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ERGONOMIC WORKPLACE DESIGN IN AN ASSEMBLY LINE

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ABSTRACT

The thesis presents the importance of ergonomics in industry. Enhanced productivity, higher-quality output, lower injury and absence rates, increased job satisfaction, and optimization of places are all strongly correlated with better ergonomics.

Ergonomics is often overlooked in favour of other requirements, such as engineering, economics, or place availability. However, the benefits of investing in ergonomics for the business have been thoroughly proved over time, though. Moreover, regulations require a minimum of ergonomic quality in all workplaces.

Therefore, the ergonomics should be included in the design phase of any workplace to be considered throughout the process and save redesign costs. On the other hand, it is advisable to analyse the current workplaces to make sure that productions are efficient, and they are compliant as well. The thesis will develop this case.

A practical application of the ergonomics improvement in a workstation of a production line is carried out to meet the ergonomic requirements.

The current ergonomics are evaluated from a recreation of the workstation in the laboratory. The worker's movement data is collected through a sensor suit of Xsens in a pilot test, and a software simulation is used to recreate the operator in his working environment and analyse his ergonomics.

Finally, solutions are proposed to adapt the spaces with minimum investment.

ACKNOWLEDGEMENT

My education as a licenced industrial engineer comes to a close with this thesis. I would want to express my gratitude to everyone who has supported me with the process in some way. Also, a big thank you to all of my professors for teaching me in this profession.

I also would want to convey my gratitude to the Slovenian State and the *Universitat Politècnica de Catalunya* for making this fantastic exchange possible, as well as the University of Maribor for welcoming me. Thank you to Nataša Vujica and the laboratory managers for tutoring me and helping me with this project.

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1. INTRODUCTION

Set up a company or a production process is not an easy task. A lot of factors must be taken into consideration. Therefore, until not many years ago, the wellness of the workers had not been given much importance. The processes obeyed purely engineering requirements.

However, it was seen, but not surprised, that an improvement in characteristics of the workplace to make it more comfortable for the human, had repercussions on productivity level, job satisfaction and less job absenteeism because of injuries. That is why, a part of creating a better workplace for the operator, the industries they want to use more ergonomic models to improve the performance and quality of their employees and products. Moreover, the growing regulations in this area, force companies to adapt their spaces.

There are many ways to perform ergonomic studies. In this case the latest technology will be used for this purpose. A set of sensors to record the motion of a worker on a pilot workstation of a line production. The gathered data will be analysed by a simulation software able to do ergonomic studies.

A theoretical framework is also provided with the general considerations to take into account in terms of ergonomics when designing an assembly workstation.

2. LITERATURE REVIEW

2.1 Overview of ergonomics

The ergonomics is the way in which the careful design of equipment helps people to work better and more quickly [2]. For this purpose, it is applied psychological and physiological principles to the engineering and design of products, processes, and systems.

In general, in industry, the design of elements is always being revised and is subjected to numerous constraints: allocating, economics, company, labour union, etc. That impact directly to the worker conditions. Hence, ergonomics is a science with a combination of multiples disciplines such as psychology, sociology, engineering, biomechanics, industrial design, physiology, anthropometry, interaction design, visual design, user experience, user interface design and medical [10]. Thus, a wide background to design the workplace is required.

Ergonomics is useful to reduce injury rates, for example in the back due to material handling as well as pain in the joints in the arms, shoulders, and neck due to work posture. Also, it must be considered the psychological and sociological factors.

Aside from the injury of the workers, ergonomics increases the productivity, quality of production and industrial safety.

The ergonomics science can be applied in a wide range of fields in the industry. Many studies have reported improvements in the productivity and the quality in manufacturing besides decreasing of injury rates and comfort and job satisfaction of the workers.[3]

The ergonomic design has to take place during the preliminary system design phase. If the features are implemented in an early stage, they are cheaper. It is also important to think about the flexibility of the workstations.

Ergonomics in workstations

When an ergonomics optimization has to be made, or in the same way, when a workstation is designed, the designer should consider the existing differences within anthropometric measures. Depending on the region, the gender, genetics, and so forth, the size of the body dimensions are variable.
Usually, the variability of each dimension follows a normal distribution, characterized by the mean and its standard deviation. Traditionally, the facilities are designed to fit the population from 5th percentile

(small operators) until 95th percentile (large operator). This also impacts in the cost, the greater the design range, the greater the cost.

Anthropometric measures

The measurement of anthropometric dimensions must be standardized. The most complete source of anthropometric measures was published by the US NASA. The publication contains 306 measures of different body dimensions, from 91 different populations around the world. [3] For our purpose the following measurements have been taken. Moreover, Figure 1 shows the measurements taken.

Body dimensions:	Value [cm]:	Observations	Number in Fig. 1
Body Height	163.00	Used to determine the minimum overhead clearance required to avoid head collision.	1
Foot or Shoe length	27.00		2
Shoulder height	140.00	Objects located above shoulder height are difficult to lift, since relatively weaker muscles are employed. There is also an increased risk of dropping items.	3
Shoulder Width	40.00		4
Elbow Span	94.00		5
Wrist Span	134.00		6
Arm Span	172.00		7
Hip Height	85.00		8
Hip Width	27.00		9
Knee Height	50.00		10
Ankle Height	10.00		11
Extra Shoe Thickness	0.00	Already compensate	-

Table 1: Body dimensions required, values and observations [5].

It's important to note that, in order to reduce error, the measures should be done in the bare minimum of clothing and in a standing or sitting position. Shoes can raise the height by roughly 3.0 cm in an industrial setting, which must be considered. In the other hand, the postural slump can drop standing height by 2.0 cm and sitting height by 4.5 cm. [3]. This body compensation must be considered by subtracting it from the nominal height.

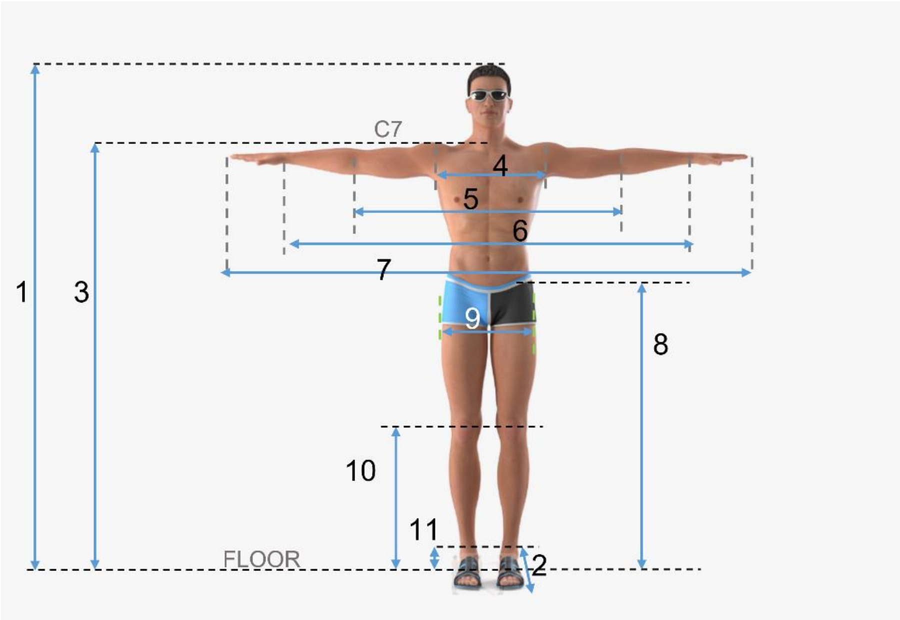

Figure 1: Body dimensions measurements [9][5]

The measurements assume that there is not bending from the waist or the hips, but since the bending cannot be sustained for a long period of time, these compensations have to be taken into account only in particular occasions.

Designing process

The designing process starts in a different point depending on the aim or the applications of the object. Different examples are showed in the following illustration.

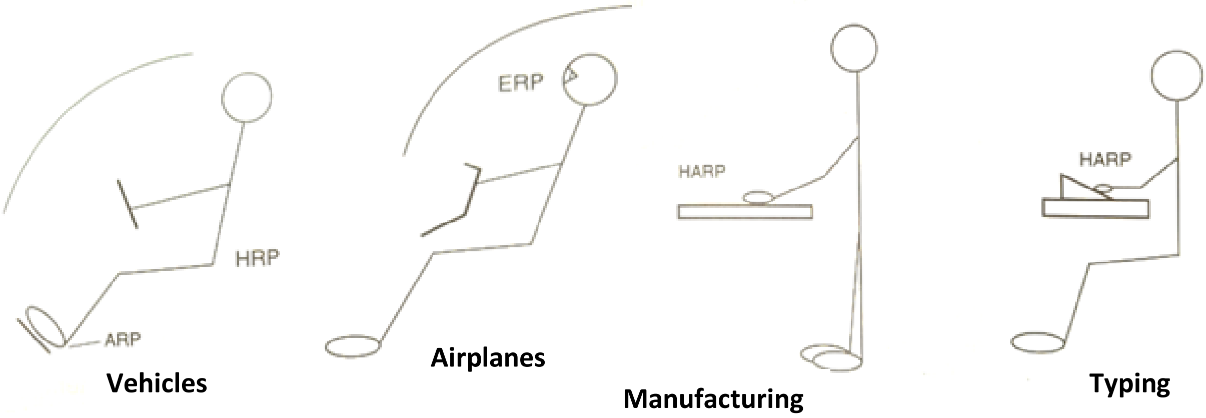

Figure 2: Anthropometric design can use different reference points. [3]

Typically, for manufacturing, assembly work, it is used the **Hand Reference Point** (HARP). The task determines where the hands should be placed. For jobs involving heavy objects, the worktable should be 20 cm below elbow height, for example. Otherwise, the hands should be roughly 5 cm above elbow height for precision activities. Hence, to design a workstation, it is necessary, first, determine the most convenient hand height for the task needed and afterwards, lay out the rest of the body by finding the measures going upwards and downwards.

As mentioned above, designs are commonly for the 5th to 95th percentile range. Therefore, more than one measure should be included. For example, for a seated job with a table at elbow height, it is necessary to include the popliteal height and the seated elbow height. In this example, an error could be introduced due to differences in the relation of the height of the back and the legs even though the same height would result if a single measurement were taken. So, it is necessary to gather two non-standard dimensions.

Despite of all the systematic errors mentioned, usually it is possible estimate the anthropometric measures with an accuracy of 1 cm. Which it is imperceptible for the worker sensitive.

Procedure

Next, the main steps for the anthropometric design are mentioned:

1. **Gather anthropometric data**: Check if there is an available database useful for the target population. If not, attempt creating a new database using current worker metrics.
2. **Determine the percentile range that must suits in the workstation:** Consider if the workplace will be occupied by men or women. In terms of equality, if the workplace has to be accessible, it must be design from 5th percentile of women measures until 95th percentile of men measures.
3. **Reaching range**: Determine the reach dimension of a little person and adjust the clearance for a large person.
4. **Anthropometric measures of the workstation:** Determine and parametrize the relevant dimensions for the workstation design.
5. **Statics to dynamics:** It is difficult to find the optimal dimensions just based in a static model. In the real world many dynamics elements are involved. To evaluate it is recommended to build a full-scale model before building the final elements.

Next, it is important to determine which posture is better for the worker. The laid out does not only must obey to engineering factors. It is also important consider the conditions of the worker and include these aspects in the early stages of the design.

Identification of poor postures

- Seats the head bend back
- Elbows in a high surface
- Cramped work posture
- Flexion of joints (mid-range)

Sitting or standing

The following table lists the main actions and their postural recommendation.

Type of task	Preferred work posture	
	First choice	**Second choice**
Lifting more than 5kg	Standing	Sit – standing
Work below elbow height (assembly)	Standing	Sit – standing
Extended horizontal reaching	Standing	Sit – standing
Light assembly with repetitive movements	**Sitting**	**Sit – standing**
Fine manipulation and precision tasks	Sitting	Sit – standing
Visual inspection and monitoring	Sitting	Sit – standing
Frequent moving around	Sit – standing	Standing

Table 2: Preferred work posture for different tasks [3]

However, it is necessary to do a holistic study, such as a task analysis of the worker situation since other factors could influence his posture. This was a general and simplistic recommendation. Although, in general sit-standing posture is a good option.

Recommendations of table height

For both seated and standing workplaces, there are standardized recommendations for work surface heights. The height of the table also varies depending on the height of the product.

The best pose is generally determined by the type of work. A height of around 5cm below elbow height is ideal for light assembly tasks. There are also personal preferences. Some people like to work with horizontal underarms, while others prefer to raise the surface to a higher elevation. A general recommendation for table height is shown in the table below. Thus, the personal preferences combined with anthropometric requirements of a 5th to 95th percentile design, yield a wide variety of values.

Type of task	**Hand height = Elbow height (approx.)**	**Preferred hand height over the floor**			
		Standing (5^{th} – 95^{th})		**Sitting (5^{th} – 95^{th})**	
		Male	**Female**	**Male**	**Female**
Heavy lifting	-15	91 -110	85 - 110	Not recommended	
Light assembly	**-5**	**101 – 120**	**95 – 110**	**59 – 79**	**55 – 73**
Typing	+3	109 – 128	103 – 118	67 – 87	63 – 81
Precision work	+8	Not recommended		72 – 92	68 - 91

* Measures of preferred hand height over the floor in cm.

Table 3: Measures of preferred hand height over the floor [3]

Repetitive motion

To end up with the overview of ergonomics, a briefly explanation about the risks of repetitive motion as it happens in a line production workstation.

Since the job of the workstation is based on a repetitive movement, we should not underestimate the injuries that can occur due to these motions. Therefore, the following recommendations should be followed to reduce the Repetitive Motion Injury (RMI).

Guidelines for	**Recommendations**
Hand posture	• **Watch out for sudden flexions or extensions of the hand and fingers.** • **Avoid Extreme ulnar deviation and radial deviation.** • **Avoid operations that require more than 90º wrist rotation** • **Keep forces low during rotation or flexion of the wrist.** • For operations that require finger pinches keep the forces below 10 N; this represents 20% of the weaker operators' maximum pinch strength.
Hand tools	• Cylindrical grips should not exceed 5 cm in diameter. • Avoiding gripping that spreads the fingers and thumbs apart by more than 6 cm. • Use hand tools that make it possible to maintain the wrist in a neutral position.

Workstation design	• **Keep the worksurface low to permit the operator to work with elbows to the side and wrists in a neutral position.** • **Avoid sharp edges on the worktable and part bins that may irritate the wrists when the parts are procured.** • **Keep reaches within 50 cm from the work surface so that the elbow is not fully extended.**
Process engineering	• **Allow machinery to do repetitive tasks and leave variable tasks to human operators.** • Provide fixtures that hold parts together during assembly and which can present the assembly task at a convenient angle to the operator. • **Minimize time pressure or pacing pressure by allowing operators to work at their own pace.**
Product design	• Minimize the number of screws and fasteners used in assembly. • Minimize the torque required for screws. • Locate fasteners and screws at natural angles so they are easy for the operator to insert. • Design a product with large parts to permit gripping with fingers and palm instead of pinching.

Table 4: Guidelines for reducing RMI through product design, process engineering, workstation design and use of appropriate hand tools. [3]

2.2 Methods for evaluating the ergonomics of workstations

This chapter describes the main methods for analysing human movements and evaluating postural loading.

Ovako Working Analysis System (OWAS)

This method allows for the assessment of the physical load resulting from work postures. This strategy approaches the postures from a broad perspective; however, it is likely less precise than other methods. Despite being one of the older methods, it is still one of the most popular approaches to assess postural load in the industry since it can consider numerous postures over time. This is the main method used to evaluate ergonomics in this thesis, hence it is the most widely described.

This method was developed in 1977 for the steel industry, but due to its simplicity of application, it was generalised to other fields. Furthermore, one of the first software implementations was in 1991 using this method. Professionals have assessed the method's results throughout time [1].

Fundamentals of the method

The OWAS method is an observational method. The observed postures of the worker throughout his task are classified into 252 different combinations based on the position of the back, arms, and legs. Is also taken into account the manipulated load [1].

A specific code is assigned to each posture that can be used to assess risk or discomfort and assign a Risk Category (within four levels). Next, for each part of the body listed above, a similar process is carried out, and a risk category is established based on the frequency of each position.

The poorest postures can be discovered and corrected using the information provided above.

The method

1. Determine whether the task is simple or complex (can be divided in a simpler task).
2. Determine the duration of observation based on the number and frequency of adopted postures. It usually takes between 20 and 40 minutes.
3. Establish the sample rate. This is the period when the worker's posture will be measured. It usually takes between 30 and 60 seconds.
4. Observation and posture recording
5. Codification of the postures observed
6. Assignation of the risk category
7. Determine the percentage of repetitions or relative frequency of each member's position.
8. Determination of the Risk Category for each body part based on relative frequency.
9. Determine the appropriate corrective and redesign measures based on the results obtained.
10. If changes have been made, re-evaluate the work using the OWAS approach to ensure that the improvement is effective.

Rapid Upper Limb Assessment (RULA)

The RULA method was developed in 1993 by McAtamney & Corlett in University of Nottinham with the aim of evaluate risk factors of the workers they are exposed that have a high posture load and can be harmful for the upper members of the body. To evaluate it, it is considered the posture, the duration, the frequency of exposition, and the forces exerted [1].

Each posture is scored from which a Performance Level is established. The Performance Level indicates if the posture is acceptable or otherwise what changes are necessary for the workplace.

At first, it is necessary to observe some work cycles and choose the postures to evaluate. If there no exist cycles, a regular interval of postures can be selected. Afterwards, angular measurements have to be made. The method should be applied to the right and left sides of the body separately or the side with more postural loads. Next, the procedure of the method:

1. Establish work cycles and observe the worker during several of these cycles
2. Select the postures to evaluate
3. Determine which side, left, right or both, will be evaluated.
4. Take the angular measurements. Directly on the worker using angle protractors, electro goniometers, or any device that allows to take angular data. Photos can also be used, ensuring that the angles to be measured appear in true magnitude in the images.
5. Determine the scores for each part of the body
6. Calculate the partial and final scores of the method and determine if there is risk in each posture and establish the Action Plan.
7. Determine the measures to take within the Plan.
8. Redesign the workplace according to the previous point.
9. Re-evaluate the new posture with RULA to check the effectivity of the measures.

Rapid Entire Body Assessment (REBA)

The repetition of poor body postures produce fatigue that can derive into health problems. This is commonly associated at high postural loads that can produce musculoskeletal disorders. That is why it is important to evaluate these loads in a workplace.

REBA is a method that can evaluate the load posture that suffers a body based in the RULA method. But, in this case, it is also included an assessment of the lower extremities. Moreover, the method considers other aspects like the load handled, the type of the grip and the type of muscular activity developed by the worker. Also, it can be considered the presence of sudden changes in postures or instabilities and if the arms are maintained in favour of the gravity. Next the steps to use the REBA method [1]:

1. Determination of the work cycles and observation the worker during several cycles.
2. Select those cycles that the posture, duration, or frequency are greater than neutral position
3. Determination of the side that will be tested.
4. Take angular measurements.
5. Determination of scores for each part of the body using the standard tables of the method.
6. Calculation of the final score and determination if there exist risk and establish if it is necessary take actions.
7. Determination of what type of actions should be taken.
8. Redesign the positions introducing the changes.
9. Re-evaluate the posture with a REBA method to check the effectiveness of the improvement.

Rapid Postural Assessment (RPA)

RPA it is not a method by itself. RPA it is a tool that allows a quick and brief assessment of the postures adopted by the worker. If RPA method provides a high level of static load, a more in-depth study should be done using more specific postural evaluation methods such as RULA, OWAS or REBA.

The method provides a numerical value based on the type of postures that worker adopts and the time he maintains them. The method also proposes an Action Plan level score.

2.3 Equipment and software package

For this work the ergonomics methods, analysis and evaluations have been done by computer with professional software and hardware. In this chapter it is described the equipment used:

XSens technology

Sensoring

Postural data gathering has been possible thanks to Xsens technology. The hardware used in this thesis is the MVN Awinda equipment that consists of the following elements [11]:

- 17(+1) Wireless Motion Trackers (MTw)
- 1 Awinda Station
- 2 Awinda Chargers
- MTw full body Velcro straps, including 3 shirts, headband, footpads, 2 pairs of gloves
- 1 Segmometer

Figure 3: Xsens Awinda kit used to gather body movement data [12]

The sensors are mounted on a Lycra suit and a set of straps to ensure a good fixation to the body and minimize skin motion errors.

The motion trackers (MTw) provide 3D angular velocity using gyroscopes, 3D acceleration using accelerometers, 3D earth magnetic field using magnetometers and atmospheric pressure using a barometer. All combined with Xsens algorithms provides a 3D drift-free orientation. Each sensor is powered by a LiPo battery that can supply the sensor for six hours operating or ninety hours in sleep model.

Figure 4: Sensor location

As every sensor a lot of factors can influence the precision of the measures thus, a sensor calibration is needed. Sensor-to-segment calibration is typically obtained being stand up with a known pose (e.g., N-pose or T-pose), and estimating the sensor orientation by combining the sensor readings. Short-term changes in orientation are tracked by the gyroscope, while long-term stability is ensured by the accelerometer and the magnetometer.

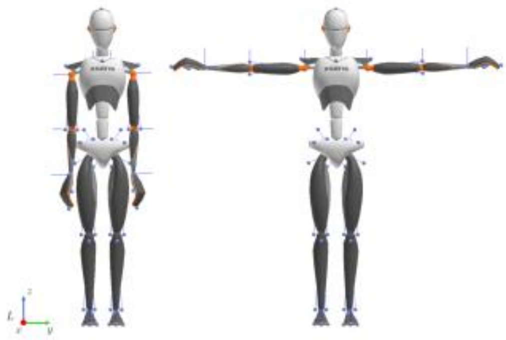

Figure 5: Xsens MVN avatar in N-pose (left) and T-pose (right). [6]

[5] The sensors send the data at a relatively low rate (60Hz) for our model. It is good for dynamics movements such as our case, but it cannot track a high dynamic movement [12].

Data processing

In this work MVN Analyze software engine have been used to record and process the sensors data. This program allows to view the data in real-time, however, for our purpose and off-line playback and analysis have been needed. The program combines the data of the individual motion trackers into a biomechanical model of the human body to obtain segment positions and orientations.

Motion tracking and limitations

The biomechanical model used consist of 23 segments: the pelvis, vertebrae (L5*, L3*, T12*, T8), neck*, head, shoulders, upper arms, lower arms, hands, upper legs, lower legs, feet and toes*. The segments indicated with an * do not have a specific sensor attached and the movement is estimated by combining the information of connected segments and the biomechanical model [6].

Combining the data mentioned of the sensor and adjusting the errors like the sensors have not a rigid connection with the segments, it is obtained an accurate and drift-free estimate of relative position and orientation of the individual body segments.

Calibration

The purpose of subject calibration is to estimate the dimensions of the person being tracked, as well as the orientation of the sensors with respect to the corresponding segments.

1. Scaling

The dimensions are obtained by applying a generalized scaling model to a set of input parameters given by the subject. In this case, the data provided to the engine was the included in the Table 1. Based on a general model, the engine finds the best fit from the given parameters.

2. Sensor-to-segment Calibration

To be able to estimate the segment kinematics using the measurements form the sensors it has to be known the current alignment between sensors and segments. Since it is not possible provide specific measurements of this data a reference pose is used where segment orientations are assumed to be known. The calibration procedure for our purpose was to be in N-pose and walk a few meters back and forth for a short period of time. While assuming the static pose, the quality of the performed pose is crucial since the segment orientations are assumed to be known. This method is immune to the effects of magnetic distortions.

3. Axes definition

After the calibration sensor-to-segment, the subject has to be un a standing N-pose facing the forward direction of the measurement environment. In this way, the forward direction of the local coordinate system is defined as well as its origin.

Simulations

Process Simulate is one application of the Tecnomatix suite that has the capability to design, analyse, simulate, and optimize manufacturing process [7].

For our case, Process Simulate program in its 16.1.2 version has been used to integrate the data of the sensors with the simulations and other elements such as the workplace and the robot elements. The software can provide a 3D virtual environment for design as well as use a virtual human model. The human functions also include ergonomic reports that has been used to characterize and assess the conditions of the workplace for the operator.

3. METHODS

In the following chapter it will be discussed the experiment design, data acquisition and data analysis procedure of the experimentation.

The workplace was recreated at the FS faculty's J2-327 laboratory, which is equipped with the proper instrumentation to transform human movements into a virtual environment. In the laboratory the necessary elements were disposed to emulate a workstation of a production line.

At our hypothetical station, a robot arm retrieves a piece form a platform placed by the worker within reach of the robot before the cycle begins. The robot presents the component to the user in a certain way, and two more parts must be assembled to complete the robot's set. This is a manual task: the human has to take two pieces from both bags of semi-finished items from another industrial process. The operator must next properly assemble the elements into the robot piece. Once this operation is completed, the operator presses a button to instruct the robot to continue the cycle.

The robot will dispose the finished product on another panel with the rest of the semi-finished products of the cycle. The cycle ends when the nine pieces of the panel are assembled with their matching parts and placed in the final panel. The operator is responsible for transporting the semi-finished product back to the origin station for further processing.

The goal of this project is to build a workstation that is as ergonomic as feasible for humans. Because various ergonomics standards have been ignored in the current situation, it is suspected that the workplace is not comfortable for the worker. As a result, the operator may become unproductiveness, suffer injures or pain.

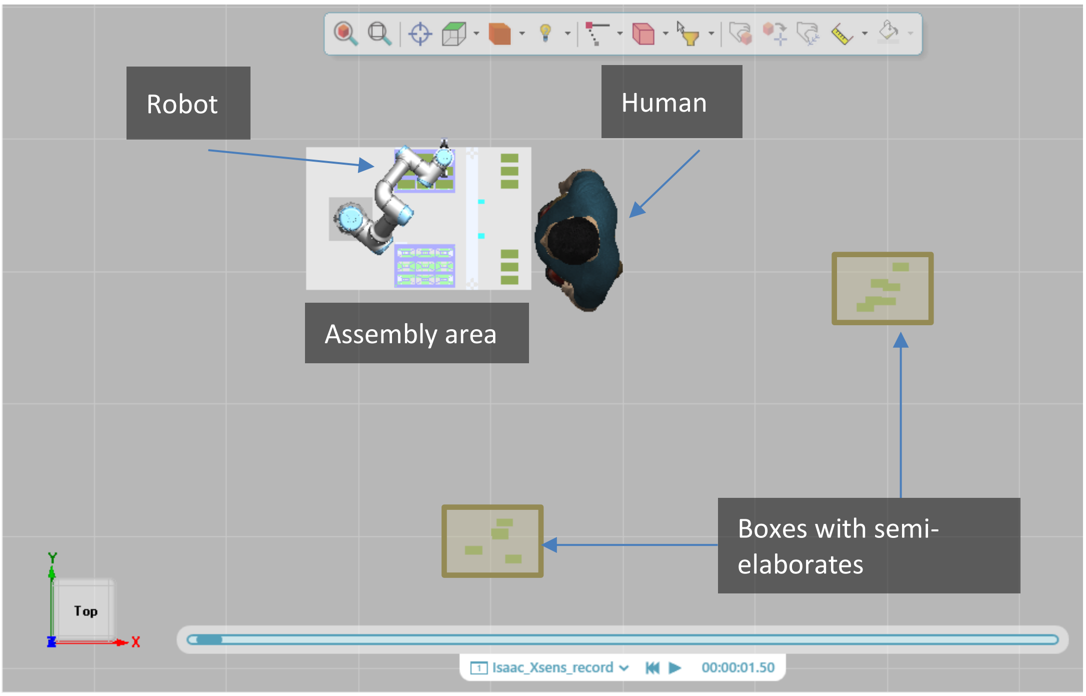

Figure 6: Plan map of the workplace

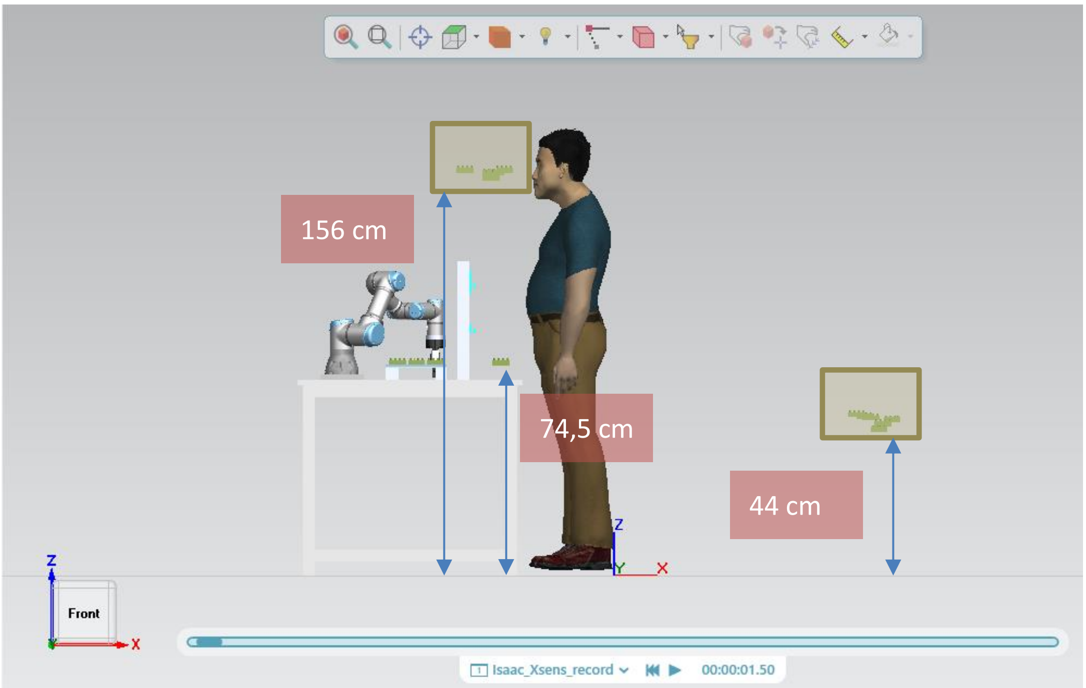

Figure 7: Elevation map of the workplace

The map above shows the current layout of the workplace of the station. We will attempt to enhance it in this project.

3.1 Xsens suit

Once the layout is established in the lab, it is necessary to include the human movements. For this purpose, it was used a specific tracksuit built by Xsens company. The tracksuit is equipped with a set of 17 sensors able to record the motions, positions, and posture. A summary of the suit's performance described in chapter 2.3.

The author of this paper, wearing the tracksuit described above, was in charge of representing the operator at the workplace under investigation. As it was mentioned above, the emulation took place in the lab, with all the parts set up similarly to a workstation.

For the simulation, the subject had to reflect the normal movements of the common worker The emulation can begin after the calibration phase, which consists of performing some conventional movements.

During the process the receiver gets the data of the suit which is recorded on a PC. After that, the data is compiled by the programme Xsens MVN, and the simulation is now available.

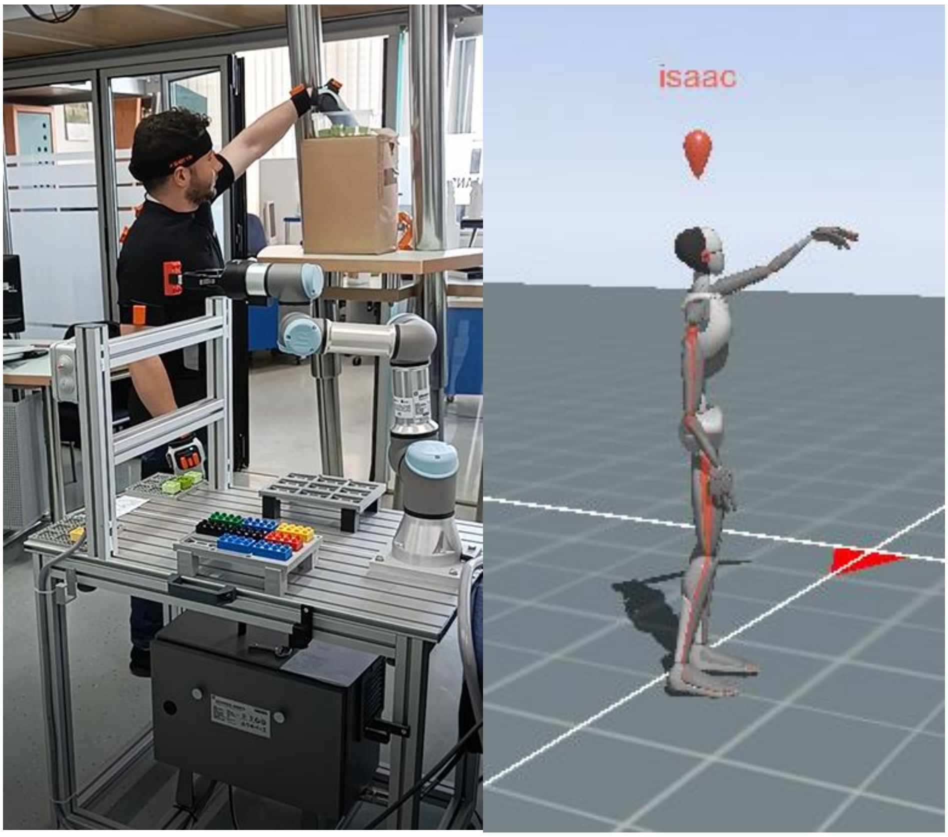

Figure 8: Picture and software animation of the simulation

3.2 Simulation

The program used for the simulation it is Process Simulate by Siemens. This program allows to import data form different sources besides modelling elements and performing different analysis.

Next, it is described the approach used in Process Simulate to condition the data and prepare the program for the ergonomic analysis.

Firstly, it is established a connection between Xsens and Process Simulate. Because the data collected by Xsens was stored on a separate computer than Process Simulate a LAN connection was established between both computers, and the data was transferred to the target computer. A valid Xsens licence is required for this operation. The model was unconstrained to release the human model of the motion capture markers.

The data is loaded in PmCompoundOperation format. This format contains the data loaded by frames. A total of 3754 frames makes up the Xsens simulation of three minutes duration. This is a raw data, and it is not interpretable by Process Simulate to carry out ergonomic studies. The proper format, recognizable by the program is Task Simulation Builder.

To create the movements, it is necessary to access to Task Simulation Builder menu and create a new simulation to the Operation Root. Afterwards, it is possible to create a task using the posture recorder. By selecting the human model and running the simulation it is possible to record and save the simulation in a Task Simulation Builder format. For our purposes, we employed a one-second transmission.

The entire simulation is now under one generic task: Pose. Since the software is unable to distinguish between each basic task. The differentiation procedure must be carried out manually.

The unique task (Pose) must be edited in order to characterise the tasks. To facilitate the process, a video of the real simulation recorded in parallel with the sensors data, can be attached to the splitting task. After the correct synchronization, the individual following tasks can be assigned to the simulation:

- Get: Take an object.
- Put: Put the transported object on a surface.
- Regrasp: Change the grip type.
- Apply force

A manual process of split and characterize each individual task has been done for the whole simulation. It is possible to specify the grip type or change specific posture factors during the assignment.

4. RESULTS

A few analyses were released in Process Simulate to evaluate the ergonomics of the current workstation. Next, the results are discussed.

The OWAS analysis reveals some ergonomic problems for the worker due to the set-up of the auxiliary elements: shelves, boxes of semi-finished elements, height of the table, etc. Some of these problems are mandatory to take actions in order to correct it because they are potentially harmful for the operator. Other poses also need corrections as well in a long term.

First, the human has to bring a pallet of nine semi-elaborate elements to the robot platform where it can reach each piece. The pallet from another industrial process it is situated on a platform at ground level. This, forces to the operator to pick it up inducing a bad posture classified as level 4 according to OWAS analysis, so it must be corrected immediately. Moreover, the program advises that also the lower back can be harmed.

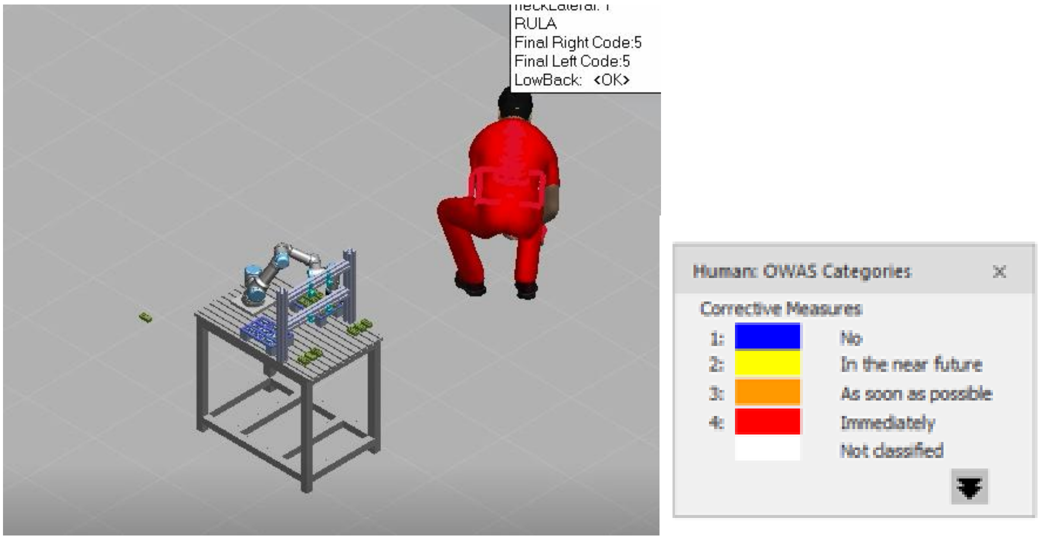

Figure 9. OWAS results in the pickup of the pallet and colour legend according to categories.

Continuing with the process, the analysis shows that the worktable neither meets ergonomic standards. The worker adopts a poor posture when he has to work on it. This is due to the table height is too low. It must be taken into consideration that the height of the pilot worker when the corrections are made to adapt the workplace to as many heights as possible.

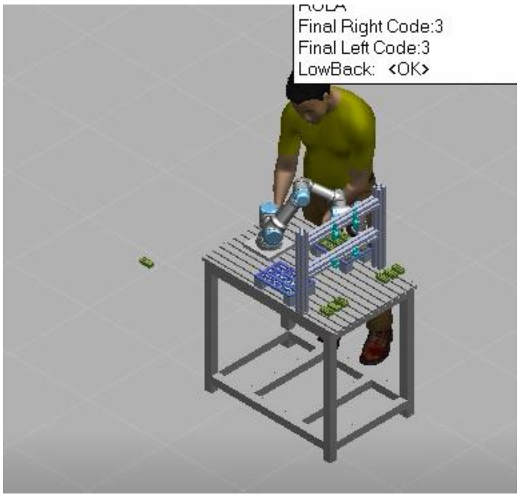

Figure 10: Pallet placement

Other problems have been found in the location of the semi-finished elements. Some of the elements have to be ensembled by hand by the operator. These products come in boxes and have to be close to the workplace. The supports of these boxes need some corrections because are potentially harmful:

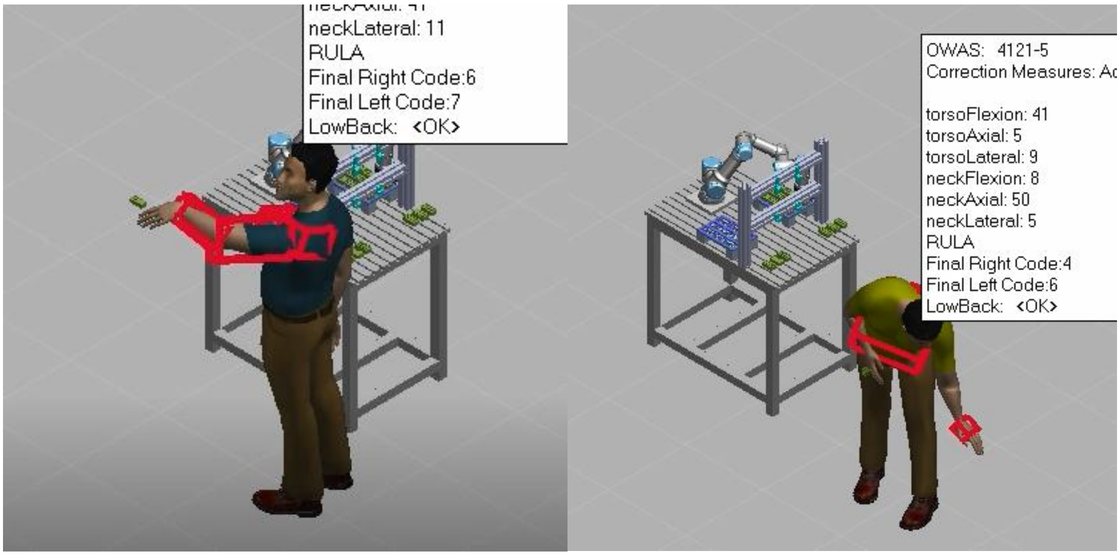

Figure 11. Taking of semi-elaborate products form the boxes

From the analysis we can find two problems. On the one hand, the heigh of the boxer has to be corrected. In the first case the arm and shoulder adopt a bad posture and potentially harmful due to the cumulative fatigue. In the second case, the worker has to bend his back.

On the other hand, the pieces inside the box do not maintain any kind of order. The worker has to search for a piece that, together with the lack of visibility induce malpositions of the wrist.

These last corrections have not a direct impact on the workers' health if are only executed once. However, the industrial process requires shift of between seven or eight hours of duration. The cumulative fatigue may harm the body of the operator in mid or long term. Hence, it is also mandatory to fix these problems.

In the simulation, the subject only performs nine cycles of the process which is equivalent to assemble the pieces of one entire pallet of final product with a total duration of three minutes. Along the shift the worker gets tired, lose attention span, and involuntarily adopts worse postures that can aggravate the damage caused by the poor ergonomics of the station.

The execution was also done in three different ways in order to represents the variability that the operator can work. All three ways present ergonomic problems. The two first situations consisted of to take the pieces from the boxes situated on their supports (changing the order between the first and second one) with the problems mentioned above. The third situation consisted of to put first the boxes on the worktable and take the pieces without moving around the workstation. As it is said before, the table height is too low for the operator that derives in ergonomic problems.

4.1 OWAS analysis report

Next, the results of the report obtained through OWAS method split by tasks chronologically sorted.

To understand the report, as explained above, an individual score is assigned to the back, arms, and legs, to the load managed and, in this case, also to the head. They are assigned based on the positions listed in table 5.

BODY PART	POSITION	CODE
BACK	Right back	1
	Bent back (>20º)	2
	Twisted back (>20º)	3
	Bent back with twist	4
ARM	Both arms lowered	1
	One arm low (below shoulders) and the other raised (above shoulders)	2
	Both arms raised (above shoulder level)	3

LEG	**SEATED**	**1**
	Stand with both legs straight	2
	Stand with one leg straight and the other bent	3
	Standing or squatting with both legs bent and weight balanced between both	4
	Standing or squatting with both legs bent and weight unbalanced	5
	Down on my knees	6
	Walking	7
LOAD	< 10 kg	1
	> 10 kg and < 20Kg	2
	> 20 kg	3

Table 5: Coding of the positions of the different parts of the body.[1]

From the relationship of the individual scores and following the table in Appendix 1, the overall score is assigned. Resulting in the implications collected in table 6.

Risk category	Posture effect	Required action
1	Normal and natural posture without harmful effects on the musculoskeletal system.	No action required.
2	Posture with the possibility of causing damage to the musculoskeletal system.	Corrective actions are required in the near future.
3	Posture with harmful effects on the musculoskeletal system.	Corrective actions are required as soon as possible.
4	The load caused by this posture has extremely damaging effects on the musculoskeletal system.	Corrective action is required immediately.

Table 6: Risk Categories and corrective actions.[1]

Time (Sec)	Operation	Object Weight (kg)	Action Category	Code Posture Combination Back	Arms	Legs	Load	-	Head
0	Pose_Jack_3_Pose	0	1	1	1	2	1	-	1
9	Get_Jack_3_Pallet_Reach	0	4	4	1	4	1	-	1
14.23	Put_Jack_3_Pallet_Reach	0.2	2	2	1	2	1	-	1
23.17	Get_Jack_3_Lego_brick4x2_9_1_Reach	0	1	1	2	2	1	-	1
24.7	Regrasp_Jack_3_Lego_brick4x2_9_1_Transfer	0.02	2	2	1	2	1	-	1
26.23	Get_Jack_3_Lego_brick4x2_9_2_Reach	0.02	2	4	1	2	1	-	5
32.07	Put_Jack_3_Lego_brick4x2_9_1_Reach	0.04	1	1	1	2	1	-	1
39.1	Get_Jack_3_Lego_brick4x2_9_1_1_Reach	0	1	1	2	2	1	-	1
42.23	Get_Jack_3_Lego_brick4x2_9_2_1_Reach	0.02	2	4	1	2	1	-	5
47.27	Put_Jack_3_Lego_brick4x2_9_1_1_Reach	0.04	1	1	1	2	1	-	1
53.47	Get_Jack_3_Lego_brick4x2_9_1_2_Reach	0	1	1	2	2	1	-	1
56.7	Get_Jack_3_Lego_brick4x2_9_2_1_1_1_1_Reach	0.02	2	4	1	2	1	-	5
63.4	Put_Jack_3_Lego_brick4x2_9_1_2_Reach	0.04	1	1	1	2	1	-	1
70.17	Get_Jack_3_Lego_brick4x2_9_2_1_1_Reach	0	4	4	1	4	1	-	5
73.3	Get_Jack_3_Lego_brick4x2_9_1_2_1_1_Reach	0.02	1	1	2	2	1	-	1
77.67	Put_Jack_3_Lego_brick4x2_9_1_2_1_1_Reach	0.04	1	1	1	2	1	-	1
84.8	Get_Jack_3_Lego_brick4x2_9_2_1_1_Reach	0	2	4	1	2	1	-	5
88.3	Get_Jack_3_Lego_brick4x2_9_1_2_1_Reach	0.02	1	1	2	2	1	-	1
94.83	Put_Jack_3_Lego_brick4x2_9_1_2_1_Reach	0.04	1	1	1	2	1	-	1
99.77	Get_Jack_3_Lego_brick4x2_9_2_1_1_1_1_1_Reach	0	2	4	1	2	1	-	5
102.3	Get_Jack_3_Lego_brick4x2_9_1_3_Reach	0.02	1	1	2	2	1	-	1
107.9	Put_Jack_3_Lego_brick4x2_9_1_3_Reach	0.04	1	1	1	2	1	-	1

Table 7: Categorization of base case tasks. Process Simulate.

The table above shows the results for the first two assembly methods, which consists of picking up the pieces from the trays located outside the artboard. On the other hand, the table below shows the results of the third methodology, which consists of having the semi-finished products on the worktable itself, as well as the return of the final product.

Time (Sec)	Operation	Object Weight (kg)	Action Category	Code Posture Combination Back	Arms	Legs	Load	-	Head
0	Repositioning__Pose	0	1	1	1	2	1	-	1
1.33	Get_Jack_3_Lego_brick4x2_3_1_1_Reach	0	2	4	1	2	1	-	1
3.67	Regrasp_Jack_3_Lego_brick4x2_3_1_1_Transfer	0.02	1	1	1	2	1	-	1
52.17	Get_Jack_3_Pallet_Reach	0	2	2	1	2	1	-	1
60.93	Put_Jack_3_Pallet_Bend_And_Reach	0.38	3	2	1	4	1	-	1
61.9	Description_9_Pose	0	2	2	1	2	1	-	1
62.13		0	2	2	1	3	1	-	1
62.43		0	2	2	1	2	1	-	1
62.47		0	2	2	1	3	1	-	1
62.5		0	2	2	1	2	1	-	1
62.53		0	1	1	1	2	1	-	1
62.7		0	2	2	1	2	1	-	1
62.9		0	1	1	1	2	1	-	1
63.57		0	1	1	1	3	1	-	1
63.97		0	1	1	1	2	1	-	1
64		0	1	1	1	3	1	-	1
64.6		0	1	1	1	2	1	-	1
64.67		0	1	1	1	3	1	-	1
65.03		0	1	1	1	2	1	-	1
65.37		0	1	1	1	3	1	-	1
65.63		0	1	1	1	2	1	-	1

Table 8: Categorization of base case tasks working on the worktable. Process Simulate.

As can be seen, the tasks of the second 9 and 70 stand out, which correspond to the collection of the pallet and a task of collecting pieces. These processes, as previously mentioned, must be corrected as quickly as possible. In addition, a large number of actions are shown during the collection of parts (practically all) that must be corrected.

On the other hand, it also highlights the task of putting the pallet with the final product, which has a rating of 3, so it must be corrected before continuing with the activity of the workstation.

4.2 RULA analysis report

On the other hand, the results of RULA do not indicate major defects in the ergonomics of the workstation since the movements are punctual and infrequent as it is a pilot test. However, the repetition of such postures can cause long-term damage as discussed above.

TABLE C Right							
Final A Score	Final B Score 1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

TABLE C Left							
Final A Score	Final B Score 1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Table 9. RULA report results. Process Simulate.

5. DISCUSSION

As seen in the previous chapter, the layout of the workstation does not meet the ergonomic standards and poses a danger for the worker health. Some actions must be taken immediately other actions are recommended to solve as soon as possible.

6.1 Proposed solutions

Based on the results and the ergonomics context following there are some actions to take on the workplace in order to make it more comfortable for the worker as well as safe that probably will have repercussions increasing productivity and reducing injuries in the long run.

a) Arrival of the pallet of semi-finished products

In the current situation the pallet with the semi-finished products from the previous workstation are located at ground level. This is one of the most harmful postures for the worker.

An auxiliary table or conveyer belt is necessary to rise the workplace at ergonomic level and avoid the back bending and other potentially harmful poses. A conveyor belt is a good option because has the advantage that the operator can push items from a moving conveyor to the assembly line while it is not paced by the line. The operator can work faster or slower, as long as the buffer capacity of the storage conveyor it is not exceed.

The commonly height of the conveyor is fixed at 92 cm which is the same as for industrial standing workstations, however, it can be treated as a worktable following the recommendations for sitting or standing heights. It has to be designed to respond to the human necessities not industrial or engineering purposes.

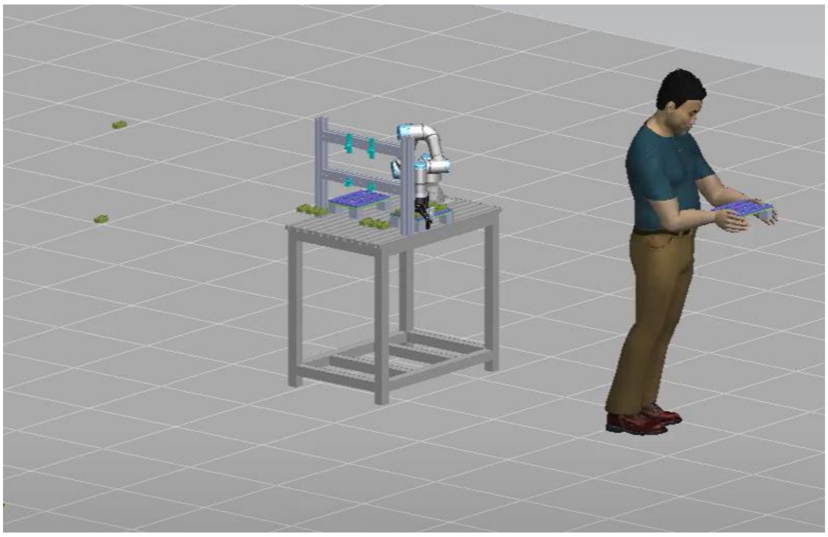

Figure 12: OWAS results in the pickup of the pallet with ergonomic modifications

In the other hand, if the work is performed sitting, the hand height should be about 55-79 cm for light assembly. Additionally, to avoid a bad posture work, the conveyor should be thin enough to fit in the space between the thighs and underarms. Moreover, the conveyor has to be accessible from both sides in order to break up the jams. One more consideration, the conveyor belt has to provide crossing points or gates if they are long enough to block the pass of products or humans.

To make more ergonomic this solution, a slide system from the conveyor until handling is better than lifting. A special roller might be used. In the loading, and especially unloading operations, the back can suffer, also because the movement is paced by the conveyor. High velocities (> 10 m/min) can also cause dizziness, mainly if the person sits sideway to the conveyor.

A similar analysis has been done for the final product, that it is presented in the same format and leaved at ground level.

b) Boxes of semi-finished products

The second biggest problem of the workplace is the allocation of the boxes with semi-elaborated products that are taken by the operator to ensemble to the robot's piece. The current of the boxes, perhaps due to some adaptation of a previous workplace, use of old furniture or difficulty in adapting the space, force the worker to have a bad posture. The elevation of the hand over the head forces an overexertion of the shoulder. At the end of the shift or over time, will cause wear or injury to the joint. In addition to the breaks due to shoulder discomfort and absenteeism from work.

The solution for this case is simple. Make the necessary modifications to rise or lower the surface to make it accessible without force the shoulder or the back. A standard recommendation to situate the material at the same height of the worktable.

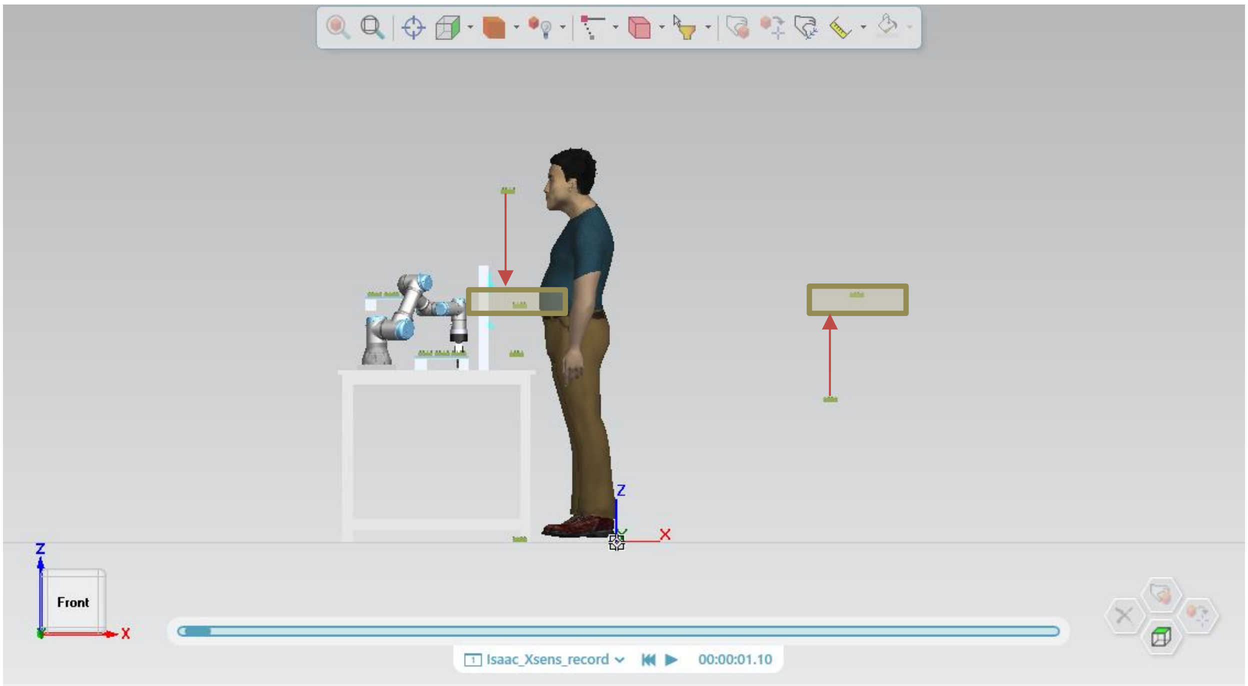

Figure 13. Replacement of the boxes according to the ergonomic rules.

In addition, there is a second problem with the boxes. Lack of the visibility due to the position of the boxes and the chaos of the product inside the boxes make it more difficult to obtain the pieces. It can be a waste of extra time and unnecessary wrist movements.

A redesign of the previous industrial process can help in facilitating the process of this workstation.

c) Worktable

The third problem founded is that the heigh of the worktable is too low. Even though the robot is within the acceptable height range, the worksurface forces the operator to bend his back when manipulating objects on the surface.

Figure 14. Ergonomic problems when the operator works on the work surface

Reviewing the Table 3 it is determined that the worktable does not meet ergonomic requirements. Therefore, a worktable elevation is required. This has two implications, on the first hand, rise the worksurface by changing the table or adding an auxiliary element. On the other hand, the kinetics of the robot must be changed in order to modify the trajectory to adapt it to the new position. Furthermore, the final relative position of the robot has to be lower than the previous one to compensate the rising of the table. In this way the placement of the pieces remains ergonomic for the user as they were initially.

With the above corrections, an assembly cycle has been repeated. The results of the report obtained by the OWAS method are shown below.

Time (Sec)	Operation	Object Weight (kg)	Action Category	Code Posture Combination					
				Back	Arms	Legs	Load	-	Head
0	Get_Assem1_2_Jack_3_Walk	0	1	1	1	2	1	-	1
0.03		0	1	1	1	7	1	-	1
1.43		0	1	1	1	7	1	-	5
1.5		0	1	1	1	7	1	-	1
1.53		0	1	1	1	7	1	-	5
1.67		0	1	1	1	7	1	-	1
3.67	Get_Assem1_2_Jack_3_Reach	0	1	1	1	2	1	-	1
4.27	Put_Assem1_2_Jack_3_Walk	0	1	1	1	7	1	-	1
4.5		0	1	1	1	7	1	-	5
4.53		0	1	1	1	7	1	-	1
5.27	Put_Assem1_2_Jack_3_Reach	0	1	1	1	2	1	-	1
5.6	Get_Lego_brick4x2_9_1_5_1_Jack_3_Walk	0	1	1	1	7	1	-	1
6.9		0	1	1	1	7	1	-	5
7.37		0	1	1	1	7	1	-	1
9.07		0	1	1	1	2	1	-	1
9.7	Get_Lego_brick4x2_9_1_5_1_1_Jack_3_Walk	0.02	1	1	1	7	1	-	1
11.17		0.02	1	1	1	2	1	-	1
11.57	Put_Lego_brick4x2_9_1_5_1_1_Jack_3_Walk	0.04	1	1	1	7	1	-	1
11.77		0.04	1	1	1	7	1	-	5
11.83		0.04	1	1	1	7	1	-	1
12.37		0.04	1	1	1	2	1	-	1

Table 10: Categorization results of the optimized workplace. Process Simulate.

As can be seen in the table above, all ergonomic defects have been resolved. All actions are categorized with risk 1. In this way, a suitable work environment has been achieved for the worker throughout the shift.

Following the indications of the Table 2, the preferred position for the assembly of light materials is seated. This option avoids overloading the legs and avoiding bad positions due to bending or the postural slump. The seated pose can be combined with other tasks in a standing or walking posture, such as picking up boxes or materials in each work cycle. In addition to introducing other types of activities, such as cleaning, order, or administration, from time to time.

The sitting position has been tested in Process Simulate obtaining excellent results.

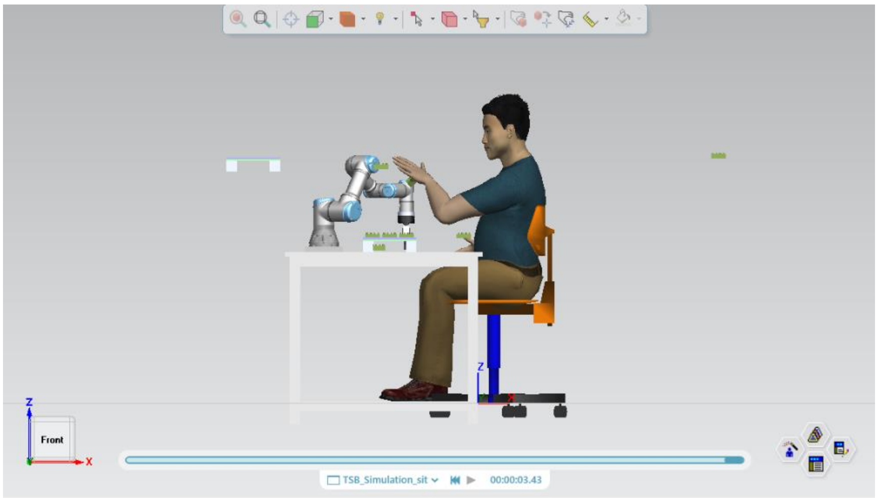

Figure 15. Worker sitting ergonomically at the workstation.

As with the conveyor belt, the table should be thin enough to fit in the space between the thighs and underarms. The chair must be adjustable in several degrees of freedom, mainly in height, armrests and backrest inclination. The manipulation of the chair must be easy and accessible for the user, and it must be adjusted whenever necessary. It is convenient to carry out training in occupational risk prevention where the basic principles of ergonomics and the correct handling of the elements are explained.

The space under the table should be as free as possible to encourage changes in posture. The arms must be able to rest on the worktable to reduce tensions. Finally, the elements must be within easy reach of the worker in a sitting position to avoid forced work postures of the upper limbs and neck. [6]

d) Layout

All the previous points are solutions for the individual ergonomic problems founded in the workstation. However, there are some potential points for improvement in the workstations, which are not harmful but improve the ergonomics and efficiency of the station. Thus, it would be convenient to redesign the station applying the aforementioned measures. The overall improvement would be aimed at reducing downtime while improving ergonomics. For example, travel time within the station is unwanted as it is unproductive.

Corrections previously announced are maintained. Moreover, the different elements can approach the work area surrounding the operator in such a way that they are available within his reach without the need to get up or force his limbs. Easy access to the operation and maintenance area must be ensured, as well as the free movement of the worker in the chair.

The elements that the worker commonly uses must be located in the anterior semi-circumference of the operator so that he can easily see and access it without the need to rotate or force the shoulders.

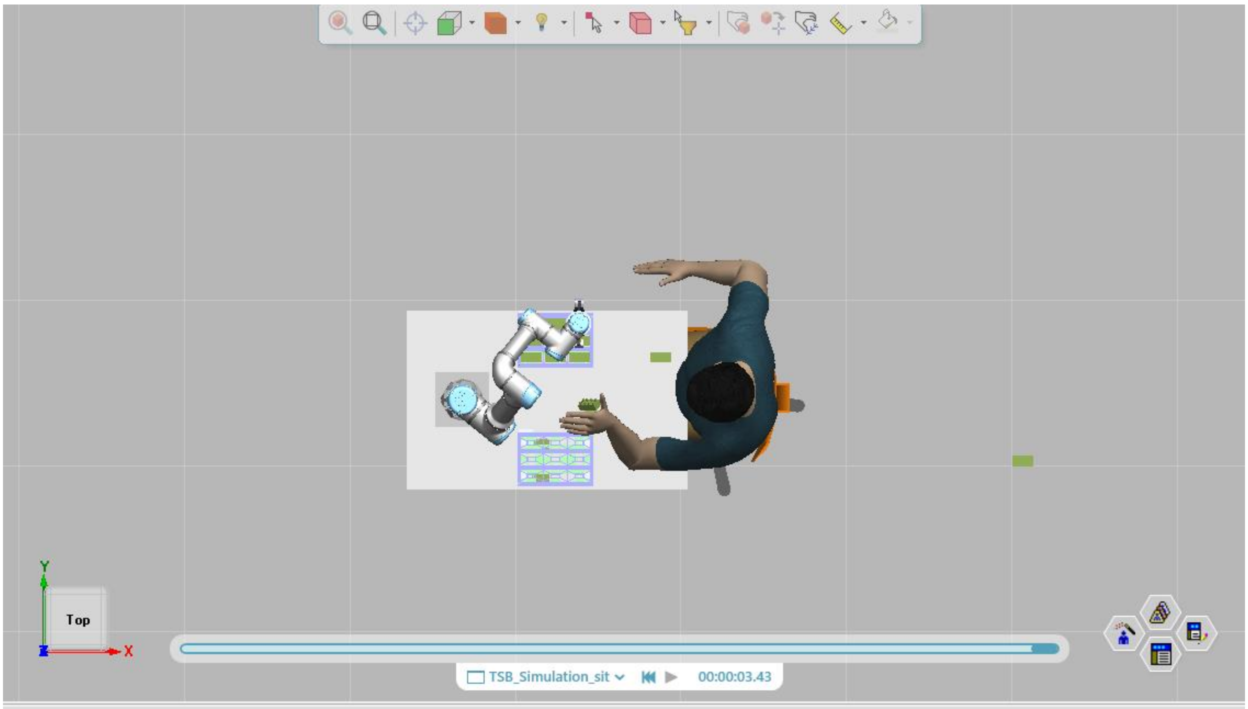

Figure 16. Plan view of the workstation layout

Analysing the ergonomics of the workplace with the OWAS method, the following result is obtained.

Time (Sec)	Operation	Object Weight (kg)	Action Category	Code Posture Combination					
				Back	Arms	Legs	Load	-	Head
0	Go_to_target_Jack_3_Walk	0	1	1	1	1	1	-	1
0.03		0	1	1	1	7	1	-	1
0.27		0	1	1	1	7	1	-	5
0.3		0	1	1	1	7	1	-	1
0.43		0	1	1	1	7	1	-	5
0.63		0	1	1	1	7	1	-	1
0.93		0	1	1	1	1	1	-	1
0.97	Pose_Jack_3_Pose	0	1	1	1	2	1	-	1
1.03		0	2	1	1	4	1	-	1
1.87		0	1	1	1	1	1	-	1
2.17	Get_Lego_brick4x2_6_1_Jack_3_Reach	0	1	1	1	1	1	-	2
2.43	Put_Lego_brick4x2_6_1_Jack_3_Reach	0.02	1	1	1	1	1	-	1
2.53		0.02	1	1	2	1	1	-	1
2.73	Get_Lego_brick4x2_6_1_1_Jack_3_Reach	0	1	1	1	1	1	-	1
2.83		0	1	1	1	1	1	-	2
3.13	Put_Lego_brick4x2_6_1_1_Jack_3_Reach	0.02	1	1	1	1	1	-	1
3.27		0.02	1	1	2	1	1	-	1

Table 11: Categorization results of the optimized workplace in a seated position. Process Simulate.

The table shows the scores given to each of the tasks. As can be seen, all ergonomic and safe actions are maintained.

Only the position of the first second that corresponds to the action of sitting on the chair stands out. With a suitable chair and the pertinent adaptations, such as footrests and ergonomic adjustments of the chair itself, this action is also risk-free.

6.2 Results comparison

Finally, the results of the OWAS method are collected and compared before and after the improvements to show the relevance and impact of the corrections applied.

Task	Original	Improvement 1 (stand)	Improvement 2 (seated)	Risk reduction
Get the pallet	4	1	1	-3
Put the pallet on the worksurface	2	1	1	-1
Take pieces	2	1	1	-1
Ensemble	1 – 2	1	1	-1
Put the finished pallet	3	1	1	-2

Table 12: Results of OWAS analysis and risk reduction value.

As can be seen in the table above, all critical tasks have seen a reduction in risk. With the improvements designed, the risk level has been reduced to the lowest possible value. Therefore, a safe, ergonomic, and comfortable working environment for the worker has been achieved. Moreover, the risk of injury has been considerably reduced.

According to the OWAS method, there is no difference between sitting and standing in terms of ergonomics. However, the related literature advises the use of an ergonomic chair to carry out the type of activity studied. Therefore, it is the chosen option.

The workplace, while subject to the designated ergonomic conditions, allows for some (or a great deal of) flexibility in layout. This allows it to be adjusted to other requirements, such as available space, floor layout, engineering requirements, etc.

In any case, after the final design of the workplace, it would be convenient to carry out another simulation of the worker activity and re-study the ergonomics to verify that the theoretical measures have taken effect or that other factors not considered have arisen.

6. CONCLUSION

Ergonomics in the industry must be one more factor to consider when designing a workplace and the budgets. Not only technical criteria should be taken into account. The ergonomic spaces benefit to the worker as well as increment the productivity, decrease absenteeism because of injuries and a large etcetera.

To assess the ergonomics of a workplace, first it is necessary to know the characteristics of the stuff that will work on it. It is recommended to look for an existing database, or if does not exist, consider gathering the data by oneself. There are differences in the human dimension depends on the region, gender, populations sectors, etc.

It is also important to define the range of the extremities and evaluate the dynamic ergonomics that can vary form static measurements. All of this data must be considered in the early phases of design to be considered throughout the process.

To design an ergonomic space, the engineer revises the regarded literature to know which model is preferred. For the case we have reviewed in this thesis, assembly of low grammage pieces, the best posture for work is sitting position or standing-sitting position. Work surfaces are designed around the ideal height of the forearms and hands, which in particular, is slightly below elbow height.

Once the workplace is already designed, an ergonomic evaluation is needed. There are many methodologies, each with its peculiarities and specifications. Some of them place more emphasis on the torso, others on extremities, and others are simply quick assessments to see if the environment is potentially safe.

In this case has been mainly used the OWAS methodology which is still the most widespread and incorporated in software. To assess the ergonomics of the workstation a simulation has been done. Through the use of sensors and emulating the natural movements of the worker, angular and positional variations have been recorded. With Process Simulate software the work environment has been recreated and the ergonomics have been verified using various ergonomic methods.

Various shortcomings have been detected, such as a misplacement of the semi-finished trays, a worktable that is too low and the need to include conveyor belts to lift and facilitate the exchange of materials between stations.

Regarding the position, the sitting position has been chosen so as not to overload the legs, always alternating with other types of standing tasks.

Summarizing, it has been provided a theoretical framework and a practical application for the remodelling of a workstation in favour of ergonomics. The growing regulations in this area force companies to "adapt" more and more. With the collateral effects of improving worker productivity and well-being, which has a positive impact on all areas of the company.

The thesis includes an example of this process that can undoubtedly inspire and encourage more companies to carry out ergonomic change.

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