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Redesigning of a production line for ergonomic standadrs compliance. Before and after evaluation.

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POLITÉCNICO
DO PORTO

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KEYWORDS

Mass production, manual manufacturing, assembly lines, ergonomics

ABSTRACT

The main objective of a production line is the manufacture of certain products in a large scale. The best way to achieve that goal is without a doubt the full automatization of the manufacturing process. By reducing the human intervention to a minimum, it is possible to eliminate various causes for variations of a production process. However, the full automatization of a certain process is not always possible or economically practicable. In these cases, there is no alternative but to resort to duly qualified operators to perform the various functions inherent to the process. In these cases, process engineering, together with industrial management and internal logistics engineering, play a key role in two equally important aspects. The first is reflected in obtaining the maximum possible income from the available resources, whether they are the available operators, equipment or materials stock. The second, which focuses more on process engineering, is to give employees all the necessary conditions in terms of safety and ergonomics to perform their tasks in the most "comfortable" way possible. These improvements generally result in increased operator performance and satisfaction, lower rates of work-related incidents and higher production volume, which ultimately translates into increased profits earned by the organization. In both aspects it is possible to use various tools (production instructions, SMED's, Poka-Yoke devices, support gauges, etc.) that allow the minimization of the causes of variance in a purely manual production process, to achieve a process as stable as possible.

PALAVRAS CHAVE

Produção em massa, produção manual, linhas de montagem, ergonomia

RESUMO

O principal objetivo de linhas de produção em série é o fabrico em larga escala de um determinado produto. A melhor forma de atingir este objetivo é, sem dúvida, automatizar ao máximo o processo. Ao reduzir ao mínimo a intervenção humana, é possível eliminar diversas causas de variância num determinado processo produtivo. Contudo, nem sempre é possível, ou economicamente viável recorrer à automatização total dos processos de produção. Nestes casos, não existe outra alternativa senão recorrer a operadores devidamente qualificados para desempenhar as diversas funções inerentes ao processo. Nestes casos, a engenharia de processo, juntamente com a engenharia de gestão industrial e logística, têm um papel fundamental em dois aspetos igualmente importantes. O primeiro reflete-se em obter o máximo de rendimento possível dos recursos disponíveis, sejam eles os operadores disponíveis, equipamentos ou stock de materiais. O segundo, que incide mais sobre a engenharia de processo, consiste em dar aos colaboradores todas as condições necessárias a nível de segurança e ergonomia, de forma a realizarem as suas tarefas da maneira mais "confortável" possível. Estas melhorias acabam, de uma forma geral, por se traduzir num maior rendimento e satisfação dos operadores, menores taxas de incidentes no trabalho e num maior volume de produção que, por fim, se traduz num aumento de lucros obtidos pela organização. Em ambos os aspetos referidos, é possível recorrer à utilização de diversas ferramentas (instruções de produção, SMED's, dispositivos Poka-Yoke, gabaris de suporte, etc) que permitem a minimização das causas de variância num processo produtivo puramente manual, de forma a ser conseguido um processo o mais estável possível.

LIST OF SYMBOLS AND ABBREVIATIONS

List of abbreviations

CAD	Computer Aided Design
CAT	Customer Acceptance Test
CT	Cycle time
DDI	Dual Delegate Interface
FcT	Functional Test
FILI	Frequency Independent Lifting Index
GALBP	General Assembly Line Balancing Problems
HVT	High Voltage Test
IGEL	Integrated Calculation of Load Limits
JIT	Just in Time
LB	Line Balancing
MOE6	Manufacturing Operations and Engineering
MS	Model Sequencing
NIOSH	National Institute for Occupational Safety and Health
OCRA	Occupational Repetitive Actions
PFEP	Plan for Every Part
RI	Risk Index
RML	Recommended Mass Limit
RWL	Recommended Weight Limit
SALBP	Simple Assembly Line Balancing Problems
STLI	Single Task Lifting Index
VS	Value Stream

List of units

€	Euro
cm	Centimeter
h	Hour
kg	Kilogram
kN	Kilonewton
m	Meter
m^2	Square meter
min	Minute
mm	Millimeter
mm^2	Square millimeter
N	Newton
s	Second

GLOSSARY OF TERMS

5S	The 5S methodology was created in Japan and consists in Sort (Seiri), Set in order (Seiton), Shine/Sweep (Seiso), Standardize (Seiketsu) and Sustain/Self-discipline (Shitsuke).
JIG	A type of custom-made tool used to control the location and/or motion of parts or other tools.
Milkrun	The Milkrun supplier performs the delivery and collection of the different materials used in a factory. This process is made in a programmed way and in stipulated quantities, reducing the stocks and making the lead times more predictable.
Stabs	Stab is a document where the operators loops throughout the manufacturing process, are represented. It differs according to the line layout, number of operators and product to manufactured.

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INTRODUCTION

1 INTRODUCTION

1.1 Contextualization

Mass production is a term used to describe the large-scale production of standardized products, using production lines as the main tool to achieve this goal. Although this term was popularized by Henry Ford in the early 20th century (particularly in the production of the Ford T model), many production techniques used pre-date the industrial revolution. It is possible to affirm that it was with the creation of machine tools and other techniques to produce interchangeable parts (mid-19th century) that made modern mass production possible [1]. Tools such as screw-cutting lathe, metal planer, milling machine and jigs, provided the prerequisites for the modern assembly line by making interchangeable parts a practical reality. Over time these tools evolved which allowed an increase in both the production volume and the complexity of products. However, modern mass production is not a reality due only to the technological evolution of the equipment used.

When total automatization of manufacturing processes is not profitable the only way to achieve high standards of quality is thru qualified workers. With the increasing competitivity in markets, it is of all companies' interest to invest in workers training but it is also their responsibility to assure a safe work environment. Assuring an ergonomic work environment is crucial for the companies' development as well as for the satisfaction of the work force.

The present paper portrays a situation in which unfortunately these security requirements were not met. Consequently, a case of professional disease has been detected in an operator who has been exposed to risk factors for a long time. This has led to interim actions being taken that currently represent an impediment to increasing productivity. This work has emerged from the need to create definitive solutions so that these measures are withdrawn and most of all ensure all the necessary conditions for the workers to perform their required tasks without being subjected to any risk factors. Hopefully the work developed will establish new standards, and situations like the one mentioned will not be repeated.

1.2 Objectives

The objective of the work presented, is redesigning an assembly line to overcome the ergonomic deviations found. However, in doing so, some fundamental premises need to be respected. These premises are:

- All ergonomic deviations must be eliminated;
- The designed solution should be limited to the available area;

- The assembly line current output should not be affected;
- The costs regarding the new layout should be as low as possible;
- The final layout should be flexible, meaning that the installation and future transportation should be possible and without too much complexity.

The challenge in this work will be to accommodate all of this premises along with the individual requirements of the products manufactured in the assembly line.

1.3 Methodology

The methodology adopted in the development of the work presented consisted in several different steps:

1. A background study of the different subjects involved;
2. Analysis of the current manufacturing process;
3. Problem identification;
4. Setting the main goals of the presented work;
5. Establishing a hierarchy between the goals that were set;
6. Collecting feedback among more experienced professionals regarding possible solutions;
7. Choose the best suitable solution;
8. Elaboration of the 3D models of the solution chosen;
9. Estimating costs of the solution presented.

1.4 Structure of the dissertation

This dissertation is divided in two main parts, the first part related with bibliographic study regarding assembly lines and ergonomics, and the second the work developed.

In the bibliographical work, the reader will be firstly introduced to the general aspects of an assembly line. Here, topics such as types of assembly lines and supply to assembly lines will be presented, as well as an introduction to an automated assembling process. The second part of the bibliographical work will discuss ergonomics. The objective is to familiarize the reader with this subject for better understanding of the practical work developed. Finally, in the first part of this dissertation the main ergonomic standards will be presented.

After the bibliographical work, the development part of this dissertation will be presented. The development part will initially describe the current manufacturing process as well as the deviations found in each product. After this, the process of selecting the best solution will be presented and in conclusion the new layout will be described in detail for each product.

In the end of this dissertation, there will be presented the achievements of this study, the learned lessons and suggestions of future works.

1.5 Hosting Company

The project presented in this thesis was developed in Bosch Security Systems, in Ovar as part of a professional internship. It was supervised by Tiago Vaz and Lara Barbosa between March and September of 2018.

BIBLIOGRAPHIC WORK

2 BIBLIOGRAPHIC WORK

In this chapter various concepts about assembly lines and ergonomics will be presented. The objective to familiarize the reader with both topics, for better understanding the various challenges of the practical work developed. As these two topics are complex and with a lot of bibliographic work available, the focus is on the subjects that are more applicable in the study case presented.

Regarding assembly lines the initial focus will be on the many existent types of assembly lines and common balancing issues. Furthermore, the different ways of supplying an assembly line will be explained as well as the difference between the concepts of flexibility and agility. Lastly, a general approach to automated assembling processes will be made.

Since the main objective of this work is very deeply related to the subject of ergonomics, the part of this section dedicated to this subject will be more detailed. Standing and seated workstations basic design rules, working reach zones and good practices to have when handling heavy loads are some subjects addressed in this part of the chapter.

2.1 Assembly Lines

Assembly lines are very common in modern mass production since they allow the production of superior products with reduced costs and production times.

Assembly lines are essentially a set of tasks performed in a specific order that allow the obtainment of a final or partial product. These tasks are divided by several stations (depending on the complexity of the product) and are usually performed by specialized operators with machine and tool support. According to Henry Ford [2], these are the three main principles of an assembly line:

1. Both the operators and the tools must be positioned in such a way that the component to be worked travels the least distance possible. This way shorter lines can be achieved saving space on the factory floor.
2. Use work slides or some other form of carrier so that when an operator completes his tasks, he is able to drop the part always in the same place. The lines must be designed so that this location is easily accessible and if possible have gravity carrying the part to the next workman for his own.
3. Use sliding assembling lines where the different parts to be assembled are delivered at convenient distances.

Although its extensive use in modern mass production, it is important to balance between the pros and cons of using assembly lines. Table 1 presents some examples of pros and cons of its utilization:

Table 1 - Pros and Cons of Assembly Lines

Pros	Cons
Working Costs	Initial Investment
Workers Specialization	Repetitive Work
Uniform Products	Bottlenecks and Delays
Complexity of Products	Flexibility

Although assembly lines can reduce the total cost per part produced, they can have a high initial cost. They often need a large area on the factory floor and renting this space can be expensive. Often large and expensive equipment is needed, and small businesses may not have the capacity to acquire them. Although the initial investment is high, over time and as the process matures, this approach can become quite profitable. As the production process is replicated to each unit, this process becomes very consistent which minimizes costs with defects, maintenance and repairs.

Every operator on an assembly line oversees a certain task or equipment. This factor together with proper training provided by the company, allows the operator to become more efficient. The operator is better prepared to detect any defects and can also contribute with suggestions that increase the robustness of the process. The repeated nature of the tasks that the operators must carry out, often ends up leaving marks on them. As the type of tasks performed are not of technical profile the pay of these operators is often low. This combined with the monotony of tasks causes the operators to lose their motivation over time. To avoid this kind of problems is suggested some rotatability in the tasks performed, without compromising the quality of the final product.

One of the most important advantages in the use of assembly lines is the obtainment of uniform products. In other words, the products obtained by an assembly line tend to show only small variations. For example, if a worker produced an entire product alone, his product would probably show some variation when compared to the same product made by other worker. On the other hand, in assembly lines all operations are dependent on the action that comes before. Basically, this means that a product cannot advance the production process without having completed the previous stages. This reality can sometimes give rise to bottlenecks or even stagnation of production. These stops, whether caused by the lack of efficiency of a given operator on a given day, due to equipment malfunctions or inventory delays, can sometimes generate tension between the work force. It is therefore recommended that there be some flexibility in the productive process to combat these situations.

Assembly lines are usually developed for a specific product [3]. This factor means that it is very difficult for companies to start producing other types of products. Depending on the type of industry, the equipment used may be designed to a specific type of product and require specific training of operators. Introducing new products in a factory will imply new investment both in equipment and in training. However, the lack of flexibility in adapting assembly lines to different products is compensated by the degree of complexity that the products produced can have. An assembly line can achieve higher rates of production even when high product complexity is required.

2.1.1 Types of Assembly Lines and common balancing Issues

In this chapter the different types of assembly lines will be discussed, as well as the various challenges that each one of them raises regarding balancing and management. Figure 1 summarizes the different types of classification that can be given to an assembly line.

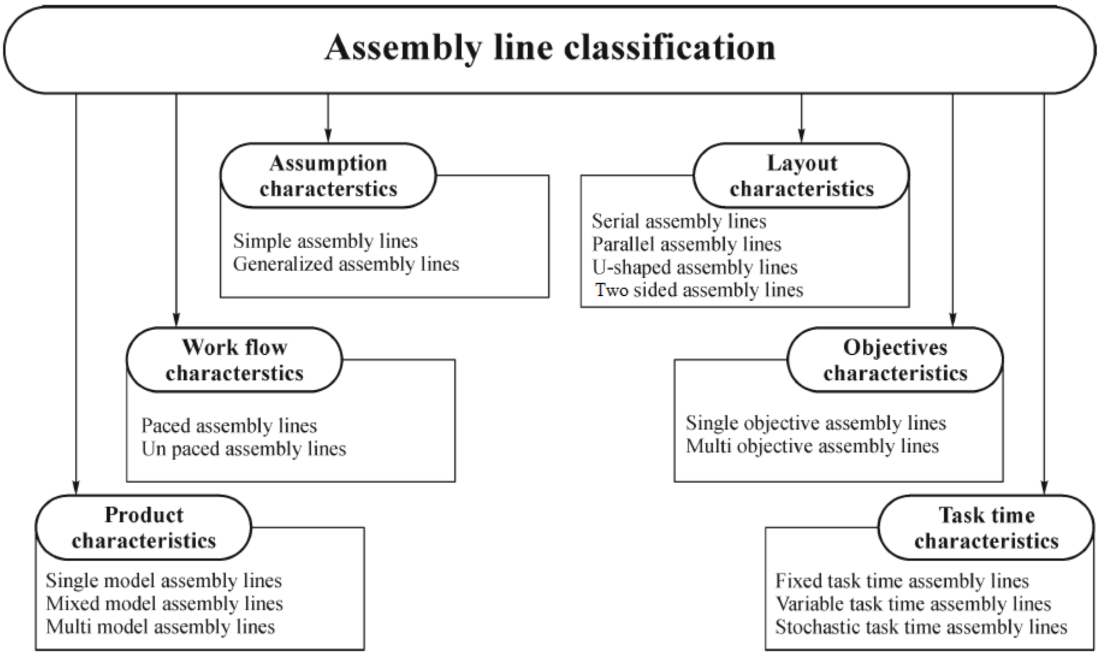


Figure 1 - Assembly line classification

2.1.1.1 Assumptions Characteristics

When trying to identify/resolve problems that occur in an assembly line, there are two categories to which it is possible to divide the **assumptions** made. Those categories are Simple Assembly Line Balancing Problems (SALBP) and Generalized Assembly Line Balancing Problems (GALBP) [4].

In SALBP, a lot of assumptions are made to make assembly line problem easily solvable. Some of the assumptions made are:

- In terms of layout, the various workstations are aligned in a straight line and a single type of product is assembled on it;
- Many paraments of the assembly line such as task time and product demand are assumed to be known beforehand;
- Task time is assumed to be smaller than the cycle time of the assembly line;
- The setup time of tasks is assumed as zero or included in the task time;
- It is possible to allocate tasks to any workstation, but no more than one task can be processed at the same time on a single workstation;
- Each task is assigned to only one workstation and must follow the precedence constraints;
- Only a single line is operating, and no other assembly line is connected to the main assembly line;
- All workstations have equal resources.

Also, depending on the objective function of the SALBP it is possible to divide them in four different versions [5]. Table 2 describes both the version and the objectives in which we can divide SALBP:

Table 2 - Different versions of SALBP

Version	Objective function
SALBP - 1	The station time is equal in all stations and the goal is to minimize idle station time.
SALBP - 2	Aims to minimize cycle time (CT).
SALBP - E	Aims to maximize the overall line efficiency.
SALBP - F	This version focusses on identifying the feasible solution with a known number of stations and cycle time.

As this model has several assumptions that in an industrial environment can hardly be verified, the probability of giving good results is reduced. For example, in terms of layout often the lines do not have the stations arranged in series, they may have another arrangement such as U-shaped. And, it is not also realistic to assume that the task time or the demand of the product is known. These values can change due to several reasons.

To make a more realistic analysis of the problems of balancing an assembly line, not so many assumptions should be made. Assembly line problems in which one or more of the assumptions made in SLABP are eliminated, are defined as GALBP. In this category, other variants such as cost functions, equipment selection, paralleling, U-shaped line layout and mixed-model production are taken in consideration. It is important to note that this is a recent approach and much research is still needed to make this method of analysis more robust [5].

2.1.1.2 Work Flow Characteristics

Regarding the work flow characteristics, assembly lines can be divided into two categories. These are paced and un-paced assembly lines. In the first type all stations are assumed to have a similar CT, and after each CT each station moves the product to the following station. If any station finishes the tasks before the CT ends, the parts need to wait and are not allowed to proceed to the next station. It is common in these assembly lines, the use of a conveyer belt to move the finished parts between the different stations. The minimum value of CT in these lines can be estimated according to the maximum workload of all the stations in the assembly line i.e.

$$max \sum_{i=1}^{n} X_{ij} t_{ij} \tag{1}$$

The maximum workload of a station *j* is the product between the rate of appearance for product *i* on station *j* (X_{ij}) and the process time of product *i* on station *j* (t_{ij}). In paced assembly lines the workload on each station is desired to be finished before the CT is over. For any station the difference of CT with its workload is the degree to which a station can compensate variations in the task time. In sum, the production rate in these types of lines is dependent on CT of the line and there are no buffers between stations.

The second type of assembly lines are un-paced assembly lines. In un-paced assembly lines work pieces are moved from one station to the next once they are finished. There are two different types of un-paced assembly lines based on the movement of the finished parts from the stations. **Synchronous** un-paced assembly lines transfers finished parts from all stations simultaneously. In these systems, all stations move their finished parts after a fixed time simultaneously, so buffers don´t exist in between the different stations. They are like paced lines if the task time is considered as deterministic. In un-paced **asynchronous** assembly lines each station may have different cycle time which is equal to the workload of that station. In these systems when all parts to produce are finished on a station, there is chance that the next station may have not finished its work. In this situation, the station that has already finished its tasks may have to wait for the next station. On the other hand, when a station finishes its tasks, there is possibility that the station located before may have not finished its all tasks. In this case the station remains idle up until the previous station finishes all tasks and can send its finished. One way in which the waiting time between stations can be reduced is by using buffers. They temporarily store the semi-finished parts between the stations, and by doing so help to balance the line.

Buffers are not only significant to compensate the fluctuations in the task time, but they are also helpful in a situation when a station fails, or an uncertain breakdown occurs. They are useful in smoothing and balancing the flow of materials between stations. However, big buffer storage space can incur subsequently larger holding costs and there is always a trade-off between cost of buffer allocation and profit achieved.

Appropriate buffer size design is important for the reduction of manufacturing costs with a required production rate in the assembly lines. Due to these facts, buffer allocation is a critical optimization problem for the assembly line designers. Buffer sizing problem are divided in two types. The objective of the first type is to minimize total size of buffers on the assembly line while trying to achieve a known production rate. The second type of buffer sizing problem is focused to maximize production rate of the line with a known value of maximum buffers size in the assembly line [6]. In literature, un-paced assembly line research is mostly focused on allocate buffer sizes, estimate production rate or balance the line. These objectives are mostly treated separately and due to interdependencies between all three problems, a simultaneous solution for the three objectives is desirable [7]. Their simultaneous consideration may balance un-paced assembly lines in the presence of buffers and optimize the buffer size with efforts on guaranteeing the production rate of the line.

2.1.1.3 Product Characteristics

According to the characteristics of the product manufactured, assembly lines can be divided in single model, mixed model and multi model.

In **single model** assembly lines, only one kind of product is produced, and each task is dependent of only one precedent task [8]. Since only one kind of product is produced, there's a higher possibility for learning effect to occur. This means that with time, task times will decrease, and the overall efficiency will increase. Furthermore, automation in these assemblies is easier which can also help to reduce the assembly operation time. However due to recent trend in the customized products, the just in time method (JIT) has been used to satisfy the customers demand. Using single model assembly lines in this situation will required a separate assembly line construction for each type of product. This represents a major investment, and because of this another type of assembly line is required in this case.

Mixed model assembly lines are chosen when manufacturing different models which have few differences from each other and derive from the same basic product. Different models of the same product family can have different process constraints each defining its model task durations and precedence relations. The precedence relation in a mixed model assembly line is obtained by combining the precedence diagram of all models of the product [9]. Based on the precedence relation the mixed model assembly line problem deals with the allocation of the various tasks to their respective stations. The tasks that are common to all the models are assigned to the similar stations. This helps leveling the capacity of the stations, and at the same time helps in reducing the setup time when producing different models [9]. In mixed model assembly line, some specific assembling demand of each model can be different and due to this, there is possibility that different models may have different assembly times. Some stations may process models of larger time duration and some stations may process models of smaller time duration. This may lead to an uneven workload distribution on the different stations and production in this situation may not be smooth. There are two main problems regarding mixed model assembly lines. The first is related to the assignment of tasks to the various stations i.e. line balancing (LB). LB aims to distribute the tasks of different models of product among stations in such a way that some objectives of the assembly line are optimized and precedence relation between the tasks are not violated. The second problem is called model sequencing (MS) problem and focuses in establishing the sequence in which different models of the product are assembled.

The third type of assembly lines is called **multi model** assembly line and deals with the production of different products on an assembly line. In multi model assembly line, different products are assembled in batch form. Once a batch of one model is produced, the setup of stations is changed according to the requirement of the next batch of products. The main problem associated with this type of assembly line is the lot sizing for different batches of models. If the lot sizes of the models are large each batch of product is separately balanced [7]. However, different products may use similar resources for some of their tasks and it may take larger setup time and cost if some resources are shifted multiple times to make a new setup for manufacturing different products. This can be reduced if the lot sizing is incorporated with assembly line balancing simultaneously.

2.1.1.4 Layout Characteristics

An assembly line can also be classified according to the layout chosen [10]. The four main types of layouts used are:

- Serial assembly lines;
- Parallel assembly lines;
- U-shaped assembly lines;
- Two sided assembly lines.

Serial assembly lines: In serial assembly lines the stations are arranged in a serial manner (Figure 2). This type of layout is very simple, and it is commonly used when manufacturing small size products.

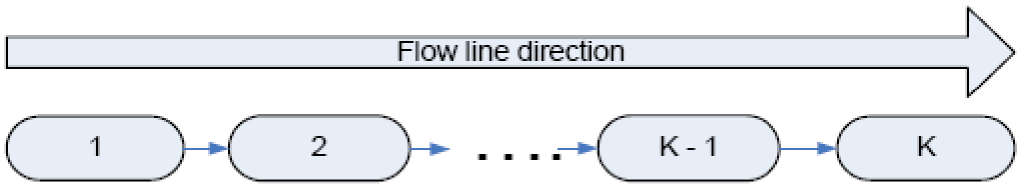


Figure 2 - Serial assembly line layout

In these lines the CT is calculated by the station with the maximum workload and dead time. Both the stations workload and the dead time are added to determine the CT of the line. Dead time is the time necessary to transport parts from one station to the next.

Although very commonly used, this kind of layout has some disadvantages such as:

- Inflexibility (cannot be adapted to different models9;
- Sensibility (if one station is stops, the process is compromised);
- Monotone work;

Parallel assembly lines: The main objective of parallel assembly lines is dividing the workload among all workstations [11]. If the cycle time of the line is more than desired, then the workload of the station with maximum workload can be divided by paralleling this station (Figure 3).

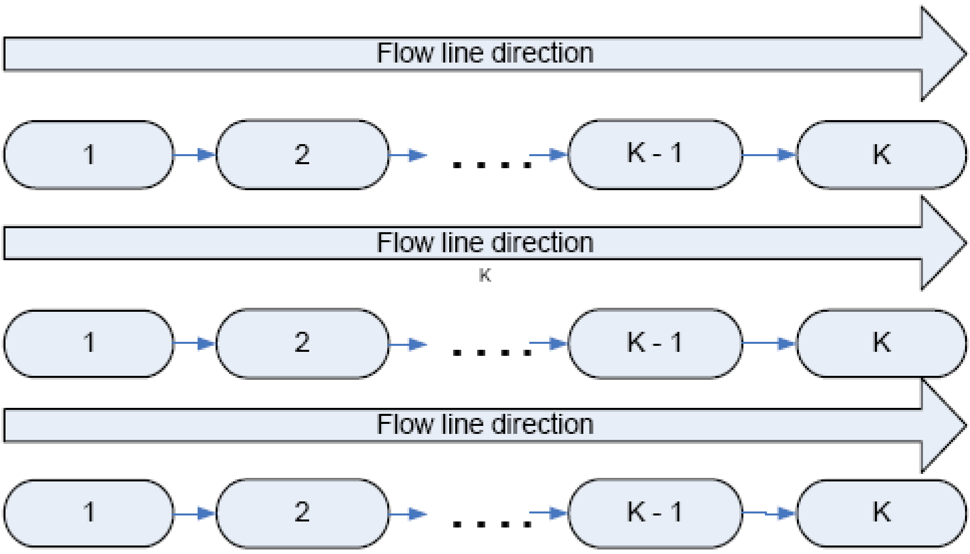


Figure 3 - Parallel assembly line.

Listed below are some of the main advantages of this type of assembly line [12]:

- Cycle time can be more flexible;
- Lower risk of machine breakdown stopping production;
- Increased flexibility for mixed-model systems.

U-shaped assembly lines: In U-type assembly lines, as the name suggests, the assembly line is arranged in a form of a U (Figure 4). In this type of assembly lines, operators work closer to each other, this results in an improvement of communication, and in case of emergency they are able to help each other more effectively [13].

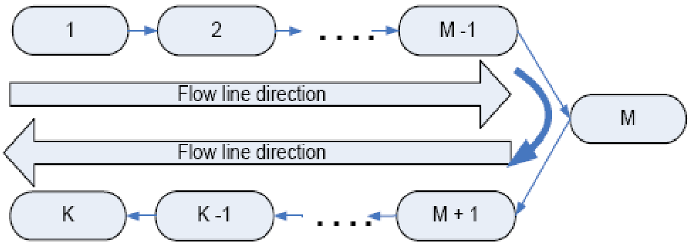


Figure 4 - U-shaped assembly line.

With this type of layout, in case of breakdown, lines have better performance with the presence of buffers [14]. This happens because the buffer spaces between the cross station may be larger in U-shaped lines. Some advantages of this kind of layout are:

- Since workstations are closer together the transportation times are reduced.
- Operators are more involved in the manufacturing process and this factor contributes to a better professional development;
- Stations can be easily revisited if needed.

Two sided assembly lines: Two sided assembly lines are ideal when manufacturing larger products such as automobiles, trucks, busses and large construction machinery. Instead of single working-place, there are pairs of two directly facing stations (Figure 5) that allow more than one worker to operate simultaneously on both sides of the assembly line. This fact makes the line much more flexible [15].

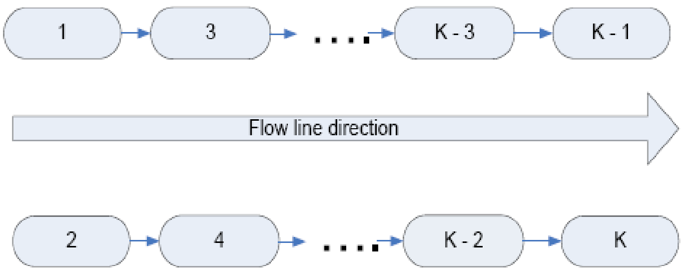


Figure 5 - Two sided assembly line

Two sided assembly lines, when compared with serial assembly lines, have the following advantages:

- They can reduce unnecessary work reaching to the other side of the workpiece;
- Can shorten the overall line length.

2.1.1.5 Objectives characteristics

Depending on the number of objective functions used for their optimization, assembly lines can be divided in two types: **single objective and multi objective**.

Single objective lines normally aim two optimize functions such as minimization of cycle time, reduction of workstations, maximization of line efficiency, optimization of smoothness index and minimization of design cost. The CT minimization helps reducing the production time of parts in the assembly line and it can be helpful in reducing to the idle time in different stations. Reduction of the number of workstations is used when a new assembly line is designed. It can help to reduce the investment cost by making less stations for the desired output production. In assembly lines there is variation in the workload of all stations from the cycle time of the line. The smoothness index is used to reduce these deviations by minimizing the overall differences of workload of each station from the line CT. Smoothness index given by:

$$SI = \sqrt{\sum_{j=1}^{m} [CT - t(S_j)]^2} \tag{2}$$

In real life manufacturing environment, many times the goal of industrial and process engineers is to satisfy two or more objectives simultaneously (**multi objective**). The problem with this is that most of these objectives conflict with each other. Usually, achieving one objective may have significant results but at the same time another objective of the same assembly line can be sacrificed. So, solutions for multi objective assembly lines are a tradeoff between objectives. In order to improve some aspects others must be compromised [16].

2.1.1.6 Task time characteristics

In this category, assembly lines are divided in three types: fixed task time, varying task time and stochastic task times. When talking about a production line that manufactures simple products and where machines are very reliable, is expected that the task time does not change. In this case the task time is considered a fixed variable what makes planning and management of the line easier [17].

However, in real life assembly lines, task times can vary due to several reasons such as operators experience (specially in manual operation), uncertain breakdown of machines, workers fatigue, poorly maintained equipment, defect in the raw material, etc. Assembly lines in which the task time is considered an unknown variable are called stochastic assembly lines. In this type of lines, planers use something called robust analysis for line balancing. In robust analyses the objective is to try to find a solution or a set of solutions that perform well when compared with the worst possible scenarios [18].

2.1.2 Types of supply to assembly lines

There are three main principles of supply to an assembly line: **continuous supply, batch supply, and kitting** [19]. These principles are differentiated depending on whether a selection of part numbers, or all part numbers, are supplied at the assembly station and whether the components are sorted by part numbers or assembly objects (Table 3).

Table 3 – Types of material supply

	Selection of part numbers	All part numbers
Sorted by part	BATCH	CONTINUOUS
Sorted by assembly object	KITTING	-

However, in later research, a fourth principle named **sequential supply** is identified [20].

2.1.2.1 Continuous supply

In continuous supply, materials are delivered to the assembly station in units, which are best suitable for handling, and the units are replaced immediately when they are empty in the line [19]. All part numbers required for producing a certain product will be always available in assembly lines. The refilling of parts in the assembly line is usually done by the store operators, in fixed bins or in a two-bin system.

The main advantage of this type of supply method is that preprocessing of the parts is not necessary and, more often there will be continuous availability of stock at the assembly line [21]. On the other hand, this method as some disadvantages as well. For example, if there are excess numbers of parts to be assembled in the line, a huge capital must be invested for maintaining the stock. At the same time the shop floor will be overcrowded by the parts and operator will spend a lot of time moving parts here and there and looking for the right part numbers.

2.1.2.2 Batch supply

Batch supply consists of supplying the line with a specific number (batch) of assembly objects [19]. It will usually be a batch of necessary part numbers or a batch of specific part numbers in required quantity. This type of supply differs from continuous supply in some senses. First, only small quantities must be stored at the assembly line and that different part numbers are filled at different points in time. Second, the job of returning the left-over materials to the warehouse after completion of the batch of assemblies is eradicated in batch supply. However, there is a need for counting the parts supplied, which involves technical and administrative systems.

2.1.2.3 Kitting

When using the concept of kitting, parts are delivered to the assembly line in kits where each unit contains the different components for one assembly object. This type of supply is recommended for assembly lines with parallelized flows, product structures with many part numbers, when there is a high requirement for quality assurance and for components with a high price. A disadvantage of kitting is that the internal transportations at the plant is increased. Also, if the material is fragile, kitting is not recommended since the risk for damage is increased when repackaging [22]. However, this type of supply also offers some advantages such as:

- Saving assembly space in the shop floor [21];
- Reduces the time spent by the operator searching and walking in the assembly line [19];
- Better shop control by just feeding the kit containers rather than supplying every component container in the assembly system [21];
- Reduces material delivery to assembly stations by removing the need to supply individual component containers [21];
- Reduces the frequency of assembling the wrong component in the end product and missing parts in the end product [21];

2.1.2.4 Sequential supply

This type of supply was born due to the rapid increase in the product variants. This fact made continuous and kitting supplies very hard to apply in most cases. Continuous supply demands high capital investment and a lot of space at the assembly stations, and kitting is less advantageous as because only few components are assembled at each station.

In sequential supply (Figure 6), the part numbers required for any given product in production are displayed at the assembly stations. However before entering the final assembly line, a sequencing operation is needed [20].

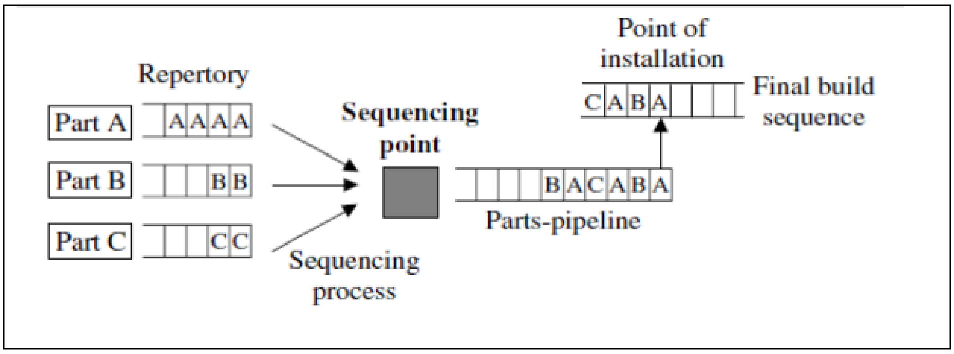


Figure 6 - Sequential supply

2.1.2.5 JIT (Just In Time)

Although the JIT concept does not refer to a specific type of supply to assembly lines, it is a philosophy that as some characteristics in this regard. In this philosophy areas that supply the assembly line with the different parts needed are used (Figure 7). These areas are called supermarkets [23].

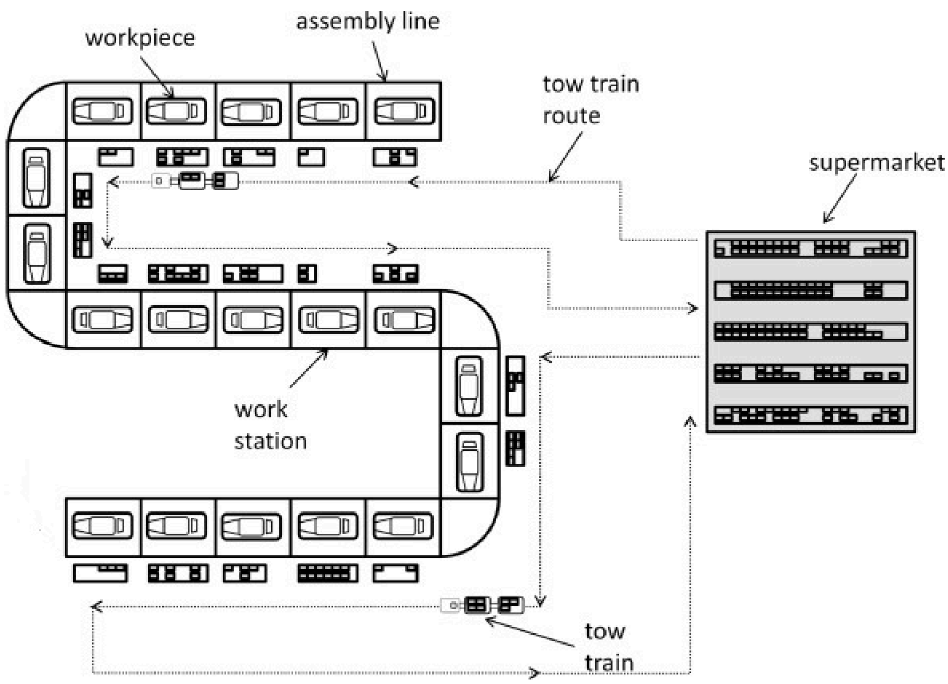


Figure 7 - Example of a plant layout with supermarkets [23]

In supermarkets the parts are divided into smaller boxes which are frequently fed to the assembly line [24]. By making frequently delivers of small containers to the assembly line, is possible to minimize the storage volume near the assembly line and reduce the longer distance deliveries that are needed in other cases. This supply is normally made by small tow trains that pick the demanded parts and deliver these parts in appropriate boxes. Also, when delivering the parts, the operators will collect the empty boxes in the assembly station. After collecting the empty boxes, the operator will return to the supermarket to refill them, and then will go back to the assembly line. This process is repeated throughout the day [23].

2.1.3 Flexibility and agility in assembly

In present times is possible to witness very important changes in the global markets for manufactured products. There has been an increasing demand for product variety as well as for shorter times to market. So, company's need to be able to cope with increasingly frequent changes both in products variants as well as variation I the volume of production. The main challenge in this is, keeping quality standards high, not sacrificing the lean philosophy and keep investing in value-adding activities. The two characteristics that make this possible are flexibility and agility. A company must have the flexibility to accommodate expectable changes in costumers demands (either are they in volume or in variety of products), and the agility to respond positively to the unexpectable ones. As sometimes the difference between these two concepts is not very clear, in this chapter both will be discussed.

2.1.3.1 Flexibility

The **concept of flexibility** was born in the 1970s, however its definition can sometimes be a little ambiguous. Some interpretations of flexibility include:

- It can act as a filter and absorber of external disturbances that may cause disorder [25];
- Can be defined as the potential of adaptation to external changes. In other words, it is the ability that a certain system haves to maintain its equilibrium and efficiency [26];
- The organization’s ability to meet an increasing variety of customer expectations without excessive costs, time, organizational disruptions, or performance losses [27];
- The capability of an organization to move from one task to another quickly and as a routine procedure [28].

As it is possible to see, the term flexibility does not possess a single definition however it always associated with the robustness of the process and how to improve/maintain the quality of the products manufactured.

As has already been said in the beginning of this chapter, the **need for flexibility** comes mainly from uncertainties of the market and variety of products. However other reasons for investing in flexibility may include:

- Demand uncertainty;
- Shorter life cycles of products;
- Shorter life cycles of technologies;
- Wider product range;
- Customization;
- Instant delivers.

Regarding the **types of flexibility** is possible to define four categories [29]. Table 4 summarizes these four categories:

Table 4 - Types of flexibility

Type of Flexibility	Description
Volume	Amount of parts needed to satisfy market demand.
Product	The ability to produce new/different products.
Mix	It is the ability of a process to handle variety of product mixes in simultaneous.
Delivery	Delivery flexibility copes with high uncertainty and low variety as well as low uncertainty and high variety.

2.1.3.2 Agility

As it happens with the term flexibility, **agility** does not have a single specific definition. Many authors offer different interpretation of this term, however, it is possible to establish a certain pattern. Agility is more associated with the capability of a company to adapt to new products, dealing with threats and creating opportunities. In a sense, it is a more proactive approach to change. Following, are some definitions that support this idea:

- The ability to accelerate the activities on a critical path that commences with the identification of a market need and terminates with the delivery of a customized product [30];
- The ability of an enterprise to respond quickly and successfully to change [31];
- The organization's capacity to gain competitive advantage by intelligently, rapidly and proactively seizing opportunities and reacting to threats [32];
- It is the ability to both create and respond to change in order to profit in a turbulent business environment [33].

For an organization to be considered agile, there are nine main areas in which it must invest [34]. These areas are:

- Design of product and processes;
- Process planning;
- Production scheduling, planning and control;
- Design of facility and location;
- Material handling systems;
- Information system;
- Supply chain;
- Human factors;

- Business practices and processes.

Summarizing, the difference between agility and flexibility is that agility deals with all the areas mentioned in a context of extreme uncertain changes of business environment, whereas flexibility remains in a context of expected and minor changes in manufacturing environment.

2.1.3.3 Flexibility *vs* agility

To have a better understanding of both concepts, a comparison between them is necessary. Here are some measures in which is possible to distinguish flexibility from agility [35]:

Diversity of Product Creation: in this measure flexibility follows a strategy of engineer to order and agility a strategy of innovate to order. In the engineer to order strategy, only small modifications are made to the product in order to minimize the impact in the manufacturing process. In the strategy of innovate to order new products are designed from scratch making the most of existing competencies and enhancing competencies where needed.

Intensity of Changes Faced: both agility and flexibility address a changing environment however, the level of intensity in the nature of these changes is different. Flexibility deals with predictable changes and uses predetermined strategies to deal with these changes. On the other hand, agility has the ability to neutralize unpredictable changes by using innovative responses.

Individual Vs Group of Systems: flexibility and agility also can be distinguished according to the type of system in which they focus. Flexibility focus mainly in an individual system of the manufacturing system. Agility however, addresses a larger group of systems all interconnected.

Constituent Elements: regarding its constituent elements, flexibility is more concerned with equipment and processes. Agility in the other hand, is more focused on the structure an in the business network.

Variety and Responsiveness: Flexibility works very well when medium variety is required. Agility, on the other hand, focuses on swiftness of response against any uncertain change. Responding to the change quickly with smaller cost and less effort differentiates agility from flexibility.

Final comparison: For better understanding both concepts, is important to see their differences and similarities. Table 5 summarizes the differences between both concepts:

Table 5 - Differences between agility and flexibility

Agility	Flexibility
Copes with unexpected changes	Copes only with expected changes
Ability to be profitable tomorrow	Ability to be profitable today
Is applicable at strategic level	Is applicable at process level
Emphasis on system	Emphasis on resources
Is a proactive approach	Is a reactive approach
Focuses directly on customers	Focuses indirectly on customers
Is applicable at design stage	Is applicable on execution stage

Some similarities between agility flexibility are:

- Focuses on changes in customer demands;
- Enables to be profitable in uncertainties;
- Takes input from forecasting;
- Has potential of adaptability.

2.1.4 Automated assembling processes

The definition of automated assembling processes is applied to systems that use mechanized and automated devices to perform the various assembly tasks in an assembly line or cell. These systems are mainly designed to fixed sequence of assembly on certain product. They are appropriate when a process has the following characteristics:

- High product demand;
- Stable product design;
- Limited number of components to be assembled (normally a maximum of twelve parts);
- The product is designed specifically for automated process.

Although these systems usually have a higher initial investment associated than traditional assembly lines, they can be more financially attractive to the organization. This happens because the production rate is much higher, the quality of the products is higher and easier to control, and the line is usually smaller, which saves space within the factory.

Some products typically made by automated assembly lines are:

- Alarm clocks
- Ball bearings
- Ball point pens
- Cigarette lighters
- Door mechanisms
- Gear boxes
- Light bulbs
- Locks
- Mechanical pencils
- PCB assemblies
- Small electric motors
- Wrist watches

2.1.4.1 Systems configuration

The most common configuration associated with automated assembling lines are:

- In-line;
- Dial-type;
- Carousel;
- Single station.

In-Line: This configuration is basically a straight line where a series of automatic workstations are located along conveyor (Figure 8).

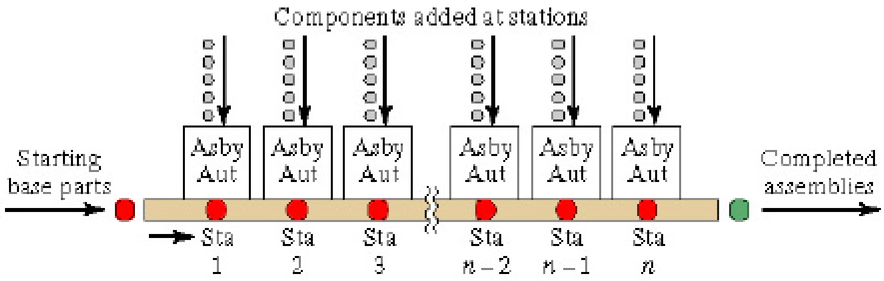


Figure 8 - In-Line configuration

Dial-Type: in this configuration parts are loaded in to fixtures or nests around the periphery of the circular dial, and—as the dial table turns—components are assembled sequentially onto the base part (Figure 9).

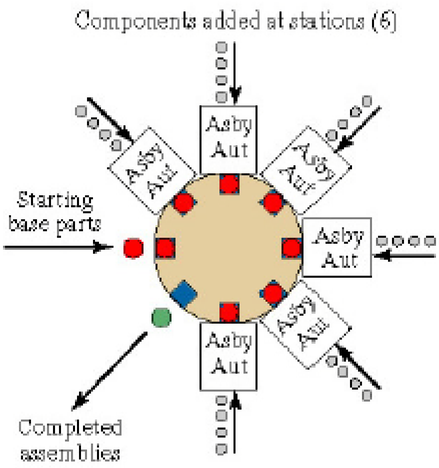


Figure 9 - Dial-Type configuration.

Carousel: the carousel configuration is essentially a hybrid between the circular work flow of the dial-type assembly machine, and the straight work flow of the in-line system (Figure 10).

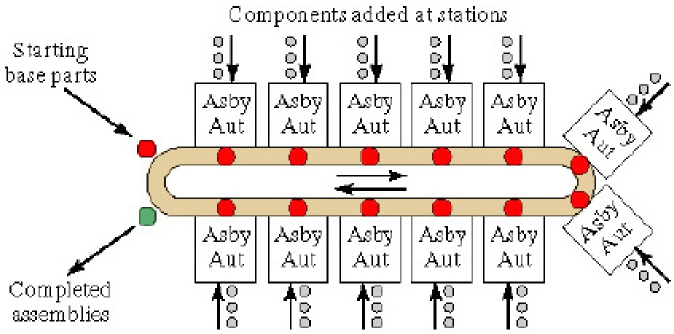


Figure 10 - Carousel configuration.

Single-Station: the single station configuration consists in a single workstation where all components are assembled onto a main part (Figure 11). Once all the components have been assembled, this main part leaves the system. This configuration is inherently slower than the other three system configurations, manly because only one main part is assembled at a time.

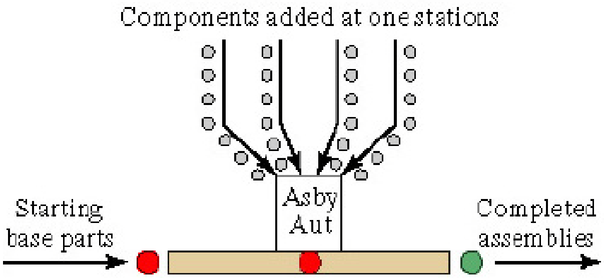


Figure 11 - Single-Station

2.1.4.2 Parts Delivery at Workstations

The feeding of parts to the automatic assembly lines represents a major role in assembly. Parts must be fed in correct amounts, sequence and position to the assembly line to achieve a correct assembly. This is made by an automatic delivery system (Figure 12) that consists in the following five pieces of hardware:

- Hopper;
- Parts feeder;
- Selector and orientor;
- Feed track;
- Escapement and placement device.

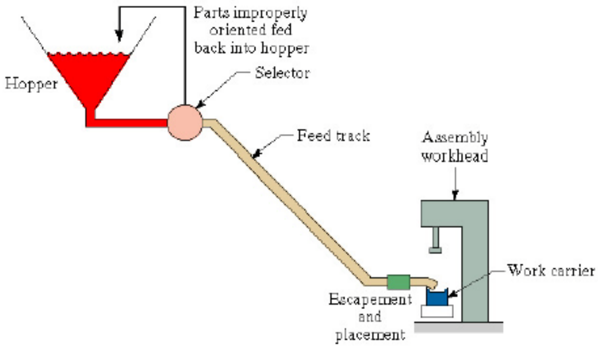


Figure 12 - Delivery system hardware

Hopper: the hopper is the container in the workstation in which the parts to be assembled are loaded (Figure 13). The parts are usually randomly oriented in the hopper.

Figure 13 - Hopper mounted in a conveyor [36]

Parts Feeder: This hardware has the task of removing the components from the hopper to the feed track. Usually the parts feeder is connected to the hopper to form one unit. One example of this is the typical Vibratory Bowl Feeder (Figure 14).

Figure 14 - Vibratory Bowl Feeder and Feed Track [37]

Selector and orientor: these devices are found in the parts feeder and have the task of defining the proper position of the components. The selector works as a filter that only allows correctly oriented parts to continue, and the orientor re-orients parts that are not correctly oriented (Figure 15).

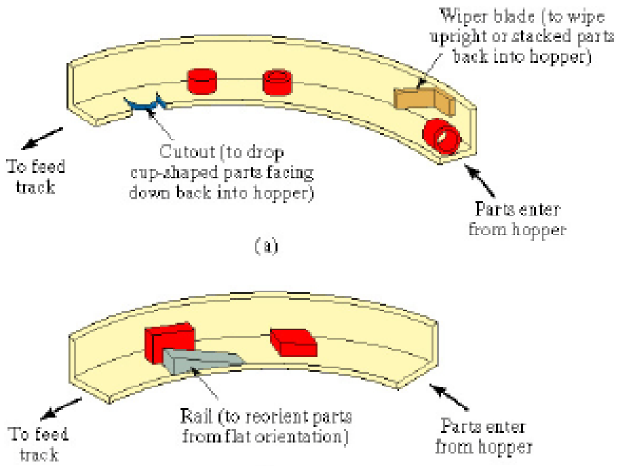


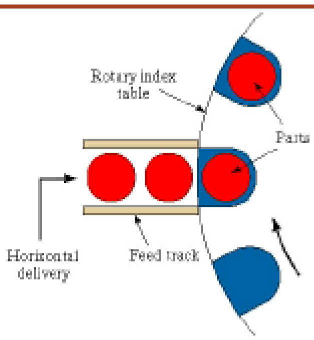
Figure 15 - Selector and orientor

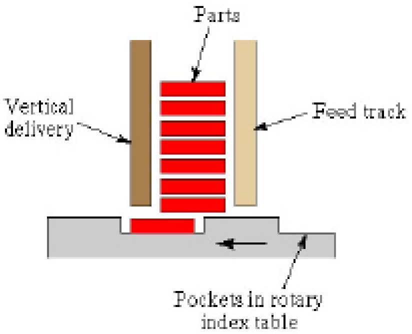
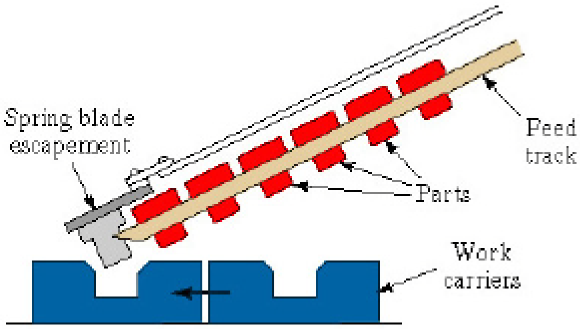
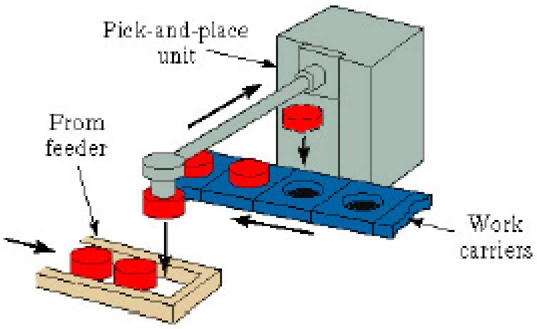
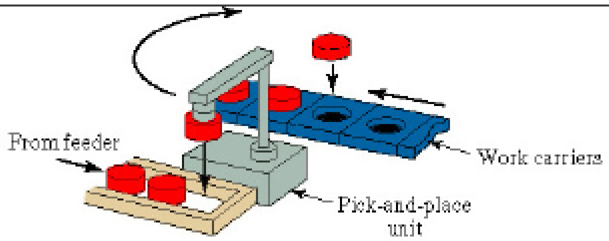
Feed track: the feed track is the pathway along which the components pass from the hopper and parts feeder to the assembly workhead. Feed tracks are divided in two categories:

- Gravity - hopper and feeder are placed at a higher position than the workhead;
- Powered - uses air or vibration to move parts toward workhead.

Escapement and placement device: the purpose of these two devices is to remove components from the feed track (escapement) and physically placing them in the correct location at the workstation for the assembly operation (placement). These devises can be combined into a single operating mechanism. Table 6 shows some typically used escapement and placement devices.

Table 6 - Escapement and placement devices

Device	Description
	Horizontal placement device: parts are fed horizontally to a dial-type machine. As the dial machine rotates, parts are always delivered to the empty slots.

Device	Description
	Verica placement device: it is very similar to the horizontal placement device, but parts are fed vertically instead of horizontally.
	Escapement device: this device is actuated by the top of the carrier contacting the lower surface of the rivet-shaped part, causing its upper surface to press against the spring blade, which releases the part into the work carrier nest.
	Pick and place mechanism (1): This mechanism uses a pick-and-place unit with a horizontal arm that may be extended and retracted as necessary, so that parts may be removed from the feed track and placed into work carriers.
	Pick and place mechanism (2): this mechanism uses a pick-and-place unit with a revolving arm, so that parts may be removed from the feed track and placed into work carriers.

2.1.4.3 Guidelines for designing and operating of automated assembly systems

Some guidelines for the design and operation of automated assembly systems and the products made on such systems include:

- The parts delivery system at each station must deliver components to the assembly operation at a net rate greater than or equal to the cycle rate of the assembly workhead;
- Component quality has an important effect on system performance - poor quality means:
  - Jams at stations that stop production;
  - Assembly of defective components in the product.
- As the number of stations increases, uptime efficiency and production rate are decrease. This is due to parts quality and station reliability effects;
- The slowest workstation of the assembly system is the one that dictates the cycle time;
- When comparing with a multi-station assembly system, it is possible to say that a single-station assembly cell that has the same number of tasks, achieves a lower production rate but a higher uptime efficiency;
- Multi-station assembly systems are recommended when high production applications and long production runs are desired;
- By comparison, the cycle time of a single-station assembly cell is greater than a multi-station assembly system. Because of this, this system is more appropriate for production of mid-range quantities;
- On partially automated production lines, in order to isolate the manual stations from breakdowns at the automated stations, storage buffers should be used;
- An automated station should only be substituted for a manual station if it has the effect of reducing cycle time sufficiently to offset negative effects of lower reliability.

2.2 Ergonomics

Ergonomics can be defined as the study of the interaction between people, machines and the factors that affect the interaction. Its purpose is to improve the performance of production systems by improving human machine interaction [38]. Some ways in which productions systems can be improved consist in:

- Designing the user-interface to make it more compatible with the task and the user. This makes it easier to use and more immune to errors that people are known to make;
- Changing the work environment to make it safer and more appropriate for the task;
- Changing the task to make it more compatible with user characteristics;
- Changing the way work is organized to accommodate people’s psychological, and social needs.

In simplified terms, the main objective of ergonomics is to improve the production system by eliminating the negative aspects usually associated with them. These aspects generally include:

- Inefficiency;
- Fatigue;
- Accidents and injuries;
- User difficulties;
- Low morale.

Although the subject of ergonomics is crucial to a good work environment, its applicability is sometimes very hard. One of the barriers to its applicability is due to the enormous physical variability among the general population. To overcome this challenge, is necessary to develop a set of solutions that cover the larger amount of people possible. This is achieved by analyzing anthropometry statistical data of the population.

2.2.1 Ergonomic rules

There are some general practical guidelines for the proper designing of workstations. These guidelines can be translated into seven rules [39].

The first rule says that any bent or unnatural posture of the body should be avoided always. Figure 16 shows an example of bad posture because of bad designing.

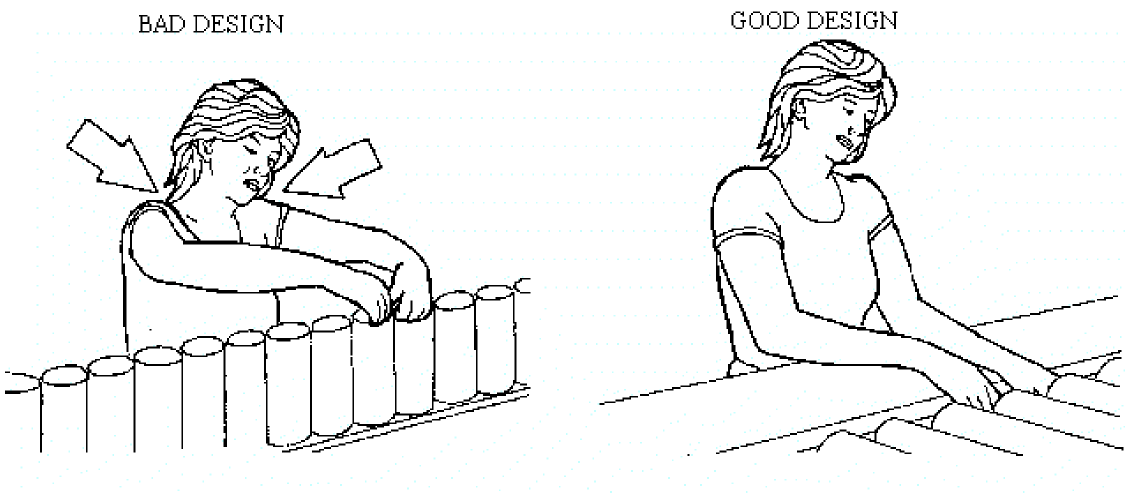


Figure 16 - Influence of bad design in body position

The second rule says to avoid immobility of the arms extended, forward or to the side, as this leads to fatigue and decreased precision and dexterity of movement.

The third rule says that, whenever possible, standing positions should be avoided.

The fourth rule tells us that the movement of the arms must be in the opposite direction each one or in symmetrical direction.

The fifth rule says that the height of the work surface should allow optimal visual observation with the most natural body posture possible. Figure 17 shows an example of a task that requires that the height of the work bench is elevated to allow a good visualization of the whole process.

Figure 17 - Elevated work surface

Basically, as the visual requirements for the operation increase, the closer the work surface should be to the operator.

The sixth rule tells us that handles, levers, tools and work materials should be arranged on the workplaces in such a way that the movements more frequently done are with the elbows bent and close to the body. This position allows the arms to find a support to rest on the work surface. If the arms are always away from the trunk tension in the muscles will be created, and therefore causing fatigue.

The seventh rule says that in continuous manual labor (in seated position), the workstation should have supports for the arms and elbows to rest. These supports should be covered in soft material and height adjustable.

2.2.2 Standing Workstation Height

When dimensioning a workstation, several factors must be considered. Some of these factors may be the proper body posture, necessary bodily movements, reaches of the movements, anthropometry of occupants, lighting needs, ventilation, dimensions of machines, equipment and tools [40].

One of the parameters to take in consideration in designing of the workstation is the height of the worksurface. In this case, it is difficult to choose one of the extremes in which to work, since the bench should not be too high because lower people would have to raise their shoulders and arms to compensate for distance, but also should not be too low because taller people would have to bend the trunk (Figure 18).

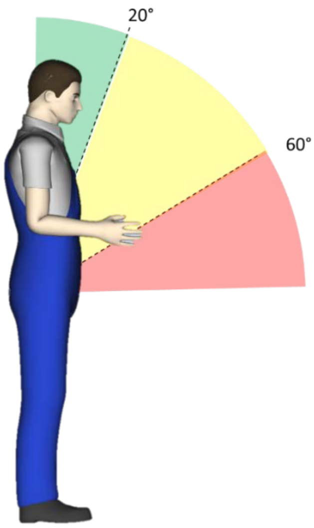


Figure 18 - Upper body bend limits

Some authors argue that the height of the bench depends on the height at which the elbows are found. In standing work, the recommended heights are 50 to 100 mm below the elbow. So, being that the average height of the elbows in males is 1050 mm and in females 980 mm, the recommended height would be:

- Between 950 mm and 1000 mm for man;
- Between 880 mm to 93 mm for woman.

The type of work to be carried out, also influences the height that the bench must have. Thus:

- For delicate work, support for the elbows is desired. This way, the trunk muscles will be relieved from tension. The appropriate height is between 50 and 100 mm below elbow height.
- In manual activities, space may be required for containers, tools and work materials. The appropriate height would be 100 to 150 mm below the elbow height.
- If the standing job requires the use of relative strength and uses the help of trunk weight, then lower heights are appropriate (for example, to work with wood or heavy work assemblies). The appropriate height is 150 to 400 mm below the elbow height.

In Figure 19, the various possible heights depending on the type of work to be performed are shown. The ideal solution for dealing with these problems, would be using height adjustable tables. In this way the height recommendation would be always followed no matter the height of operators or the type of work performed [39].

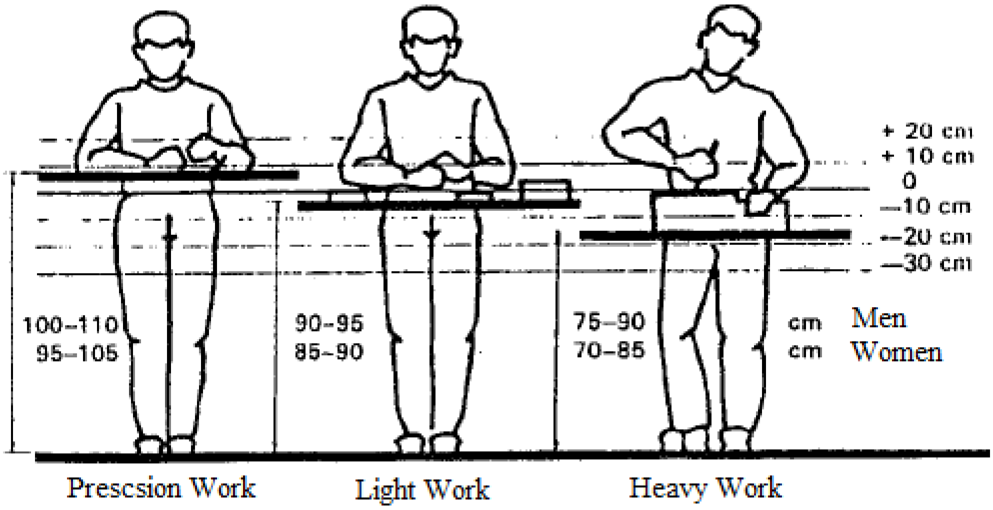


Figure 19 - Recommended work heights for various types of work

In the impossibility of having a height adjustable table, taller people should be privileged, since the adoption of solutions for the lower people is simpler.

In some countries, anthropometric measures are already adopted as standards and, in addition, there are specific rules for sizing of certain products [40]. Figure 20 shows the recommended dimensions for a standing workstation according to the French standard AFNOR X-35-104: 1980.

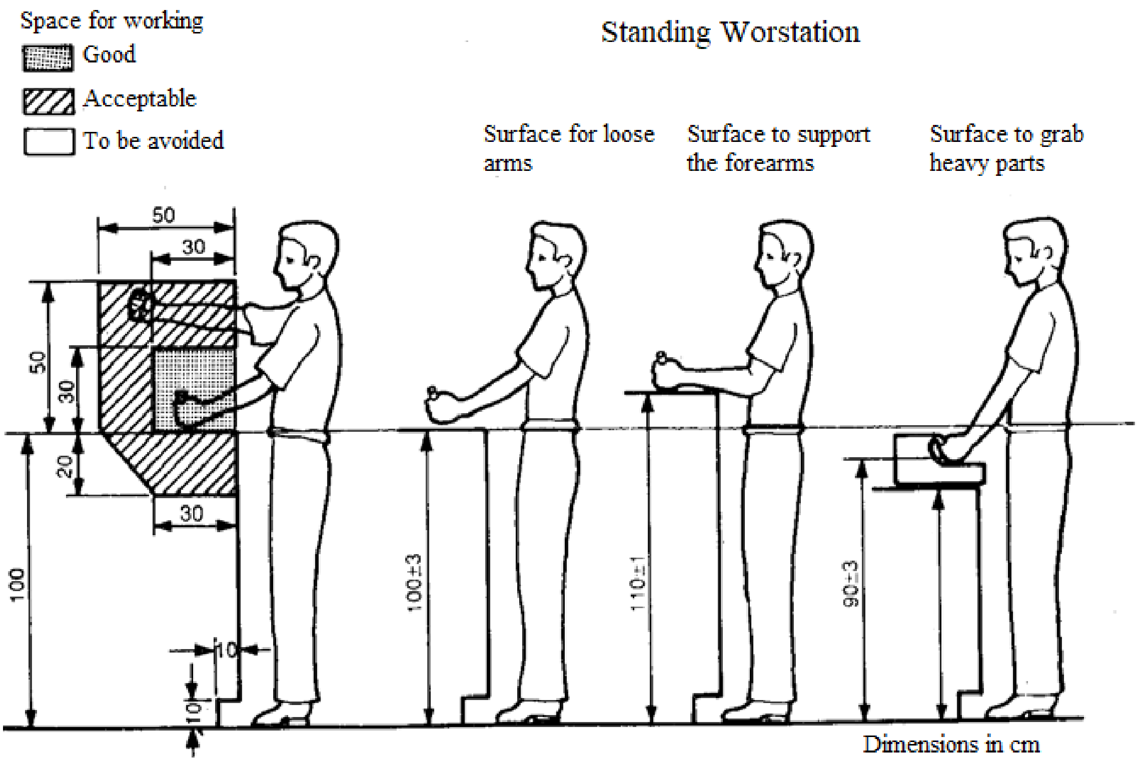


Figure 20 - Recommended standing work positions according to AFNOR X-35-104

As rule of thumb, some authors suggest that all objects that are to be used by standing individuals should be located between hip height and shoulder height to minimize wrong postures [38]. The height of the work surface should be approximately the same as the height of the elbow, but the type of task to be performed should also be taken in to consideration. Table 7 shows the recommended work height depending on the work to be performed.

Table 7 - Bridger recommended heights depending on task performed (dimension in mm)

Task requirement	Male	Female
Precision Work	1090 – 1190	1030 – 1130
Light assembly work	990 – 1090	870 – 980
Heavy work	850 – 1010	780 - 940

Another standard usually used in dimensioning workstations, is the German standard DIN 33 406: 1988. Regarding the minimum dimensions that should exist in the workplace this standard indicates some measures depending on the type of posture (sitting or standing). These measures are showed in Table 8 and Figure 21:

Table 8 - Minimum dimensions for workspaces according to DIN 33 406

Dimensions	Seated workstation (mm)	Standing workstation (mm)
Lateral free room, D	≥ 1000	
Sagittal free room, W	≥ 1000	
Depth, leg room T_1	≥ 350	≥ 80
Depth, feet room T_2	≥ 550	≥ 150
Free room height for legs, G	≥ 350	--
Free room height for feet, I	--	≥ 120
Width, legroom B	≥ 550	--

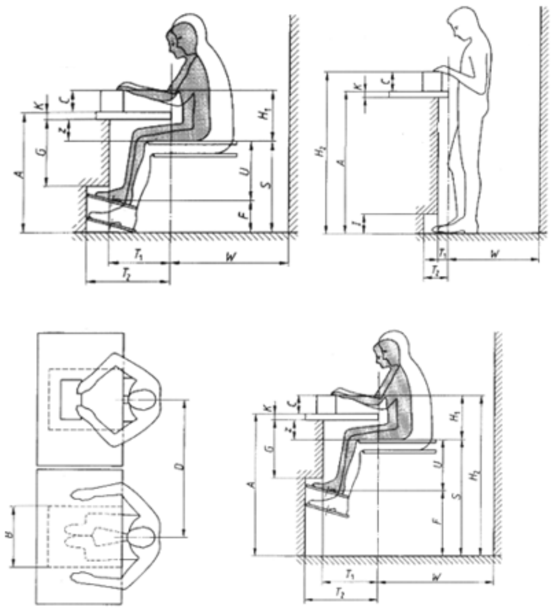


Figure 21 - Representation of minimum dimensions for workspaces.

Knowing that working height can positively or negatively influence a person's performance, DIN 33 406: 1988 defined, according to the different percentiles and to the person's gender, which reference values should be used for this parameter. Table 9 shows the recommended values for standing positions.

Table 9 - DIN 33 406: 1988 recommended working heights

Working demands	Work Height			
	5%		95%	
	Female	Male	Female	Male
High demands for: • Visual inspection; • Fine motor skills.	1100	1200	1250	1350
Medium demands for: • Visual inspection • Fine motor skills	1000	1100	1150	1250
Low demands for: • Visual inspection High demands for: • Elbow-room	900	1000	1050	1150

Figure 22 shows the reference values for the jobs, according to the gender of the person and the type of task to be performed.

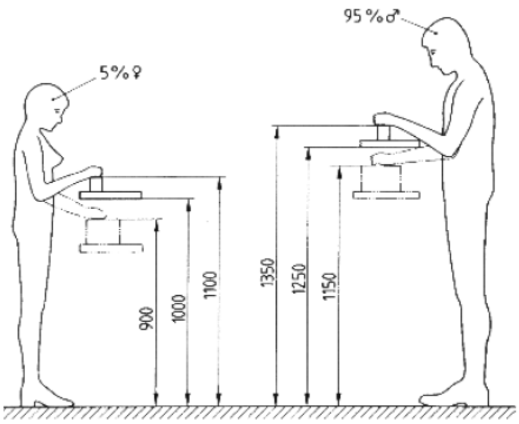


Figure 22 - Standing working heights males/female according to DIN 33 406

According to this standard, if the workbench is not adjustable, the laying of worktops is not recommended as they represent a greater risk of accidents, restrict mobility in the workplace and are unsuitable as a solution for adapting operators with different heights in the same workstation. When both men and women work there in the same workstation, the arithmetic measure of the reference should be the 5th man percentile and the 95th woman. The 5th man percentile represents approximately the height of the 50th woman percentile and the 95th woman percentile corresponds approximately to the 50th percentile-man [41].

2.2.3 Working Reach Zone

Reach zone refers to how containers, equipment, and operating elements are displayed in the workstation. They must be easily accessible, and operators should not have to rotate the torso to reach them. In Figure 23 it is possible to see the three groups in which these reach zones are divided. Each zone has specific rules that should be respected [42].

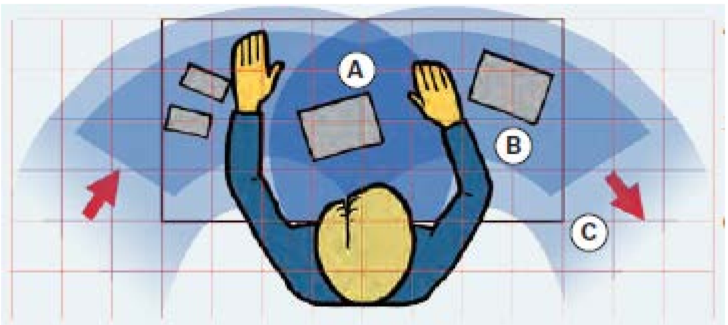


Figure 23 - The three areas in a workstation

Center of work, two-handed zone (Area A):

- Optimum for operating with two hands, as each hand will reach this zone and are within the employee's field of view;
- For precision movements;
- Possible to handle lighter weights and additionally permits the improvement of review and coordination activities;
- Forearm movements only;
- Only smaller muscles groups are used;

Large reach zone (Area B):

- For gross motor movements;
- Area designated for tools and components that are typically grabbed with one hand;
- Upper and lower arm movements without required use of shoulders or torso rotation.

Extended one-hand zone (Area C):

- For occasional handling, e.g. of empty containers or transferring components to a position where the next employee can reach them without difficulty;
- With shoulder and torso movement.

2.2.4 Height Range

Range is related to the movements necessary to make in order to perform a given task. It is usually related to tasks of grabbing and / or operating manual controls or pedals. Thus, it is intended to determine the maximum height that can exist, so that people with smaller physical dimensions can reach a certain object or control. Therefore, the 5^{th} percentile should be used as reference because if these people are accommodated all the others will be. It is also considered a one-way limitation since only one extreme of the population are considered [43]. In Figure 24 is showed a representation of the minimum limits of posterior reach of males and females (5^{th} percentile male and female), using as reference the axis of articulation of the shoulder. This figure also indicates the range that can be reached when making sporadic movements with the help of simultaneous movement of the shoulders and trunk without any damage [39].

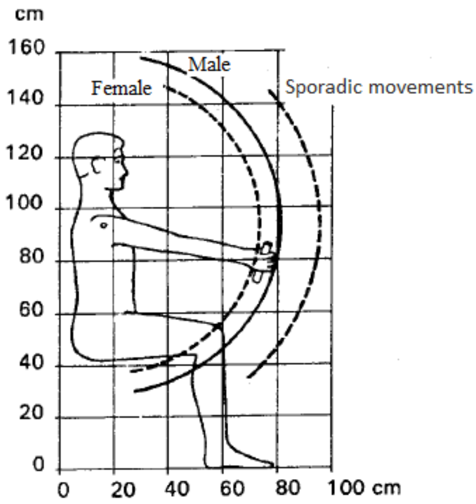


Figure 24 - The minimum limits of posterior reach of males and females

In Table 10, are showed the maximum distances reached by men and women considering the different percentiles (5th, 50th and 95th).

Table 10 - Maximum distances reached by males and females [39].

		Percentile	Range height (mm)
Female	Tallest	95	2060
	Medium	50	1930
	Shorter	5	1800
Male	Tallest	95	2180
	Medium	50	2060
	Shorter	5	1950

In a seated position the highest shelves should be at:

- Between 1500 and 1600 mm for men;
- Between 1400 and 1500 mm for women.

At this height, the shelves can be accessible up to a depth of 600 mm.

In standing position, the shelves recommended height can be calculated using the following expression [39]:

$$Maximum\ reach\ height = 1.24 \times height \quad (3)$$

2.2.5 Loads

As the strength of an individual can vary according to various factors such as age, sex, and training, it is necessary to define the limits for the handling of loads required of the operators. So, when studying the maximum loads limits allowed, the individuals with less force should have priority because if they do not have problems the rest will not have problems either.

The maximum strength of a muscle or group of muscles is dependent on: age, sex, constitution, degree of fitness, and motivation of the moment [39]. It is also important to note that, women have about 2/3 of men's strength. The maximum force that can be reached when working in standing position is shown in Figure 25:

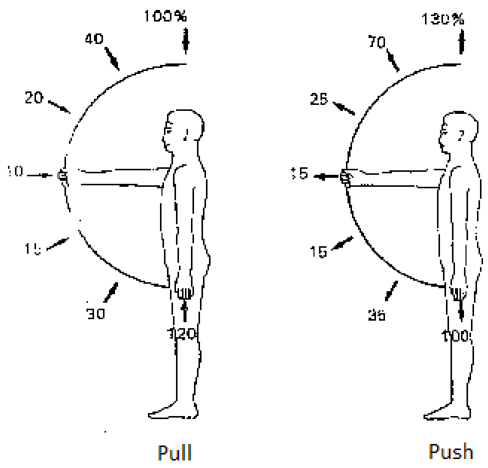


Figure 25 - Maximum force that can be reached when working in standing position (pull and push)

Some conclusions related to working in a standing position are:

- When standing in most arm positions, the pushing force (pressure) is greater than the pulling force;
- The pushing and pulling forces in the vertical position are the highest and in the horizontal position the lowest.
- The pushing and pulling forces in the sagittal position is of the same order as with the arm extended to the sides.
- The force of pushing in the horizontal position in men reaches 160-170 N and in women 80-90 N.

2.2.6 Good practices to have when handling heavy loads

The handling of loads (especially the lifting of loads) should be considered heavy work. The main problem with handling heavy loads is not so much the requirement of the muscles but the wear of the intervertebral discs [39]. The position adopted when lifting heavy loads directly influences the wear of the intervertebral discs, and for this reason some care is essential. Some basic consist in having the legs bent and the back straight, as shown in Figure 26.

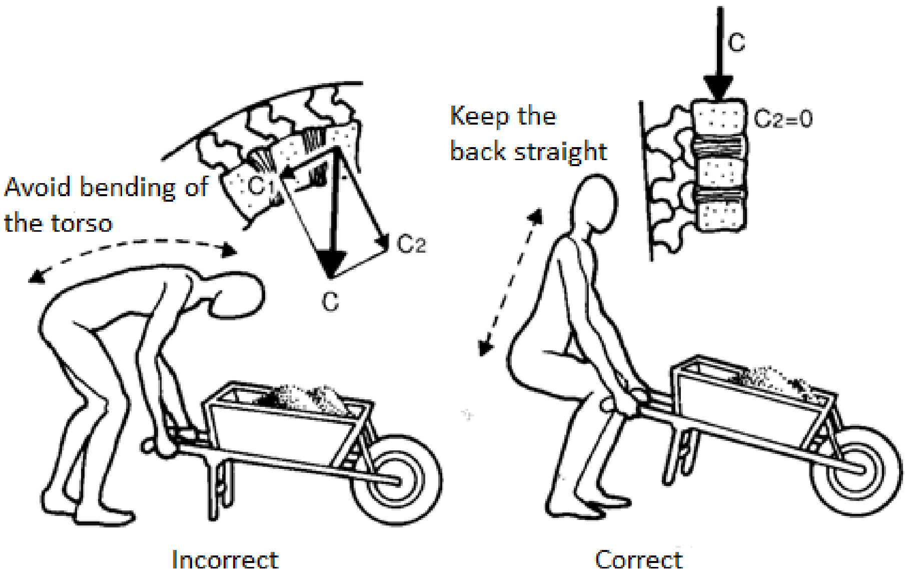


Figure 26 - Incorrect and correct posture for lifting a hand cart.

The wear of the intervertebral discs can result in problems in the spine and legs causing pain and limiting the mobility of operators. Diseases of the spine may lead to a prolonged absence from work and today are considered one of the main causes of premature disability.

Some other ways of avoiding accidents when handling loads are:

- Using mechanical equipment for lifting heavy loads;
- Ask for support, when moving heavy and bulky loads operators should ask for help whenever possible;
- Avoid trunk rotation, one should always rotate the entire body;
- Team coordination, one person should assume the coordinating role and give the team clear instructions for lifting and transporting.
- Carrying loads close to the body and well-balanced;
- Avoid obstructed vision, it is important to have unobstructed vision on the entire carrying course;
- Using Personal Protective Equipment (PPE);
- Whenever possible, one should push rather than pull;
- Using transport equipment with appropriate tires and bearings, and do not overload transport equipment;

Table 11 shows illustrations to help the better understanding of the ways of avoiding accidents mentioned above:

Table 11 – Correct and incorrect positions when handling heavy loads

Advice	Correct	Incorrect
Ask for support		
Avoid trunk rotation		
Team coordination		
Carrying loads close to the body		
Carrying loads well-balanced		
Avoid obstructed vision		

2.2.7 Maximum loads allowed in manual handling

The limit values for the manual transport of loads depend on several factors, which may be of individual risk (personal factors) or inherent to the work (material factors). The material risk factors are: weight, load location (vertical and horizontal), frequency / duration, stability (bulky or compact object according to its center of gravity), handle (quality / structure and shape), geometry of the workplace and the environment (noise, temperature, vibrations, etc). Regarding personal factors they are: gender, strength (within the same sex there are differences), age (muscle strength decreases with age), physical condition, body dimensions and proportions (anthropometry) training.

There are several studies that intend to determine the maximum limits for lifting loads however, it is necessary to consider all the external factors mentioned above that relativize this type of studies. Therefore, the determined limit values should only be considered as general guidelines as they only reduce the risk of spinal injuries.

Table 12 shows the recommended maximum weight limits for loads, depending on the handling frequency:

Table 12 - Maximum recommended limits in kg for handling heavy loads

Frequency of lifting and / or manual transport (in % of one 8 hours day work)	Male			Female		
	Training			Training		
	High	Medium	Low	High	Medium	Low
0 – 17	50	40	30	30	20	15
18 – 54	32	25	18	16	12	9
55 – 82	20	14	9	9	6	4
83 – 100	10	6	3	5	3	1

The maximum load capacity varies considerably, depending on whether the muscles of the legs, arms or back are used. Women have about half the strength of men for lifting weights. To calculate the maximum weight values that can be carried, the horizontal and vertical distance between the load and the body should be taken into consideration. This way and according to the existing principles for lifting loads, the lifting capacity will be smaller the greater is the distance between the load and the body.

The Institute for Occupational Safety and Health (NIOSH) has developed a method for assessing limits for manual lifting of loads that may pose a health risk to employees. The NIOSH equation consists of multiplying a load constant (23 kg) by multipliers of a horizontal, vertical, distance, asymmetry and frequency nature. The following formula is used to calculate the Recommended Weight Limit (RWL):

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (4)$$

Their multipliers are explained in Table 13:

Table 13 - Multipliers of NIOSH equation

Multiplier	Definition	Formula/Constants
LC	Load Constant	$LC = 23\ kg$
HM	Horizontal Multiplier	$HM = 25/H$
VM	Vertical Multiplier	$VM = 1 - (0.003) \times \lvert V - 75 \rvert$
DM	Distance traveled Multiplier	$DM = 0.82 + (\frac{4.5}{D})$
AM	Asymmetry (trunk rotation) Multiplier	$MA = 1 - (0.0032 \times A)$
FM	Frequency and duration of lifting activity	Value dependent on the frequency of elevations
CM	Coupling or quality of the workers grip on the object	Value depending on the quality of the handle

In Figure 27 below, the distances H, V and D are shown.

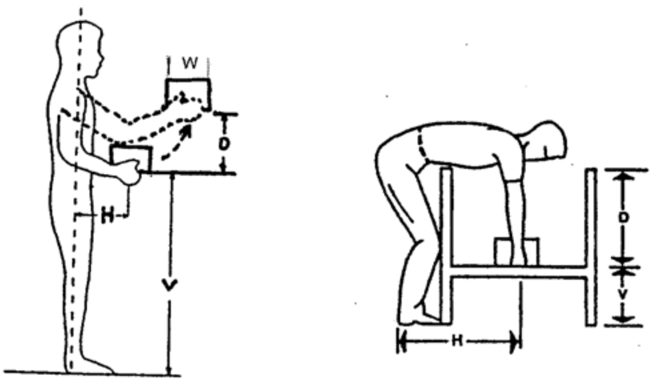


Figure 27 - H, V and D distances

The coupling multiplier depends on handle factors such as the ease of handling, the dimensions and shape of the handle. Table 14 shows the various values depending on the quality of the handle.

Table 14 - Values for the coupling multiplier

Handle Quality	Coupling Multiplier	
	V < 75 cm	V ≥ 75 cm
Good	1.00	1.00
Acceptable	0.95	1.00
Poor	0.90	0.90

Figure 28 show the different types of handles and their classification.

Figure 28 - Types of handles and respective classification

The frequency multiplier (FM) is calculated by considering the duration of the period with lifting tasks, the vertical distance (V) and the frequency of elevations. Table 15 shows the values that the frequency multiplier can assume.

Table 15 - Values for the FM

Frequency (Elevations per minute)	Duration of the period with lifting tasks, T					
	T ≤ 1 h		1 < T ≤ 2 h		2 < T ≤ 8 h	
	V < 75	V ≥ 75	V < 75	V ≥ 75	V < 75	V ≥ 75
0.2	1,00	1,00	0,95	0,95	0,85	0,85
0.5	0,97	0,97	0,92	0,92	0,81	0,81
1	0,94	0,94	0,88	0,88	0,75	0,75
2	0,91	0,91	0,84	0,84	0,65	0,65
3	0,88	0,88	0,79	0,79	0,55	0,55
4	0,84	0,84	0,72	0,72	0,45	0,45
5	0,80	0,80	0,60	0,60	0,35	0,35
6	0,75	0,75	0,50	0,50	0,27	0,27
7	0,70	0,70	0,42	0,42	0,22	0,22
8	0,60	0,60	0,35	0,35	0,18	0,18
9	0,52	0,52	0,30	0,30	0,00	0,15
10	0,45	0,45	0,26	0,26	0,00	0,13
11	0,41	0,41	0,00	0,23	0,00	0,00
12	0,37	0,37	0,00	0,21	0,00	0,00
13	0,00	0,34	0,00	0,00	0,00	0,00
14	0,00	0,31	0,00	0,00	0,00	0,00
15	0,00	0,28	0,00	0,00	0,00	0,00
>15	0,00	0,00	0,00	0,00	0,00	0,00

Whenever possible, help auxiliary means should be used to transport loads. Such means may be:

- Hand cars;
- Mechanized systems;
- Rollers, small diameter tubes and skates;

- Suction cups, vacuum operated (glass transport);
- Tweezers or claws;
- Cranes;
- Magnet (transport of iron plates).

2.3 IGEL

The IGEL (Integrated Calculation of Load Limits) software has several methods to ergonomically evaluate production lines, jobs, tasks, MilkRun routes according to the characteristics of the tasks that are performed. In addition to making it possible to determine if the recommended limit values for load handling are respected, it provides indicators that can be extremely useful in assessing the risk of spinal injury (Lumbar spine load).

The software can be applied in different situations. According to the characteristics of the tasks to be evaluated, different methods are available to evaluate a global work place (Screening analysis) or a particular task (Detailed analysis). Some of the most common tasks evaluated are:

- Manual handling of loads;
- Activities where it is necessary to pull and / or push;
- Repetitive activities (> 30 actions per minute);
- Milk-Run Activities.

Each of the methodologies, besides considering the conditions in which the task is performed, considers individual risk factors, such as age and sex and physical preparation [43].

2.3.1 NIOSH

Previously addressed, the NIOSH analysis, allows to evaluate activities of manual manipulation of loads, in order to prevent the risk of lumbar injuries, serving as support in the search of solutions for the improvement of jobs. The main result of the analysis is the RWL. The method also allows the assessment of the possibility of occurrence of these diseases through the load lifting condition, reflected in the single task lifting index (STLI) and the frequency independent lifting index (FILI).

2.3.1.1 STLI

From the recommended weight limit it is possible to calculate the elevation index, STLI. This index is defined by the ratio between the average weight of the load lifted and the recommended weight limit:

$$STLI = Average\ weight\ lifted/RWL \tag{5}$$

The average weight lifted is used to determine the STLI, as it gives a better representation of the required effort to perform the task. According to the obtained result, the tasks can be considered low risk, possible risk or high risk (Table 16):

Table 16 - STLI levels of Risk

STLI	Risk
≤ 1	Low Risk
1-3	Possible Risk
≥ 3	High Risk

2.3.1.2 FILI

The frequency independent lifting index reflects the compressive force exerted on the spine and the muscular strength requirements of each task. It is the result of the ratio between the maximum weight of the manipulated load and the recommended weight limit, not considering the frequency of the task. According to the obtained result the tasks are classified as being of low or high risk (Table 17).

Table 17 - FILI levels of Risk

FILI	Risk
<= 1	Low Risk
> 1	High Risk

2.3.1.3 Application Conditions

The following are the conditions for applying this methodology:

- Manipulated weights greater than 3 kg;
- Use of two hands;
- Constant movements;
- Horizontal distance to the object, less than 630 mm and vertical height to which the object is located, lower 1750 mm (measured from the ground to the center of the hands);
- Movement frequency less than 15 cycles per minute;
- Shift duration ≤ 8 h.

2.3.2 EN-1005-2: 2008

The EN-1005-2: 2008 method, such as the NIOSH method, aims to prevent and / or reduce the occurrence of issues related to manual handling of loads. The method allows evaluating tasks of manual manipulation of loads weighing more than 3 kg with one hand and / or performed by two operators. The analysis also provides as a result the recommended mass limit (RML) and the risk index (RI) [44].

2.3.2.1 RML

The RML according to EN 1005-2 is based on a maximum weight, which is referred to as the reference mass (M_{ref} = 25 kg). The M_{ref} is variable and can be modified to fit the manufacturing reality. It is still further adjusted by applying different multipliers (usually below the unit) to allow for deviations that the task has in relation to the optimum conditions. The equation for calculating the recommended weight limit is the following:

$$RML = Mref \times HM \times VM \times DM \times AM \times CM \times FM \times OM \times PM \times AT \qquad (6)$$

M_{ref} = reference mass (in kg);

HM = Horizontal multiplier (distance from operator to load, in cm);

VM = Vertical multiplier (vertical location of the load, in cm);

DM = Distance multiplier

AM = Asymmetry multiplier

CM = Handle multiplier;

FM = Frequency multiplier;

OM = 1 hand multiplier;

PM = Multiplier for tasks carried out by 2 people;

AT = Additional tasks multiplier.

OM: This factor penalizes operations done with only one hand, under these conditions the OM multiplier assumes the value of 0.6, otherwise OM = 1.

PM: Using two operators to pick a particular load can be used to reduce the load on an operator, but on the other hand creates additional risks due to the difficulties of coordinating the movements and forces exerted by both operators. The multiplier PM assumes the value of 0.85 if the handling of the load is performed by two persons, otherwise PM = 1.

AT: If additional physical requirements are required, such as push hold raise or walk, this multiplier assumes the value of 0.8 otherwise AT = 1.

2.3.2.2 RI

From the recommended mass limit, it is also possible to calculate the RI. This index is defined by the ratio between the weight of the load lifted and the recommended weight limit.

$$RI = Weight\ lifted/RML \quad (7)$$

This index provides an estimate of the physical effort to perform the task. According to the result obtained, the tasks can be of low risk, possible risk or high risk (Table 18):

Table 18 - RI risk levels

RI	Risk
≤ 8,5	Low Risk
0,85> RI <1	Possible Risk
≥ 1	High Risk

2.3.2.3 Application Conditions

The following are the conditions for applying this methodology:

- Manipulated weights greater than 3 kg;
- Transport by foot < 2 m (for example 2 or 3 steps);
- Shift duration ≤ 8 h;
- In relation to the NIOSH method, it is possible to analyze ne- or two-handed lifts, tasks carried out by one or two operators and considers additional physical requirements.

2.3.3 ISO 11228-1: 2003

This methodology is applicable in situations of lifting loads, weighing more than 3 kg, followed by manual transport at distances of more than 2 m. This method makes it possible to determine the RWL during the work shift in accordance with ISO 11228-1: 2003. For this purpose, the following variables are considered: posture, frequency, duration and type of handle. In the best scenario, as in the EN-1005-2: 2008 method the weight limit is equal to the reference mass (25 kg). Since the method also includes transport of the cargo, a risk analysis is carried out considering the weight of the load, the quality of the handle during transport, the position in relation to the body, as well as the frequency and duration the task [45].

2.3.3.1 RWL

The RWL according to ISO-11228-1: 2003 is based on a maximum weight, which is also referred to as a reference mass or load constant (LC = 25 kg). Like in other methods, this reference value is later adjusted through the application of different multipliers according to the deviations that the task presents in relation to the optimum conditions. The equation for calculating the recommended weight limit in this method is equal to the NIOSH (equation 4).

2.3.3.2 Risk evaluation

The risk assessment is performed in five steps:

- Step 1 – Evaluate the mass of the object is greater than the reference mass 25 kg;
- Step 2 – Evaluate if the frequency of lifts falls within the expected limits (see Table 15);
- Step 3 – Evaluate if the weight is below the recommended weight limit;
- Step 4 – Check if the accumulated weight (weight x carrying frequency) meets the established limits. The frequency should not exceed 15 lifts per minute (step 2) and the weight should not exceed 25 kg (step 1). In these circumstances the accumulated weight is 10000 kg for 8 hours of work. However, if the transport distance is considerable, the accumulated weight reduces to 6000 kg;
- Step 5 – Check if the recommended limits for the accumulated weight according to transport distance are respected (see Table 19).

Table 19 - Recommended limits for the accumulated weight according to transport distance

Carrying Distance	Carrying Frequency f_{max}	Cumulative Load m_{max}			Examples
m	min^{-1}	kg/min	kg/h	kg/8 h	
20	1	15	750	6000	5 kg × 3 times/min 15 kg × 1 time/min 25 kg × 0.5 times/min
10	2	30	1500	10000	5 kg × 6 times/min 15 kg × 2 times/min 25 kg × 1 times/min
4	4	60	3000	10000	5 kg × 12 times/min 15 kg × 4 times/min 25 kg × 1 times/min
2	5	75	4500	10000	5 kg × 15 times/min 15 kg × 5 times/min 25 kg × 1 times/min
1	8	120	7200	10000	5 kg × 15 times/min 15 kg × 8 times/min 25 kg × 1 times/min

2.3.3.3 Application Conditions

The following are the conditions for applying this methodology:

- Loads transportation;
- Push-Pull activities;
- Manipulated weights greater than 3 kg;
- Shift duration ≤ 8 h.

2.3.4 ISO 11228-2: 2007

This method allows to determine according to ISO 11228-2: 2007 the maximum force that can be applied in the pull-push movement. The methodology considers the maximum force that can be exerted in the muscles (FB-Basic force limits) and in the vertebral column (FC-compressive strength-limits). Subsequently these limits are adjusted according to the performance characteristics of the task. The frequency of accomplishment of the task, height of application of the force, distance traveled and the characteristics of the operator (sex / age) are considered [46].

2.3.4.1 FR-Risk evaluation force

The FR calculation is divided into four phases (Figure 29):

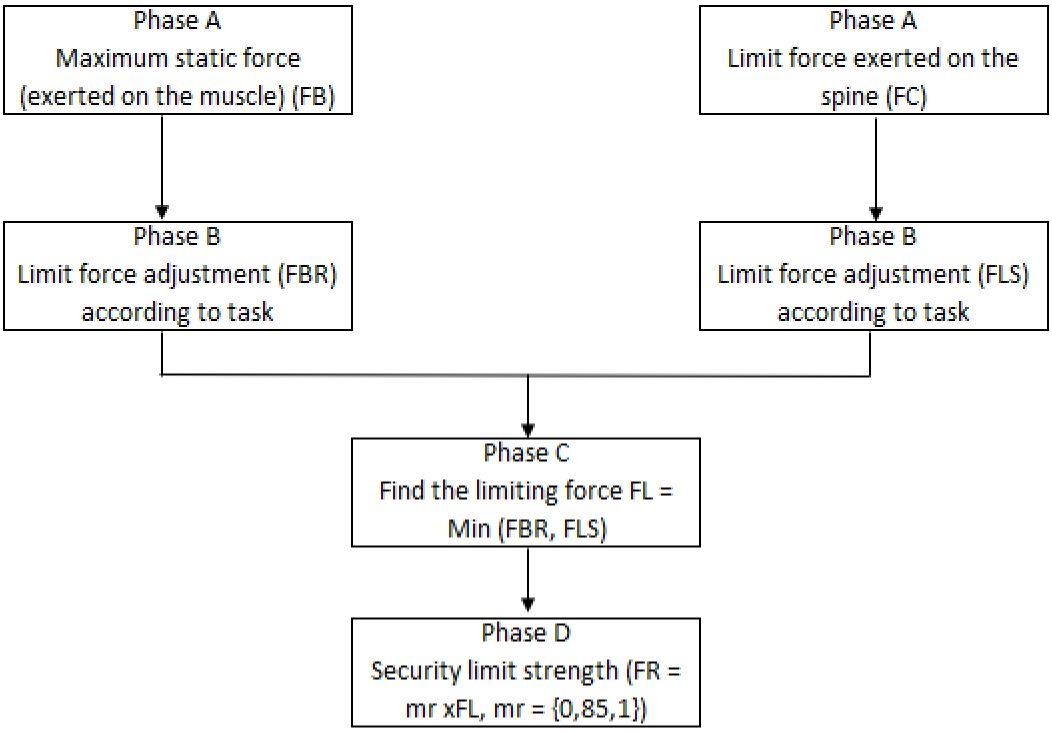


Figure 29 - FR calculation phases

The FR results, from the multiplication of the minimum force by a risk factor (mr).

- mr = 0.85 represents the maximum limit for the yellow-green zone;
- mr = 1.0 represents the maximum limit for the yellow-red zone.

For pull-push tasks it is essential to determine the initial force (to start the movement), and / or the sustained force (to keep the object moving). To evaluate whether the force applied falls within the calculated limits, it is necessary to measure the actual force exerted to pull / push the object for later comparison with the force obtained in the analysis. According to the distance traveled, the forces to be measured are those shown in Table 20.

Table 20 - Force to measure according to traveled distance

Distance (m)	Force to measure
≤5	Static force
>5	Dynamic force

2.3.4.2 Application Conditions

The following are the conditions for applying this methodology:

- Short distances (<5 m) and long distances (≥5 m);

- Different heights of handle;
- Working position (standing / walking);
- Forces exerted by two hands;
- Forces exerted to move or stop objects;
- Actions carried out by a single person;
- Forces applied without the use of external supports;
- Shift duration ≤ 8 h.

2.3.5 OCRA Checklist

The OCRA Checklist (Occupational Repetitive Actions) method is based on European Standard EN-1005-2: 2008 and ISO 11228-3: 2007 and seeks to assess the risk of upper limb musculoskeletal injuries. The construction of this method is based on the integration of five risk factors: recovery period, duration and frequency, strength, posture and additional elements (vibration, muscle contraction, precision and work rhythm) [48].

2.3.5.1 Frequency and duration factor

In a work cycle the total duration of activities involving repetitive and / or forced upper limb movements are important in determining the total exposure of the worker to risk. The OCRA analysis establishes the use of a multiplier taking into account the total duration (minutes), used in the execution of the repetitive activities, according to Table 21.

Table 21 - OCRA multiplier according to task duration

Duration (min)	Multiplier
60-120	0,50
121-180	0,65
181-240	0,75
241-300	0,85
301-360	0,93
361-420	0,93
421-480	1,00
>480	1,50

2.3.5.2 Strenght factor

Work activities that require repetitive actions of intense and / or moderate force, such as handling objects weighing more than 3 kg, handles held between the index finger and the thumb with lifting objects weighing more than 1 kg, pulling or pushing levers, loading commands, opening or closing, pressing or manipulating objects, and using tools, determine a score to assign to this factor.

2.3.5.3 Posture factor

The repetition of identical gestures for at least 50% of the cycle time constitutes a potential risk factor, as well as the execution of extreme movements and / or postures during 1/3 of the cycle time. The classification for posture is made through the association between the postures verified at the level of the upper limb (shoulder, elbow, wrist and hand / finger / handle), considering their duration in the work cycle and recording the highest value.

2.3.5.4 Additional factors

Although they are defined as additional, these factors are of equal importance, since they may be present or not in the contexts examined. These factors can be vibrations, precision work, localized mechanical compression, exposure to heat or cold, slippery surfaces, jerking or stretching, rapid movements, repeated impacts (use of a hammer on hard surfaces, for example), etc.

2.3.5.5 Recovery periods factor

Recovery period is the period during which muscles and / or tendons are at rest, such as intervals and lunch periods, visual control activities, periods of the cycle in which the muscles are at rest. Using as a starting point the existing literature, the ideal is a recovery period every 60 minutes of work, in the case of repetitive activities, during the work shift. The method presents six possible scenarios, to which specific scores on the distribution of the pauses are attributed, being chosen the one that best identifies with what the operator is exposed.

2.3.5.6 Application Conditions

The following are the conditions for applying this methodology:

- Activities carried out by the upper limbs;
- Repetitive activities (20 to 70 actions per minute);
- Hand weights less than 3 kg;
- Pull-push and pull activities (buttons, switches etc ...);
- Constant movements;
- Shift duration > 8 h (12 h is possible).

2.3.6 BOSCH method

The BOSCH method allows the evaluation of muscular fatigue and energy expenditure (metabolic rate), caused by the handling of different loads throughout the work shift. It also allows determining the maximum compressive force exerted on the vertebral column, more specifically on the L5 / S1 invertebral disc. This method is generally used to evaluate ergonomics in Milkrun tasks [43].

2.3.6.1 Maximum compressive force exerted on the vertebral column

The maximum compressive force exerted on invertebral disc (L5 / S1) that affects the lumbar region is calculated using the highest load handled during a work shift. The limits of strength stipulated for this methodology, are represented in Table 22:

Table 22 - Load limits considered in BOSCH method

Age (Years)	Women Fmax (kN)	Men Fmax (kN)
20	4.4	6.0
30	3.8	5.0
40	3.2	4.1
50	2.5	3.2
≥60	1.8	2.3

2.3.6.2 Metabolic Rate

Although the metabolic rate of an activity is not directly related to biomechanical factors, it plays an important role in the appearance of lumbar injuries. They may occur due to fatigue, incoordination or a biomechanical destabilization of the lumbar spine. Unnatural movements and working under stress can accelerate the onset of injuries. Therefore, the metabolic rate in cargo handling is important.

The metabolic rate translates the energy expended during load-handling activities and is determined by the personal characteristics of each employee. For a work shift of 480 minutes, the stipulated limits are 17 × 480 kJ for males and 11.5 × 480 kJ for females. For the calculation, there are mathematical expressions appropriate to the type of physical effort performed.

2.3.6.3 Application Conditions

The following are the conditions for applying this methodology:

- Milkrun activities;
- Cargo pulling, transport and lifting activities;

- Handling weights less than 3 kg;
- Shift duration > 8 h (12 h is possible).

THESIS DEVELOPMENT

3 DEVELOPMENT

In the development section the actual work developed in the hosting company will be described. The objective here is to explain the problems analyzed and present the solution found to solve the problem.

This section will begin with a small introduction to the hosting company where the practical part of this work was developed. After, the original manufacturing process will be described, and its issues pointed out. The section continues, and the reader will be presented with the process adopted for analyzing possible solutions and selecting the best one. With a solution chosen, the new manufacturing process will be explained to the reader as well as a general financial evaluation of the project.

3.1 Company presentation

This thesis was developed during a part of a professional internship at Bosch Building Technologies in Ovar.

Bosch is a world leading multinational engineering and electronics company headquartered in Gerlingen, near Stuttgart, Germany. The company was founded by Robert Bosch in Stuttgart in 1886. Bosch's core operating areas are spread across four business sectors:

- Mobility solutions;
- Consumer goods;
- Industrial technology;
- Building Technologies.

The principal objective of Bosch is to protect lives, buildings and assets. The product portfolio includes video surveillance, intrusion and fire detection, and voice evacuation systems, as well as management and access control systems. Professional audio and conferencing systems for voice, sound and music communication complete the range of products. Bosch Ovar is considered to be one of Bosch's leading video surveillance, communication and fire detection plants. Its products are installed and used in many iconic places such as the White House, Dubai airport or the US Navy.

3.2 General Introduction of the process

The assembly line studied in this thesis belongs to the Value Stream (VS) COMM and produces five different types of products. All the products manufactured in this assembly line are similar regarding the production flow seen in Figure 30.

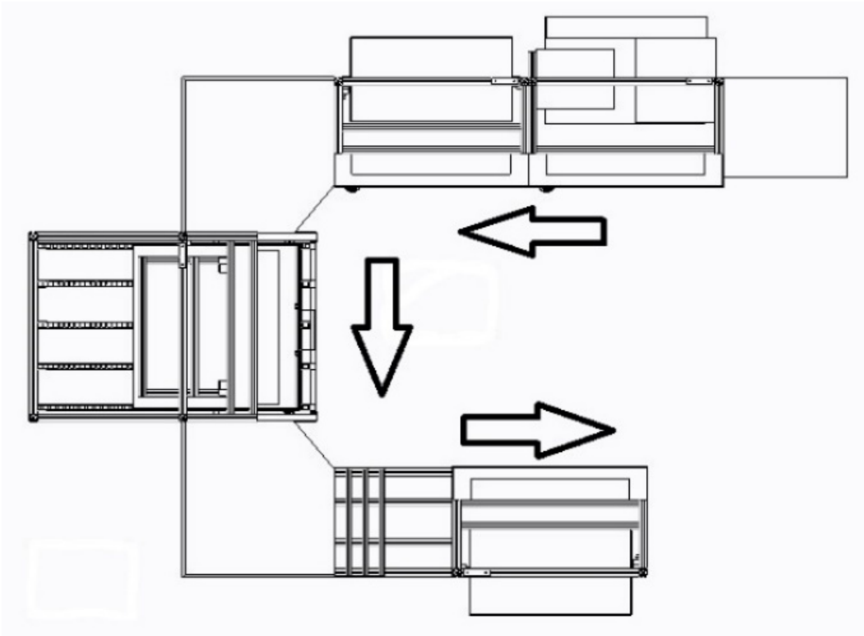


Figure 30 - Production flow

All products pass at least three different workstations where three different types of operations are performed. These operations are:

- Encasing, is the main assembly of parts. This operation is often divided in more than one workstation;
- Tests, where the product is subjected to a Functional Test (FcT) and High Voltage Test (HVT);
- Packaging, the last stage of production. Here the product is prepared to export.

3.2.1 Products manufactured

The products manufactured in this assembly line are:

- Dual Delegate Interface (DDI);
- Radiator Medium Power (M);
- Radiator High Power (H);
- Integrus Charging Case;
- Integrus Cabinet.

In Table 23, it is possible to see some relevant characteristics of all products manufactured.

Table 23 - Products manufactured

Description/Picture	Main dimensions (mm)	Weight (kg)
DDI 	200×100×35	0.69
Radiator M 	477.2×200×178	9.74
Radiator H 	477.2×300×178	13.1
Integrus Case 	688×514×224.4	17.38
Integrus Cabinet 	659×521×113	14.2

3.2.2 Assembly Line 18

The assembly line as shown in Figure 31 and Figure 32, is formed by two workstations for encasings (workstations 1 and 4), one workstation for testing (workstation 2) and one workstation for packaging (workstation 3). There are also two corners that supply the assembly line with materials, and one extra table to hold a vacuum peeler.

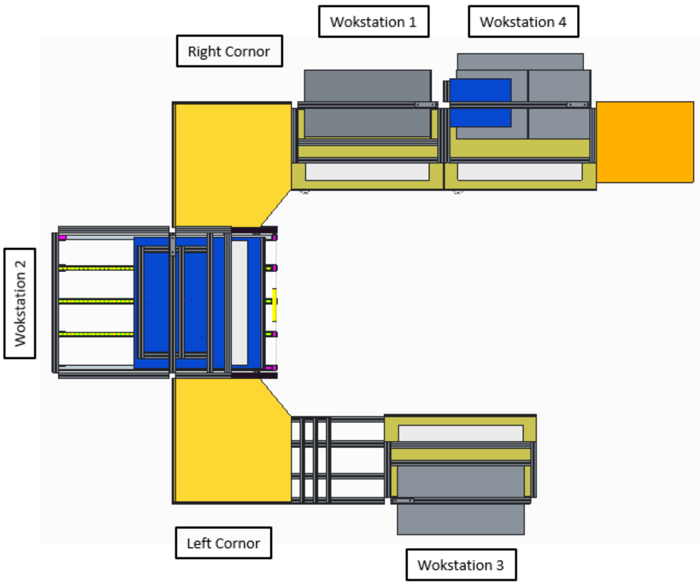


Figure 31 - Top view of L18

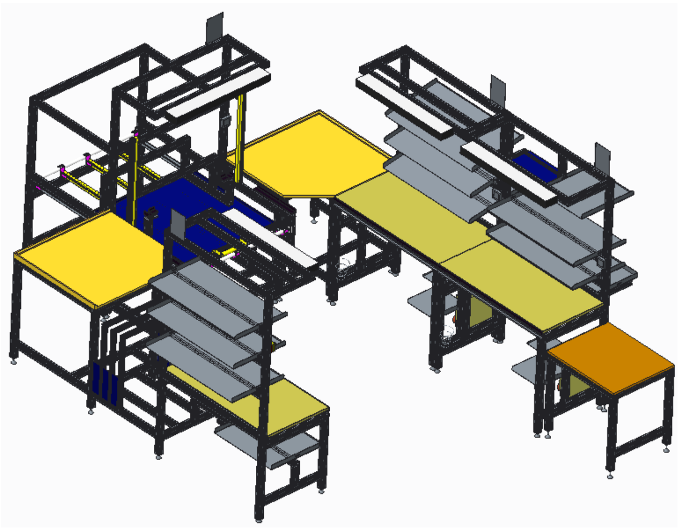


Figure 32 - Isometric view of L18

3.2.2.1 Workstation 4

Workstation 4 (Figure 33) is a Customer Acceptance Test (CAT) workstation but in this case, it is also used as an encasing station. Figure 33 is a 3D Computer Aided Design (CAD) representation of the workstation.

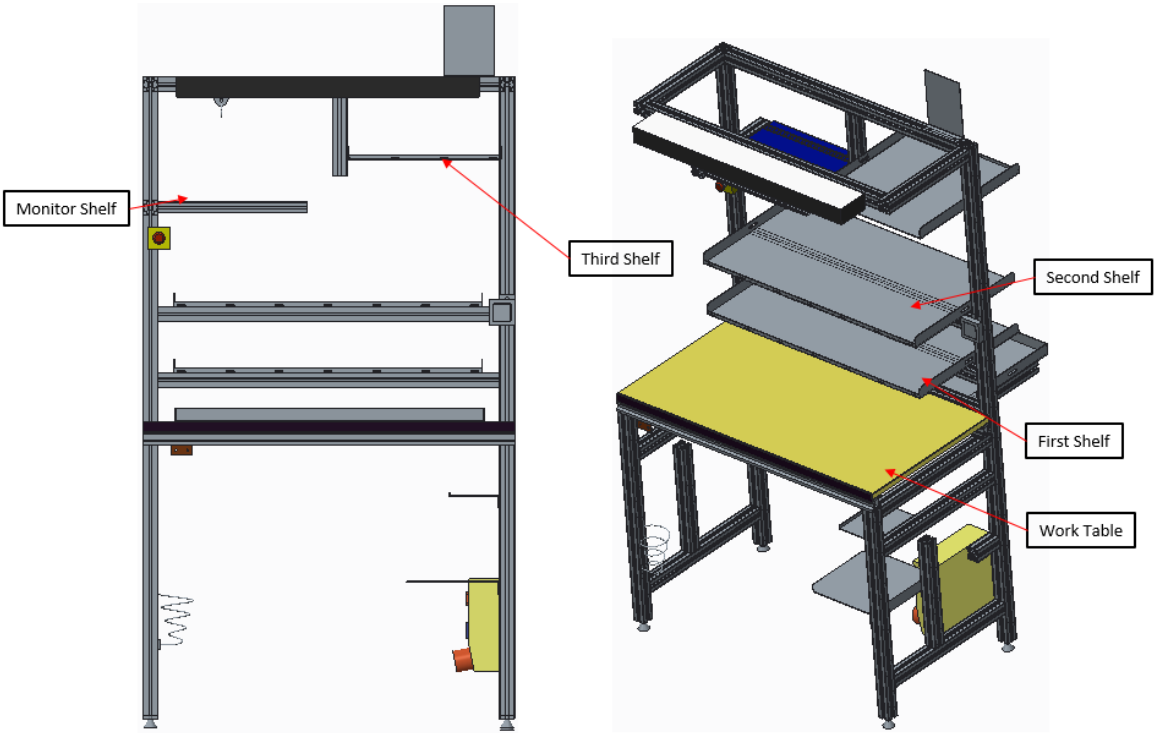


Figure 33 - Workstation 4

The main dimensions of the workstation 4 can be seen in Table 24.

Table 24 - Workstation 4 main dimensions

Location	Height (mm)	Width (mm)	Depth (mm)
Work Table	920	1100	580
First Shelf	1050	909	490
Second Shelf	1245	909	490
Monitor Shelf	1555	440	350
Third Shelf	1685	450	495

3.2.2.2 Workstation 1

Workstation 1 is a standard assembly workstation used in many assembly lines within the factory. Figure 34 is a 3D CAD representation of the workstation.

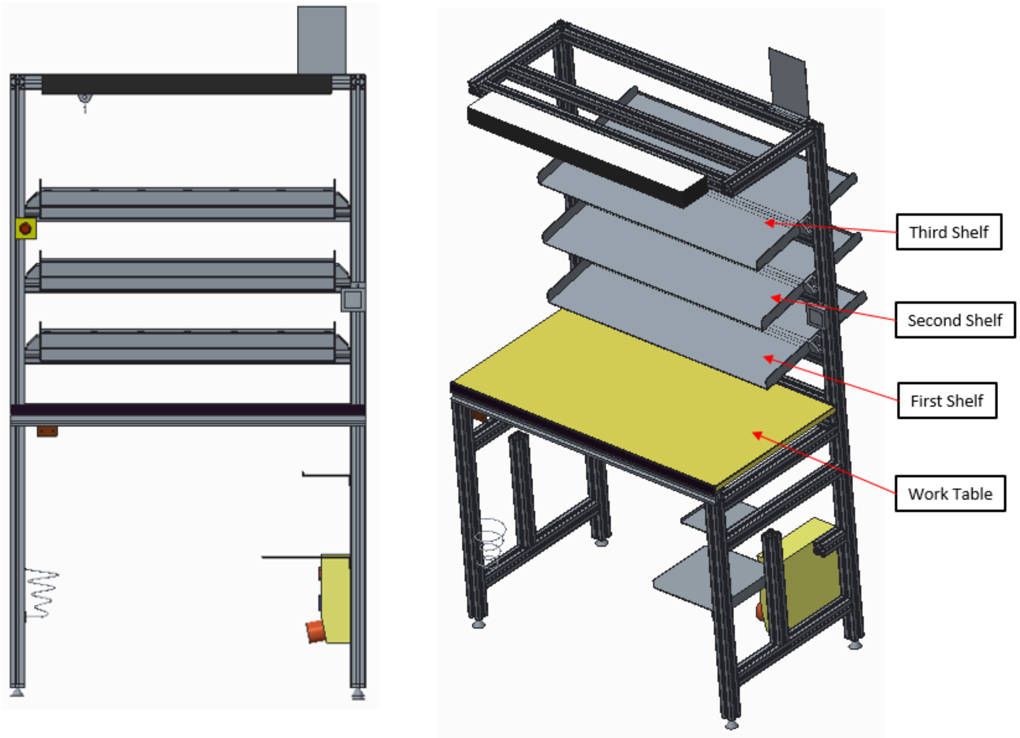


Figure 34 - Workstation 1

The main dimensions of workstation 1 can be seen in Table 25.

Table 25 - Workstation 1 main dimensions

Location	Height (mm)	Width (mm)	Depth (mm)
Work Table	920	1100	580
First Shelf	1070	909	490
Second Shelf	1290	909	490
Third Shelf	1510	909	490

3.2.2.3 Workstation 2

Workstation 2 is the test station where both the FcT and HVT are performed. This is a custom workstation specifically designed for the products manufactured in this assembly line. Figure 35 is a 3D CAD representation of the workstation.

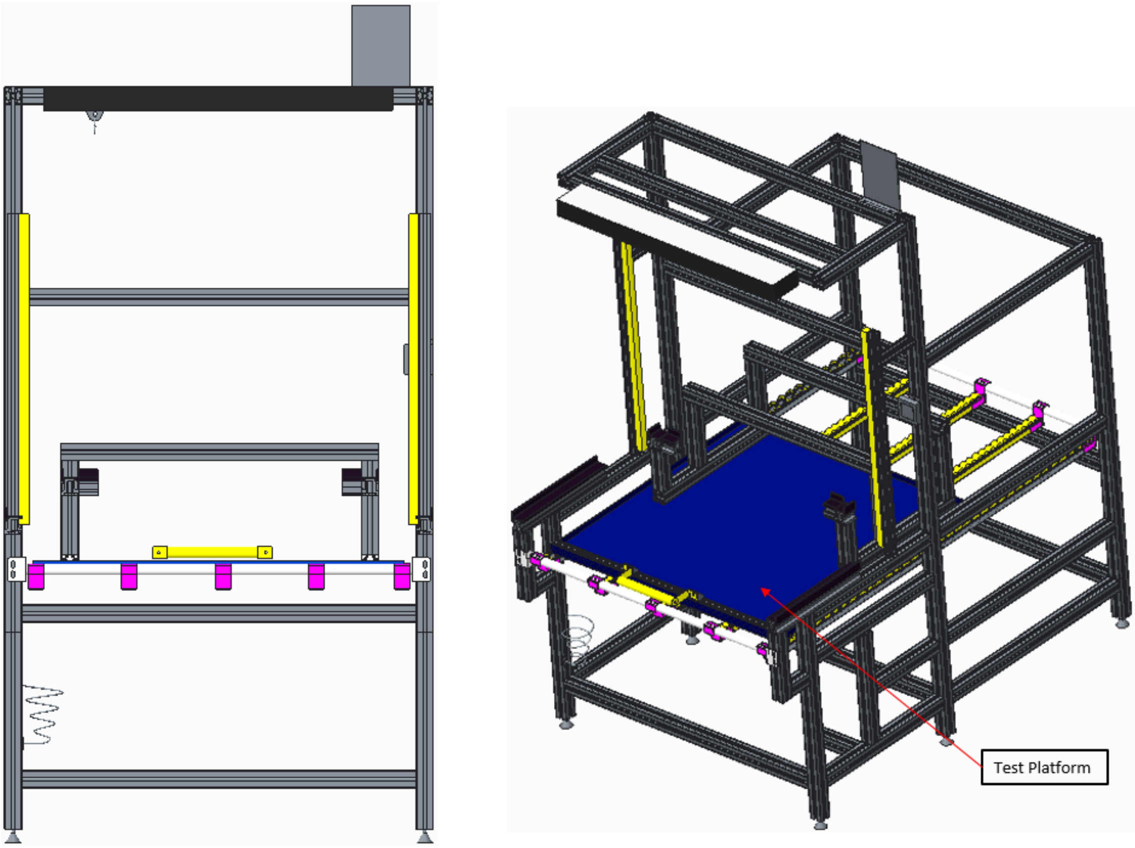


Figure 35 - Workstation 2

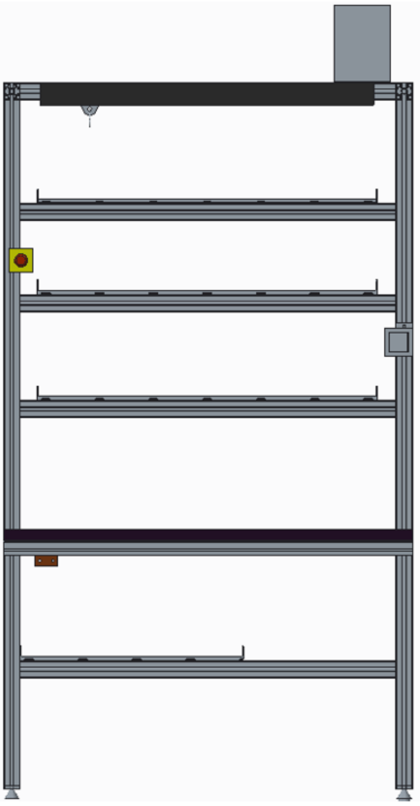
The test platform dimensions are shown in Table 26.

Table 26 - Workstation 2 dimensions

Location	Height (mm)	Width (mm)	Depth (mm)
Test platform	690	950	950

3.2.2.4 Workstation 3

In workstation 3, is where all products are packed and prepared for transportation back to the warehouse. Figure 36 is a CAD representation of the workstation.



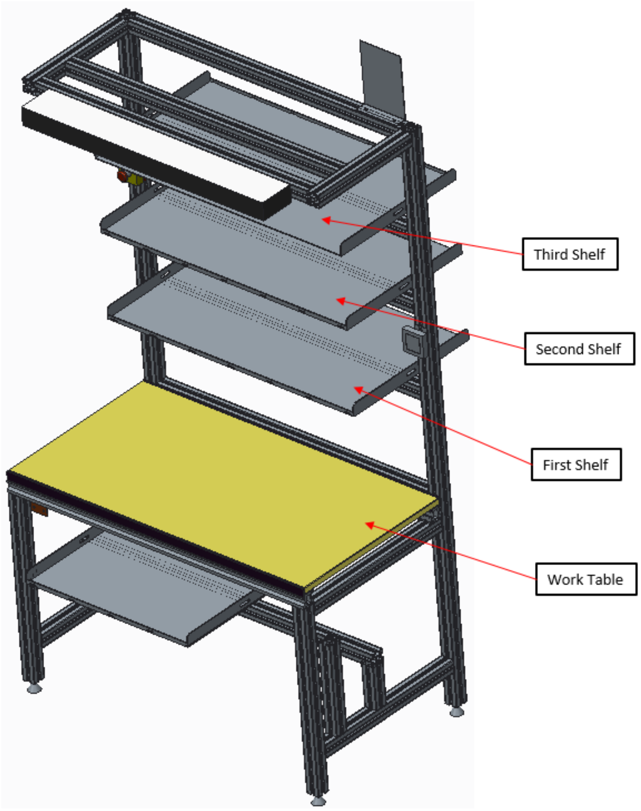


Figure 36 - Workstation 3

The main dimensions of workstation 3 can be seen in Table 27.

Table 27 - Workstation 3 main dimensions

Location	Height (mm)	Width (mm)	Depth (mm)
Work Table	730	1100	580
First Shelf	1070	909	490
Second Shelf	1290	909	490
Third Shelf	1510	909	490

3.2.2.5 Corners

The two identical corners are located besides workstation 2. As said before, these corners supply materials for the assembly but also serve as storage for jigs and test dummies of all products manufactured. Figure 37 is a 3D CAD representation of the right corner.

Figure 37 - Corners

The main dimensions of the corners can be seen in Table 28.

Table 28 - Corners main dimensions

Location	Height (mm)	Width (mm)	Depth (mm)
Corner Table	920	900	860

3.3 Process description and problems identification

This chapter will be divided into three parts, according to the different families of products manufactured. Two of the three processes will be described in detail, and some general notes will also be given according to the product family.

3.3.1 Dual Delegate Interface (DDI)

As this product does not represent any difficulty in its assembly, and regarding ergonomics does not raises any issues, only a general description of the process will be made.

The product only has one stage of assembly in workstation 1.

After this, the product is carried by hand to workstation 2 where the FT is performed.

After the tests, the product is again carried by hand to workstation 3, where is packed. After packaging, the product is placed in a Milkrun trolley, and this is also done by hand.

Some general notes about this process are:

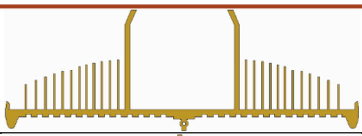
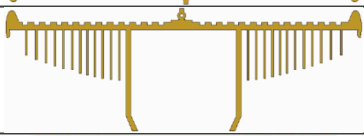
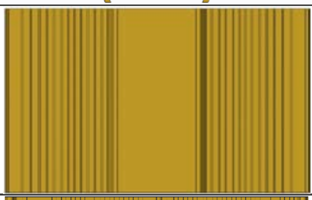
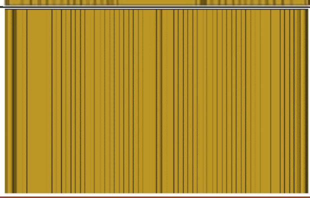
- The product only passes three workstations;
- In workstation 3 a base is placed in the work table to raise the working height. This avoids ergonomic problems;
- The feedback given by the operators was that this product does not raise any specific difficulty.
- Ergocheck does not detect any ergonomic problems.

3.3.2 Radiator (M, H)

The only differences in both these products are the height (model M 200 mm and model H 300 mm), and the weight. Regarding the manufacturing process, they are identical.

Through the process, the extrusions will assume four different positions. Table 29 shows these positions as well as the number chosen to describe them.

Table 29 - Radiators positions

Position	Definition Chosen
	1
	2
	3
	4

3.3.2.1 Stage one (Supply and Initial encasing):

The extrusions are supplied in cars of four units at two different heights (315 mm and 555 mm) in workstations 4 and 1 (Figure 38).

Figure 38 - Supply of workstation 1 and 4

The first operation is therefore picking up the extrusions and placing them in the worktable.

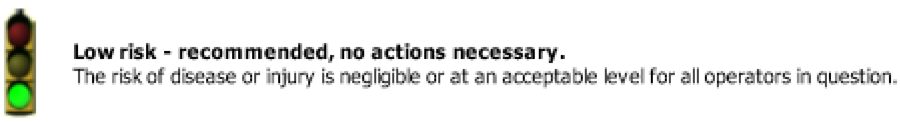
Using IGEL, the follow scenarios were evaluated:

Picking model M from first car shelf (Table 30)

Table 30 - Parameters and values of picking model M from first car shelf

Parameters	Values
Number of lifts (per hour):	3.1
Maximum load (kg):	6.72
Origin grip height (cm):	55.5
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	50
Grip conditions:	Poor

Result:



Picking model M from second car shelf (Table 31)

Table 31 - Parameters and values of picking model M from second car shelf

Parameters	Values
Number of lifts (per hour):	3.1
Maximum load (kg):	6.72
Origin grip height (cm):	31.5
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	25
Destination horizontal grip distance (cm):	50
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Picking model H from first car shelf (Table 32)

Table 32 - Parameters and values of picking model H from first car shelf

Parameters	Values
Number of lifts (per hour):	3.1
Maximum load (kg):	10.08
Origin grip height (cm):	55.5
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	50
Grip conditions:	Poor

Result:

Possible risk - not recommended, redesign task or take actions to lower the risk.
For the operators in question there is considerable risk of disease or injury.

Picking model H from second car shelf (Table 33)

Table 33 - Parameters and values of picking model H from second car shelf

Parameters	Values
Number of lifts (per hour):	3.1
Maximum load (kg):	10.08
Origin grip height (cm):	31.5
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	25
Destination horizontal grip distance (cm):	50
Grip conditions:	Poor

Result:

Possible risk - not recommended, redesign task or take actions to lower the risk.
For the operators in question there is considerable risk of disease or injury.

NOTE: When supplying the extrusions in workstation 4 it´s necessary to carry them to workstation 1. This was also evaluated according to the two possible scenarios:

Carrying extrusion of model M from workstation 4 to 1 (Table 34)

Table 34 - Parameters and values of carrying extrusion of model M from workstation 4 to 1

Parameters	Values
Load weight (kg):	6.72
Carrying distance (m):	1.1
Number of load transfers (per hour):	3.1
Origin grip height (cm):	92
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	35
Grip conditions:	Poor

Result:

Task analysis

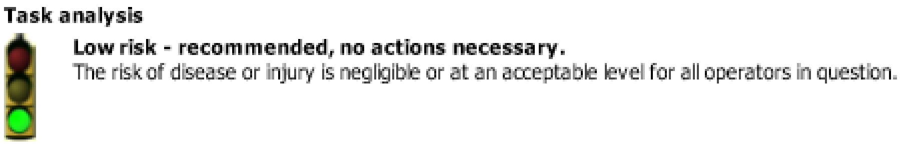
Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Carrying extrusion of model H from workstation 4 to 1 (Table 35)

Table 35 - Parameters and values of carrying extrusion of model H from workstation 4 to 1

Parameters	Values
Load weight (kg):	10.08
Carrying distance (m):	1.1
Number of load transfers (per hour):	3.1
Origin grip height (cm):	92
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	35
Grip conditions:	Poor

Result:



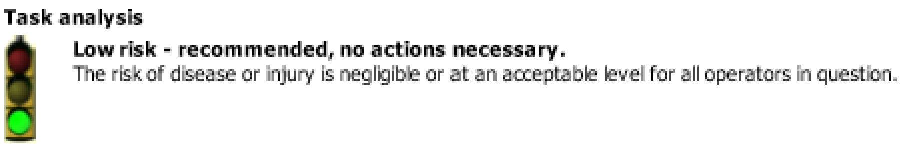
After the first stage of assembly, it is necessary to carry the semifinal assembled extrusion to workstation two. The two possible scenarios regarding this task were evaluated.

Carrying semifinal assembled extrusion model M from workstation 1 to 2 (Table 36)

Table 36 - Parameters and values of carrying semifinal assembled extrusion model M from workstation 1 to 2

Parameters	Values
Load weight (kg):	8.76
Carrying distance (m):	1.5
Number of load transfers (per hour):	3.1
Origin grip height (cm):	92
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	35
Grip conditions:	Poor

Result:



Carrying semifinal assembled extrusion model H from workstation 1 to 2 (Table 37)

Table 37 - Parameters and values of carrying semifinal assembled extrusion model H from workstation 1 to 2

Parameters	Values
Load weight (kg):	11.79
Carrying distance (m):	1.5
Number of load transfers (per hour):	3.1
Origin grip height (cm):	92
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	35
Grip conditions:	Poor

Result:

Task analysis

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Besides the handling of the extrusions, there are another two ergonomic issues with this product at this stage of assembly. To assemble some components, it is necessary to place the extrusion in position 3, which raises the height of the work surface. This means that both products surpass the maximum height allowed of 1100 mm. When manufacturing version M this limit is surpassed by 20 mm, and when manufacturing version H the limit is surpassed 120 mm. The other issue is the excessive torso bending required from the operators to pick the extrusions. This happens whether picking the extrusions from the first or second car level.

3.3.2.2 Stage 2 (Final encasing and testing)

In workstation 2, the semifinal assembled extrusion is placed on JIG 0047 (Figure 39) were the final parts are assembled on the extrusion.

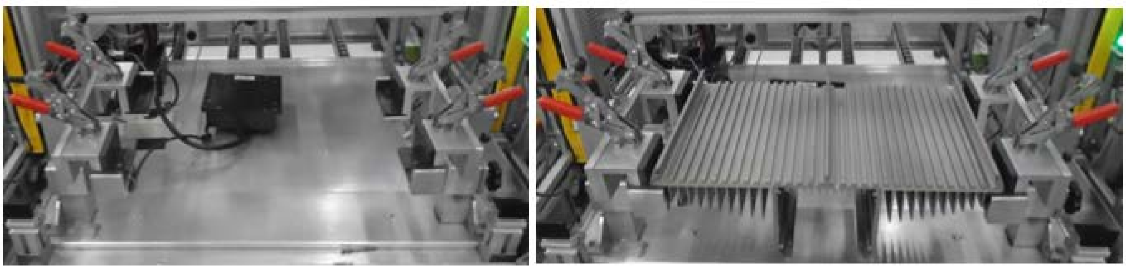


Figure 39 - JIG 0047

As there are no lifting or carrying actions in this task, the only aspect evaluated was the work height trough the assembly. This is important due to the different positions of the extrusions. Table 38 shows the different work heights (mm) in both model M and H.

Table 38 - Radiators work heights in workstation 2

Model	Position 1	Position 2	Position 3	Position 4
M	1066	952	1020	1020
H	1066	952	1070	1070

The difference of heights in position 4 is justified by the JIG design. When producing model M, it is necessary to lock two pieces for height adjustment (Figure 40).

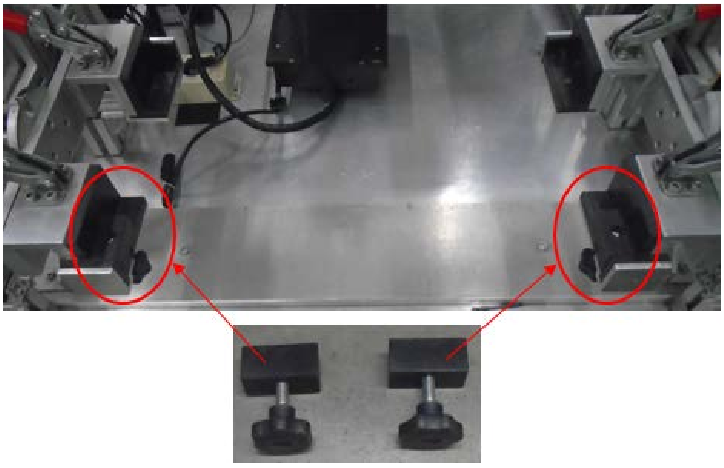


Figure 40 - Height adjustment pieces of JIG 0047

After the final assemble is completed, the product is subjected to the FT and HVT before passing to the next station (Figure 41).

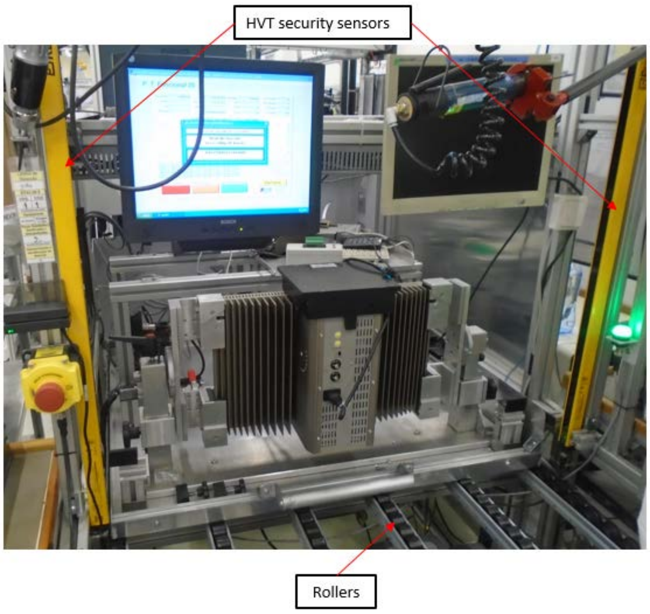


Figure 41 - Radiator H in the HVT

The operator must push the worktable through rollers pass the security sensors for the test to run. This particular task represents no difficulty as the worktable slides very easily through the rollers. After all tests are done, the final assembled extrusion is once again carried by hand to workstation 3 were it is putted directly inside the packaging box. Using IGEL the possible scenarios were evaluated.

Carrying fully assembled model M from workstation 2 to 3 (Table 39)

Table 39 - Parameters and values of carrying fully assembled model M from workstation 2 to 3

Parameters	Values
Load weight (kg):	9.74
Carrying distance (m):	1.7
Number of load transfers (per hour):	3.1
Origin grip height (cm):	92
Destination grip height (cm):	73
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	25
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Carrying fully assembled model H from workstation 2 to 3 (Table 40)

Table 40 - Parameters and values of carrying fully assembled model H from workstation 2 to 3

Parameters	Values
Load weight (kg):	13.1
Carrying distance (m):	1.7
Number of load transfers (per hour):	3.1
Origin grip height (cm):	92
Destination grip height (cm):	73
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	25
Grip conditions:	Poor

Result:

High risk - avoid, actions needed to control the risk.
The risk of disease or injury is apparent and it is not acceptable to expose the operators in question to such risk.

3.3.2.3 Stage 3 (Packaging and milk run trolley loading)

After the packaging is completed, the final box is placed in the trolley using a vacuum lifter (Figure 42).

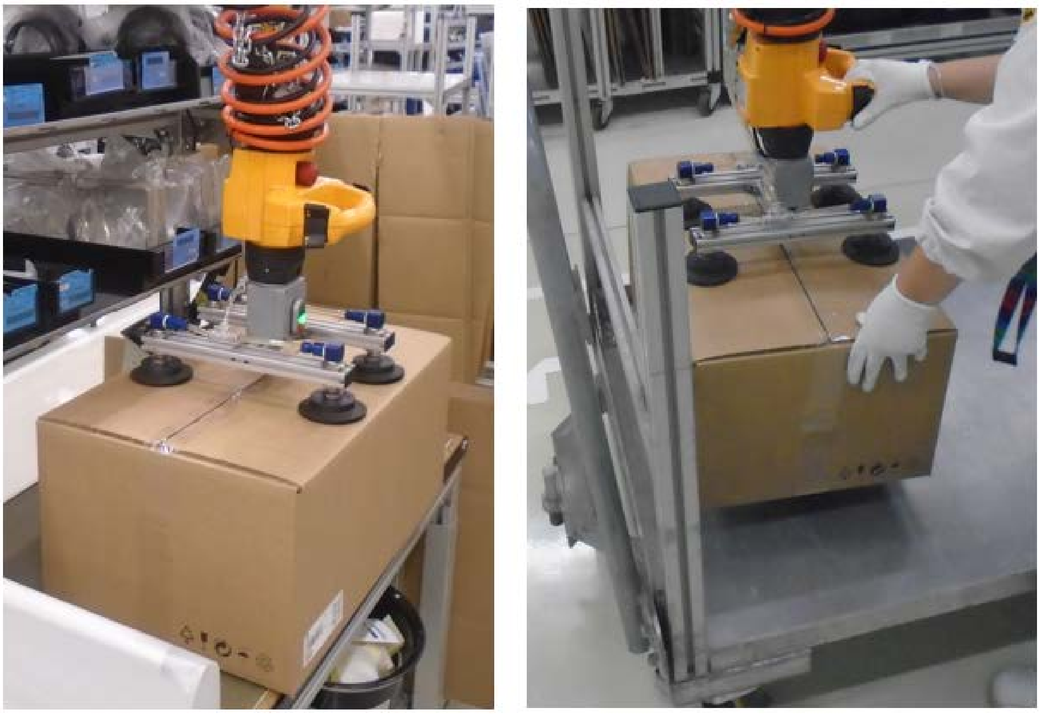


Figure 42 - Placing one Radiator H packaging in the finished product car

This means that despite there is a difference in heights, the operator is not subjected to any kind of stress.

Additional information:

- In workstation two a visual inspection is made at two different distances, 60 cm and 2 m;
- JIG used in test workstation (0047) is heavy.

3.3.3 Integrus (Case, Cabinet)

In the case of Integrus cases and cabinets, the process is also very similar being the only difference the operation of placing the product in the milk run trolley.

3.3.3.1 Stage one (Supply and textplate assembling)

The cases/cabinets are supplied under workstations 4 and 1 at a one height (Figure 43). The bottom part of the case/cabinet is transported directly to workstation 2, the top part of the case remains in the supply car and the textplate is placed on workstation 4 for assembling.

Figure 43 - Supply of Integrus cases

Using IGEL the following results for unloading and transportation of the bottom parts, were obtained:

Carrying bottom part of Integrus case from workstation 4 to workstation 2 (Table 41)

Table 41 - Parameters and values of carrying bottom part of Integrus case from workstation 4 to workstation 2

Parameters	Values
Load weight (kg):	5.5
Carrying distance (m):	2.6
Number of load transfers (per hour):	1.3
Origin grip height (cm):	45
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	30
Destination horizontal grip distance (cm):	45
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Carrying bottom part of Integrus case from workstation 1 to workstation 2 (Table 42)

Table 42 - Parameters and values of carrying bottom part of Integrus case from workstation 1 to workstation 2

Parameters	Values
Load weight (kg):	5.5
Carrying distance (m):	1.5
Number of load transfers (per hour):	1.3
Origin grip height (cm):	45
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	30
Destination horizontal grip distance (cm):	45
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Carrying cabinet from workstation 4 to workstation 2 (Table 43)

Table 43 - Parameters and values of carrying cabinet from workstation 4 to workstation 2

Parameters	Values
Load weight (kg):	6.7
Carrying distance (m):	2.6
Number of load transfers (per hour):	1.3
Origin grip height (cm):	45
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	30
Destination horizontal grip distance (cm):	45
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

Carrying cabinet from workstation 1 to workstation 2 (Table 44)

Table 44 - Parameters and values of carrying cabinet from workstation 1 to workstation 2

Parameters	Values
Load weight (kg):	6.7
Carrying distance (m):	1.5
Number of load transfers (per hour):	1.3
Origin grip height (cm):	45
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	30
Destination horizontal grip distance (cm):	45
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

3.3.3.2 Stage two (Testing and textplate encasing)

After finishing assembling the textplate in workstation 1, the operator carries it to workstation 2 to assemble it in the bottom case or the cabinet, before performing both the FT and HVT. The fully textplate is carried by hand from one workstation to another.

Using IGEL to evaluate this action, the following result was obtained (Table 45):

Table 45 - Parameters and values of carrying the assembled textplate from workstation 1 to workstation 2

Parameters	Values
Load weight (kg):	7.5
Carrying distance (m):	1.5
Number of load transfers (per hour):	1.3
Origin grip height (cm):	92
Destination grip height (cm):	92
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	35
Grip conditions:	Poor

Result:

Low risk - recommended, no actions necessary.
The risk of disease or injury is negligible or at an acceptable level for all operators in question.

With the textplate assembled in the bottom part of the case/cabinet, the product is pushed through the rollers pass the HVT sensors. Just like radiators, this task does not raise any difficulty to the operators.

3.3.3.3 Stage 3 (Packaging and milk run trolley loading)

In this stage there are some differences between the cases and cabinets. However, both products have one action in common, which is the transport from workstation 2 to workstation 3. Using IGEL the following scenarios were evaluated:

Carrying bottom case and textplate from workstation 2 to workstation 3 (Table 46)

Table 46 - Parameters and values of carrying bottom case and textplate from workstation 2 to workstation 3

Parameters	Values
Load weight (kg):	13
Carrying distance (m):	1.7
Number of load transfers (per hour):	1.3
Origin grip height (cm):	92
Destination grip height (cm):	73
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	25
Grip conditions:	Poor

Result:

High risk - avoid, actions needed to control the risk.
The risk of disease or injury is apparent and it is not acceptable to expose the operators in question to such risk.

Carrying cabinet and textplate from workstation 2 to workstation 3 (Table 47)

Table 47 - Parameters and values of carrying cabinet and textplate from workstation 2 to workstation 3

Parameters	Values
Load weight (kg):	14.2
Carrying distance (m):	1.7
Number of load transfers (per hour):	1.3
Origin grip height (cm):	92
Destination grip height (cm):	73
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	25
Grip conditions:	Poor

Result:

High risk - avoid, actions needed to control the risk.
The risk of disease or iinjury is apparent and it is not acceptable to expose the operators in question to such risk.

From this point forward, the process is slightly different for each product. The case is placed on workstation 3 for assembling the top part with the rest of the product. The packaging box is assembled on top of the Milkrun trolley and the fully assembled case is loaded directly inside this box. This operation is made with the support of a lifter, thus the operator is no subjected to any physical stress (Figure 44).

Figure 44 - Integrus Case being picked with a lifter

Regarding the cabinet version, the cabinet is also placed on workstation 3 where it is putted inside a plastic bag. The packaging box is assembled on top of the Milkrun trolley (Figure 45) and the operator places the product inside this box.

Figure 45 - Integrus Cabinet being packed.

In this case, this operation is manual which means that the operator is subjected to substantial physical stress. This action was evaluated, and the following results were obtained (Table 48):

Table 48 - Parameters and values of placing the fully assembled cabinet in the Milkrun trolley

Parameters	Values
Load weight (kg):	14.2
Carrying distance (m):	2.02
Number of load transfers (per hour):	1.3
Origin grip height (cm):	73
Destination grip height (cm):	26
Origin horizontal grip distance (cm):	35
Destination horizontal grip distance (cm):	35
Grip conditions:	Poor

Result:

High risk - avoid, actions needed to control the risk.
The risk of disease or injury is apparent and it is not acceptable to expose the operators in question to such risk.

Additional information:

- The product passes all workstations;
- The product is carried by hand in almost all stages of the manufacturing process;
- A JIG is used in workstation 2 for orienting the chargers when assembling the textplate.

Table 49 and Table 50 summarize all ergonomics deviations found in the current manufacturing process in each product.

Table 49 - Radiators individual tasks analyses

Product	Task	Result
Radiator	Picking model M from first car shelf (55.5 cm).	
	Picking model M from second car shelf (31.5 cm).	
	Picking model H from first car shelf (55.5 cm).	

Product	Task	Result
Radiator	Picking model H from second car shelf (31.5 cm).	
	Carrying extrusion of model M from workstation 4 to 1.	
	Carrying extrusion of model H from workstation 4 to 1.	
	Carrying semifinal assembled extrusion model M from workstation 1 to 2.	
	Carrying semifinal assembled extrusion model H from workstation 1 to 2.	
	Carrying fully assembled model M from workstation 2 to 3.	
	Carrying fully assembled model H from workstation 2 to 3.	

Table 50 - Integrus individual tasks analyses

Product	Task	Result
Integrus Case/Cabinet	Carrying bottom part of Integrus case from workstation 4 to workstation 2.	
	Carrying bottom part of Integrus case from workstation 1 to workstation 2.	
	Carrying cabinet from workstation 4 to workstation 2.	
	Carrying cabinet from workstation 1 to workstation 2.	
	Carrying fully assembled textplate from workstation 1 to workstation 2.	
	Carrying bottom case and textplate from workstation 2 to workstation 3.	

Product	Task	Result
Integrus Case/Cabinet	Carrying cabinet and textplate from workstation 2 to workstation 3.	
	Carrying cabinet from workstation 3 to milk run trolley and placing it inside the packaging box.	

The cumulative load was also evaluated for each product. Table 51 shows the results obtained:

Table 51 - Cumulative load results

Product	Cumulative Load (kg)	Result
Radiator H	1734.51	
Radiator M	1250.91	
Integrus Case	618.8	
Integrus Cabinet	1111.76	

3.4 Analysis of the possible solutions

After analyzing the present process, the time came to think of possible solutions for the problems found. For this, suggestions were collected among the team and the scenarios were created and weighted based on the collected suggestions.

The team was formed by all elements of the Machines Operations and Equipment (MOE6) department which is divided into three subgroups (process engineering, industrial engineering, and logistics). The process of collecting the different inputs of each subgroup consisted in several meetings in the assembly line with different elements of each subgroup. Throughout these meetings it was possible to gather different solutions for each individual problem and possible issues that could arise from each one. The possible solutions obtained after these meetings, as well as advantages and disadvantages associated with each one, were:

Fully automated assembly

Advantages:

- Would fit in a smaller space than the available;
- Ergonomic issues would be solved;
- Greater line output.

Disadvantages:

- High cost;
- Inflexibility in moving the assembly line;
- High programming complexity;
- High maintenance.

Manual assembly with the product suspended

Advantages:

- The operators would not have to carry the products by hand;
- Would not affect the current line output.

Disadvantages:

- Hard to apply in the products manufactured;
- High cost;
- Despite solving some ergonomic issues, others could raise;
- It would be harder to handle the products, especially Radiators.

D-stand workstations

Advantages:

- No carrying actions needed;
- Smaller assembly line area required;
- Elimination of the vacuum lifter.

Disadvantages:

- Line output would be affected;
- Ergonomic issues related to the handling of products would not be eliminated;
- Considerable investment necessary.

Automatic conveyor work stands

Advantages:

- Some ergonomic issues would be solved;
- The line output would not be affected;
- Area available would be enough.

Disadvantages:

- Issues regarding the products handling would not be solved;
- It would not be possible to establish a work height that would be suitable for all products;
- Automation needed would require special technician for day to day use.

Height adjustable trolleys

Advantages:

- Issues regarding the products transportations would be solved;
- Regarding the investment is the less expensive solution;
- Easy adaptation of the workers.

Disadvantages:

- Does not solve every ergonomic issue;
- May no be suitable for all products.

Hybrid solution

Advantages:

- Every issue can be analyzed individually;
- Adjustments for each product are possible;
- Estimated costs lower than other options.

Disadvantages:

- Capacity of the line could not be improved;
- Space required may be larger than other solutions;
- May require some pieces of equipment that are only used in some family of products.

3.5 Selection of the best solution

For helping the decision between the possible solutions presented, a selection matrix was made. In this matrix, all solutions presented have got a score, depending on how well they fulfil the objectives of this study. However, before the actual building of the matrix, the objectives were compared between each to establish a hierarchy for a more precise comparison between the different solutions. Table 52 shows the ponderation matrix made between each objective.

Table 52 - Ponderation matrix

	1--2	1--3	1--4	1—5	2--3	2--4	2--5	3--4	3--5	4--5	Σ	ω_i
Ergonomics	1	0.7	0.7	1							3.4	0.34
Line output	0				0.5	0.3	0.3				1.1	0.11
Cost		0.3			0.5			1	0.7		2.5	0.25
Area			0.3			0.7		0		0.5	1.5	0.15
Flexibility				0			0.7		0.3	0.5	1.5	0.15

The main objective of this work is to ensure that the exposure of operators to elevated risk factors ceases to exist and by doing so, guarantee that no more work-related injuries will happen again. Thus, between all different objectives, the line ergonomics is considered a priority. Following ergonomics, the most important factor is the cost. Since the available funds for the restructuration of the assembly line are limited, it is imperative that the solution chosen does not have a high cost associated. Area required, and line flexibility came third in the hierarchy. These two factors are equally important in the analyses. And the least important factor to take in consideration is the line output. However, despite improving the line output is not a fundamental requirement, the solution chosen should not reduce the current line output.

In the selection matrix, different values for each factor were given, depending on the solution. The values are showed in Table 53.

Table 53 - Values of each factor according to the different solutions

Solution	Ergonomics	Line output	Cost	Area	Flexibility
Fully automated assembly	100	100	100	60	40
Manual assembly with the product suspended	50	90	80	80	30
D-stand workstations	50	40	50	50	80
Automatic conveyor work stands	50	90	50	80	50
Height adjustable trolleys	70	90	30	70	90
Hybrid solution	90	90	40	70	90

The values showed were empirically obtained, based on the opinion and experience of the different members of the department.

Table 54 shows the performance index calculated for each solution in the selection matrix.

Table 54 - Calculated performance index

Solution	Performance Index
Fully automated assembly	71.67
Manual assembly with the product suspended	50.65
D-stand workstations	47.73
Automatic conveyor work stands	59.61
Height adjustable trolleys	84.41
Hybrid solution	84.96

Looking at the performance index obtained, it is possible to see that although most of the solutions analyzed have a substantial difference in this value, the two solutions with the highest scores are very close together. The eliminating factor in this particularly case, will be how well these solutions deal with the main objective of this work, which is the elimination of exposure of the operators to ergonomic risk factors. Since the height adjustable trolleys solution does not improve the handling of products (manly when manufacturing radiators), the solution chosen is the hybrid solution. In this option, it will be possible to analyze each deviation individually. However, all solutions obtained must be implemented under one assembly line. Also, whenever its possible all materials from the old layout should be reutilized, reducing costs and waste in this project.

The selection matrix can be consulted in the attachment 6.1 of this work.

3.6 Design of selected solution

After considering all options, the solution chosen was a hybrid solution. With this approach, as it was said previously, all problems could be analyzed individually and specific solutions for each product could be implemented. The idea of this solution is to apply all ideas from other scenarios in one assembly line. However, the available space was limited to 36.74 m^2 divided into two areas (Figure 46):

- Assembly line area – 30.40 m^2
- Supermarket area – 6.34 m^2

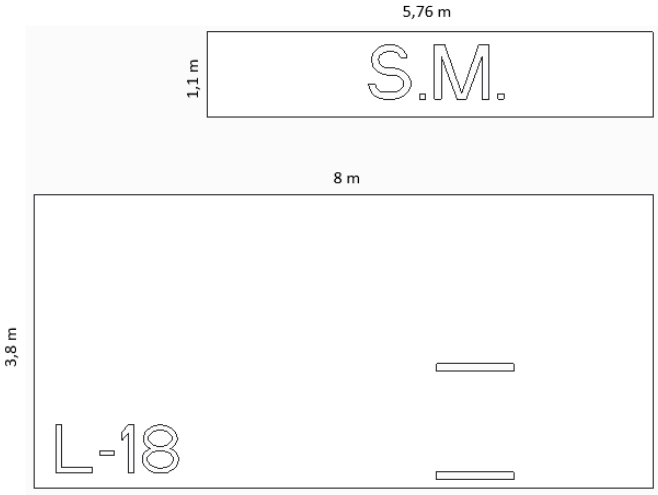


Figure 46 - L18 available area

Following, the design developed will be presented, and the new manufacturing process will be described.

3.6.1 Global view

Figure 47 shows all fixed components of the assembly line.

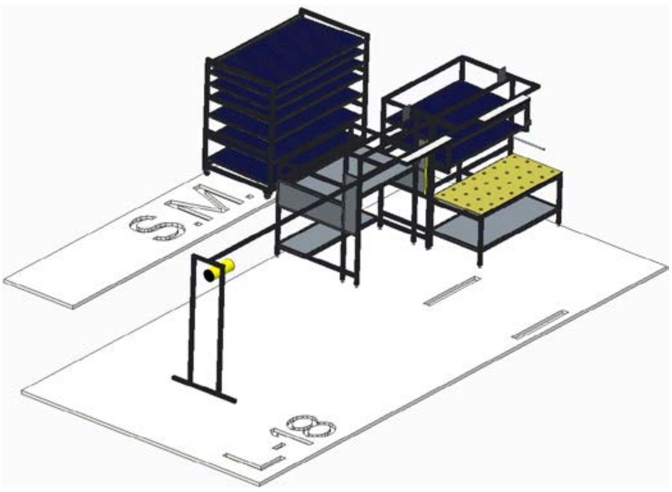


Figure 47 - Fixed elements of L18

The assembly line will have two fixed workstations, one for testing and another for packaging of Radiators and Integrus cases/cabinets. This station will also be used for all operations needed in the DDI. One fixed supermarket will also be needed for accommodating all components of DDI and some components used in packaging of Radiators and Integrus. However, there will be more components in the assembly line at any given time. Figure 48 shows the assembly line with all components that are part of the everyday use of the assembly line. Only the supply cars were omitted because only one type of car will be in the assembly line when producing.

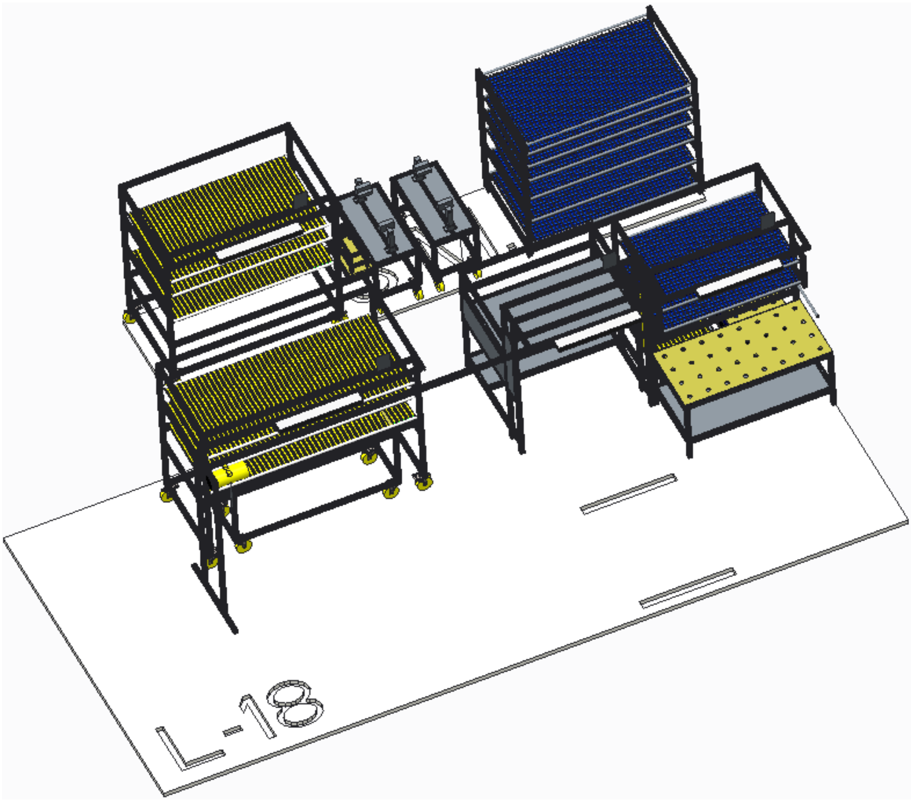


Figure 48 - L18 with all elements to be used

The remaining components represented are:

- One mobile workstation for Radiators;
- One mobile workstation for Integrus Case/Cabinets;
- Two trolleys adapted with JIG's for Radiators;
- One mobile work table to be used when producing Integrus Case/Cabinets;
- One supermarket;
- One electric suspensor;
- One electric scissor lifter;
- One-foot operated scissor lifter trolley;

3.6.2 Assembly line components selection and dimensioning

3.6.2.1 Test workstation

In order to implement trolleys, some minor changes to the present test workstation were necessary. However, before starting the redesign of the workstation a 5 S operation was carried out to eliminate any obsolete equipment that may be present in the assembly line. Figure 49 shows the original workstation.

Figure 49 - Original test workstation

The changes made to the workstation were:

- Eliminating the rollers;
- Moving PC's to the back of the workstation;
- Increasing the workstation width from 1.10 m to 1.44 m. This was made to create more space for inserting the trolleys in the test;
- Adding a fixed shelf for equipment storage;
- Adding lateral panels to avoid contact with the product during HVT.

The 3D model of the designed solution is showed in Figure 50.

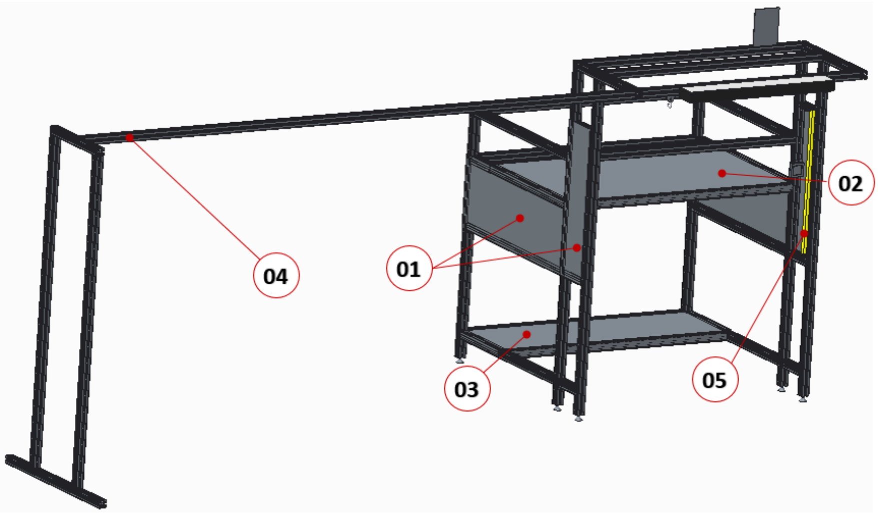


Figure 50 - 3D model of the new test workstation

The main components of this workstation are:

1. Lateral panels for operator's protection;
2. Fixed shelf at 1.15 m;
3. Base for PCs storage;
4. Added structure for electric suspensor;
5. HVT security sensors.

3.6.2.2 Packaging Workstation

The other fixed workstation in the final assembly line is the packaging workstation. In this workstation, it was necessary a more complex intervention in order to apply the adopted concept. Figure 51 shows the original packaging workstation.

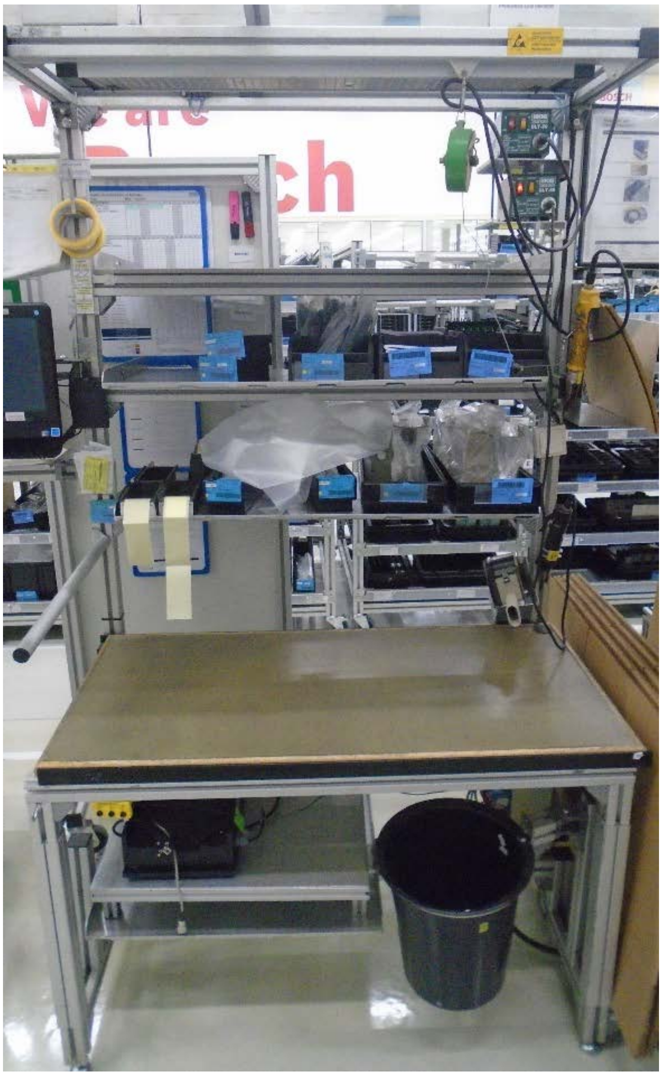


Figure 51 - Original packaging workstation

The changes made in this workstation were:

- Increasing the workstation width from 1.10 m to 1.59 m;
- Increasing the workstation depth to 0.845 m;
- Replacing the two shelves for rollers;
- Replace the workstation cover.

The workstation width was increased because of the elimination of the left corner. Therefore, the materials that were supplied in the left corner needed to be allocated in this new workstation. The workstation dimensioning was made by consulting the PFEP (Plan For Every Part) of the assembly line and verifying which product needed more space. Table 55 shows the width required for each product in this workstation.

Table 55 - Space required to allocate components supplied in the packaging workstation

Product	Width required (m)
Radiator M	2.35
Radiator H	2.40
Integrus Case	1.30
Integrus Cabinet	1.72
DDI	2.45

Being the maximum width needed 2.45 m, two shelves of 1.5 m were placed in the workstation which makes a total 3 m of available width. This was made to ensure that enough space is provided and to assemble some rollers in an opposite direction, to make an out platform (Figure 52).

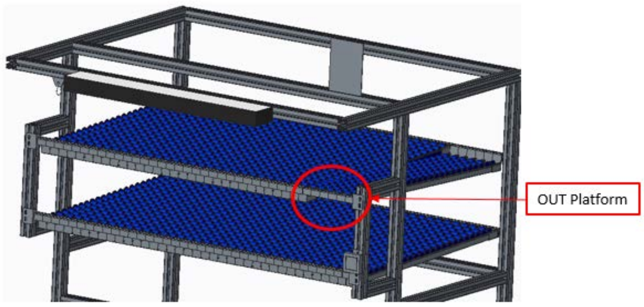


Figure 52 – “Out” platform

Regarding the depth of the workstation, the increase was made thus the workstation could accommodate all containers required for production. Accommodating all containers in the workstation, will make possible to load the materials to the assembly line on the set up, and therefore eliminate the need for continuous supply. Another aspect regarding the supply rollers is the distance between them and the edge of the work surface. It was necessary to apply bars to reduce this distance (Figure 53) for ergonomic reasons (maximum distance allowed is 0.6 m).

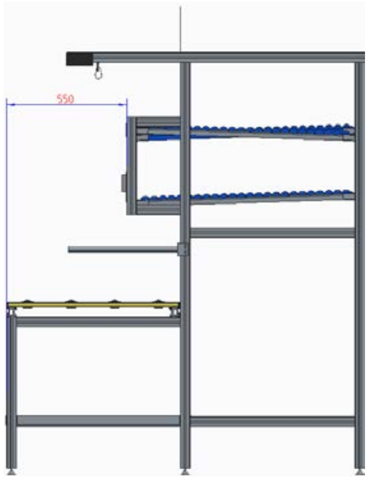


Figure 53 - Distance between shelves and the edge of the worktable

Another major change to this workstation was the cover. It was necessary to replace it with a larger one and apply 32 plastic ball transfer units. This plastic ball transfer units were chosen to avoid any damage to the products. The 3D model of the designed developed is showed in Figure 54.

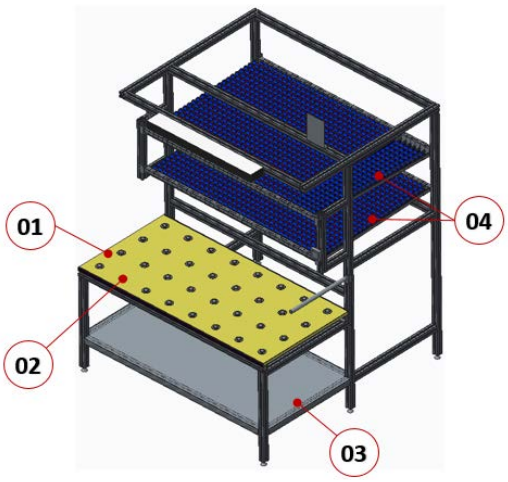


Figure 54 - Packaging workstation 3D model

The main components of this workstation are:

1. Cover (1.59 m × 0.78 m);
2. Plastic ball transfer units;
3. Base for equipment storage;
4. Two rollers for material supply at 1.275 m and 1.575 m.

3.6.2.3 Radiators and Integrus mobile workstations

The objective in both these workstations was to design them in a way so that they could accommodate all materials required in their assembly, which means that these two mobile workstations would have to accommodate all materials that are supplied in workstations 4, 1 and in the right corner. Figure 55 shows the right corner and workstations 1 and 4.

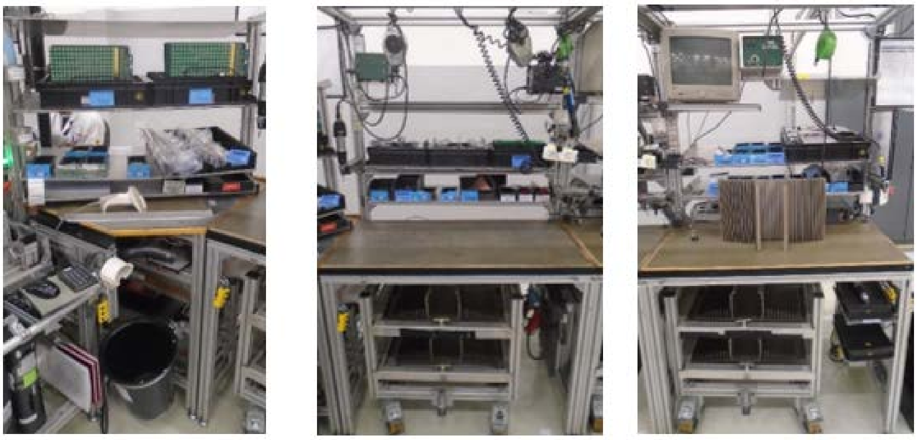


Figure 55 - Right corner, workstation 1 and 4

For the mobile workstation dimensioning, the same process used in the packaging workstation was applied. By checking the PFEP of the assembly line, it was possible to determine how much width was necessary to accommodate all materials supplied in the mentioned workstations for each product. The necessary width is shown in Table 56.

Table 56 - Space required to accommodate materials form the right corner, workstation 1 and 4

Product	Width required (m)
Radiator M	2.35
Radiator H	3.33
Integrus Case	4.37
Integrus Cabinet	3.34

In both Radiators and Integrus mobile workstation 3, shelves were used. For Radiators, the shelves are 1.75 m and for Integrus 2.25 m. Both workstations are purposely over dimensioned for two reasons:

1. Regarding Integrus (cases and cabinets) the textplates will be supplied in the workstation instead of being supplied in the supply car;
2. For Radiators, this over dimensioning will help to minimize some concerns in logistics. At the present time the assembly line is not capable of accommodating all materials needed because of lack of space.

Another aspect to consider in the dimensioning of the Radiators mobile workstation, was the vacuum peeler used in the process. This equipment needs to be allocated to this workstation thus a platform was added for this effect. Figure 56 shows the 3D models of the two mobile workstations (Radiators left, Integrus right).

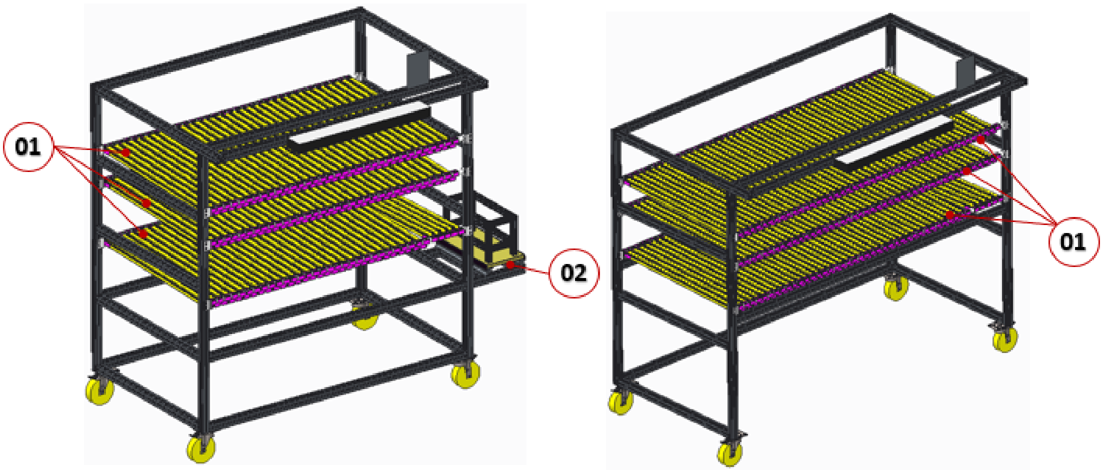


Figure 56 - 3D models of the Radiators (left) and Integrus (right) mobile workstations

The two mobile workstations are very similar being the main difference, besides the width dimension, the existence of the vacuum peeler platform in the Radiator mobile workstation. The main components of the workstations are:

1. Three roller shelves at 1.1 m, 1.4 m, 1.6 m. The distance between the first and second shelf is bigger because the first shelf will receive the larger and heavier containers;
2. Platform for the vacuum peeler.

3.6.2.4 Supermarket

The fixed supermarket of the assembly line will storage all components used in the packaging workstation. The dimensioning of this structure was done by the same process of the packaging and mobile workstations. By checking the PFEP and adding the necessary space of each product (Table 55), a total of 10.22 m was obtained. Since the maximum number of shelves usually used in supermarkets is seven (one shelf must be an “out”), a shelf width of at least 1.75 m is necessary to accommodate all components. Figure 57 is a 3D representation of the supermarket designed.

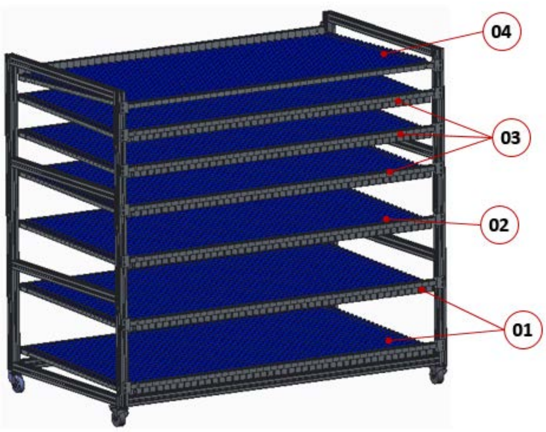


Figure 57 - 3D model representation of the designed supermarket

The main components of this supermarket are:

1. Two bottom shelves for large containers storage;
2. One shelf for medium sized containers storage;
3. Three shelves for small sized containers storage;
4. One “out” shelf for empty containers disposal.

3.6.2.5 Adapted Radiator trolley

To carry the Radiators from workstation to workstation, it was necessary to design a small trolley. For easier handling of the Radiators, the JIG used in the test workstation will be mounted in the trolley. This way, all tasks of picking the extrusion for assembly purposes will be eliminated. The only aspect to consider in designing this trolley was its height because, as it was explained before, the extrusions will assume different positions during the manufacturing process. Therefore, the height of the trolley should guarantee that the working surface height is always between 0.9 and 1.1 m. Figure 58 is the 3D model of the trolley.

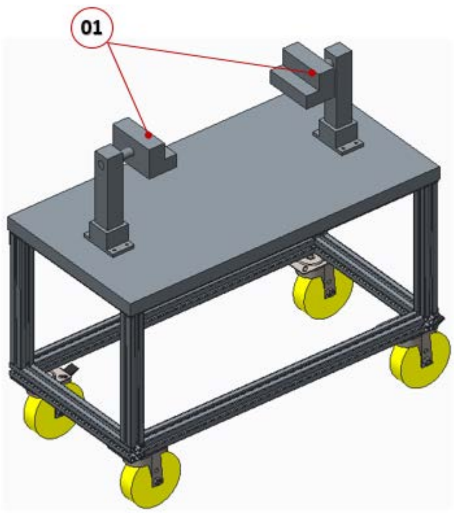


Figure 58 - 3D models of the adapted radiator trolley

In the image above, it is possible to see a representation of the JIG 0047 (1) mounted in the trolley. The working surface heights using the JIG mounted in this trolley are shown in the Table 57:

Table 57 - Working heights of both Radiators models

Model	Position 1	Position 2	Position 3	Position 4
M	1081	967	1085	1085
H	1081	967	1035	1035

With a trolley and JIG height of 0.685 m and 0.250 m, it is guaranteed that the working surfaces heights limits are always respected.

3.6.2.6 Radiator Supply car

To supply the assembly line with the extrusion, it was necessary to design new supply cars. The cars needed to supply at least four extrusions, and because of the line concept, the extrusions needed to be accessible from above. Figure 59 is a 3D model representation of the designed car for the radiators supply.

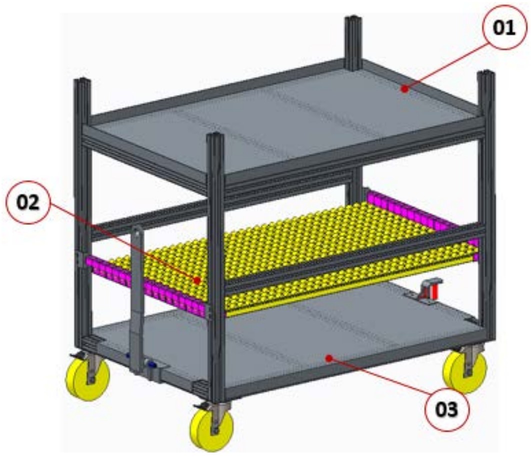


Figure 59 - 3D model of the supply car for Radiators

The main components of this car are:

1. Top shelf for carrying the extrusions;
2. Middle shelf (rollers) for carrying the packed product;
3. Bottom shelf for the boxes kits.

Due to the dimensions of the extrusions, it was possible to adapt the same car that supplies the assembly line, to also transport the packed products back to the warehouse. In addition to this, a bottom shelf was added to carry the empty boxes to the assembly line, and thus saving space in the supermarket and in the packaging station (this procedure is defined as kitting). Figure 60 shows the car in the two stages.

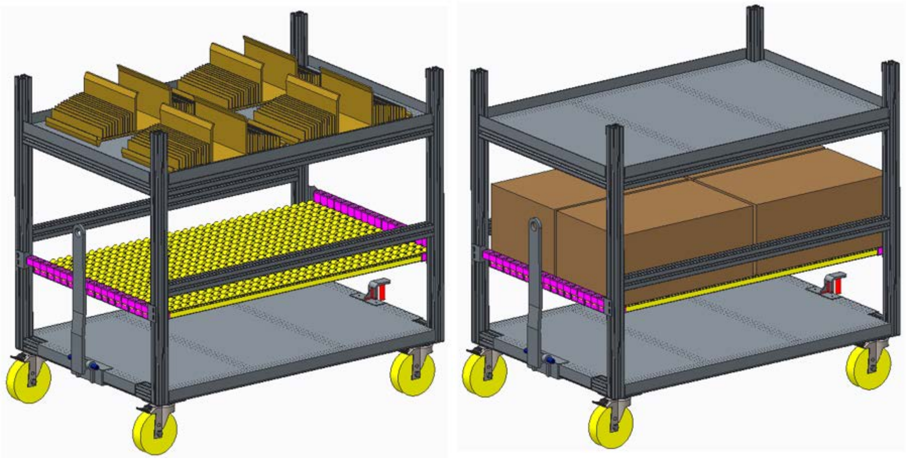


Figure 60 - 3D representations of the two stages of the Radiators supply cars

3.6.2.7 Integrus Supply car

For the Integrus product family, it was also necessary to design new supply cars. In this case, the need for the cases or cabinets to be accessible from above does not exist. Thus, the only aspect to consider was the number of cases/cabinets supplied. The car needed to supply at least four units in order to not affect the line current capacity. Figure 61 is a 3D model representation of the Integrus supply car.

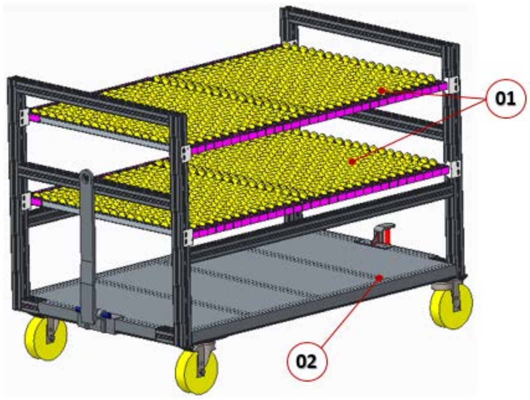


Figure 61 - 3D model of the Integrus supply cars

The cars have three different shelves for different purposes:

1. Two shelves for cases/cabinets supply and finished product transportation;
2. One bottom shelf for empty boxes supply.

Regarding the empty packaging boxes the same principle (kitting) as the radiators cars was applied, however the finished product cannot be loaded in the same car. The line will have to have two identical cars, one for supply and the another for final product loading. The same cars can be used in both Integrus cases and cabinets. Figure 62 and Figure 63 are 3D model representations of the Integrus cars in both stages of the process with the two different products.

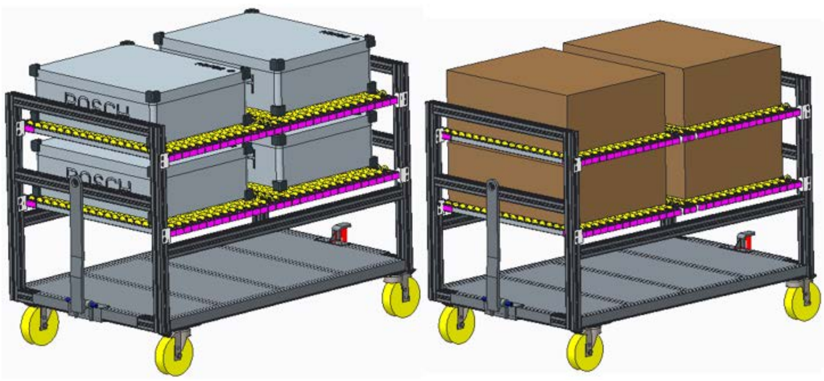


Figure 62 - 3D representations of the two stages of the Integrus Cases supply cars

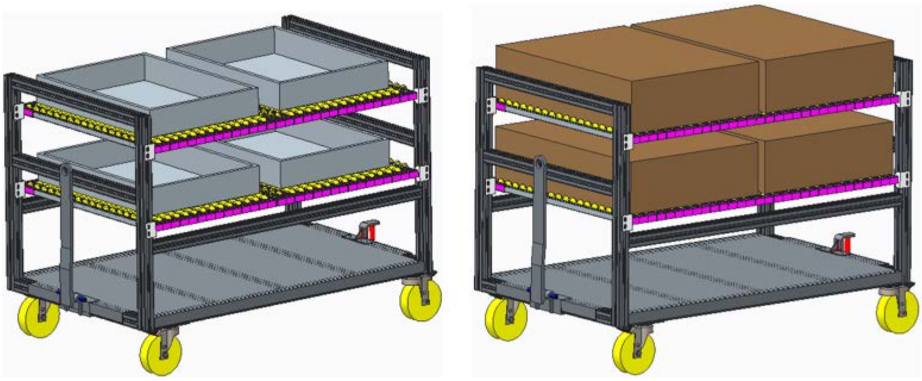


Figure 63 - 3D representations of the two stages of the Integrus Cabinets supply cars

3.6.2.8 Other equipment

The new layout also requires the acquisition of some other pieces of equipment, being they:

- One compressed air suspensor;
- One-foot operated scissor lifter trolley;
- One electric scissor lifter.

However, some modifications were needed for the concept work.

Compressed air suspensor

This suspensor will be used when manufacturing either model of Radiators. It will be used for unloading the Radiator from the supply car to the adapted Radiator trolley and for placing the final assembled Radiator inside the packaging box. This will eliminate the need for the operators to pick the Radiators manually, and therefore it will eliminate any ergonomic deviations caused by this action. The selected suspensor was LLA250 EX from Atlas Copco (Figure 64).

Figure 64 - LLA250 EX from Atlas Copco

Table 58 shows the main characteristics of this suspensor.

Table 58 - LLA250 EX from Atlas Copco main characteristics

Lifting Capacity (kg)	Lifting Speed (m/min)	Weight Without chain (kg)	Chain Weight (kg/m)	Air consumption (l/s)	Hose diameter (mm)
250	18.6	12.7	0.9	37	12.5

Electric scissor lifter

An electric scissor lifter will be placed into the test workstation when producing either the Integrus case or cabinets. Two modifications will be made to this lifter before its installation, being they:

1. Apply a work cover with plastic ball transfer units (just like it made in the packaging workstation);
2. Mount the lifter on top of a simple structure adapted with wheels.

The ball transfer units will be helpful in unloading the product from the supply car to the top of the lifter and, after the tests are performed, it will make it easier for the operators to transfer the product to the packaging workstation. Mounting the lifter in a mobile structure will make possible to push the lifter pass the HVT sensors, in order for the tests to be performed.

The four aspects taken into consideration when selecting this equipment were:

1. Table dimensions: the table needs to be large enough to accommodate both cases and cabinets;
2. Lifter capacity: this parameter is easily achieved due to weight of the products. A lifter capacity of 20 kg would be more than enough for the desired application;
3. Frequency of use: because the height adjustment will be frequent in this stage of the process, an electric version was chosen. This will guarantee that the operators are not subjected to repetitive physical stress;
4. Height range: the lifter needs to descend to the lowest platform of the Integrus supply car, and high enough to guarantee a correct posture during production;

The selected lifter was the electric scissor lift table AX 500 kg form HYMO (Figure 65).

Figure 65 - AX 500 kg form HYMO

The main characteristics of this lifter are shown in Table 59.

Table 59 - AX 500 kg form HYMO main characteristics

Load Capacity (kg)	Raised Height (m)	Lowered Height (m)	Standard platform dimensions (mm)	Weight (kg)
500	0.80*	0.20*	600 × 1200	160

*Because the lifter will be mounted in another structure, in practice these heights will have an increment of 0.19 m.

Foot operated scissor lifter trolley

This trolley will be used for the transportation of the packaged products from the packaging workstation to the supply cars in both the Integrus and Radiators product families. The platform of this trolley, however, needs to be modified in order for the products to slide in and out. A simple structure was designed in which rollers will be installed. Rollers were chosen instead of plastic ball transfer units because is intended for the packages to slide in only one direction. Figure 66 shows a 3D representation of the structure mounted in the trolley platform.

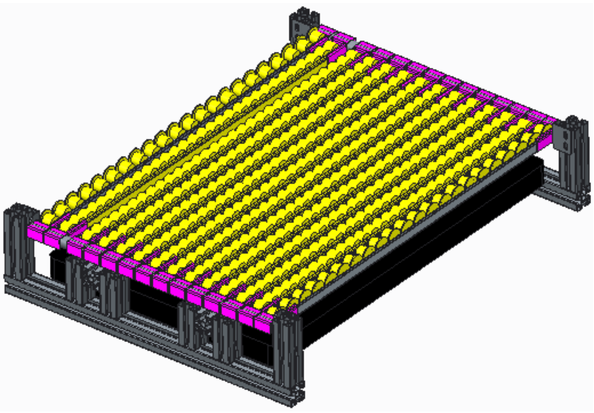


Figure 66 - Structure mounted in the trolley platform

The aspects taken into consideration were the same ones adopted for the lift table, as follows:

1. Table dimensions: the platform and structure need to be large enough to accommodate the largest package product. This product is the Integrus Cabinet with a width of 595 mm and length of 790 mm;
2. Lifter capacity: as it happens with the lift table, the requirements for this characteristic are easily fulfilled;
3. Frequency of use: despite being used in almost every product manufactured in the assembly line, this equipment will only be used at the end of each cycle. Because of this, there is no need to invest in an electric version, and therefore a foot operated trolley was chosen;
4. Height range: the trolley needs to have a height range that allows the loading of the products in the packaging workstation, and the unloading in the different supply cars;

The selected trolley was the Maximus scissor lifter trolley from Kaiser Kraft (Figure 67).

Figure 67 - Maximus scissor lifter trolley from Kaiser Kraft

The main characteristics of this trolley are shown in Table 60:

Table 60 - Maximus scissor lifter trolley from Kaiser Kraft main characteristics

Load capacity (kg)	Elevation range (mm)	Total dimensions (mm^2)	Platform dimensions (mm^2)	Weight (kg)
550	355 – 980	1150 × 600	900 × 600	94

3.7 Process Description

In this chapter, the new manufacturing process according to the new layout will be explained. The chapter will be divided into four parts, where a detailed explanation of the new manufacturing process regarding the different products will be presented. The parts in which this chapter will be divided are:

- Radiator (H/M);
- Integrus Case;
- Integrus Cabinet;
- DDI.

3.7.1 Radiator (H/M)

3.7.1.1 Unloading the extrusions in the Adapted Radiator trolley

After the supply cars are placed on the assembly line, the first task to be carried out is the unloading of the first extrusion in to the adapted radiator trolley. To eliminate the deviation in the old layout, two measures were implemented. The first was to elevate the height at which the extrusions are supplied, and the second was the use of a compressed air suspensor that picks the extrusion. Figure 68 shows a 3D simulation of this task.

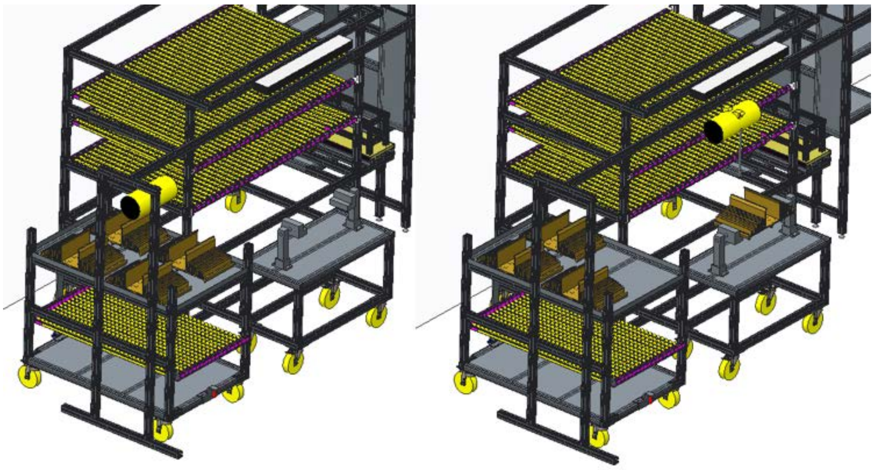


Figure 68 - Extrusion being picked from supply car ang being placed on the JIG

In the product, there are two treaded holes where two eyebolts will be screwed, and then connected to the suspensor with a cable. After the extrusion is loaded in the JIG, the eyebolts will be disconnected from the cables, but will remain in the extrusion until the end of the process.

3.7.1.2 Encasing

With the extrusion fixed on the JIG, the operators assemble all components required. As this JIG allows the easy handling of the extrusion, the operators do not have the need to pick it. Therefore, the cumulative load associated with this task is significantly lower than before. Another deviation in the old layout was the working height, when producing either model of the extrusion. As it was explained before, by performing all encasing operations in the adapted radiator trolley, the working heights are always respected independently of the extrusions position.

3.7.1.3 Testing

After the encasing stage is done, the operator will push the trolley to the test workstation. Posteriorly to aligning the trolley, the operator pushes it pass the HVT sensors and starts preparing the packaging box while the test is being performed. When the test is finished, the operator needs to perform a visual inspection at two different distances (0,6 m and 2 m). Figure 69 shows the operators placement in this task.

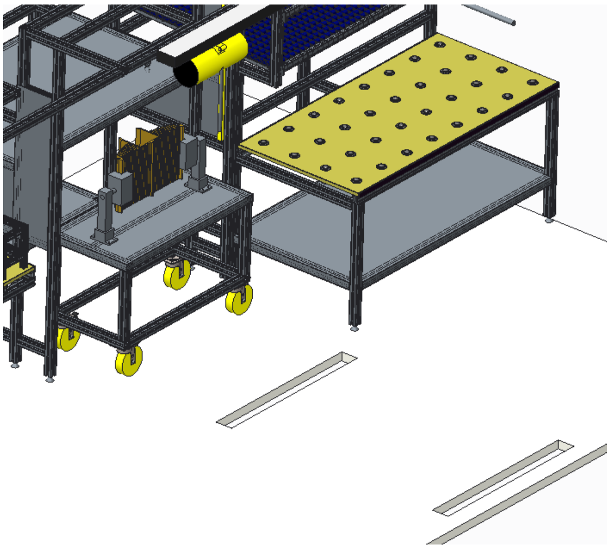


Figure 69 - Radiators testing stage

3.7.1.4 Packaging

Concluding the visual inspection required, the next step is to place the final assembled Radiator inside the packaging box. For this, the operators will once again use the compressed air suspensor, avoiding the need to pick the radiators by hand. Using the suspensor to perform this task, eliminates the deviation in the previous layout. Figure 70 is a 3D simulation of this task.

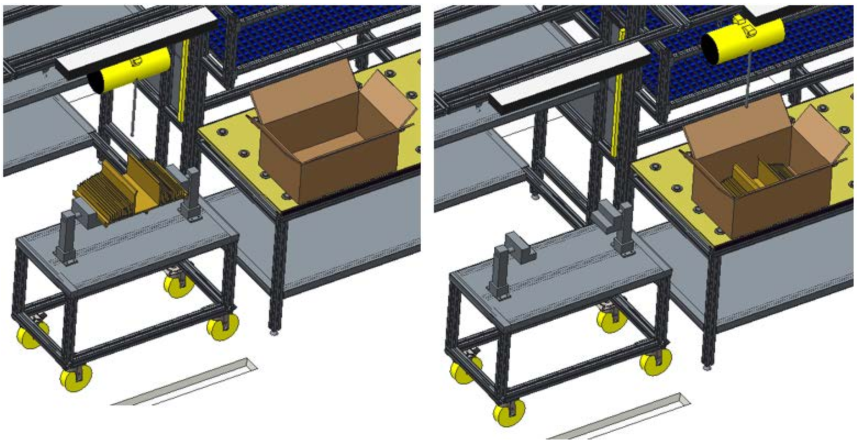


Figure 70 - Radiators packaging stage

After placing the Radiator and remaining accessories inside the packaging box, the eyebolts are removed, and the box is closed.

3.7.1.5 Loading the supply car

The last step of the process is the loading of the supply car (which also serves as the finished product car) with the packaged product. In the previous layout, this action was done with the help of a vacuum lifter and did not subject the operators to any kind of physical stress. However, since one of the main objectives of this study was to make the assembly line more flexible, it was concluded that this equipment should be replaced by other system. The solution found was the use of scissor lifter trolleys adapted with rollers.

The operators will push the packaged product to this trolley, and since the cover of the packaging workstation is covered with plastic ball transfer units, the force necessary is very low. Figure 71 is a 3D representation of this task.

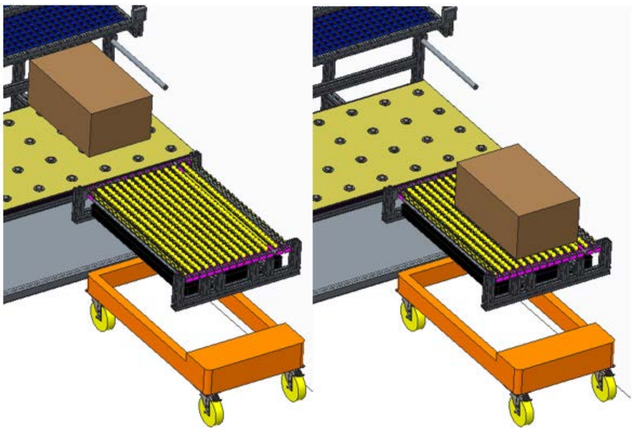


Figure 71 - Transferring a packaged radiator form the packaging workstation to the trolley

After the trolley is loaded with the package, the operator will carry it back to the beginning of the assembly line and unload the package back in the supply car (Figure 72).

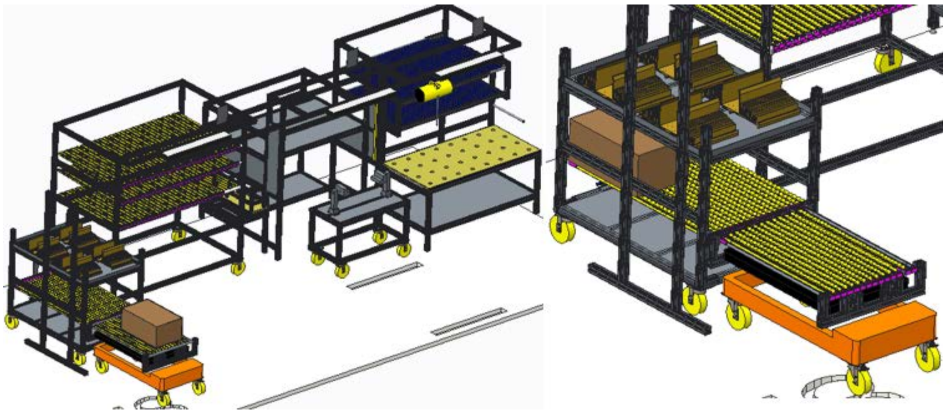


Figure 72 - Transferring a packaged radiator form the trolley to the finished product car

After the production of 4 Radiators, the milk run will bring another supply car and take the one in the assembly line back to the warehouse.

Regarding any possible ergonomic issues, the only action that can be evaluated by the current methods used, is the carrying of the loaded trolley from the packaging workstation to the trolley. This action was evaluated using IGEL (ISO 11228-2: 2007):

Table 61 - Values used in IGEL analyses (Radiators)

Parameters	Values
Shift Duration (h)	8
Pushing Force (N)	50
Pulling Force (N)	50
Distance (m)	5.7
Handle Height (m)	1
Force Angle (degrees)	30
Frequency (units per hour)	3.1
Gender mix (male : female)	25:75

Based on the parameters shown in Table 61, a maximum pushing force of 87.36 N and pulling force of 71.68 N was calculated. Since the maximum force that the operators will have to do is lower than the calculated values, there is no ergonomic issues regarding this task.

3.7.2 Integrus Case

3.7.2.1 Unloading the case on to the electric scissor lifter

The first stage of production of the Integrus Case is the unloading of the empty case onto the top of the electric scissor lifter (Figure 73). This action is done by simply pushing the case to the lifter. Since the supply car shelves are made of rollers, and the top of the lifter is equipped with plastic ball transfer units, this action has almost none physical impact on the operators. In addition, because the lifter is mounted on a mobile structure, its positioning and alignment is very simple.

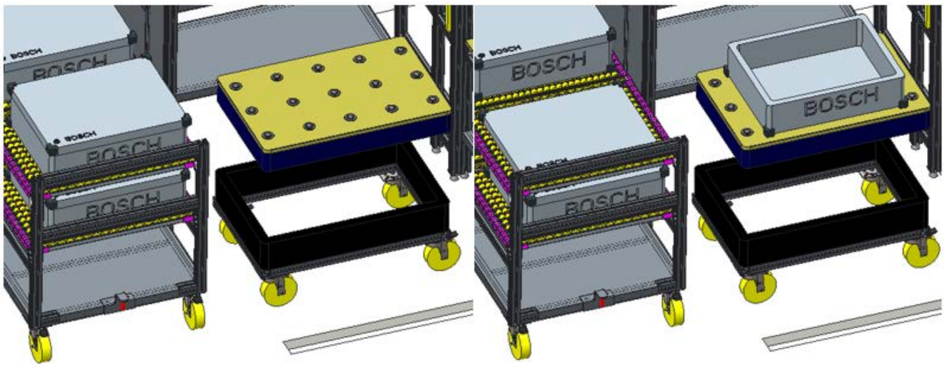


Figure 73 - Transferring bottom part of Case to test trolley

Only the bottom part of the case is necessary at this point, so the top part can be placed back at the supply car.

3.7.2.2 Textplate/chargers assemble

The disassembled textplate is supplied to the assembly line in the Integrus mobile workstation. It is placed on a trolley work stand and, after the chargers are aligned and other components are assembled to the textplate, the operators pick it and place it on top of the chargers (Figure 74).

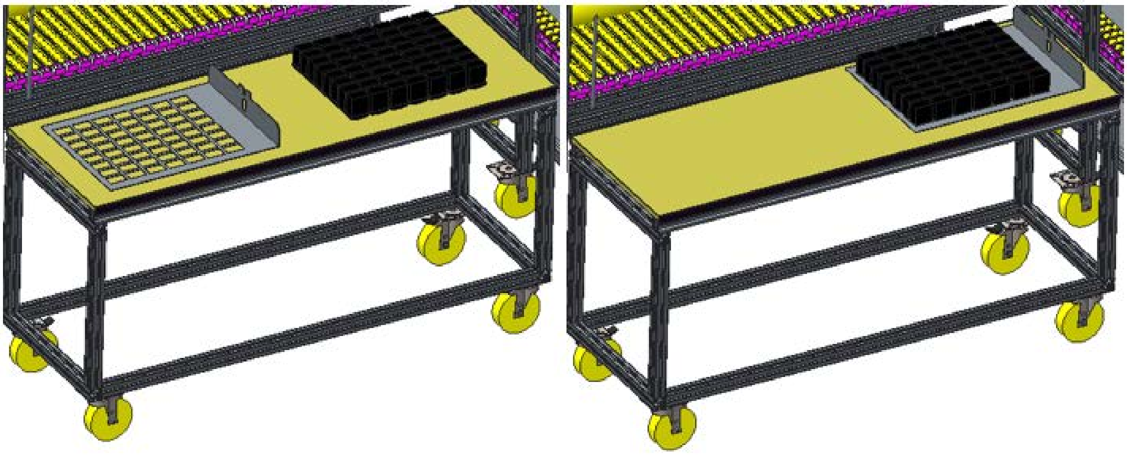


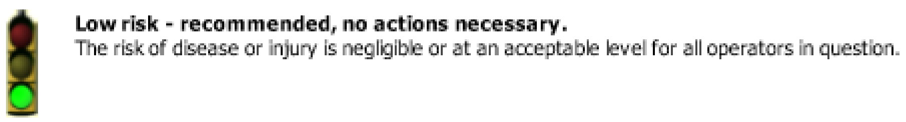
Figure 74 - Textplate assemble

After the textplate is fully assembled, the operator carries it to the test workstation, where it is assembled in the bottom part of the case (Table 62). This task was evaluated in IGEL (ISO 11228-1: 2003):

Table 62 - Parameters and values of carrying the assembled textplate to the test workstation

Parameters	Values
Load weight (kg):	7.5
Carrying distance (m):	2.5
Number of load transfers (per hour):	1.3
Origin grip height (cm):	95
Destination grip height (cm):	95
Origin horizontal grip distance (cm):	30
Destination horizontal grip distance (cm):	30
Grip conditions:	Poor

The result was:



3.7.2.3 Testing

In this stage of the process the operator only has to push the trolley pass the HVT sensors and wait for the test to be finished (Figure 75).

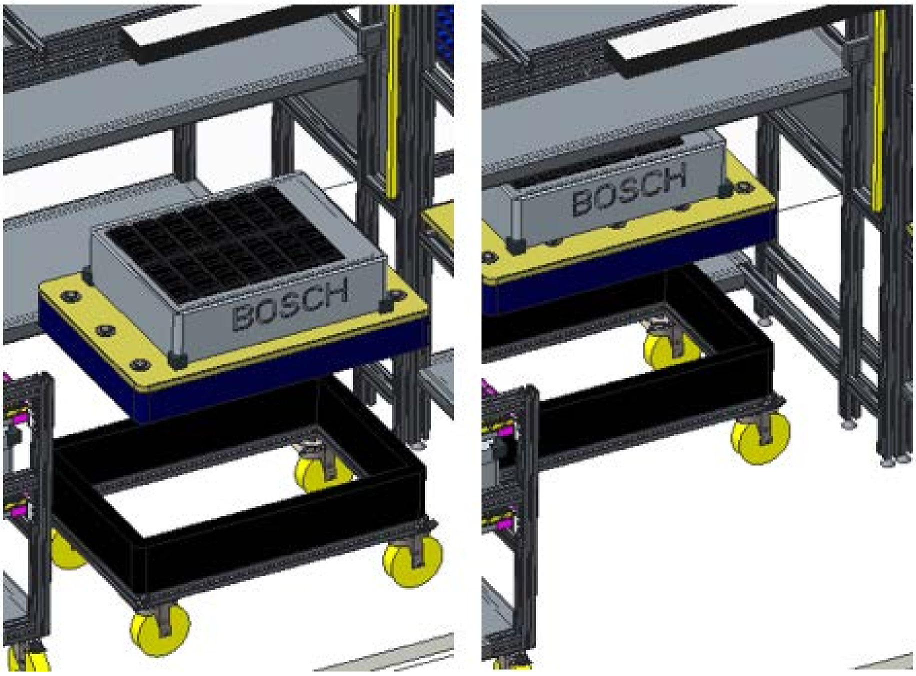


Figure 75 - Integrus Case testing stage

While the test is being performed, the operator prepares the packaging box of the product in the packaging workstation. After the test is completed, the operator assembles the top part of the case and slides it into the packaging box (Figure 76).

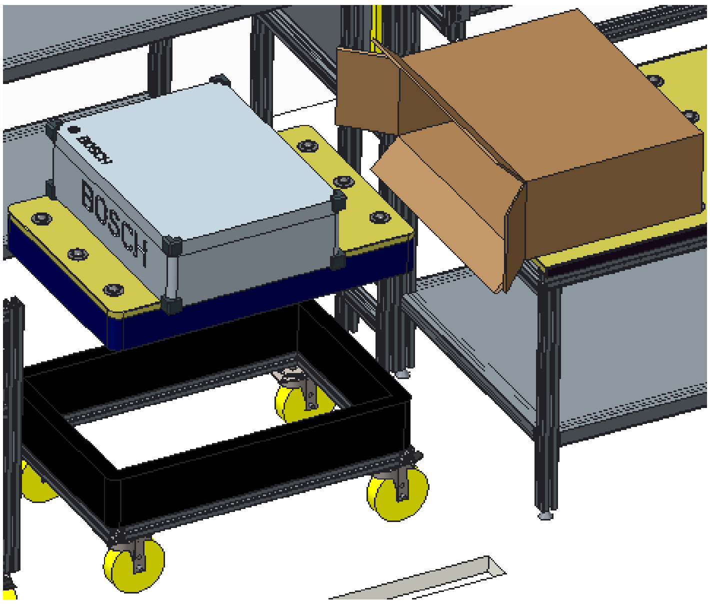


Figure 76 - Integrus Case packaging stage

The ball transfer units allow the easy alignment between the case and the box.

3.7.2.4 Loading the supply car

This stage of the process is very similar to what happens when producing Radiators. The Integrus cases were also loaded in the car with the help of the old lifter, but for the same reasons as Radiators (line flexibility), this equipment needed to be replaced. Thus, the same trolley used for transporting the packed radiators will transport the Integrus cases to the finished product car (Figure 77).

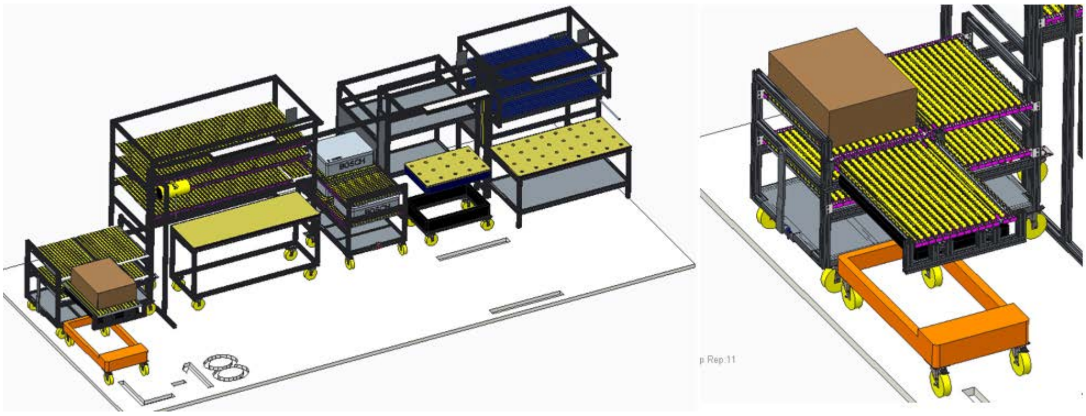


Figure 77 - Transferring a packaged Integrus case form the trolley to the finished product car

As it happens with the Radiators, the only action that can be evaluated is the carrying of the trolley to the finished product car. So, using IGEL (ISO 11228-2) a similar analysis was made.

Table 63 - Values used in IGEL analyses (Integrus)

Parameters	Values
Shift Duration (h)	8
Pushing Force (N)	60
Pulling Force (N)	60
Distance (m)	7.2
Handle Height (m)	1
Force Angle (degrees)	30
Frequency (units per hour)	1.3
Gender mix (male: female)	25:75

With the parameters shown in Table 63, a maximum pushing force of 90.48 N and pulling force of 74.24 N was calculated. As the maximum force necessary is of 60 N, there are no ergonomic issues in this task.

3.7.3 Integrus Cabinet

The manufacturing process of the Integrus cabinet is identical to the Integrus case however, some differences need to be addressed.

3.7.3.1 Unloading the case on to the electric scissor lifter

The first stage of manufacturing the Integrus cabinets is also to unload them into the scissor lifter. However, before unloading the cabinet is necessary to assemble the packaging box on top of the scissor lifter, and after this is done the cabinet is placed directly inside the box (Figure 78).

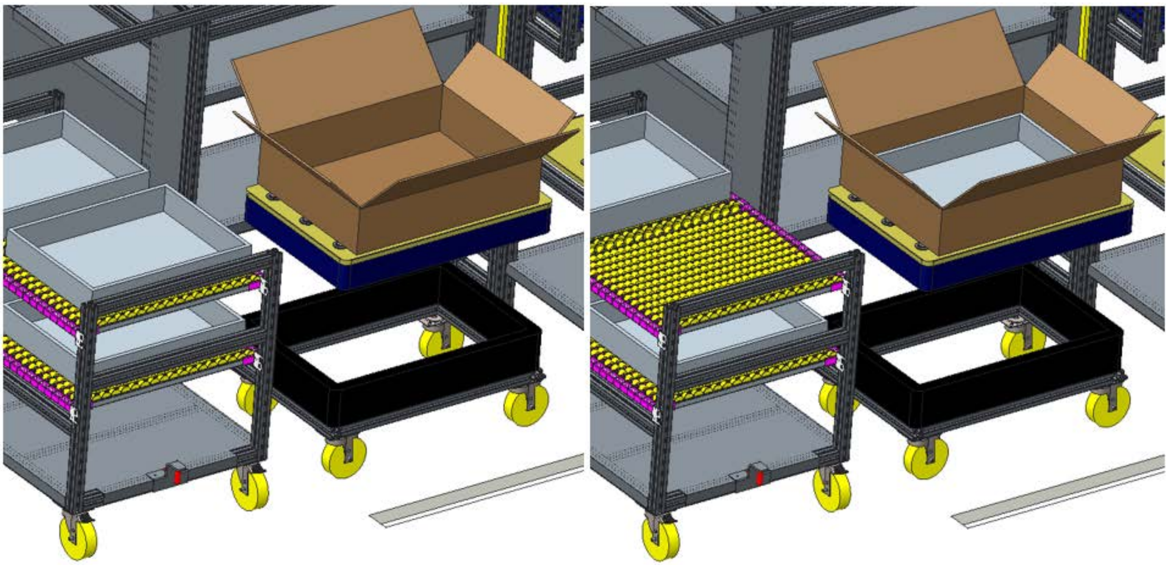


Figure 78 - Placing bottom part of the Cabinet inside the packaging box

This early action will eliminate the last deviation in the packaging of the product regarding the old layout.

3.7.3.2 Textplate/chargers assemble

The textplate assemble stage in Integrus cabinet is exactly the same as in the Integrus case. The operator has to assemble the textplate and then place it in the empty cabinet in the test workstation (Figure 79).

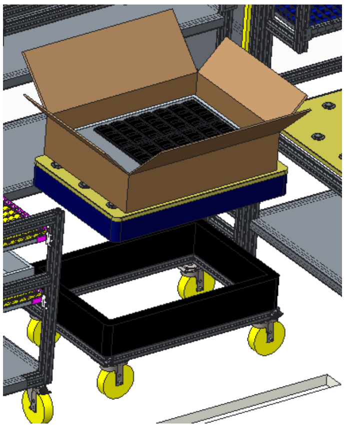


Figure 79 – Textplate assemble in bottom part of Cabinet

The same ergonomic analyses made for the Integrus cases is valid when producing cabinets, and therefore there are no ergonomic issues regarding this task.

3.7.3.3 Testing

The tests are made in the exactly same way as when producing Integrus cases however, since the product is already inside of the final box the task of sliding the product inside the box does not exist. Instead, after the tests are finished the all assemble (product and box) is pushed to the packaging workstation were the remaining accessories are added (Figure 80).

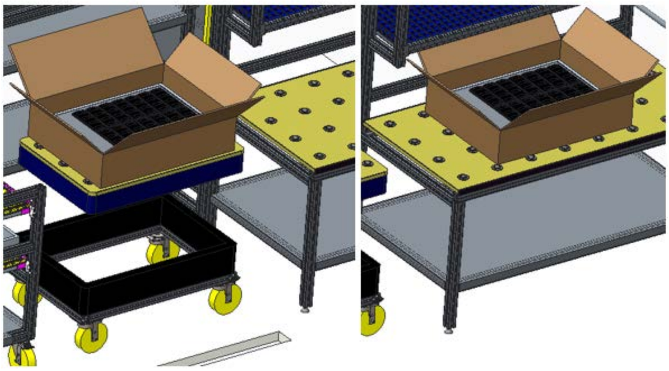


Figure 80 - Product transferred from test trolleys to packaging workstation

With the remaining accessories already placed inside the box, it is then closed and placed in the trolley used in both radiators and Integrus cases.

3.7.3.4 Loading the supply car

This task is also similar to the one performed when producing Integrus Cabinets. The scissor lifter trolley loaded with one packaged product is carried to the finished product car, were the package is unloaded (Figure 81).

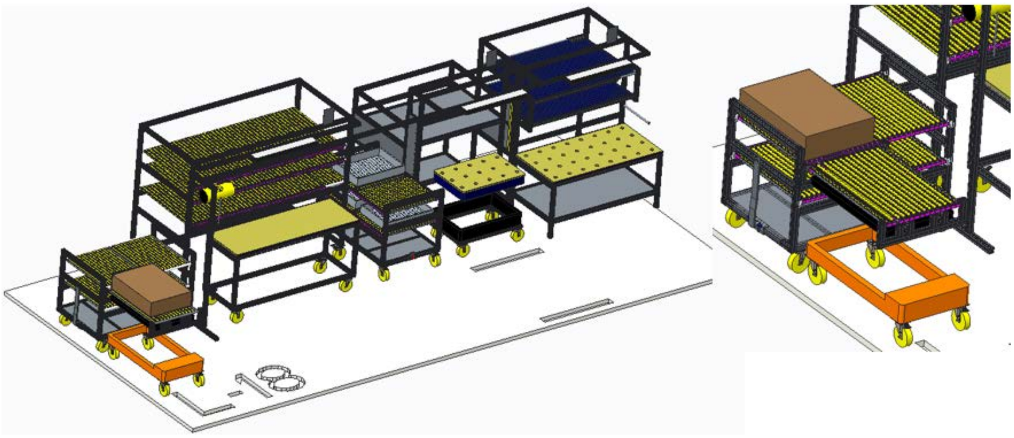


Figure 81 - Transferring a packaged Integrus cabinet form the trolley to the finished product car

Once again, the same ergonomic analyses made in the Integrus Cases is valid for the Cabinets and, therefore, no ergonomic issues were found in this scenario.

3.7.4 DDI

Regarding the DDI, all stages of the manufacturing process are performed in the packaging workstation. The only ergonomic concern that could arise is the height of the work surface. To avoid any problems, the same platform that was used in the old layout will also be used in the new one (Figure 82).

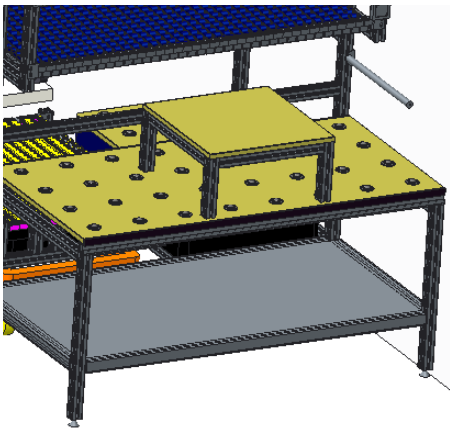


Figure 82 - Packaging workstation when producing DDI

By using this platform, the working height is of 1.05 m, which falls into the recommended limits. One other thing to consider when producing this product is that the equipment associated with the remaining products needed to be allocated somewhere within the assembly line or the supermarket area. Figure 83 shows one possible way to accommodate the equipment.

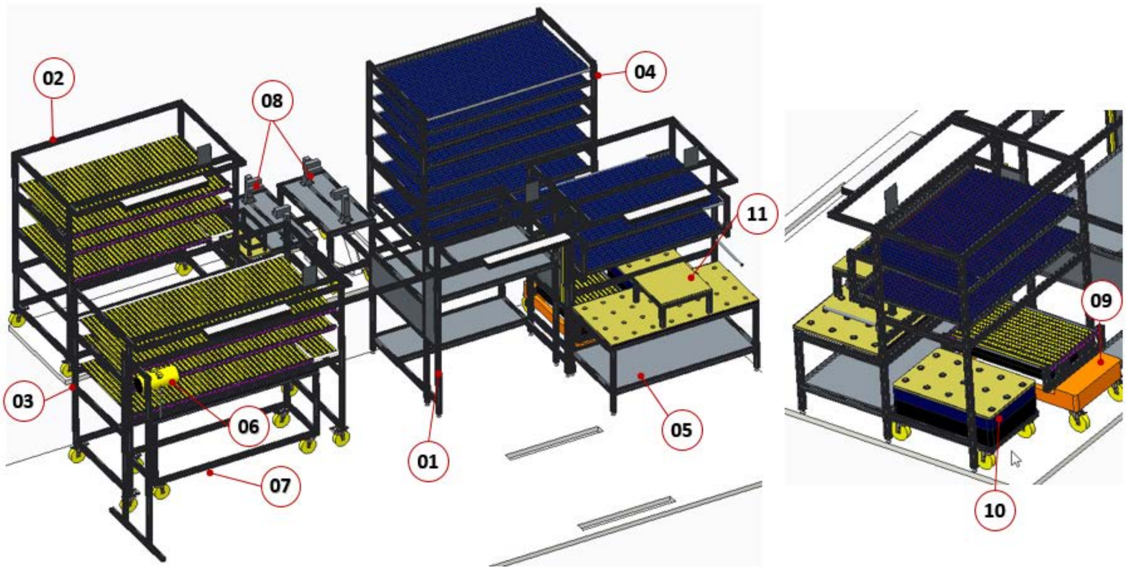


Figure 83 - Equipment accommodation

The equipment pieces represented in the image above are:

1. Test workstation;
2. Radiators mobile workstation;
3. Integrus mobile workstation;
4. Supermarket;
5. Packaging workstation;
6. Compressed air suspensor;
7. Trolley work stand for Integrus;
8. Two adapted radiator trolleys;
9. Scissor lifter trolley;
10. Electric scissor lifter;
11. DDI working platform.

3.8 Estimated costs

An important part of this study is the estimated investment required for the implementation of the assembly line presented.

Table 64 shows the amount of different materials required for this assembly line and their respective costs.

Table 64 - Main materials, quantities and respective prices

Material	Quantity	Price
Profile 45 mm (m)	259,034	1 618,96 €
Scissor lifter trolley	1	1 395,00 €
Electric scissor lifter	1	2 720,00 €
Compressed air suspensor	1	2 289,00 €
Ball transfer units	50	650,00 €
Roller conveyor with flaps (m)	51,06	368,91 €
Roller conveyor without flaps (m)	919,72	6 553,01 €
Articulated Wheel Set (Large - 4uni)	6	1 333,20 €
Articulated Wheel Set (Small - 4uni)	6	228,00 €
Corners	394	394,00 €
Replicated JIG	1	1 500,00 €

The price of acquiring every material new, would represent an investment of 19050,08 €. However, since many materials can be recycled from the old layout, the investment associated with acquiring all materials needed for this new layout is of, approximately, 9500 €.

3.9 Final Discussion

Looking back to the initial line design and comparing it to the solution described, some conclusions can be made. All ergonomic deviations identified where related to one of two issues. The firs issue was that some components (the heavier ones) where supplied to the line at a height that was not the ideal working height. Although this alone could be manageable by the operators the fact that these components where heavy, turned this situation into a threat to the long-term health of operators. Another problem with the original layout was that operators needed to carry these heavy products by hand, from one workstation to another. Again, the weight of these products turned these actions into threats. To solve these problems, a solution was studied where the need for these actions was eliminated. By using pieces of equipment such as lifters and trolleys, the operators are not subjected to any substantial physical stress. In this example, identifying all ergonomic issues of the line, analyzing them individually, finding a solution to each one and finally implement those solutions in one assembly line, proved to be a successful way of solving the initial problems.

CONCLUSIONS

4.1 Achievements

4.2 Learned Lessons

4.3 Future Works

4 ACHIVMENTS, LEARNED LESSONS AND PROPOSALS OF FUTURE WORKS

4.1 Achievements

With the implementation of the solution described, it will be possible to respond to all initial requirements and goals.

Regarding ergonomics, the implementation of the compressed air lifter and trolleys will eliminate all physical stresses imposed to operators. In addition, since the different pieces of equipment are light (compressed air lifter) and mobile (trolleys) it means that the line can be assembled in any location of the factory.

In terms of costs, with this new layout it is possible to minimize the investment by recycling many materials from the old layout. However, some investment in new equipment is inevitable.

Although that, in this thesis the line balancing has not been studied, it is possible affirm based on the number of products to be supplied on the line, that the current line output will not be affected.

Lastly, this new layout will fit in the area of the previously one, thus eliminating the need for the expansion of the available area.

Table 65 summarizes the final results obtained.

Table 65 – Initial objectives and final results summary

Initial Objectives	Final Result
Elimination of ergonomic issues	✓
Area required	-
Assembly line output	-
Costs	✓
Flexibility	✓

4.2 Learned Lessons

The study presented introduced the author to the subject of ergonomics and helped to consolidate and learn new concepts about assembly lines in general. The importance of some general factors when developing a work like this was learned. These factors include:

- Importance of communication between departments;
- Brainstorming with more experienced professionals;

- Importance of working with both logistics and industrial engineering when designing an assembly line from the beginning;
- Collecting operators' feedback about line issues and possible solutions;

At a more personal level, this work was helpful in improving some aspects such as:

- Communication skills;
- Working with the CAD software CREO Parametric;
- Researching for industrial equipment;
- Consolidate knowledge about assembly lines;
- Learn the main concepts in ergonomics and how do they can affect a company and the daily work of operators;
- See in practice some tools used in both lean management and production;
- And overall being familiarized with the industrial environment and daily routines involving working in a factory.

4.3 Future Works

For future works, the suggestion is that some work related with the balancing of the line is made. Specifically, it would be interesting to measure all task times and compare it to the old layout. Based on the new task times, the line capacity should be adjusted. In addition, all documentation related to the assembly line should be updated. The documents to be updated include:

- Stabs;
- Maintenance and autonomous maintenance plans should be created for all new equipment;
- Equipment set up lists;
- Line capacity chart;
- All production quality instructions should be updated for each individual workstation and products.

Regarding the physical space of the assembly line, it will also be necessary to create new marks on the floor to facilitate operators in positioning the different pieces of equipment depending on the product to be manufactured.

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5 References

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ANNEXES

6.1 Selection Matrix

6.2 Ergonomic evaluations

6.3 Drawings

6 ANNEXES

6.1 Selection Matrix

6.2 Ergonomic evaluations

6.3 Drawings