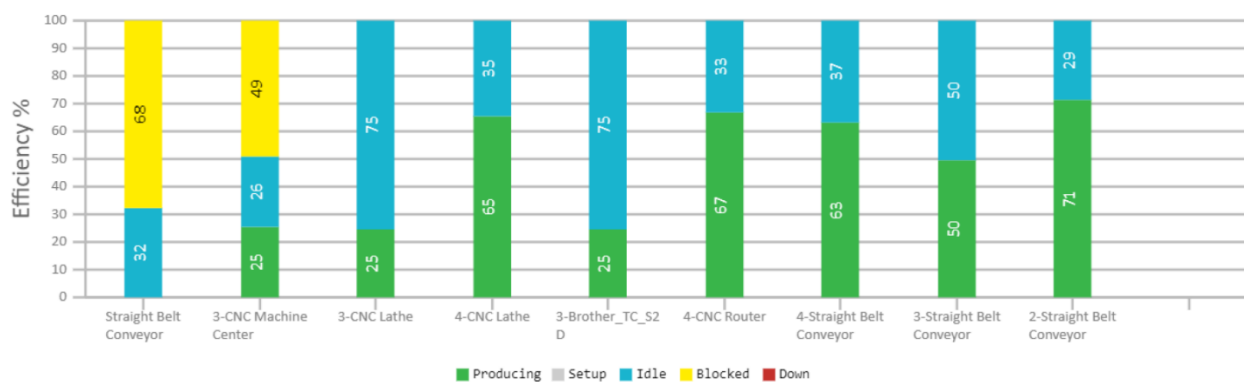
Processor Efficiency Charts

Figure 19: Machine efficiency for products 2 3 4

For product 2, 40 extra pieces where produced while for product 3 they were 1140 out of 1120 and product 4 had an extra 30% productivity. As it has been mentioned, straight belt conveyor was set up with processing time 0 in a way of mimicking the place on where belt starts, and products join. Both 3-CNC Lathe and 3-Brother_TC_S2D are affected by the conveyor belt velocity per lot, around 5 minutes in the belt plus the another 5 minutes assembling in comparison to 2,5 minutes makes a difference, constantly waiting for the products decreasing working time of both machines to a 25%. At the same time, 3-CNC Machine Center is affected by this processing time difference, because it transforms the product but the product cannot go to the next station until the previous lot has been worked, having the machine blocked for a 49% of the time. Products 2 and 4 have very high producing percentages, demonstrating that design has been carefully thought.

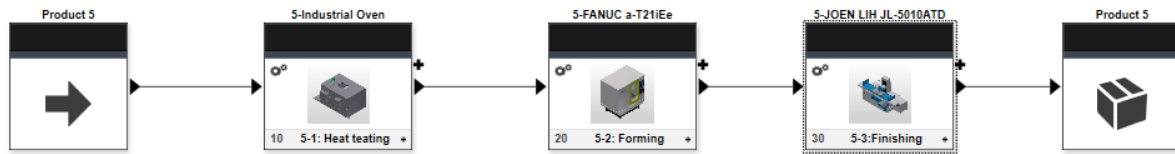## 3.4.3. Simulation process product 5

Figure 20: Workflow product 5

Product 5 workflow can be observed in Figure 20 in a schematic way while in Figure 14 is clearly defined with the spatial dimensions. It starts in the storage followed by the sequence heat-treating, forming, finishing and finally storage again. Each load carries 12 units and processing time was set for all the machines as follows:

- 5-1 Heat treating: 1 pc / 140 s

- 5-2 Forming: 1 pc / 120 s
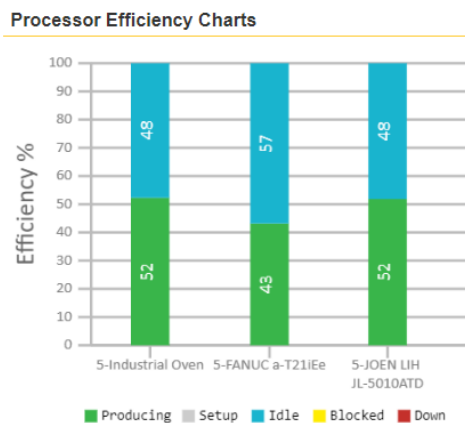
- 5-3 Finishing: 1 pc / 150 s

Figure 21: Machine efficiency product 5

Simulations state that 156 out of 150 pieces of product 5 were produced, six extras. It can be clearly observed that forming process is always waiting for the industrial oven and this is due to the industrial oven processing time, bigger than for the forming process, forcing the FANUC machine to wait until they have finished. When they switch to the las step, forming has a smaller processing time, thus, finishing department doesn't need to wait for the pieces coming, they are always ready hence, production increases to a 52%.
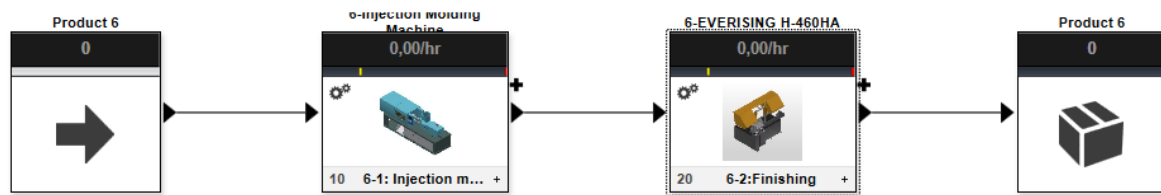
3.4.4. Simulation process product 6

Figure 22: Workflow product 6

Product 6 workflow can be observed in Figure 22 in a schematic way while in Figure 15 is clearly defined with the spatial dimensions. It starts in the storage followed by the sequence injection molding, finishing and finally storage again. Each load carries 50 units and processing time was set for all the machines as follows:

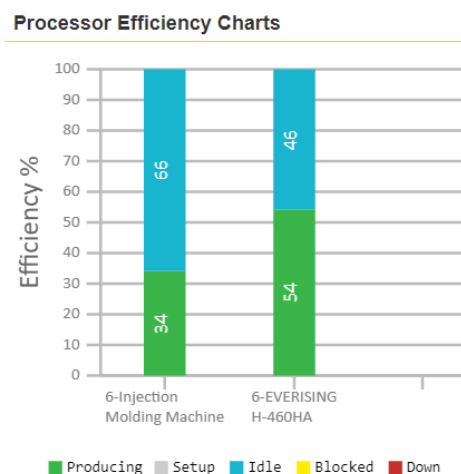- 6-1 Injection molding: 1 pc / 5 s

- 6-2 Finishing: 1 pc / 8 s

Figure 23:Machine efficiency product 6

Whenever injection molding machines are used, a big number of pieces is going to be required, because they require a very high initial investment. 3150 pieces have been manufactured, an extra surplus of 50 pieces that will help to cover possible mistakes, avoiding create the stock sea which hides production errors. A higher waiting time for the injection molding is due to the output rate of the storage, actually stablished as 400 pieces/hour, and during the 113h simulations it just "gives" to the injection molding section 3211 pieces.

4. Conclusion

Production design is a very complex task than can be approached from a multiple areas, each of which will provide its own solution to a specific problem. The range of knowledge inside this field is wide, however, the scope of this seminar work is just to understand how it t works in a general way, using the tools that are available to improve handmade sketches.

Solving this kind of problems requires data to be the start point for the operation that will come, and here is where the first problem appears; in the beginning they were taken from the literature and some others were invented in the end to mimic real life, but of course, they do not are real life. The situation presented can only be compared to the case of designing a new plan from scratch, when just an approximation of what is going to be is thought.

The first of the issues raised by the problem was to select the correct location among several options given by the problem. Differences where just a matter of transportations costs and number of trips per month. Heuristic methods were used to solve this part, coming up with the best possible site selection.

Layout design was much more difficult, involving several stages to come up with the best option. Space distribution was made was made on the basis of the machining area zone, increasing measures to have a better approach to reality. Once space was known, costs were again calculated regarding to the number of trips between them regarding the workflow of each product, stablishing the ranking of importance for them to be as together as possible. Microsoft Excel appeared to be a magnificent tool to manage with the amount of data presented in here.

First decision was to determine what was the best distribution to the factory that we were designing, either job shops or cellular; job shops fitted better with our idea, since cellular flow was not possible due to the individual product workflows. Block diagrams and CAD drawings showed which was the best option. AutoCAD Mechanical and Architecture as well as Autodesk Inventor Professional with the addition of Autodesk Factory Design Utilities

package developed all of the 2D and 3D models for the factory layout including workflows and specific machines.

With the final layout design, it just was necessary to make simulations on our design to prove it. It was Autodesk Process Analysis program that carried out all the simulations. As previously said, it was not an easy task to stablish data, and of course, some of the them might not be well determined.

The dataset consisting on distances derived from the layout design, processing time measures or output rate values together with time limited simulations builds the simulation. All of the product workflows were described and analyzed, and for sure that they can be improved with a better layout or global design. Of course, changes on the introduced data will transform the simulation, deriving on not accomplishing the production objective or having and too much extra products.

The global idea made with this work can help me to better understand how a factory layout is designed and elaborated. In addition, more specific information can be evaluated, as which machines are overloaded or underloaded, where do bottlenecks appear, reduce inventory, or increase efficiency is possible analyzing the hole seminar work.

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