



ERGONOMIC ANALYSIS OF WORKERS LOAD DURING THE ASSEMBLY PROCESS

Diploma Work

First cycle study program of Mechanical Engineering

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Diploma work

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ERGONOMIC ANALYSIS OF WORKERS LOAD DURING THE ASSEMBLY PROCESS

Key Words: Ergonomy, simulation, analysis, load, posture, operator.

ABSTRACT (English Version)

An ergonomic analysis is the study of the work tasks carried out at a workstation in order to identify and prevent hazards before they occurred, but also to improve the productivity.

This thesis focuses on the tasks accomplished in a Spanish logistics company. By means of an ergonomic programme, the Jack Task Analysis Toolkit, three different physical tasks performed in the company's workplace are analysed. These tasks are monotonous activities that involve the lifting of not very heavy loads during long periods of time. The analysis undergoes a series of evaluations to identify the possible consequences caused by the development of this tasks. The evaluations are mainly centered on the postures adopted by the operators and the fatigue generated by the tasks.

Subsequently, the execution of the task is redesigned in order to create a safer work environment for the workers by the implementation of different ergonomic measures which may involve the change of the workplace, the work posture or even the time spent performing the task.

ABSTRACT (Spanish Version)

Un análisis ergonómico es el estudio de las tareas de trabajo realizadas en una estación de trabajo para identificar y prevenir peligros antes de que ocurran, pero también para mejorar la productividad. Esta tesis se centra en los trabajos realizados en una empresa de logística española. Por medio de un programa ergonómico, el Jack Task Analysis Toolkit, se analizan tres actividades diferentes realizadas en la nave industrial de la empresa. Estas tareas son actividades monótonas que implican el levantamiento de cargas no muy pesadas durante largos períodos de tiempo. El análisis se somete a una serie de evaluaciones para identificar las posibles consecuencias causadas por el

desarrollo de estas tareas. Las evaluaciones se centran en las posturas adoptadas por los operadores y la fatiga generada por las tareas. Posteriormente, la ejecución de la tarea se rediseña para crear un entorno de trabajo más seguro para los trabajadores mediante la implementación de diferentes medidas ergonómicas que pueden implicar el cambio del lugar de trabajo, la postura de trabajo o incluso el tiempo dedicado por el trabajador para realizar la actividad.

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1. INTRODUCTION AND APPROACH OF THE PROJECT

An ergonomic evaluation is the process of performing a scientific investigation of an individual's work station and environment in order to provide recommendations for a healthier work environment based on the results of these findings. The purpose of an ergonomic evaluation is to minimize or prevent injury to the individual and to promote workplace efficiency through the application of ergonomics.

In this particular case, the analysis is going to take place in an Industrial workstation belonging to a logistics company: One2one Logistics. This is a logistics company with more than 15 years of experience in this sector. It has more than 22,000 square meters of facilities, 2.6 million orders managed and more than 31 million of kilograms moved.

The services offered cover practically all sectors: e-commerce, parapharmacy, technology, electrical and electronic industry, communications, entertainment, computer and promotional material; being specialists in the field of technological products and requiring logistics precision.

The company has opted for technology as a tool for productivity and reliability. Due to the increasing complexity and the customization of the processes, with shorter execution times and which incur in a very important way in the costs, they have opted for the intensive use of technological means that provide effective, reliable and competitive solutions for the customers. Its warehouse management system (SGA) is developed by Atos and allows total control of the process and of the goods (forecasting and planning of the demand, supplies, real time stock management, transport traceability ...). The resource planning systems (ERP) have been developed to meet the needs of the logistics sector, their own and those of their customers.

They offer the services of warehousing, preparation and expedition of customer's orders in addition to the conduction of call-center services in the supply chain, after-sales attention and inverse logistics.

The company has two warehouses. One of them is located in Azuqueca de Henares (Madrid, Spain) and the other is located in Las Palmas de Gran Canaria, which is in charge of providing the Canary Islands.

During the month of April took place the first part of this project. This first part consisted of visiting the company, learn the work routine carried out there, but also finding out by asking the workers for the main problems they highlighted above all. One of the most repeated answers during this phase was the monotony of the tasks they developed, which after a few hours of work began to be painful for them.

It is also important to take into account the factors that are external to the task but still have a great effect on the labour of the worker and their satisfaction such as:

- Heat and cold.
- Work-rest cycle.
- Organizational factors.

2. DESCRIPTION OF THE TECHNOLOGIES

Ergonomics is a word that has its origin in Greece. *Ergo* means work and *nomos* means natural law. The first time this term was used is dated back in the middle of the 19th century (1857) when Wojciech Jastrzebowski mentioned it in a Polish newspaper. According to him, the natural law of work would be divided into two main categories: the natural law of useful work and the natural law of harmful work. Harmful work is considered to be the one we develop when we do not make an appropriate use of the faculties that have been granted to us and which leads to the deterioration of the things and people. The useful work (or efficient as it would be said nowadays) is the one that succeeds in the development of the professional activity not only as a mechanical activity, but as something which is improved with the practice, overcoming a series of internal levels -sensorial, intellectual and spiritual-, until reaching happiness through work. In the USA, to make allusion to this concept they called it *human factors engineering* or *human factors*. Although both terms were different in their birth, they are getting closely related due to the introduction of computers in the workplace.

On one hand, European Ergonomy is born as a mixture of physiology, biomechanics and workstation design and focuses on human performance and systems design. On the other hand, *Human Factors* has its origin in experimental psychology and focuses on human performance and systems design. It emerged as a discipline after World War II. Back in those days, they realised that more pilots were killed during training than in battles. In such a time, where lots of new technologies were developed such as aeroplanes, radars or sonar stations, one of the main problems turned out to be how could information be better displayed and how could controls be redesigned and integrated with the task so that they were easier to handle. As a result of this study, the number of fatalities in the training decreased considerably (up to a 5%). In Europe, except from the former USSR, ergonomics was born for other needs.

Immediately after World War II, the industry's main objective, just as the one of ergonomy, was the rise in productivity. This, was a viable purpose for ergonomy due to the fact that a big part of the industrial productivity was directly determined by the physical efforts done by the workers. Gradually, the mechanical energy replaced the

human muscular efforts. However, the rise in energy also produces more accidents, just because of the simple principle that accidents are the direct consequence of the application of energy in the wrong moment in the wrong place. When the production rate gets higher, the probability of having an accident also rises. They are directly proportional.

For this reason, the industry's main concern and the purpose of ergonomics began to change from productivity to safety, just as the beginnings. This happened between the 1960s and beginnings of the 1970s. During this time, a great part of the production sector changed from the batch production to the chain production and as a consequence, the function of the operator also changed from the direct participation to labours of control and inspection. This made the accident rate go down, as the operators weren't in the action zone of the mechanical activity but, in some occasions, the accident severity rose due to the speed and energy inherent to the process.

Even though this historical description may suggest that the ergonomist has systematically ignored a series of problems and has tried to solve others, this is not the reality. Ergonomics embraces much more than the industrial production. Apart from the production ergonomics, there is the product ergonomics or the design ergonomics. In other words, the adaptation of the machine or the product to the user. In the automotive industry, for example, ergonomics is not only important in the fabrication of the different parts of a vehicle or the production lines, but also everything related with the future driver, passenger and the one in charge of the maintenance.

The human efficiency is generally optimized in-between an interval of tolerances of a relevant variable. The majority of the first ergonomists tried to reduce the muscular effort and the amplitude and diversity of the movements that the object went through didn't exceed the tolerable limits. The great changes in the working world and the arrival of the computer have caused the contrary problem. The working space with a computer, unless it is ergonomically well designed, can cause an excessively steady posture, a lack of body movement and an excessive repetition of certain articular movements.

This brief historical revision pretends to show that, although the ergonomic development has never stopped, new problems appear every day without having been able to solve the existing ones. However, knowledge in this field is also rising and getting even more reliable and valid.

Nowadays, ergonomics is implemented in most of the industries with the main objective of reducing the injury rates and the high insurance premiums. In the United States, for example, the compensation a worker may perceive due to it can go up to the 15% of the salary.

3. DESCRIPTION OF THE MODEL DEVELOPED

Due to the fact that the mechanical activities carried out in the company are countless, the analysis carried out in this project is going to focus in three activities:

- *Picking* process: In this procedure, the operators are in charge of giving shape to the order of the client. The preparation is not done in an individual way. Instead, it is carried out by groups of orders of the same characteristics and which work with the same transport companies, following the mechanisms of batch production. In this way, the activities done speed up so that if a product is needed in different orders, the terminal indicates the location, the number of units and the order to which each unit corresponds, so that the operator goes for the product only once to the picking zone. The picking zone consists of a few halls divided between each others by shelves that keep the merchandise.



Figure 1: Picking Zone.

- Order closure: During this part of the preparation of the order, the operators are in charge of finishing the orders manually in set work place with a series of specific activities. The specific activity analysed here consists of the lecture of the product's barcode and the subsequent introduction of the product in a roller path which carries the product to its final destination: the truck.



Figure 2: Order Closure.

- Preparation of particular orders: this task takes place in a section of the workplace called *Business to Consumer (B2C)*. This place is in charge of all the processes of the orders that belong to particular clients, not companies. So this task consists in taking products from the shelves shown in the image below and putting them in a bigger box which, at the end, is introduced in the roller table.



Figure 3: Preparation of Particular Orders.

In order to develop this study, it is used a computer program called Jack Task Analysis Toolkit. This, is a set of Ergonomic analysis tools that help design better work areas and evaluate physical tasks. The Task Analysis Toolkit further enhances the ability to analyze industrial tasks.

The project's main difficulty includes the virtual representation of the activities explained above by means of the programme mentioned. With the simulations done in it, various analysis included in the programme are carried out:

- ❖ **Lower Back Analysis Tool**: it helps you evaluate the spinal forces acting on a virtual human's lower back, under any posture and loading condition. This tool is used to:
 - Design workcells and tasks that make the risk of a low back injury get as low as possible.
 - Prioritize manual tasks that need the most immediate attention for ergonomic modifications.

The tool has the precision to inform you about the exact moments of a task sequence when the forces on a worker's low back exceed the prescribed limits.

- ❖ **Metabolic Energy Expenditure**: helps you predict the metabolic energy expenditure requirements of a job based on worker characteristics and a description of the simple tasks that comprise the job. It is used to:
 - Guide job design by identifying tasks that have the biggest impact on energy expenditure and by predicting how changes to the characteristics of the task affect a job's overall energy expenditure requirements.
 - Compare alternative job designs on the rate of metabolic energy they require workers to expend.

- ❖ **Fatigue Recovery Analysis**: this tool helps you assess whether enough recovery time is available for a given job to avoid worker fatigue. It computes the recovery time required for a job and compares it to available rest time. If there is not enough rest time in a job cycle to accommodate recovery time, workers are assumed to be at risk of fatigue. It is useful because:
 - It guides job design by identifying tasks that require the greatest recovery time and predicts how changes to the characteristics of the task affect worker recovery time.
 - Compares alternate job designs based on their relative risk of exposing workers to fatigue.

- ❖ **Ovako Working Posture Analysis (OWAS)**: it provides you with a simple method for quickly checking the comfort of working postures and determining the urgency of taking corrective measures. It assigns the evaluated posture a score that indicates the urgency of taking corrective measures. It is used to:
 - Design new manual tasks or guide the redesign of existing tasks for more comfortable workplaces and improved production quality.

- ❖ **Rapid Upper Limb Assessment (RULA)**: evaluates the exposure of workers to the risk of upper limb disorders based on posture, muscle use, the weight of loads, task

duration and frequency. Assigns the evaluated task a score that indicates the degree of intervention required to reduce the risk.

RULA uses a scoring system based on posture, muscle use and force to assign an action level to the evaluated task. These scores are presented in a dialog box, along with the action level identified for the task. The following levels are proposed:

- Level 1: acceptable posture if it is not maintained for a long period, and not repeated excessively.
- Level 2: more investigation about it is needed. It may require changes.
- Level 3: investigation: changes required soon.
- Level 4: investigation: changes required immediately.

3.1. Assumptions

Even though the Jack Task Analysis Toolkit is a very complete programme, there are certain aspects of the ergonomic analysis that, though being important, the programme is not able to take into account.

- The noise levels are well within the ones recommended by law.
- The people that carry out the tasks have an average size and weight.
- The work environment is adequate.

3.2. Simulations

3.2.1. Picking Process Simulation

In this simulation, the work carried out here is done by an average size woman (Height: 163 cm. Weight: 63 Kg). The task shown in the simulation (*see Image 3*) represents a woman picking six products from the shelves and putting them into a pallet, just the same as it is done in the *picking zone* in One2One Logistics. 5 of the 6 boxes have the same weight (5 kg), but the

last one is heavier (10 Kg) so that it is possible to analyse the restrictions that the weight of the merchandise can impose during the fulfillment of the task.

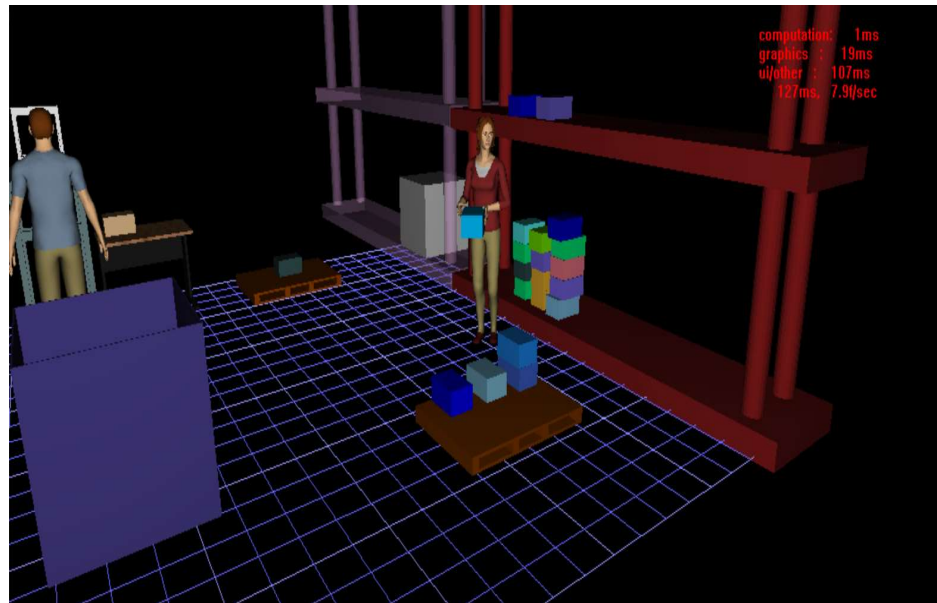


Figure 4: Picking Simulation.

3.2.2. Closure Simulation

In this simulation an average size man (Height: 174 cm. Weight: 78 Kg) is the one that carries out the task. The simulation shown below represents the operator surrounded by a roller path, a computer on a table and another table which contains the products of the order. The operator picks one by one, with one hand, the products. Then, he puts it on the table near to the computer so that the barcode of the product is read and immediately after, he puts it on the roller so that the product ends in the trailer. This process is repeated 3 times during the simulation. The weight of the products is of 1 kg this time.

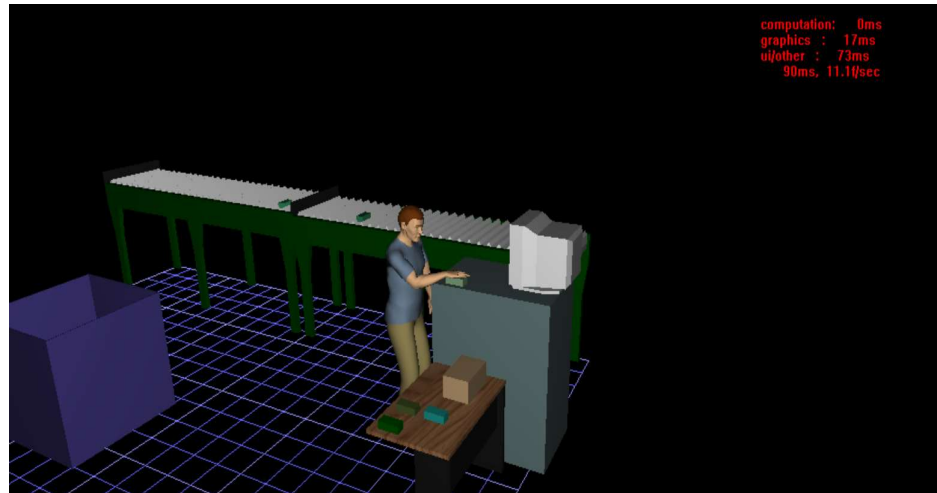


Figure 5: Closure Simulation.

3.2.3. Particular Order Simulation

In this simulation an average size man (Height: 174 cm. Weight: 78 Kg) is the one that carries out the task. The simulation shown below represents the operator between two shelves, and behind one of them, there is a roller table. During the simulation the operator, firstly, picks one heavy product (10kg), then he introduces this box in a bigger one. Then, the operator picks other two light products (1kg and 3kg), one by one, and introduces them into the same box. This simulation is representing a regular particular order.

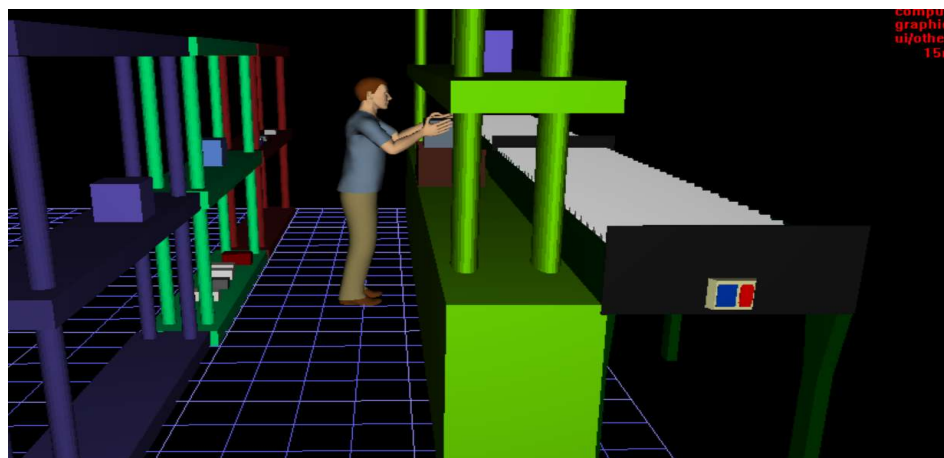


Figure 6: Particular Order Simulation.

4. ANALYSIS OF THE RESULTS

4.1. Picking Process Simulation

❖ Lower Back Analysis:

As we can see in the images below, the load that suffers the low back in this activity exceeds the recommended values for a safe development of the task. The main problems occur when the operator is lifting the boxes. The main problem in lifting is that the force from a lifted load is multiplied by about 10 times in the spine. In addition, the pallet in which the operator has to leave the boxes is so low that when she has to leave the boxes, she can make her back suffer easily.

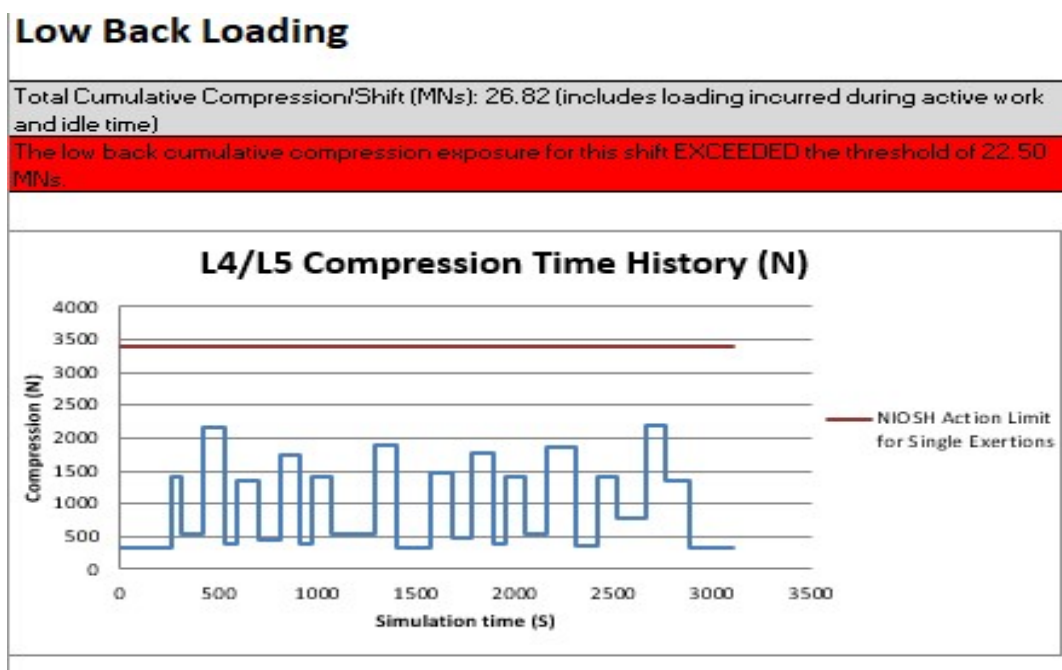


Figure 7: Low back cumulative compression exposure for the Picking Simulation.

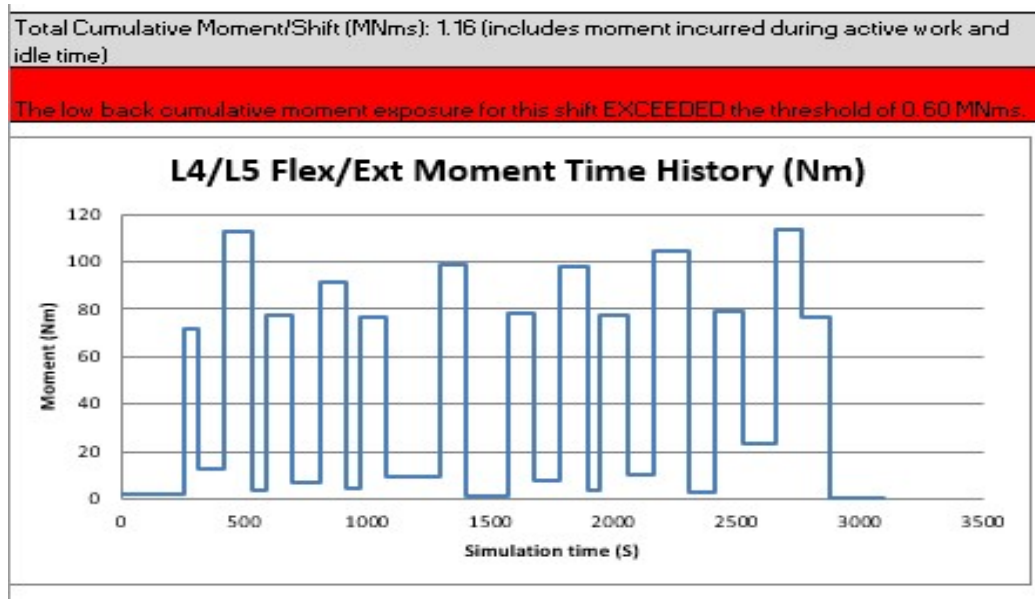


Figure 8: Low back cumulative moment exposure for the Picking Simulation.

❖ Fatigue Recovery:

The graphs below show that the ankles are the parts of the body that would need the biggest recovery time per cycle. This is because this task involves a constant standing posture and, furthermore, involves bending down sometimes when the boxes are near the floor. However, the company avoids fatigue injuries by switching tasks of 4 hours between operators. In this way, there isn't a specific body part that gets in risk of getting injured.

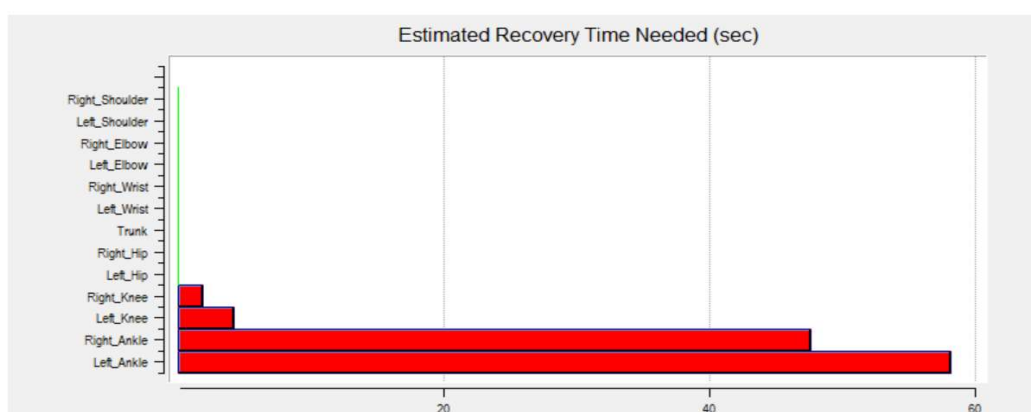


Figure 9: Estimated recovery time needed for the different body parts in the Picking Simulation.

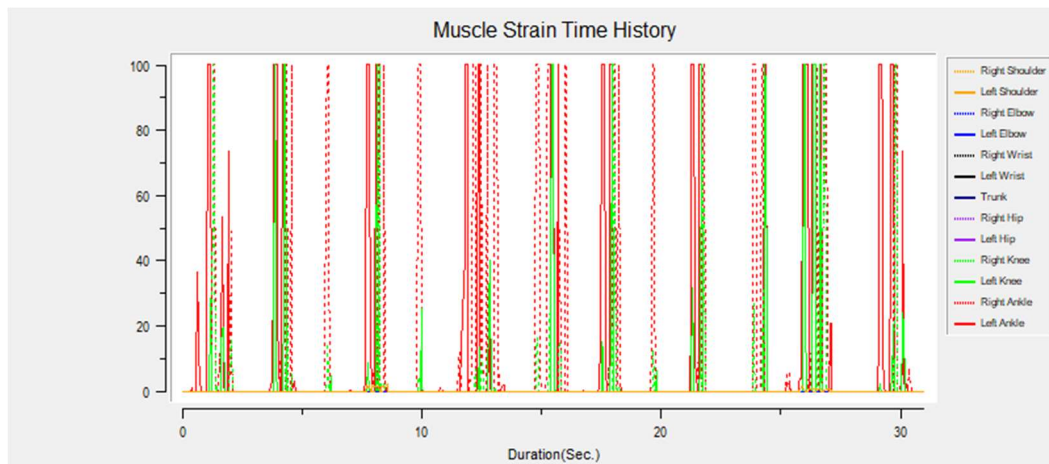


Figure 10: Muscle strain time history for the different body parts in the Picking Simulation.

Analysis Summary	
<u>Simulation Duration:</u>	31.0sec
<u>Recovery Time:</u>	
For the current task demands, the following joints require additional recovery time:	
Right Knee:	1.9 sec
Left Knee:	4.2 sec
Right Ankle:	47.6 sec
Left Ankle:	58.1 sec
<u>Potential next steps:</u>	
Consider reducing the task demands of the Left Ankle joint to start. Note that subsequent exertion reductions may be needed to avoid fatigue of other muscle groups as well.	
Consider adding time to your overall cycle (simulation).	

Figure 11: Summary of the Fatigue Recovery Analysis for the Picking Simulation.

❖ Ovako Working Posture Analysis (OWAS) Tool:

This tool provides a method for checking the comfort of the working postures, so it was expected to have such a negative feedback from the evaluation. During the simulation, every time that the operator had to leave the box in the pallet the score given was the highest (4), which means that corrective measures are required immediately.

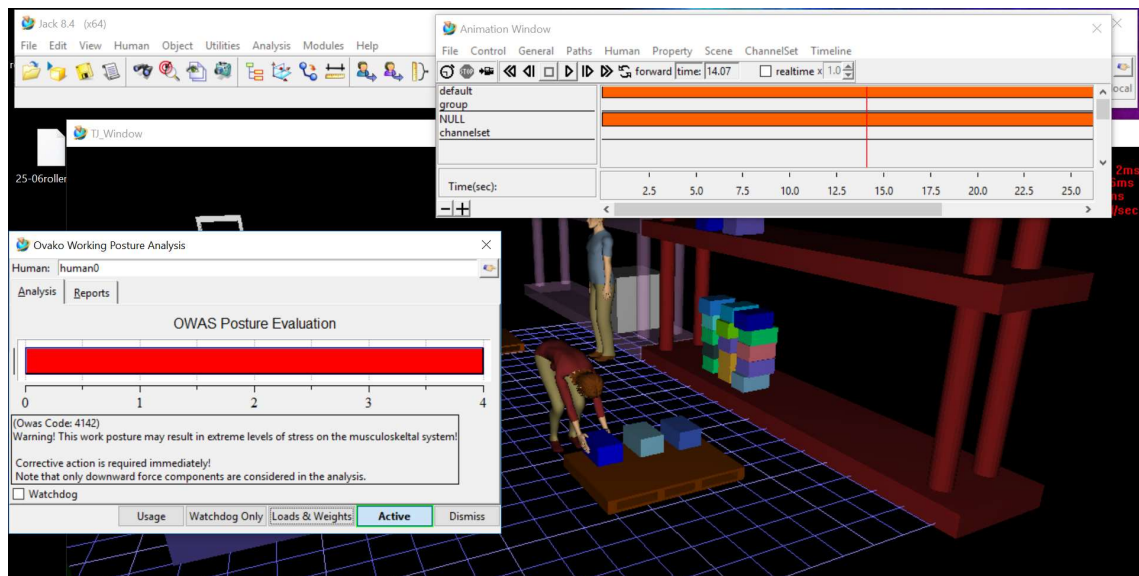


Figure 12: Screen Capture of the OVAKO Working Posture Analysis in the moment of bending.

❖ **Metabolic Energy Expenditure:**

This tool is quite useful because shows the energy expenditure rate and with a graph such as the one shown below (see *Image below*). In the graph is interesting the fact that the action that involves the highest metabolic cost without any doubt is the one of putting the box in the pallet. In addition, the analysis also adds that the overall energy expenditure rate exceeds the recommended one.

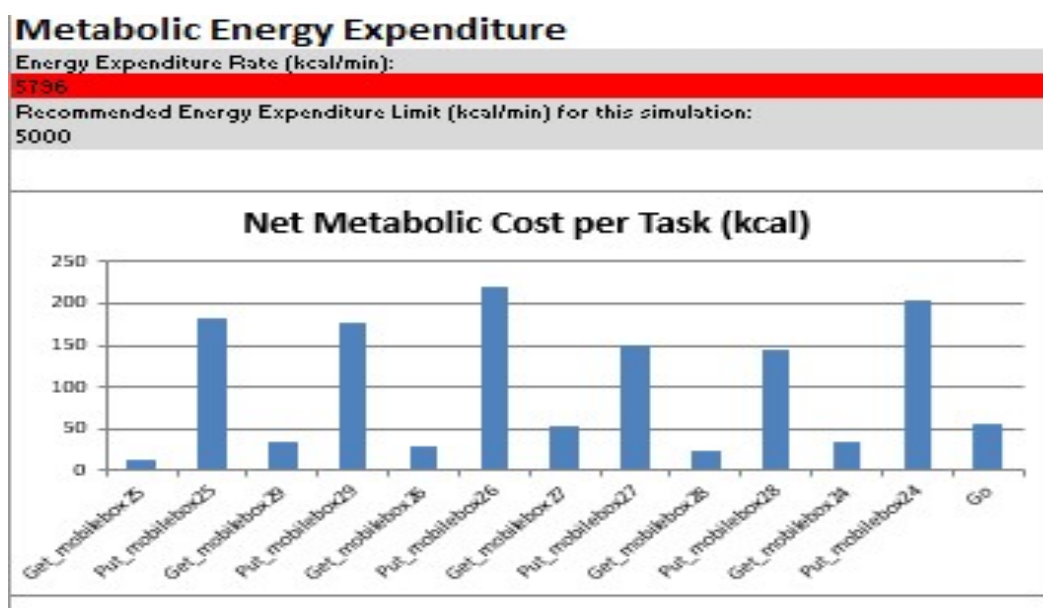


Figure 13: Net metabolic cost per task for the Picking Process.

❖ Rapid Upper Limb Assessment:

As it was said before, this tool helps evaluate the exposure of a worker's upper limb. The most dangerous situations in the task for this analysis are the ones exposed in the images below (see *Images below*). In the first of them, which represents the moment of putting the box in the pallet the analysis concludes that changes in the posture are immediately required. In the other one, the analysis doesn't have a concrete conclusion, but the posture may not be healthy for the upper limb.

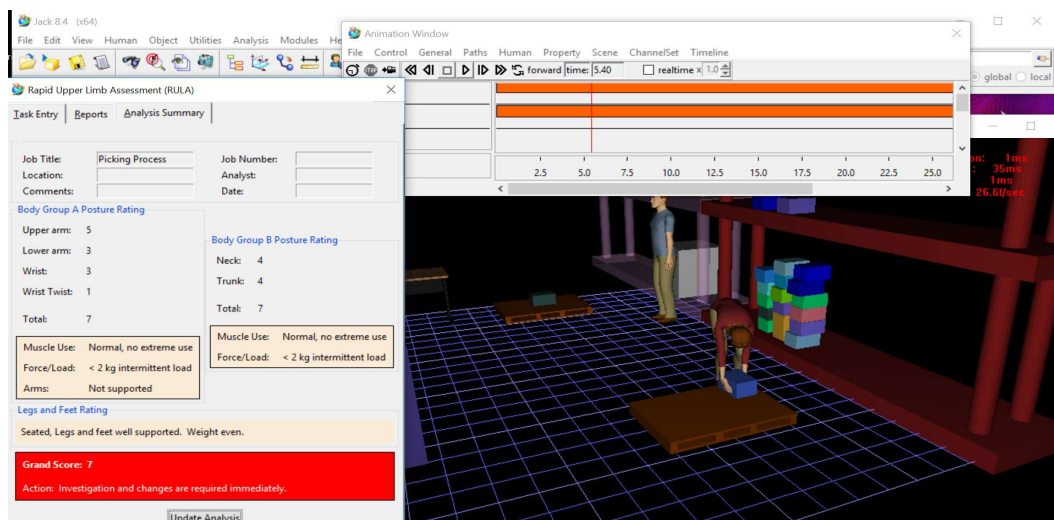


Figure 14: Screen capture of the Rapid Upper Limb Assessment in the moment of putting a product in the pallet.

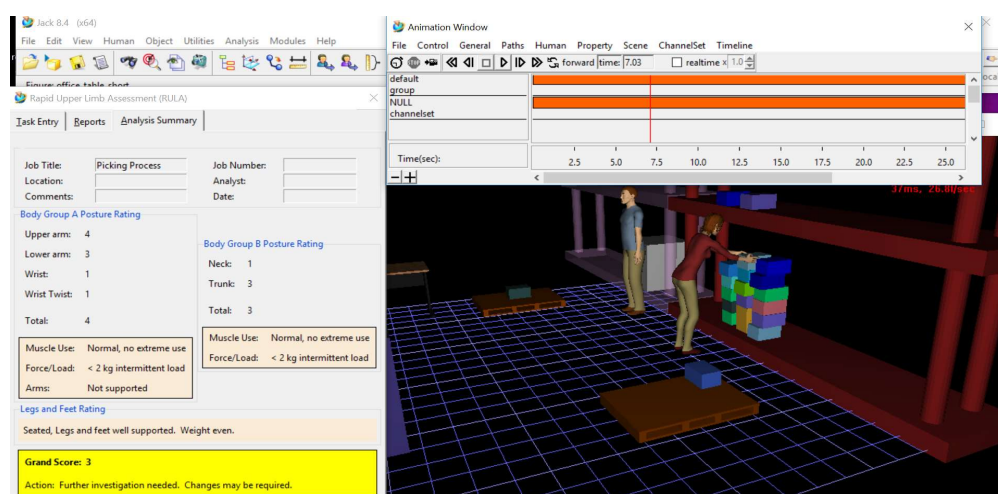


Figure 15: Screen capture of the Rapid Upper Limb Assessment in the moment of getting a product from the shelves.

4.2.Order Closure Simulation

❖ Lower Back Analysis:

The graphs shown below suggest to change the postures because they may be harmful for the low part of the backbone. Both the cumulative compression and cumulative moment exposure exceed the recommended values probably because the action of getting the products from the table demand the backbone to bend, which is not healthy for the operator.

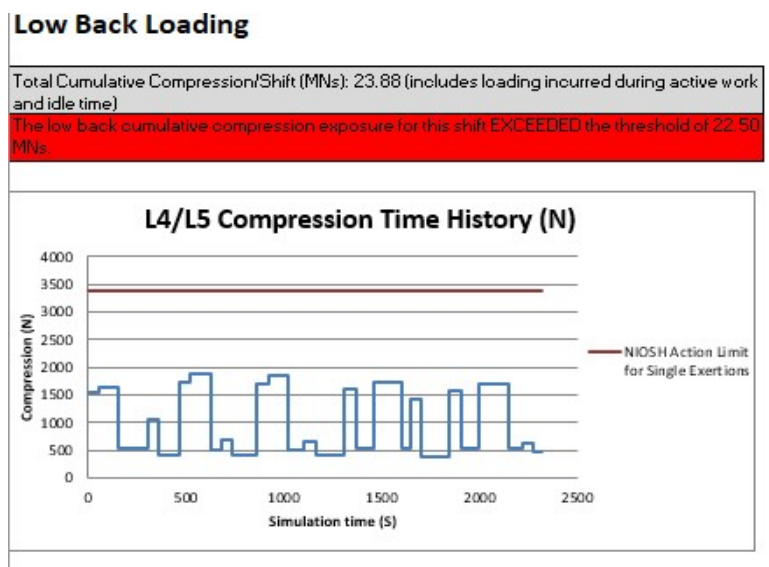


Figure 16: Low back cumulative compression exposure for the Order Closure Simulation.

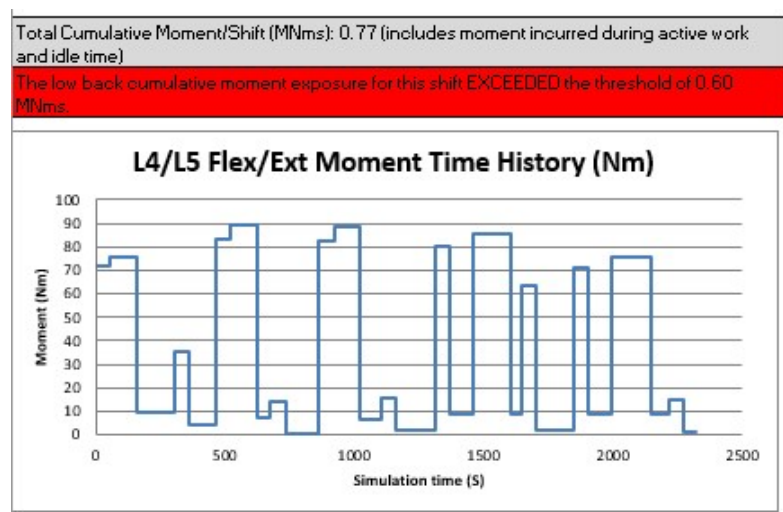


Figure 17: Low back cumulative moment exposure for the Order Closure Simulation.

❖ Fatigue Recovery:

The first graph of this analysis shows that the only body part which probably would need recovery time after developing this task is the right ankle, probably because of the orientations of the machines. Nevertheless, this tool shows us that this is not a tiring task, so in this aspect it is not problematic for the operator.

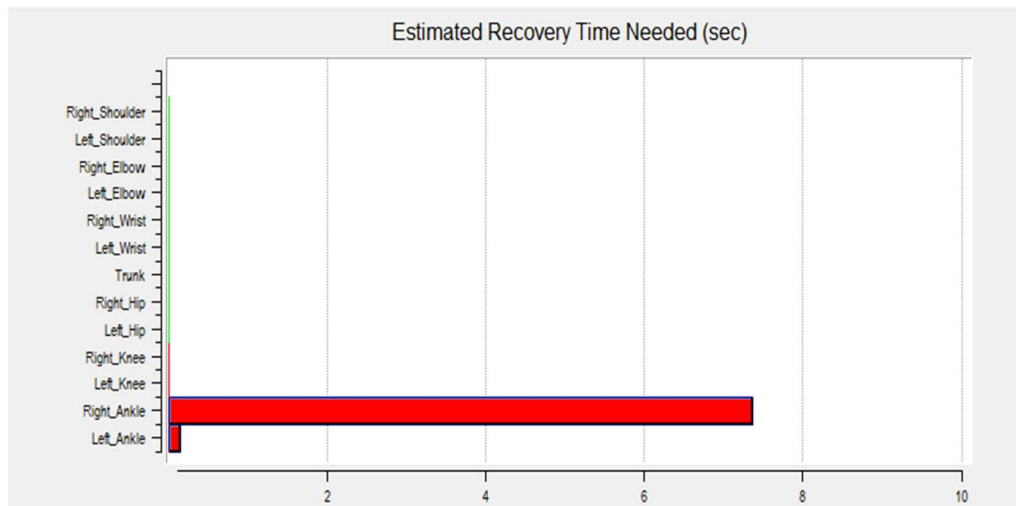


Figure 18: Estimated Recovery Time Needed for the different body parts in the Order Closure Simulation.

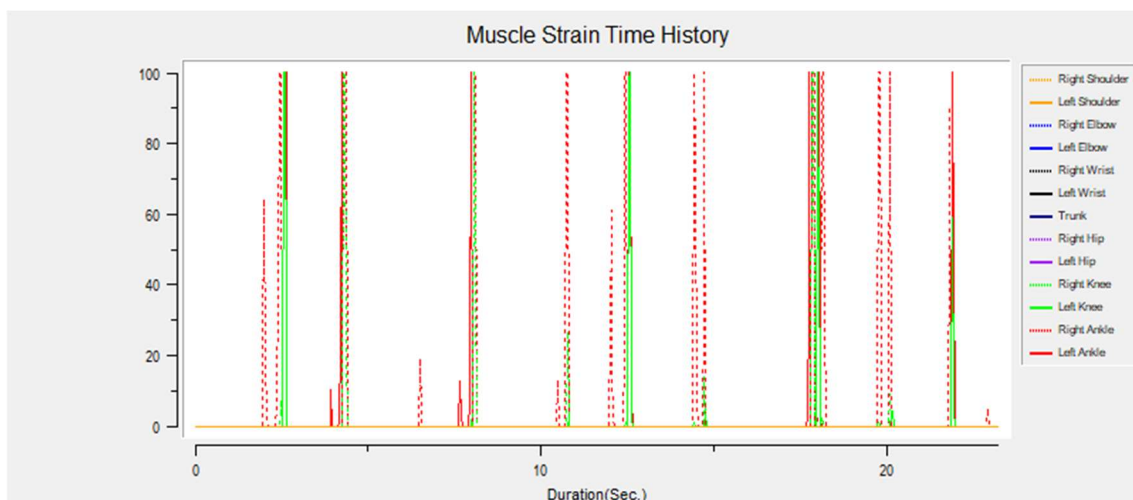


Figure 19: Muscle Strain Time History for the different body parts in the Order Closure Simulation.

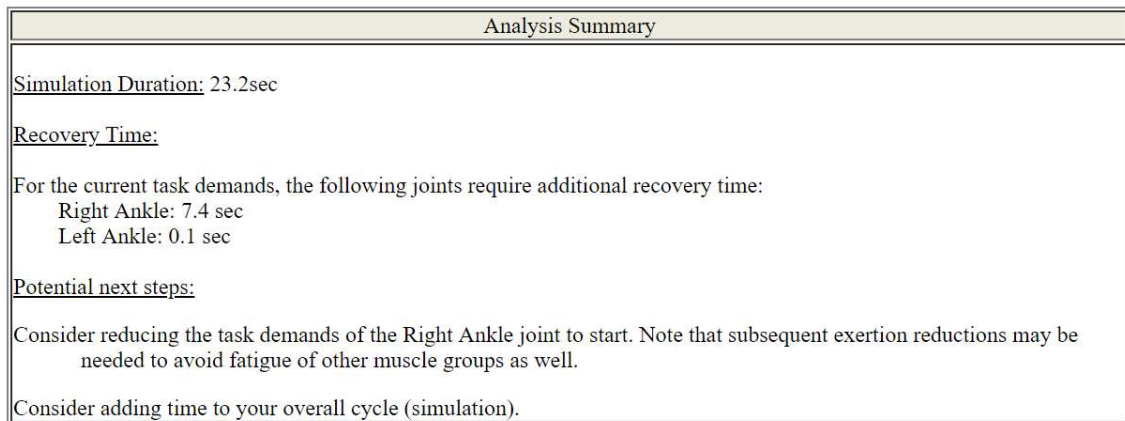


Figure 20: Summary of the Fatigue Recovery Analysis for the Order Closure Simulation.

❖ Ovako Working Posture Analysis (OWAS) Tool:

This posture analysis doesn't show a clear conclusion about the comfort in the postures when developing the task. The most critical postures during the simulation, which are shown below, are evaluated as possibly harmful. However, taking into account the low back analysis it is possible to conclude that the posture that the operator has when picking the product from the table can't be comfortable.

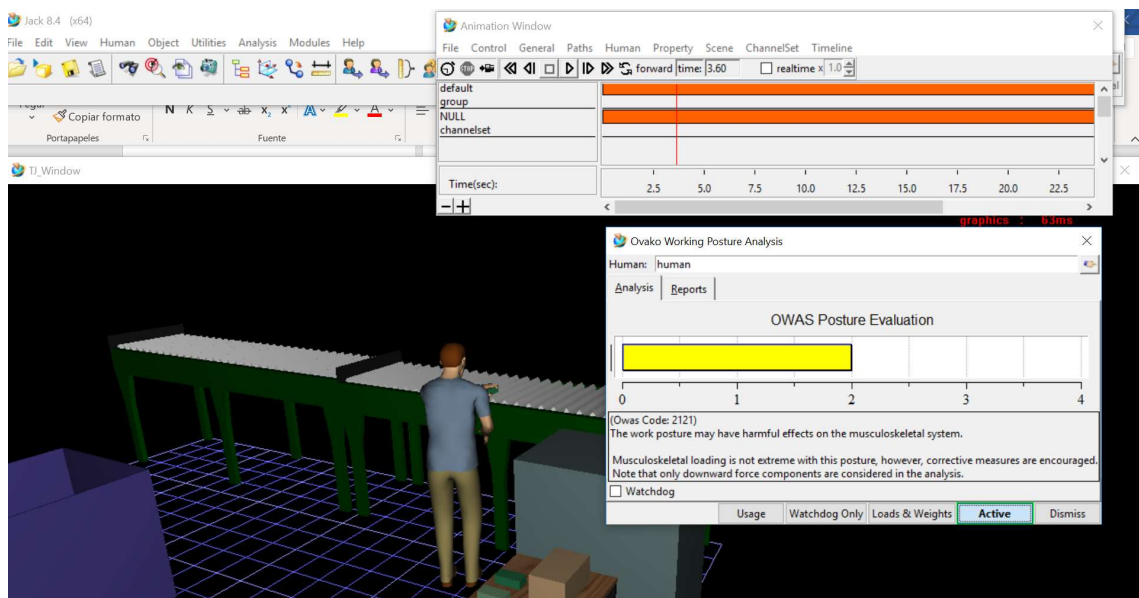


Figure 21: Screen Capture of the OVAKO Working Posture Analysis in the moment of putting a product in the roller table.

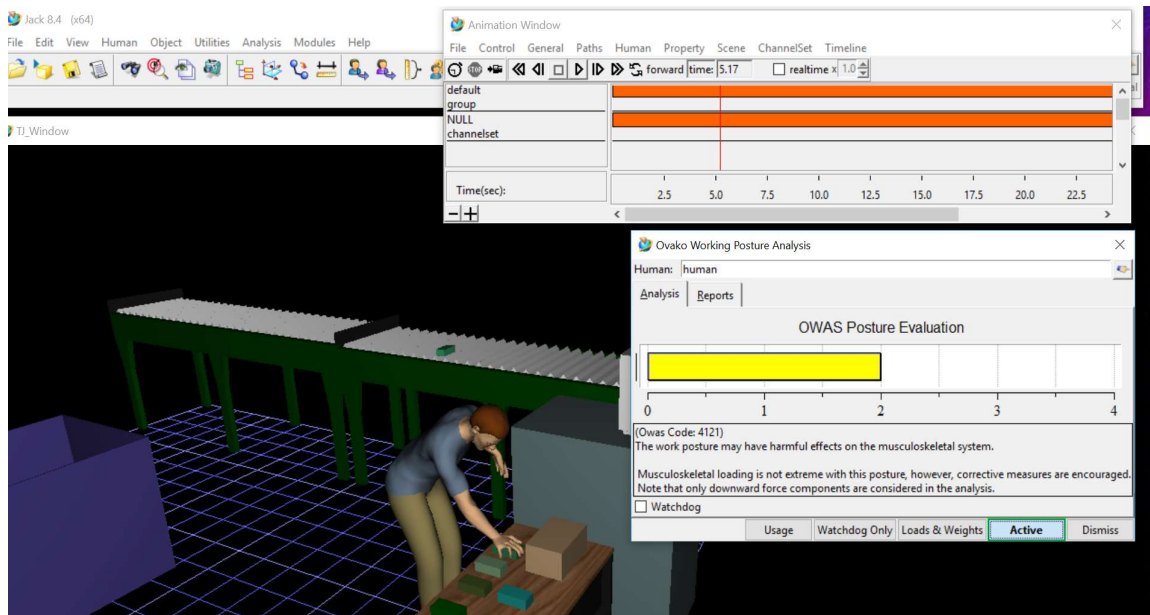


Figure 22: Screen Capture of the OVAKO Working Posture Analysis in the moment of getting a product from the table.

❖ **Metabolic Energy Expenditure:**

This analysis verifies the fatigue recovery analysis because the main conclusion that we can take from it is that the energy expenditure rate of the task is not very high, so it does not exceed the recommended limit. This result could have been assumed before the analysis as this task does not involve a lot of movement and the products involve in the simulation have a weight of 1 kg.

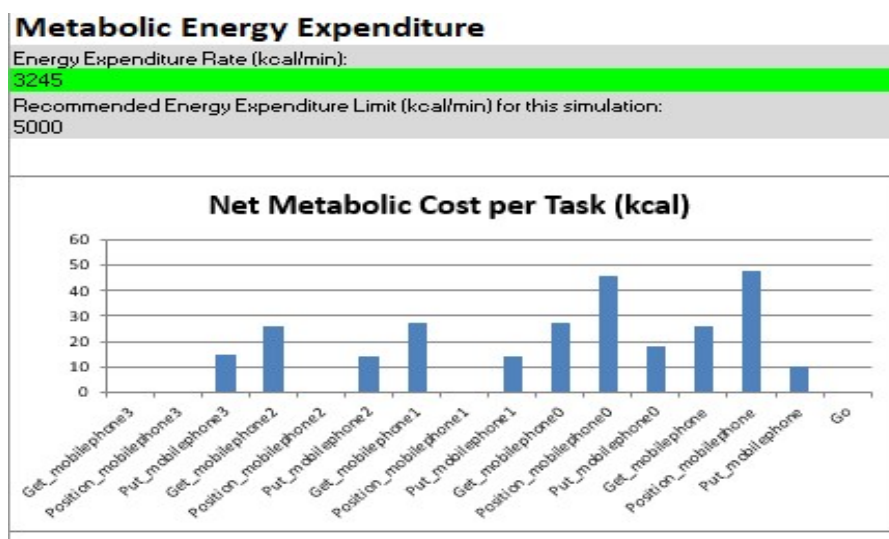


Figure 23: Net Metabolic Cost per Task for the Order Closure Simulation.

❖ Rapid Upper Limb Assessment:

This analysis continues verifying the analysis done about the lower back, because the position adopted when picking a product from the table is considered to be critical, just the same as in the other analysis. Apart from that posture, the rest of actions the operator does do not seem to be harmful for the upper limb. The table in which the operator takes the products is so low for the height of the operator that the backbone bending posture that he is forced to adopt may be harmful for the upper limb, but also for the lower part of the backbone as it was shown before.

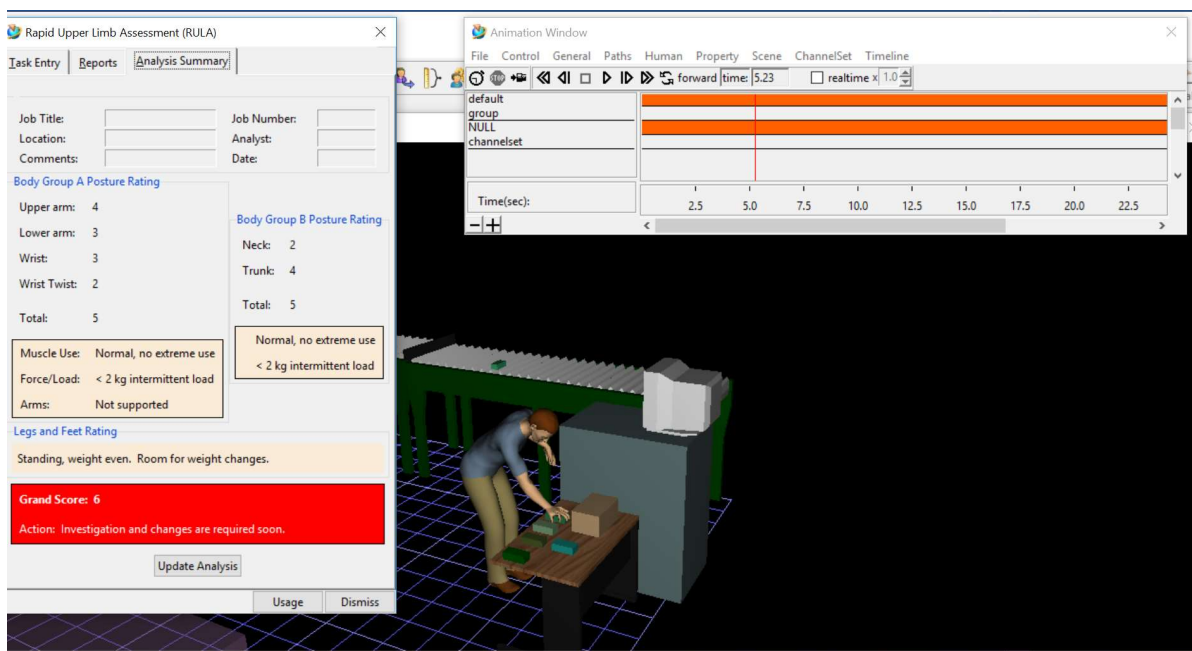


Figure 24: Screen capture of the Rapid Upper Limb Assessment in the moment of getting the product from the table.

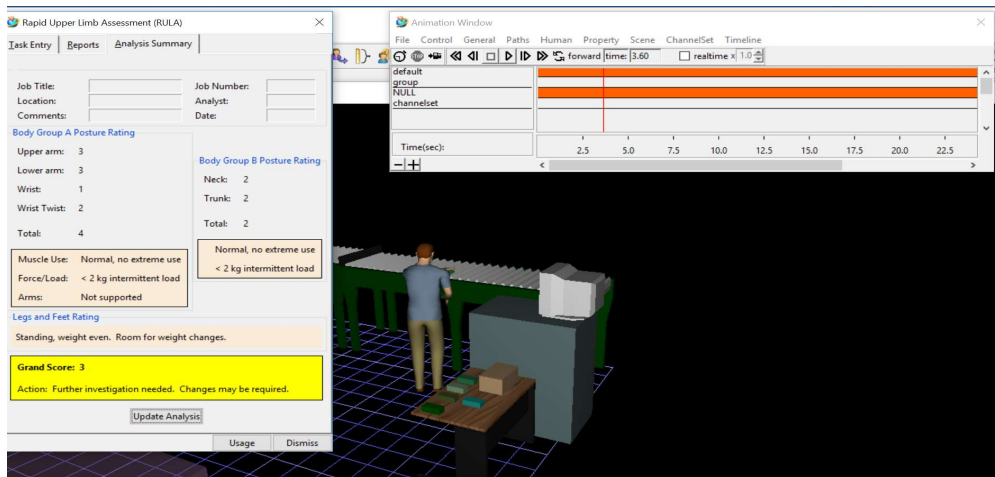


Figure 25: Screen capture of the Rapid Upper Limb Assessment in the moment of putting a product in the roller table.

4.3. Particular Order Simulation

❖ Lower Back Analysis:

The graphs shown below suggest to change the postures because they may be harmful for the low part of the backbone. Both the cumulative compression and cumulative moment exposure exceed the recommended values probably because of the actions involved in taking the products from the shelves.

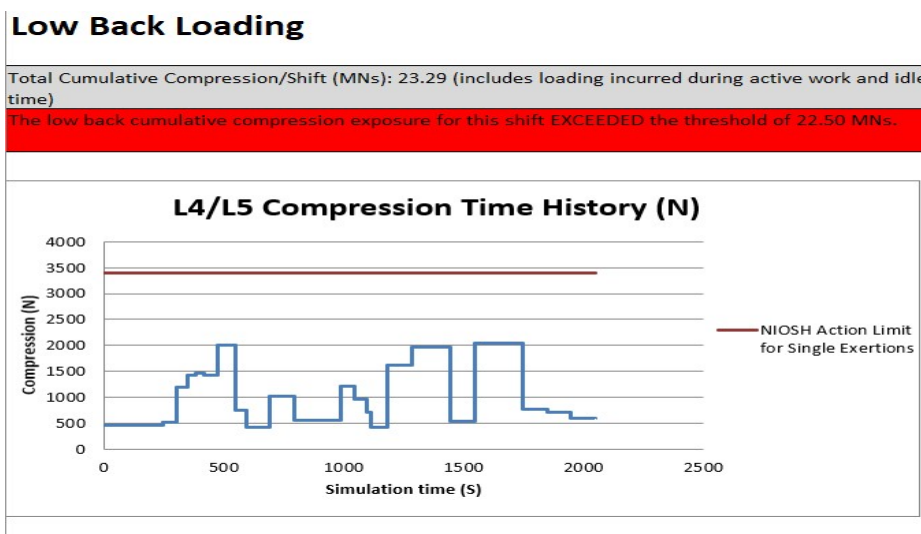


Figure 26: Low back cumulative compression exposure for the Particular Order Simulation.

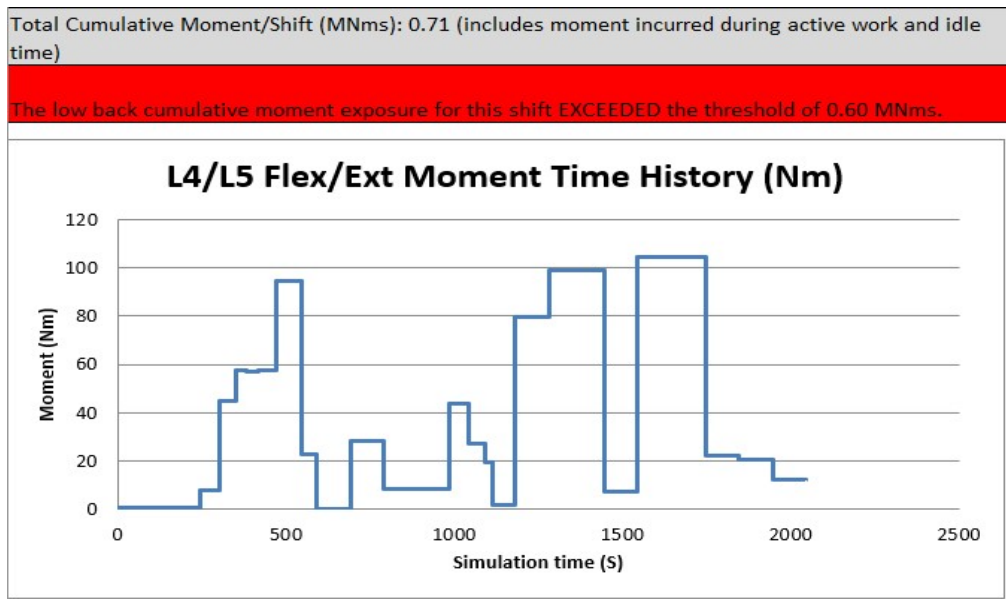


Figure 27: Low back cumulative moment exposure for the Particular Order Simulation.

❖ **Fatigue Recovery:**

This analysis does not show very much information for this task. However, it is possible to conclude that there isn't any particular body part that suffers more fatigue than it should.

Analysis Summary
<p><u>Simulation Duration:</u> 20.5sec</p>
<p><u>Recovery Time:</u></p> <p>For the current task demands there is sufficient recovery time available to avoid an accumulation of muscle fatigue.</p>
<p><u>Potential next steps:</u></p> <p>For completeness, you may choose to further evaluate this task using the other available ergonomic analysis tools.</p>

Figure 28: Summary of the Fatigue Recovery Analysis for the Particular Order Simulation.

❖ Ovako Working Posture Analysis (OWAS) Tool:

The Ovako analysis shows, as it can be seen from the images below, that the position adopted when picking the products from the higher shelves is not problematic. However, for the lower shelf the operator squats to get the product. For the posture adopted at that moment, the analysis suggests immediate changes to avoid injuries. For the postures adopted by the operator when leaving the products in the box, the analysis suggests further investigation.

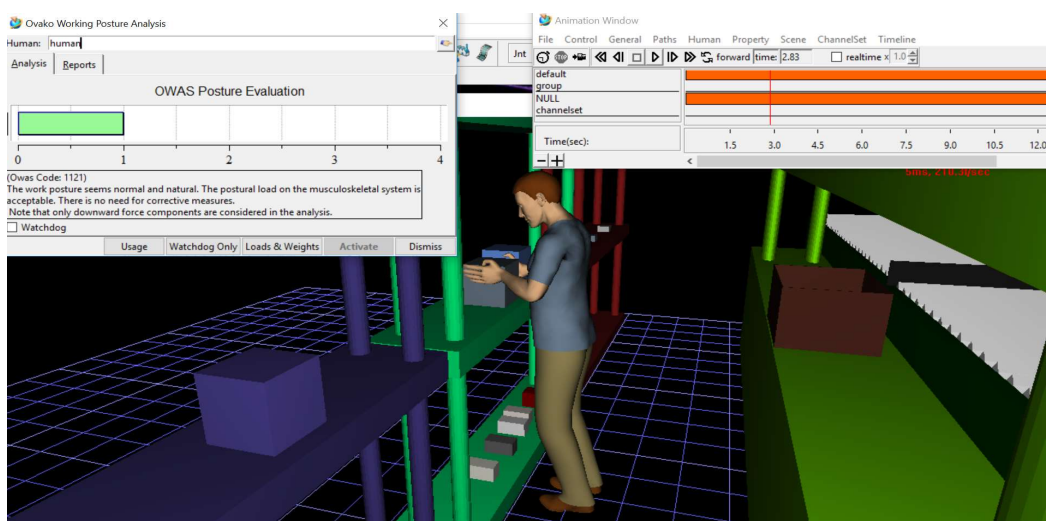


Figure 29: Screen Capture of the OVAKO Working Posture Analysis when the operator picks up a heavy product (10 Kg) during the Particular Order Simulation.

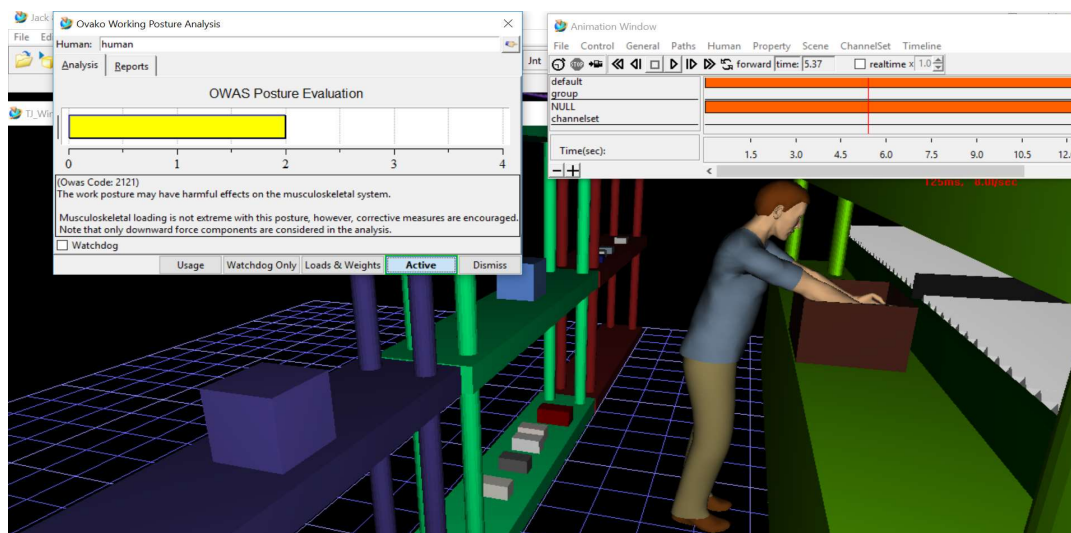


Figure 30: Screen Captures from the OVAKO Working Posture Analysis when the operator leaves a heavy product (10 kg) during the Particular Order Simulation.

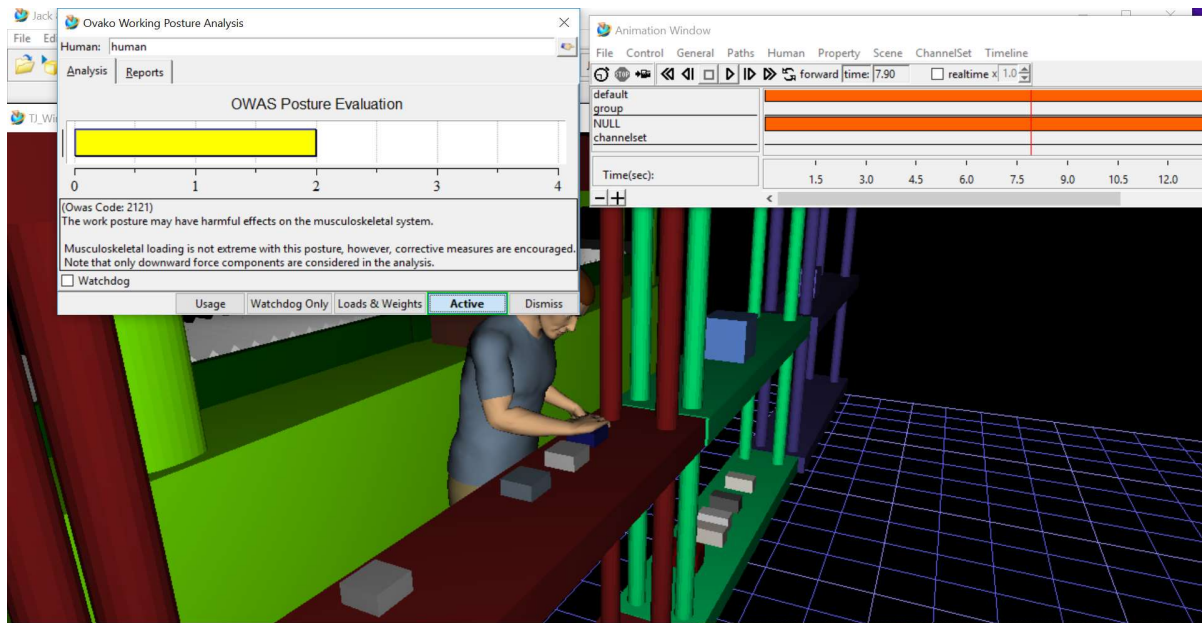


Figure 31: Screen Capture of the OVAKO Working Posture Analysis when the operator picks up a light product (3 Kg) during the Particular Order Simulation.

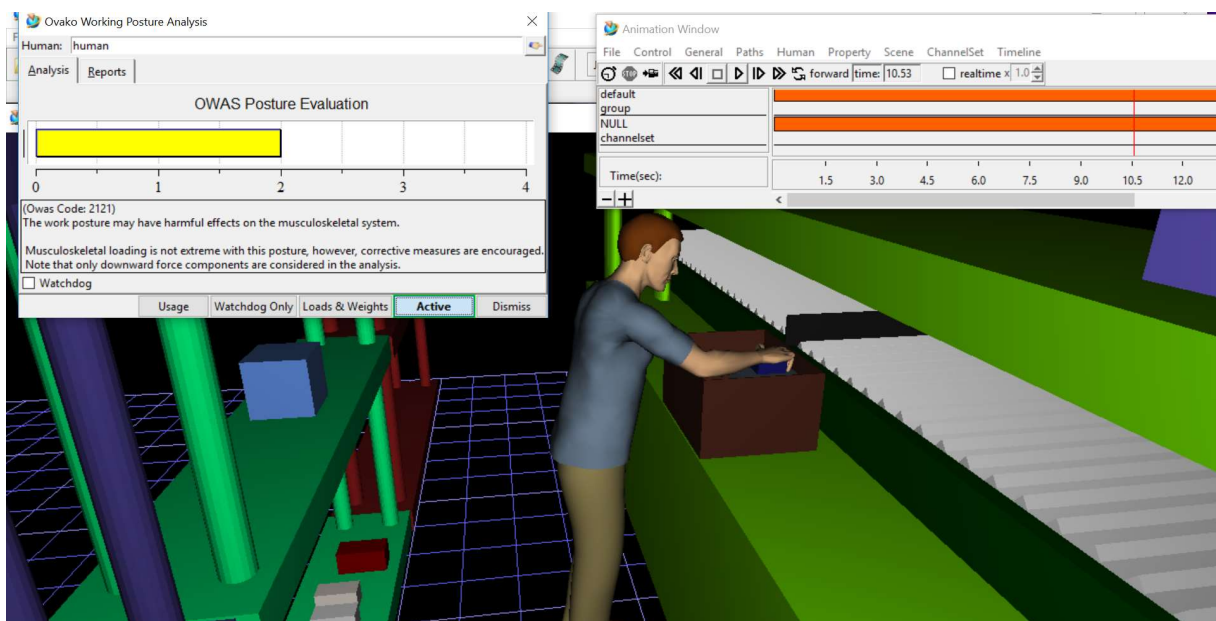


Figure 32: Screen Captures from the OVAKO Working Posture Analysis when the operator leaves a light product (3 kg) during the Particular Order Simulation.

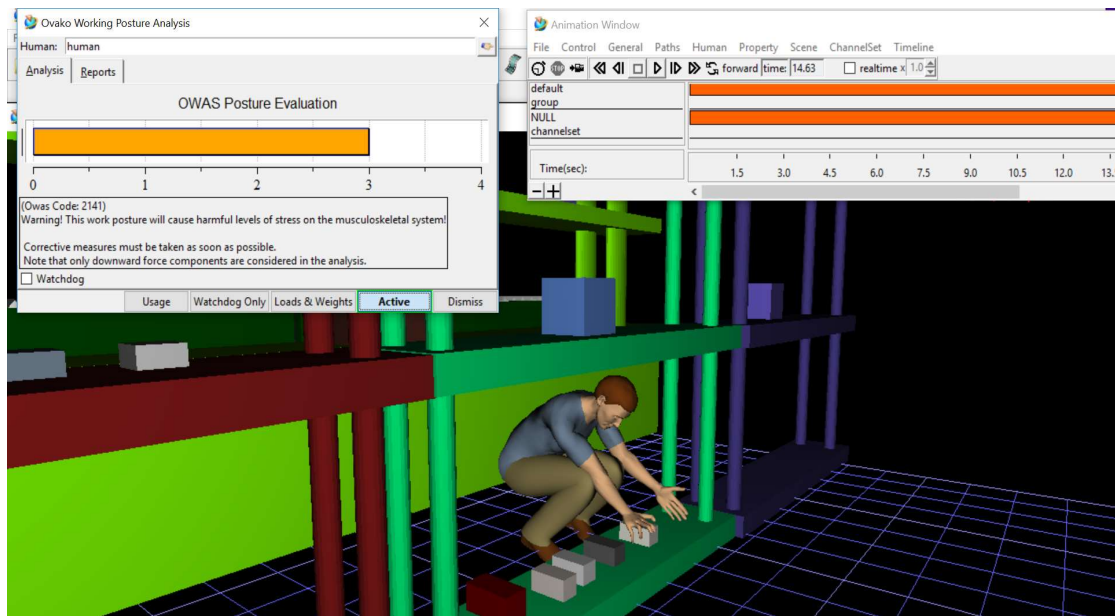


Figure 33: Screen Capture of the OVAKO Working Posture Analysis when the operator picks up a light product (1 Kg) during the Particular Order Simulation.

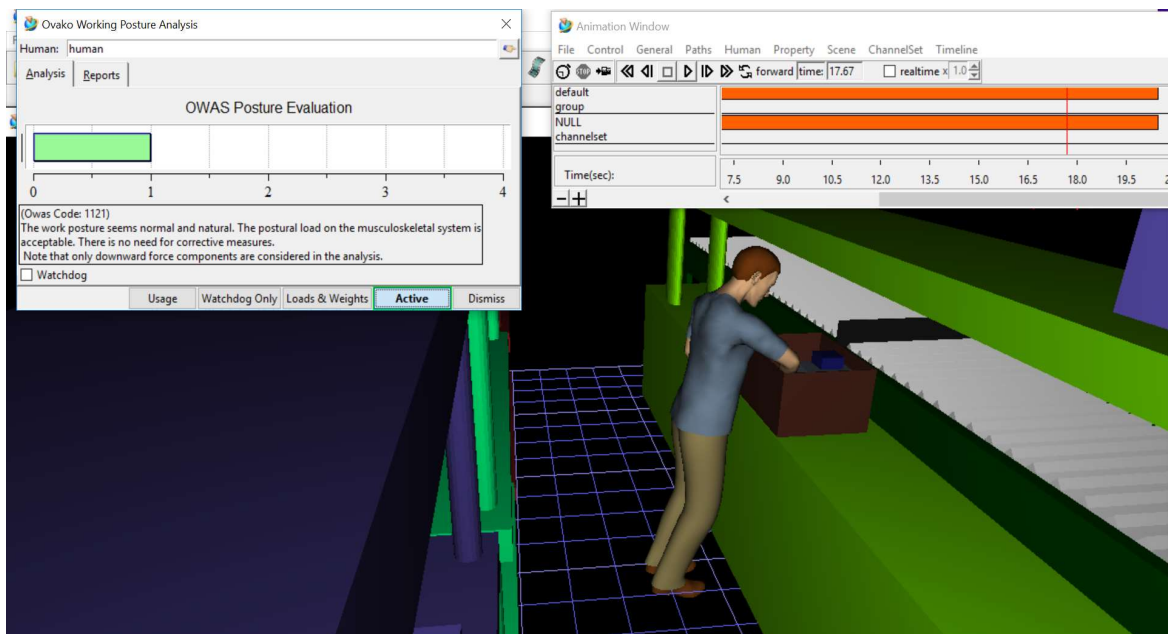


Figure 34: Screen Captures from the OVAKO Working Posture Analysis when the operator leaves a light product (1 kg) during the Particular Order Simulation.

❖ **Metabolic Energy Expenditure:**

The Metabolic Energy Expenditure Analysis verifies the information given by the fatigue recovery analysis. This task does not require a lot of time to recover because the metabolic cost per task is not very high and the total energy expenditure rate does not exceed the recommended value (5000/kcal/min).

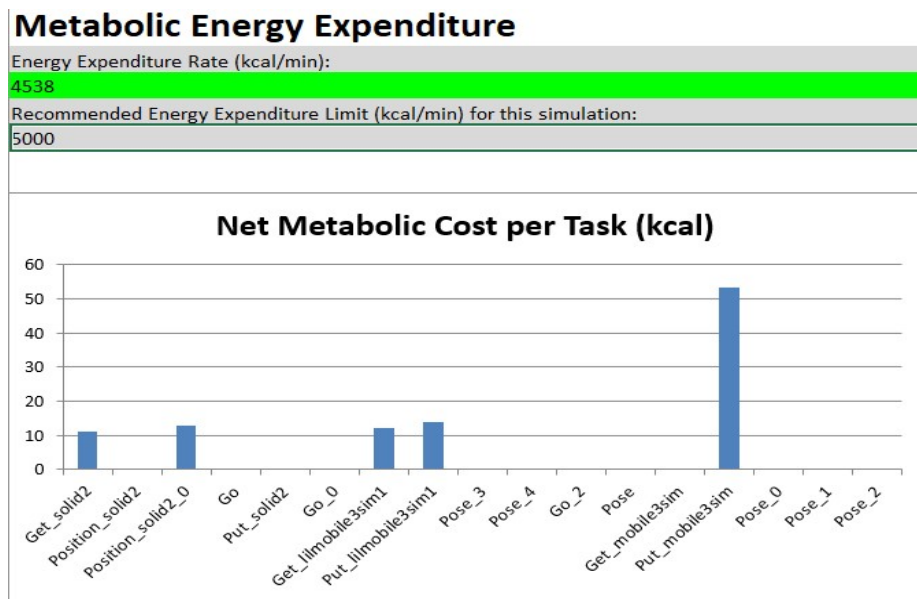


Figure 35: Net metabolic cost per task for the Particular Order Simulation.

❖ **Rapid Upper Limb Assessment:**

This analysis, just as the lower back analysis, suggests an immediate change of posture instead of squatting when picking up the object from the lower shelf. The product is located at a very low height and it is very small, so it requires the operator to bend too much when squatting to pick up the product. However the analysis isn't conclusive for the rest of postures adopted in the simulation. The analysis suggests more investigation about them.

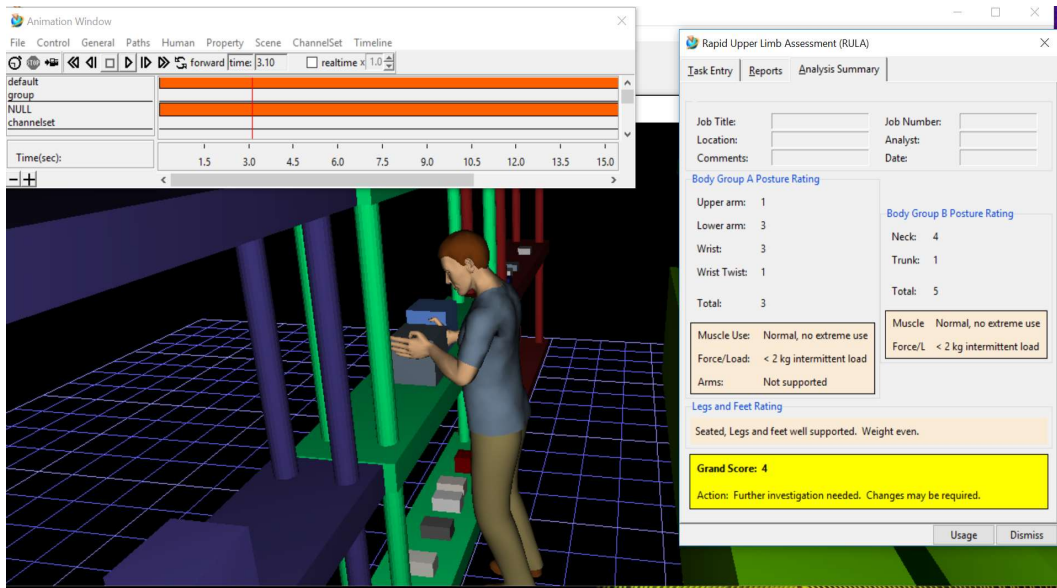


Figure 36: Screen Capture of the Rapid Upper Limb Assessment when the operator picks up a heavy product (10 Kg) during the Particular Order Simulation.

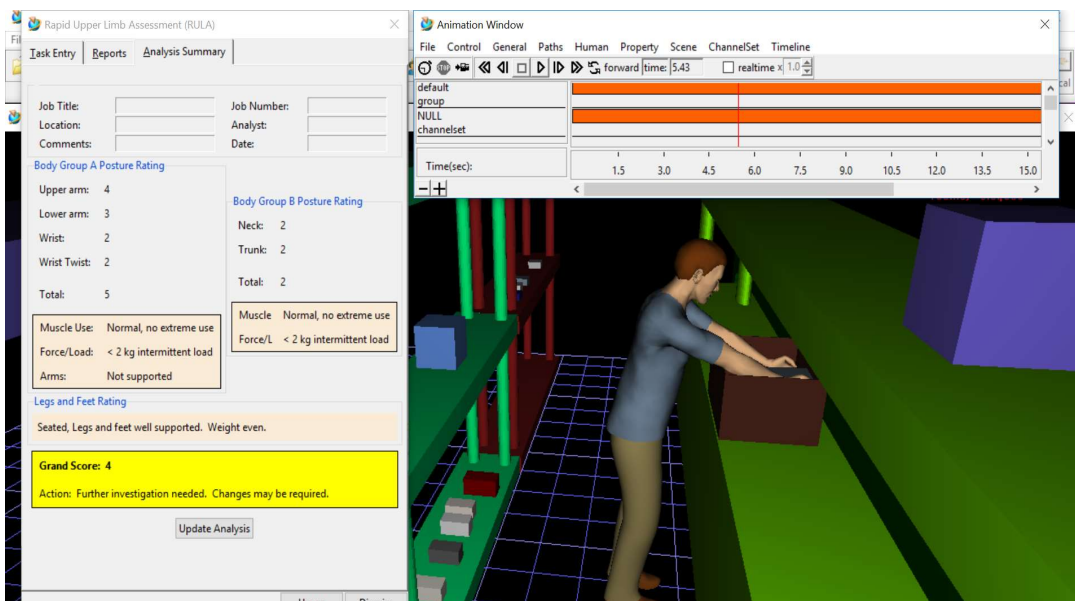


Figure 37: Screen Captures from the Rapid Upper Limb Assessment when the operator leaves a heavy product (10 kg) during the Particular Order Simulation.

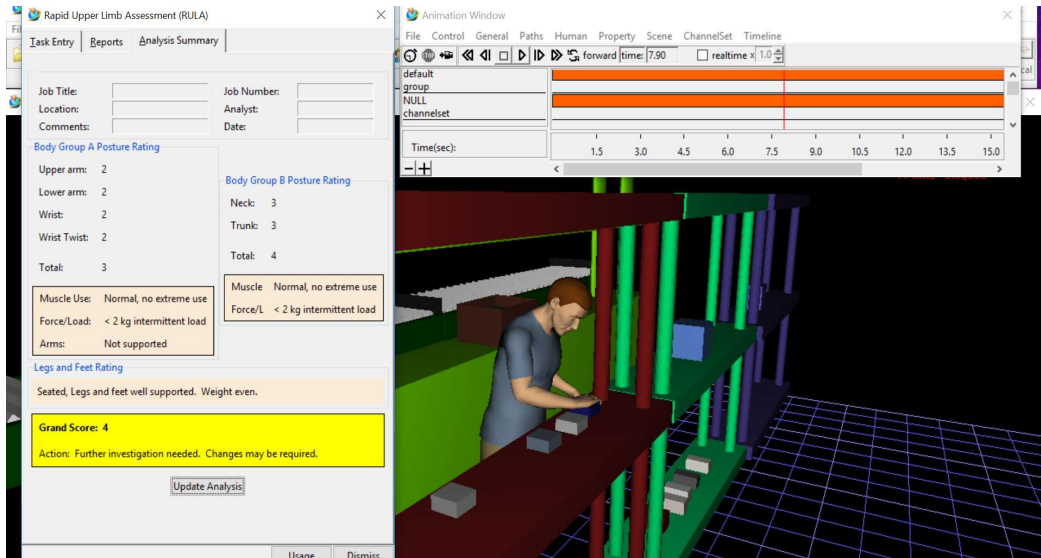


Figure 38: Screen Capture of the Rapid Upper Limb Assessment when the operator picks up a light product (3 Kg) during the Particular Order Simulation.

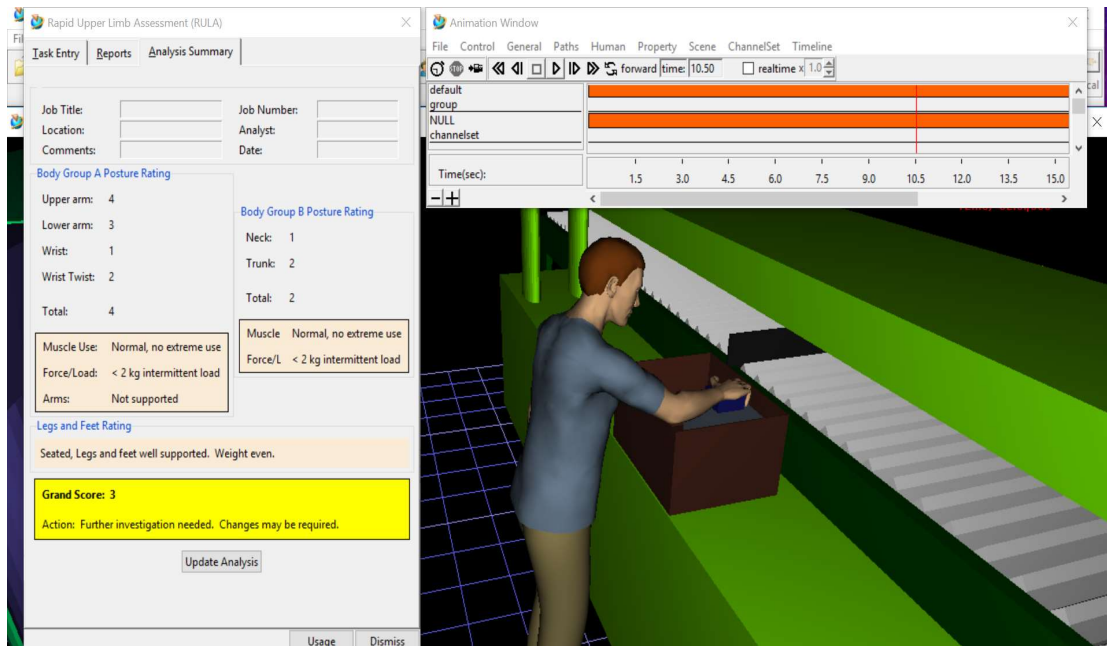


Figure 39: Screen Captures from the Rapid Upper Limb Assessment when the operator leaves a light product (3 kg) during the Particular Order Simulation.

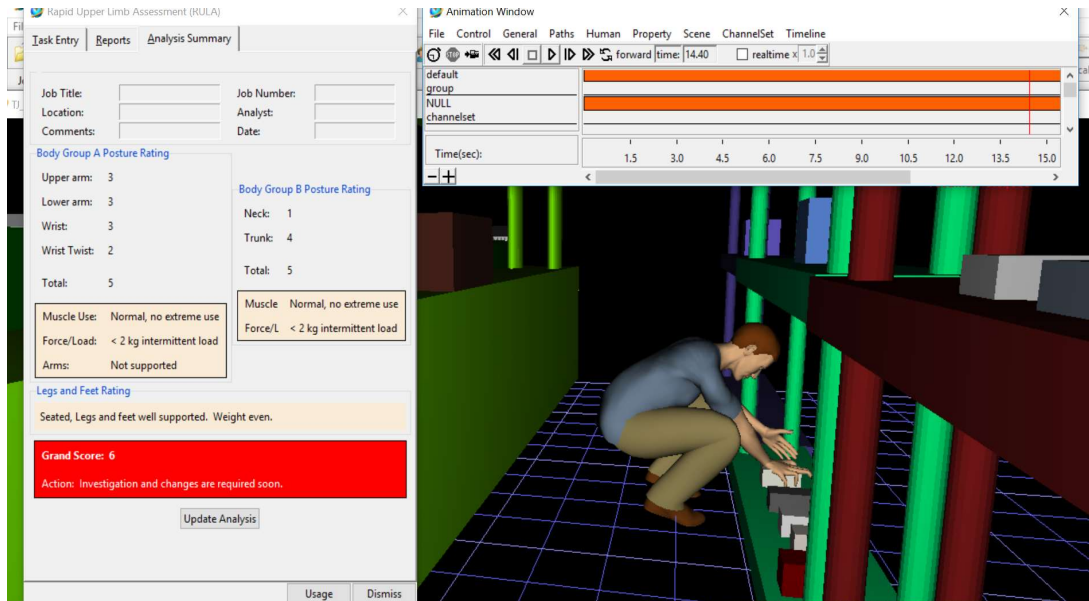


Figure 40: Screen Capture of the Rapid Upper Limb Assessment when the operator picks up a light product (1 Kg) during the Particular Order Simulation.

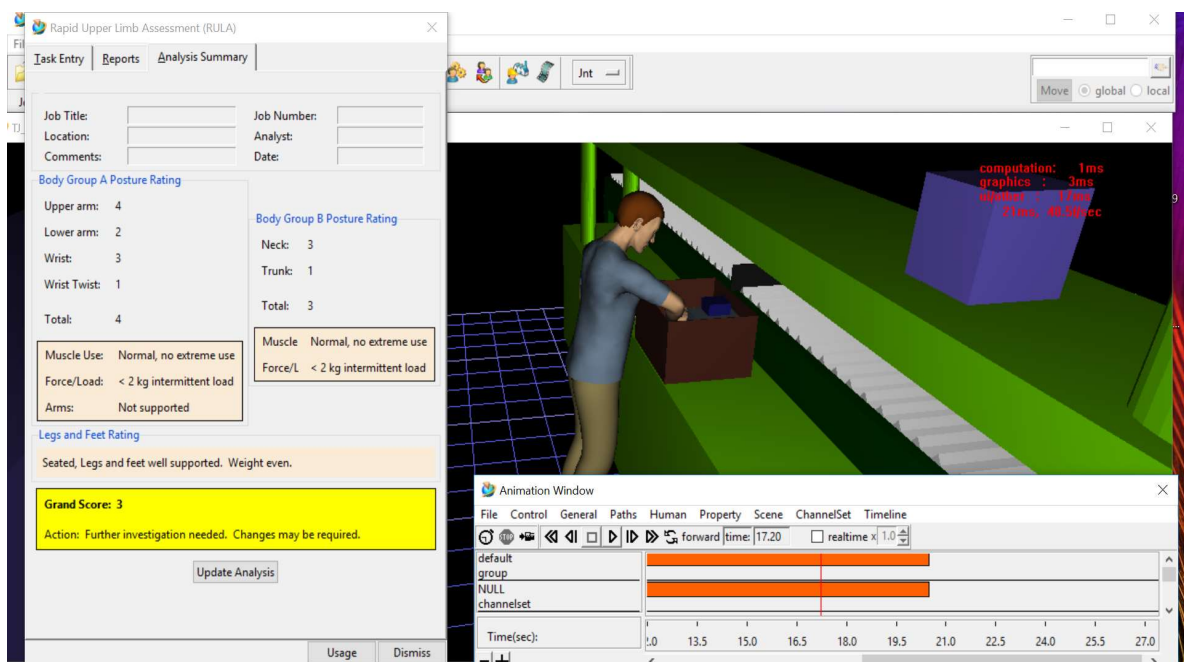


Figure 41: Screen Captures from the Rapid Upper Limb Assessment when the operator leaves a light product (1 kg) during the Particular Order Simulation.

5. CONCLUSIONS

5.1.Picking Process

The results given in the previous analysis for the picking process were all of them negative. The main reason for this feedback is the posture adopted by the operator when leaving the products in the pallet. The back is at a very high risk so the ergonomic changes should focus mainly on that.

One possible ergonomic change for that posture consists on putting more pallets one on another so that the operator would not have to bend so much to leave the products. However, for the development of this task in the real life the pallet has wheels under it to move around the picking zone, so more pallets would imply more weight which would complicate the movement of the operator in the picking zone. For that reason, other measures must be taken. Other possible solution, much simpler than the previous, consists on changing the posture adopted by the operator for a safer one. Two possible postures have been studied:

- Kneeling on one Knee.
- Squatting.

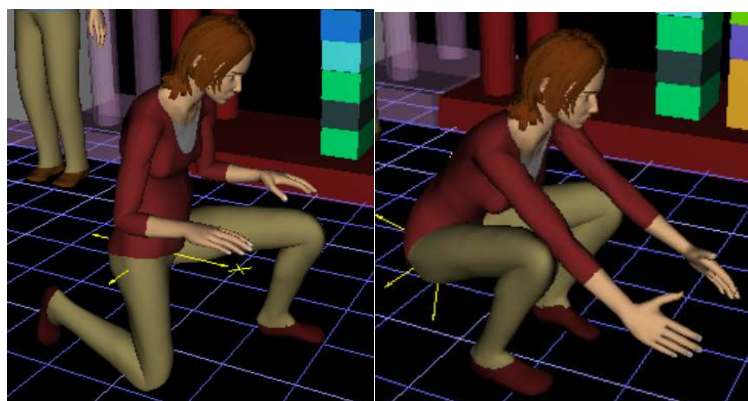


Figure 42: Kneel-on-one knee and Squatting postures.

In addition, the box that is heavier than the rest of them (10 kg) has been relocated in an upper shelf so that the operator takes the heaviest products from a higher

place than her shoulders. This procedure has the finality of protecting the backbone so that most of the load relies on the arms and shoulders.

The Lower Back Analysis, Fatigue Recovery Analysis and Metabolic Energy Expenditure Analysis are carried out with the squatting posture because as it will be explained below, the squatting posture gave better results than the posture of kneeling on one knee.

❖ Lower Back Analysis:

The results obtained in the lower back analysis are still negative. The low back cumulative compression exposure value calculated for this task (23.81 MN/s) slightly exceeds the recommended limit (22.5 MN/s). The total cumulative moment (0.92 MNms) is still above the recommended value (0.60 MNms). However, the results are better than before having introduced the ergonomic measures.

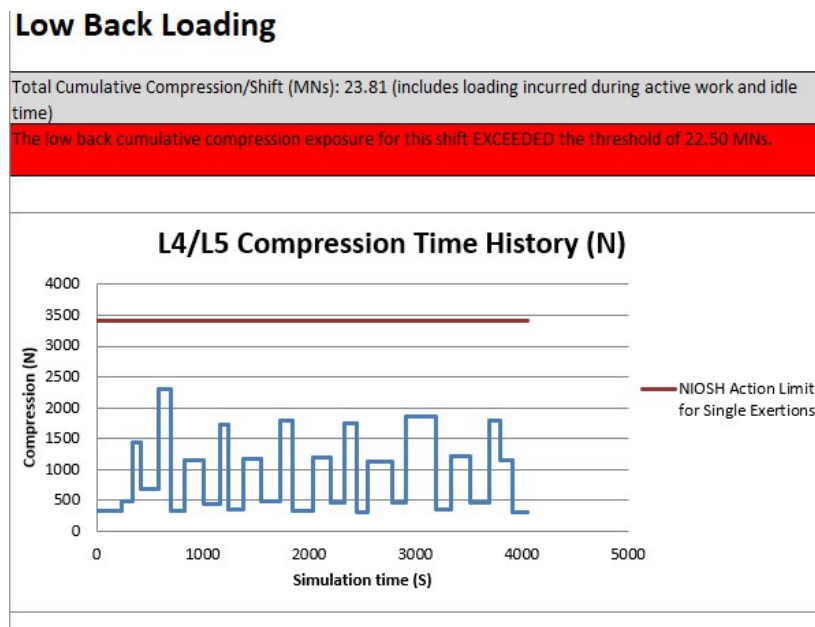


Figure 43: Low back cumulative compression exposure for the Picking Simulation.

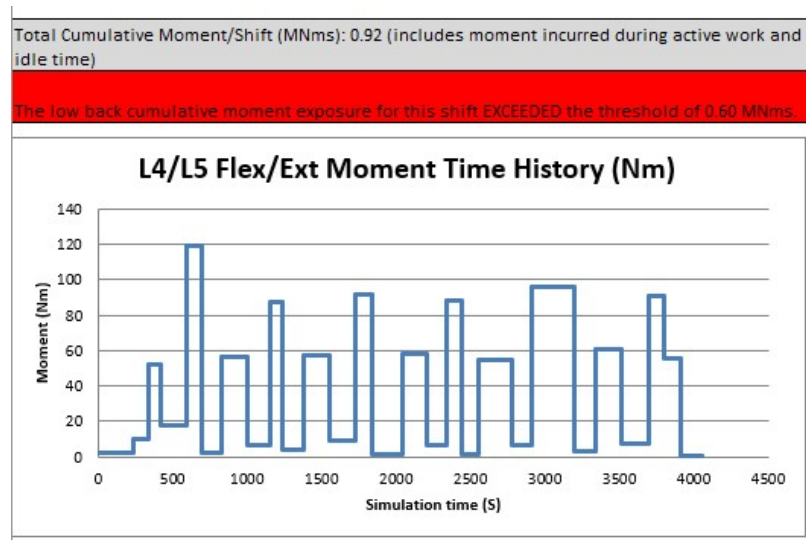


Figure 44: Low back cumulative moment exposure for the Picking Simulation.

❖ Fatigue Recovery Analysis:

The results obtained in this analysis are almost the same as the ones obtained before introducing the ergonomic measures. This outcome was expected because the task continues involving a full-time standing posture which can provoke the ankles to suffer. A possible measure to change the results of this analysis could be to make the operators alternate standing tasks with sitting tasks so that the ankles would not suffer so much.

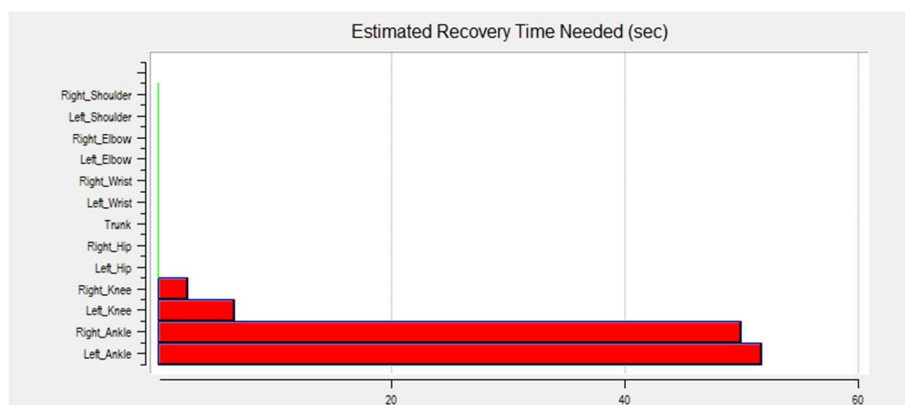


Figure 45: Estimated Recovery Time Needed for the different body parts in the Picking Simulation.

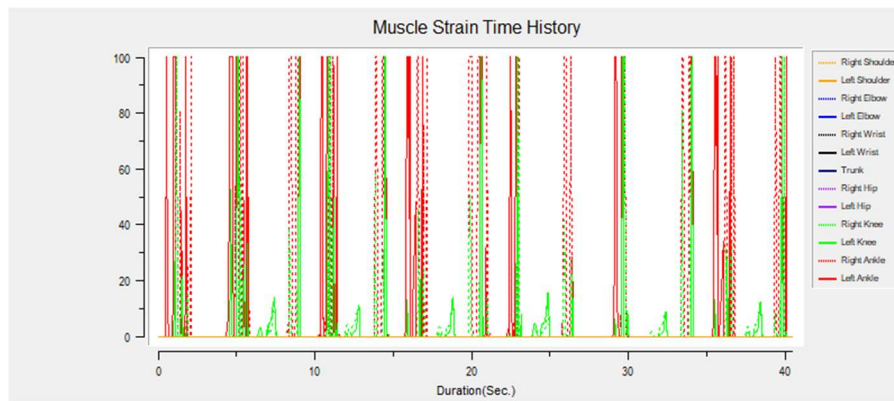


Figure 46: Muscle Strain Time History for the different body parts in the Picking Simulation.

Analysis Summary
<u>Simulation Duration:</u> 40.6sec
<u>Recovery Time:</u>
For the current task demands, the following joints require additional recovery time:
Right Knee: 2.5 sec
Left Knee: 6.5 sec
Right Ankle: 50.0 sec
Left Ankle: 51.7 sec
<u>Potential next steps:</u>
Consider reducing the task demands of the Left Ankle joint to start. Note that subsequent exertion reductions may be needed to avoid fatigue of other muscle groups as well.
Consider adding time to your overall cycle (simulation).

Figure 47: Summary of the Fatigue Recovery Analysis for the Picking Simulation.

❖ Ovako Working Posture Analysis (OWAS) Tool:

The results received from this analysis are much more positive than before, but they should be better.

Firstly, the posture adopted by the operator when getting a heavy product (10 kg) from an upper shelf gets a very positive mark so the posture can be classified as comfortable.

In second place, the posture adopted when kneeling on one knee doesn't seem to be uncomfortable for the operator, due to the grade given in the analysis (2). However, it is not an optimal posture.

In third place, the posture adopted when squatting is not comfortable for the operator according to the grade given in the analysis (3). This is probably because joints in

extreme positions, either fully flexed (like the knees when squatting) or fully extended, may develop biomechanical problems.

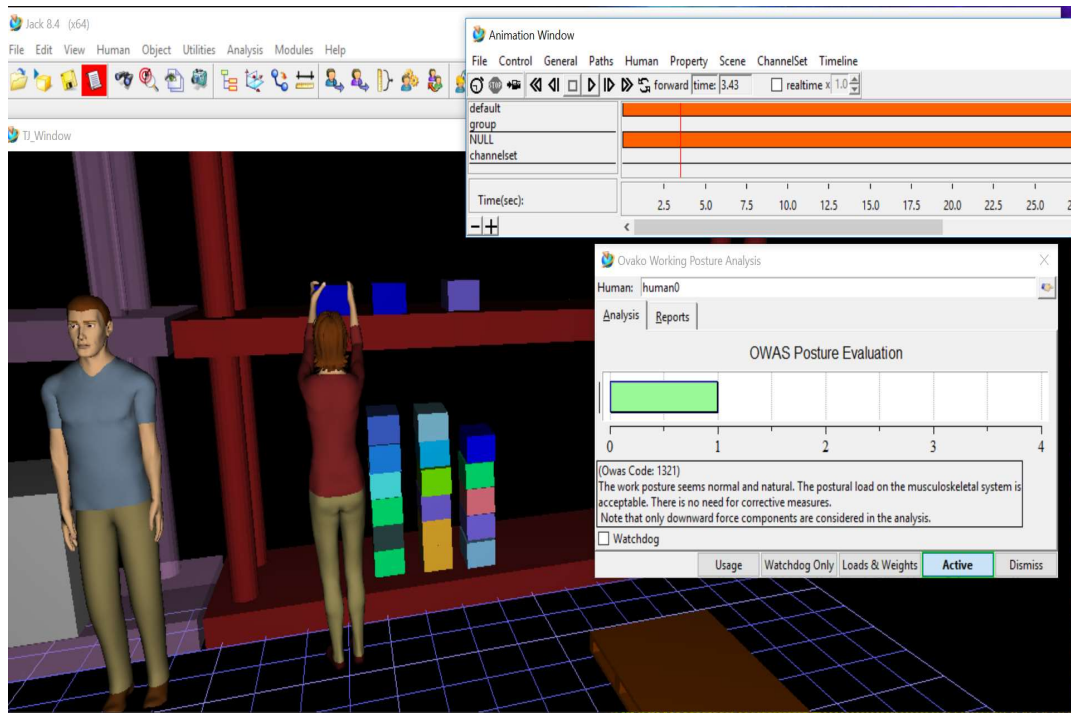


Figure 48: Screen Capture of the OVAKO Working Posture Analysis in the moment of getting a product from the shelves.

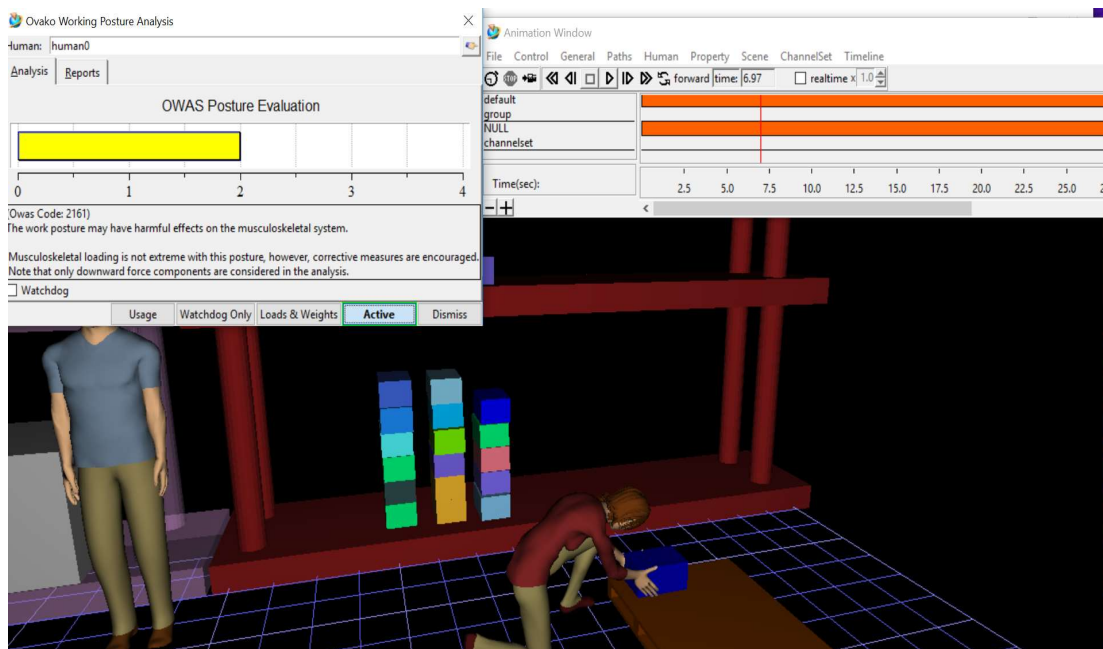


Figure 49: Screen Capture of the OVAKO Working Posture Analysis in the moment of putting a product in the pallet (Kneel-on-one-knee posture).

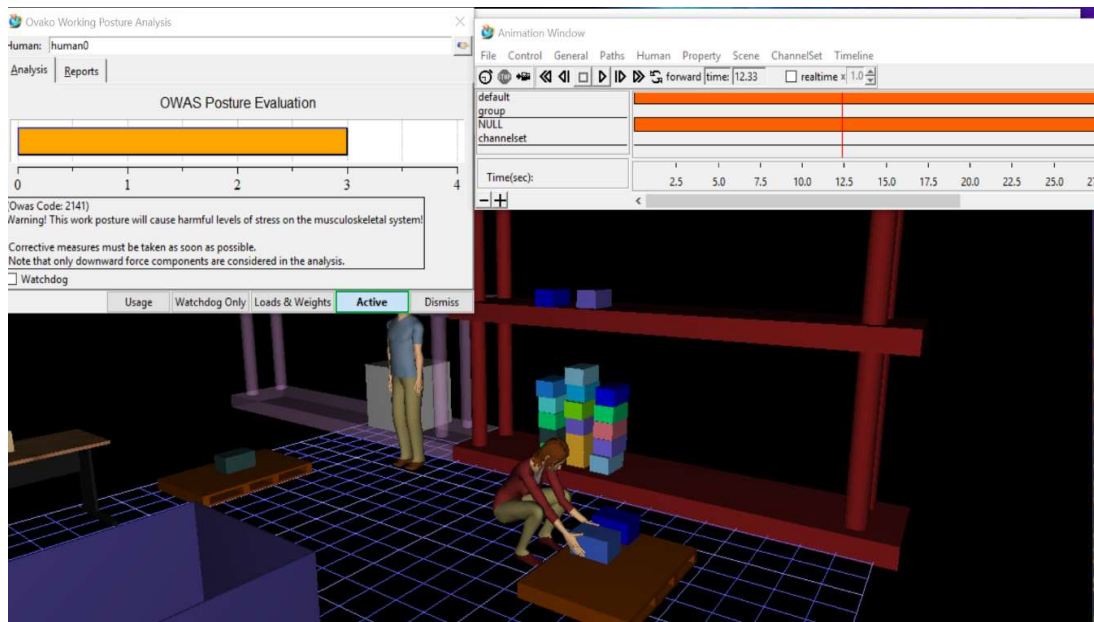


Figure 50: Screen Capture of the OVAKO Working Posture Analysis in the moment of putting a product in the pallet (Squatting posture).

❖ **Metabolic Energy Expenditure:**

For this analysis the results are much better than before introducing the changes. As it can be read on the graph below the energy expenditure rate does not exceed the recommended limit, not as before. However, the highest energy cost is produced when squatting (shown in the graph as *put-mobilebox*), which is something to take into account for the final conclusions for this task.

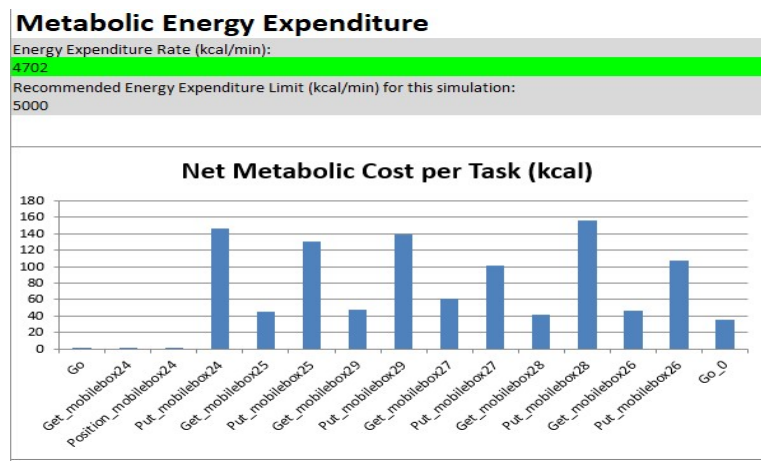


Figure 51: Net Metabolic Cost per Task for the Picking Process.

❖ Rapid Upper Limb Assessment:

The results of this analysis were completely different from the ones that the Ovako analysis gave. In this case, the posture made by the operator when picking a product from an upper shelf is highly recommended to be changed, because of the possibility of upper limb disorders. In addition, kneeling on one knee when leaving the merchandise on the pallet is considered to be very harmful, due to the grade given (7). Nevertheless, the squatting posture is not considered to be harmful. Mainly for this reason, this was the posture adopted for the Lower Back Analysis, Fatigue Recovery Analysis and Metabolic Energy Expenditure Analysis.

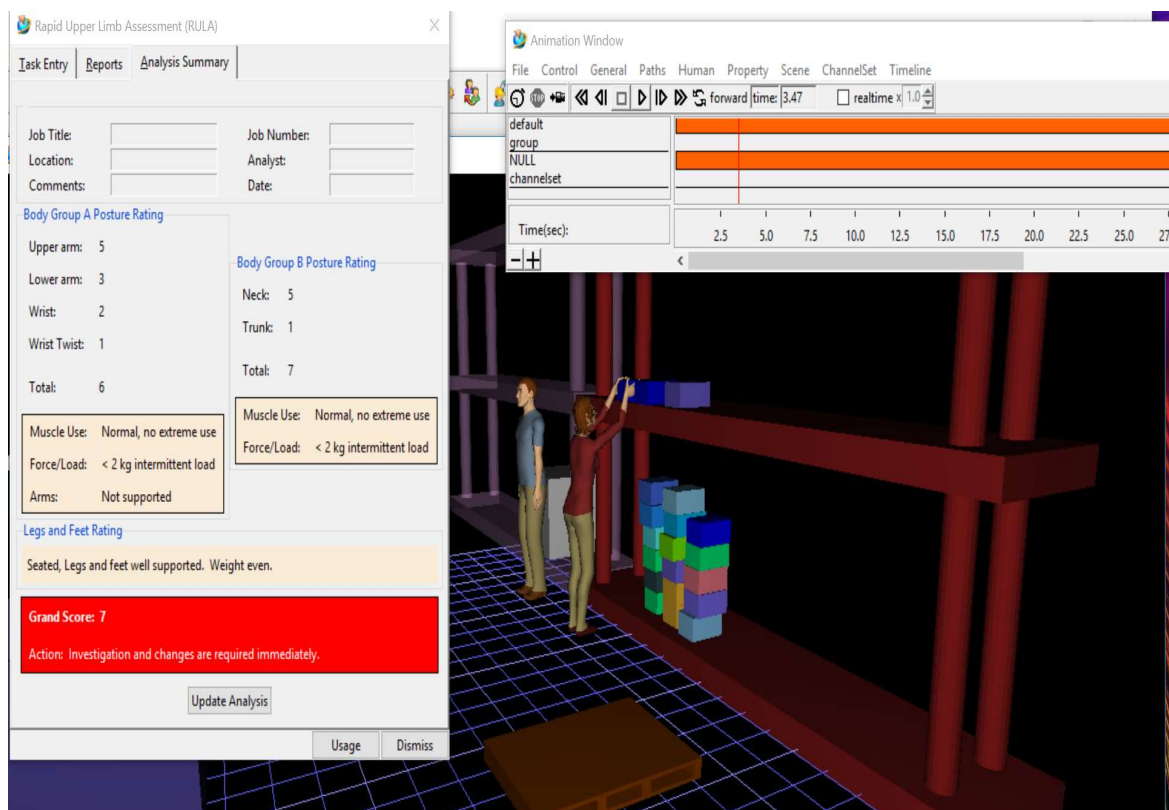


Figure 52: Screen capture of the Rapid Upper Limb Assessment in the moment of getting the product from the table.

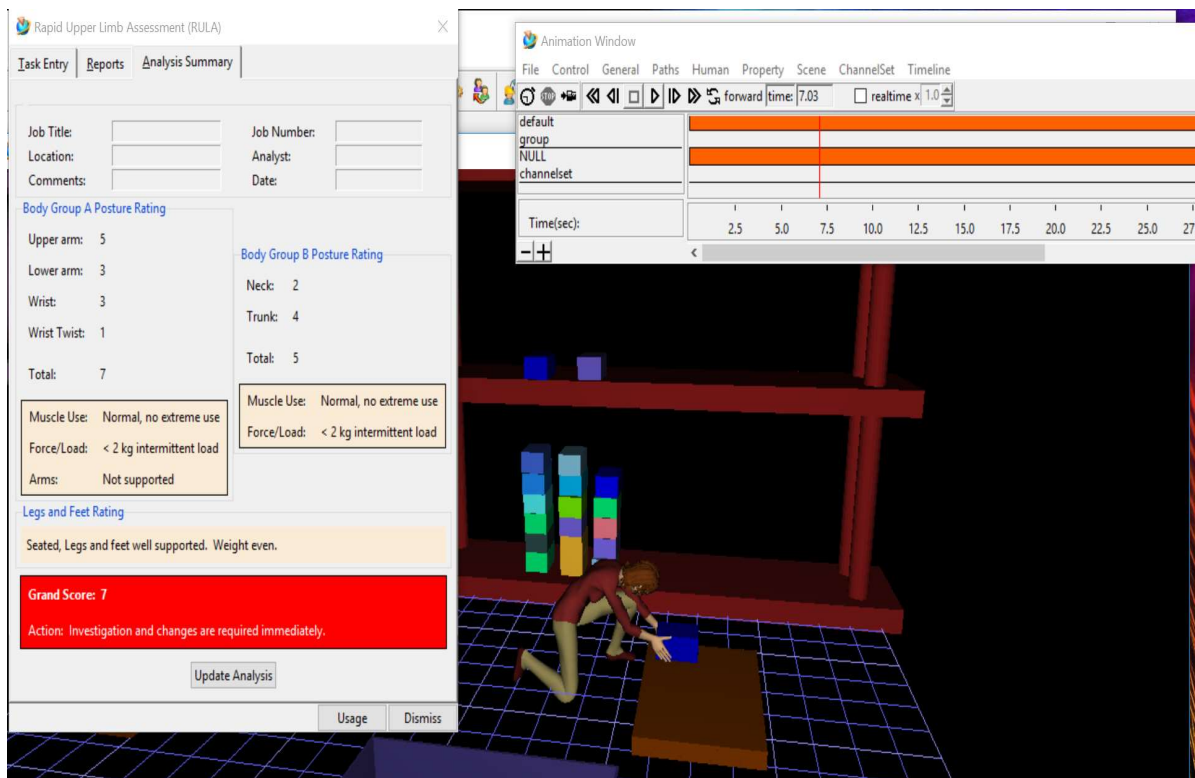


Figure 53: Screen capture of the Rapid Upper Limb Assessment in the moment of putting a product in the pallet (kneel-on-one-knee posture).

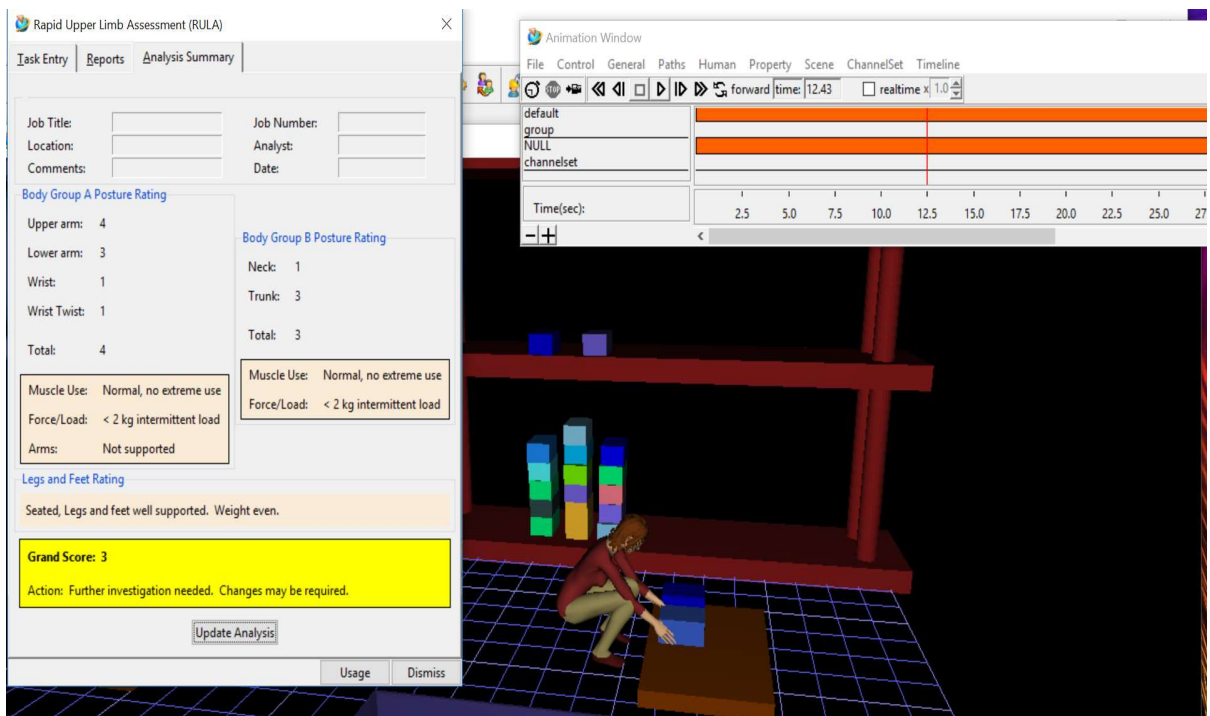


Figure 54: Screen capture of the Rapid Upper Limb Assessment in the moment of putting a product in the pallet (Squatting posture).

To conclude it is important to mention that the ergonomic measures introduced to improve the health of this task are not enough. More changes need to be made in order to make it a more efficient and safer task.

5.2. Closure Process

The results given before about this task were not good at all, especially because of the posture adopted by the operator when picking the products from the table.

In addition, the evaluations given to the postures adopted while putting the product in the roller table weren't positive neither. For that reason, and because the task is quite simple, the only possible measure to improve the ergonomic evaluations was to change the height of the surroundings that affected to the operator's task.

There are standard recommendations for a working's surface height for the development of sitting and standing workplaces. The most advantageous hand position depends on the type of task. For heavy work, for example, it is more convenient to hold the hands about 15 cm below elbow height. The arms and the body can then, perform that heavy task in a more efficient way. However, there are also sometimes individual preferences in work posture. In typing, for example, some individuals may prefer to work with horizontal underarms, while others may prefer to put the keyboard at a highest level. Therefore, the values listed in the table below are just guidelines, not absolute recommendations. Individuals indeed have different preferences which, combined with anthropometric requirements of a 5th to a 95th percentile design, result in a very wide range of values.

		Preferred hand height over floor (cm)			
		Standing (5 th -95 th)		Sitting (5 th -95 th)	
Type of task	Hand height = Elbow height ±	Male	Female	Male	Female
Heavy lifting	-15 (Range: -20 to -10)	91-110	85-110	Not recommended	
Light Assembly	-5 (Range: -10 to 0)	101-120	95-110	59-79	55-73
Typing	+3 (Range: 0 to +6)	109-128	103-118	67-87	63-81
Precision Work	+8 (Range: +5 to +10)	Not recommended		72-92	68-91

1. Table: Measures (cm) of preferred hand height over the floor.

This task could be classified as a kind of light lifting, which is not included in the table. However, a task like this one can include at any time heavy lifting of any product. For that reason, the ergonomic measures introduced to improve the development of the task are the following:

- Change of the measures of the table in which the products are left. The final height of the table introduced is of 100 cm, quite comfortable for an average sized man such as the operator working in the simulation (174 cm).
- Change of the measures of the keyboard's table. The final height of the table introduced is of 102,22 cm.
- Change of the measures of the roller table which, in some analysis turned out to be conflictive. The final height of the roller table introduced was of 115 cm.
- Change of the distribution of the elements. The main goal of this measure is to put the tables closer to the operator so that he needs to move the less possible.

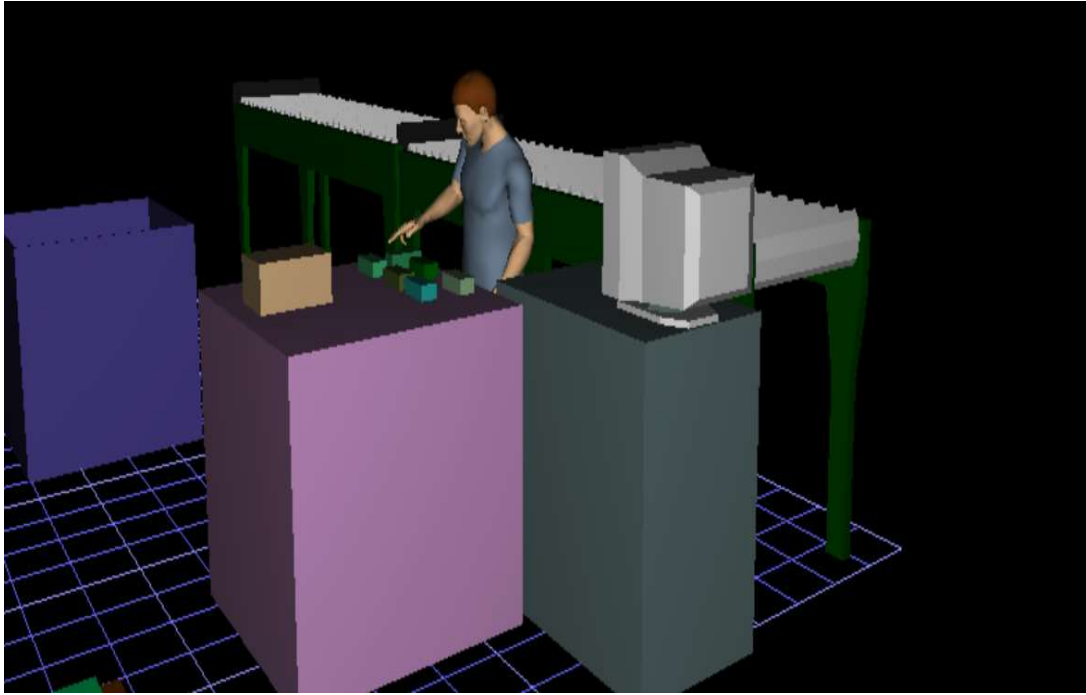


Figure 55: Screen Capture of the Closure Simulation after the Introduction of Ergonomic measures.

The results of the analysis after introducing the ergonomic changes are the following:

❖ **Lower Back Analysis:**

The graphs displayed below, in contrast to the previous analysis, show that the loading acting in the lower part of the backbone do not exceed the recommended values. Indeed, both values (compression exposure, and moment exposure) show values quite low. For the total cumulative compression per shift, the calculated value is 14.87 MN/s, while the recommended one is 22.5MN/s. For the total cumulative moment per shift, the calculated value is 0.22 MN/s, while the recommended value is 0.6MN/s.

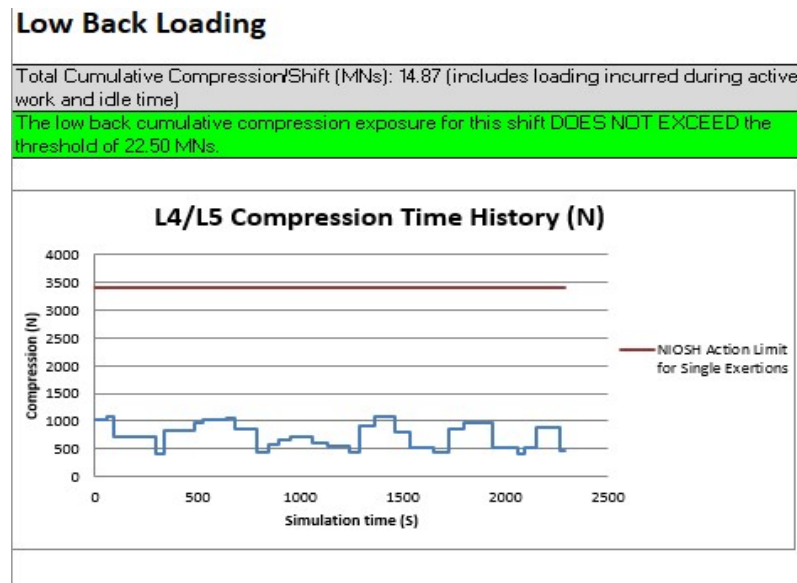


Figure 56: Low back cumulative compression exposure for the Order Closure Simulation.

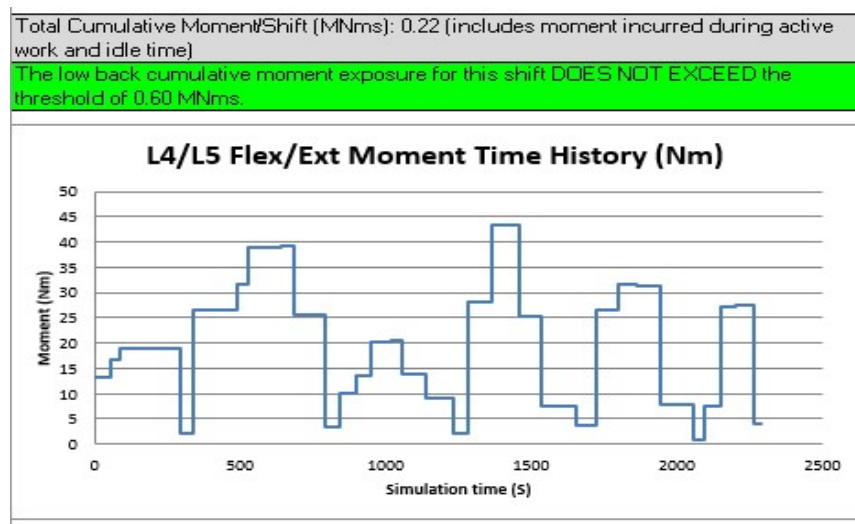


Figure 57: Low back cumulative moment exposure for the Order Closure Simulation.

❖ Ovako Working Posture Analysis (OWAS) Tool:

Although the results exhibited for this task in this analysis were not so negative as others, the working postures adopted by the operator thanks to the ergonomic measures adopted are even better. In fact, the most critical postures, which are the ones shown below, are described in the analysis as normal and natural.

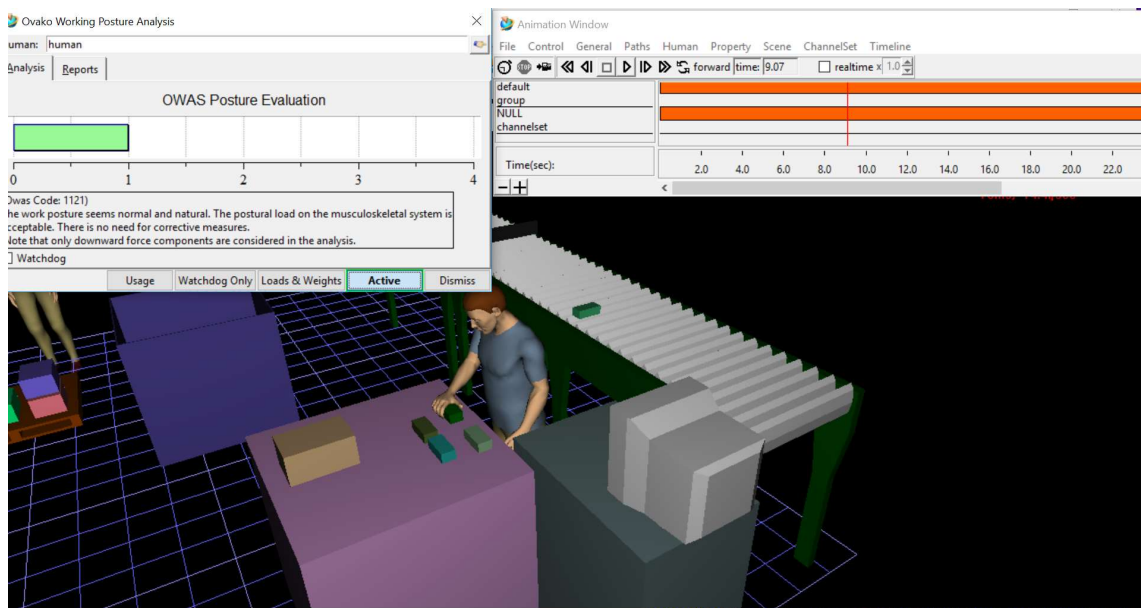


Figure 58: Screen Capture of the OVAKO Working Posture Analysis in the moment of getting a product from the table.

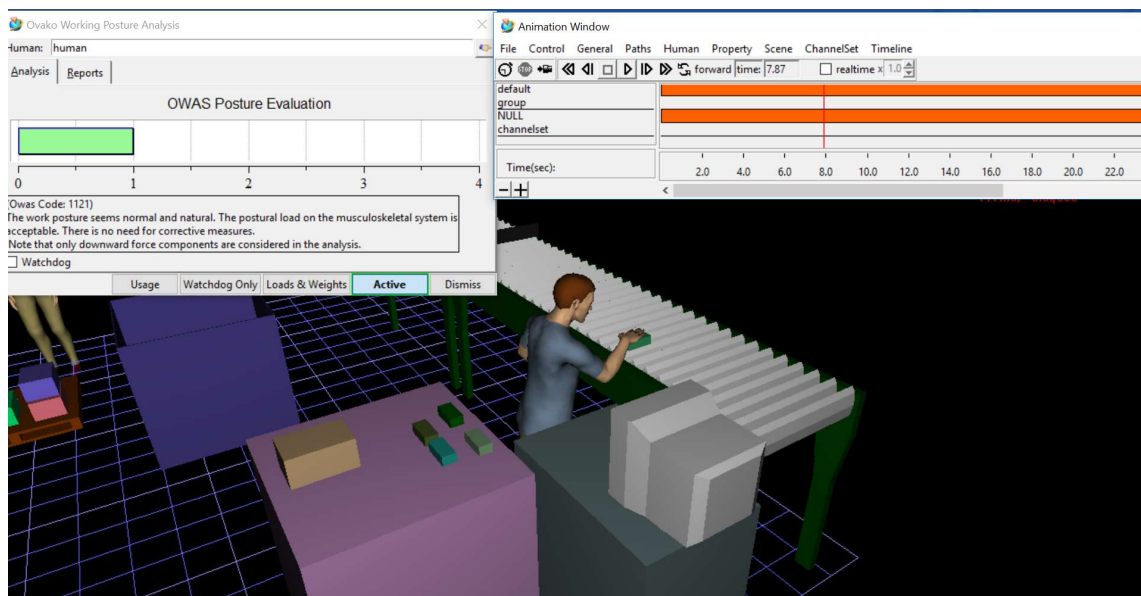


Figure 59: Screen Capture of the OVAKO Working Posture Analysis in the moment of putting a product in the roller table.

❖ Metabolic Energy Expenditure:

The results that the graph below exhibits are much better than the ones shown before the ergonomic changes. First of all, the Energy Expenditure Rate (2875kcal/min) value developed in the task is almost half of the recommended Energy Expenditure

Limit (5000kcal/min). And secondly, almost all the energy wasted when picking the products from the table isn't wasted anymore so the results here can be considered to be very positive.

Metabolic Energy Expenditure

Energy Expenditure Rate (kcal/min):

2875

Recommended Energy Expenditure Limit (kcal/min) for this simulation:

5000

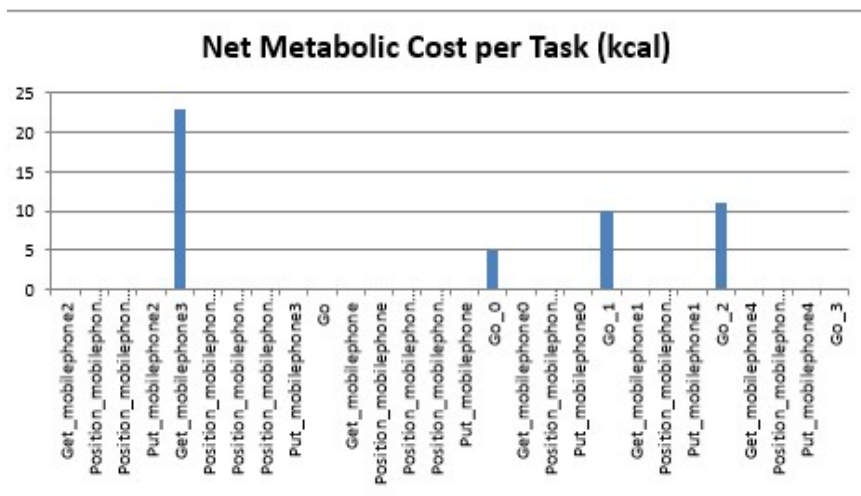


Figure 60: Net Metabolic Cost per Task for the Order Closure Simulation.

❖ **Rapid Upper Limb Assessment:**

The previous results given by this analysis suggested an immediate change in the posture adopted when picking the merchandise. Before, the task required the bending of the backbone up to an excessive point, but with the changes introduced the operator adopts quite natural postures, just as the Ovako Analysis suggests and therefore, they do not cause any upper limb disorders.

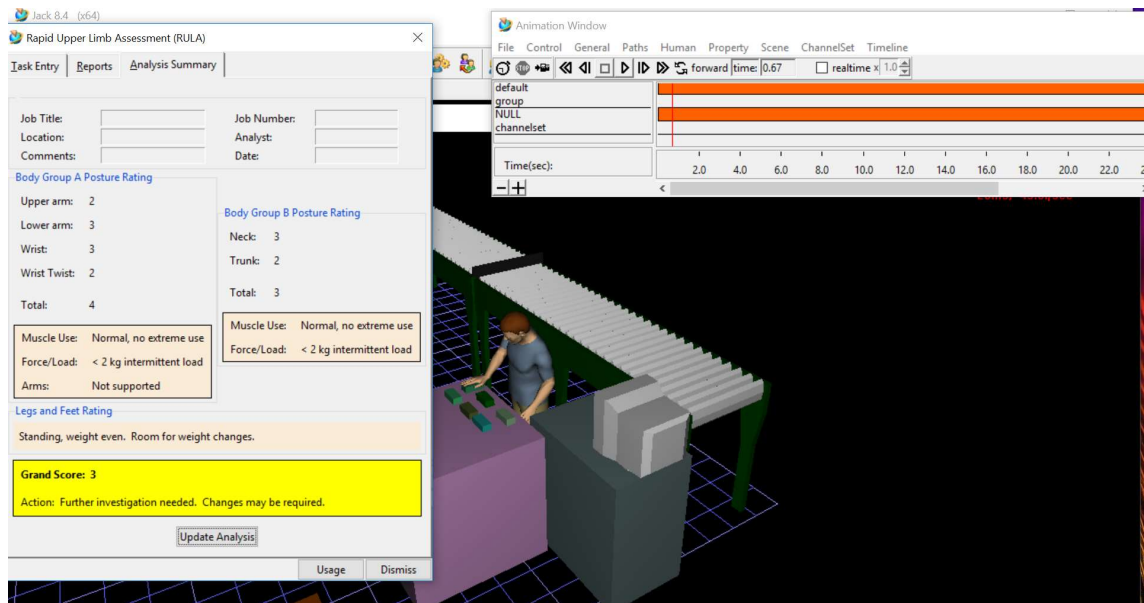


Figure 61: Screen capture of the Rapid Upper Limb Assessment in the moment of getting the product from the table.

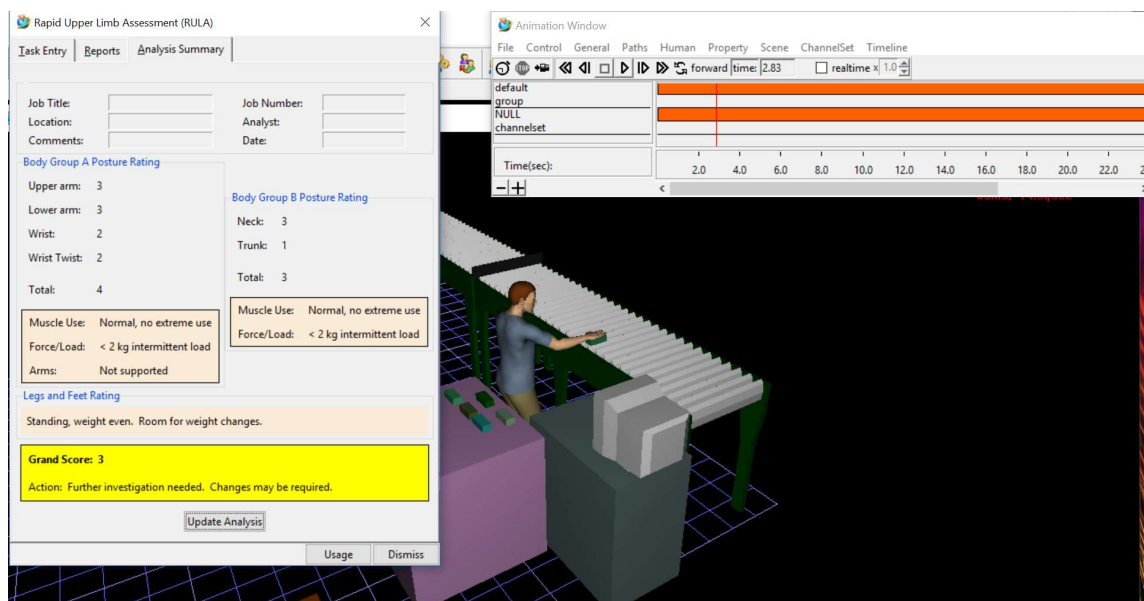


Figure 62: Screen capture of the Rapid Upper Limb Assessment in the moment of putting a product in the roller table.

In conclusion, the ergonomic changes introduced in the simulation have given very positive results in the development of the task. This results are verified in all of the analysis carried out for this simulation. Even though this study is done over a virtual

simulation, testing the changes in real cases should give a positive outcome, at least in the sanitary aspect of the ergonomic measures done.

5.3. Particular Order Simulation.

The implementation of ergonomic measures regarding the change of posture is quite difficult for the task since the products on the lowest shelves are too low. For this reason, the development of this task in long periods of time involve very high risks for the operator to end up injured in the backbone.

It is not possible either to redesign the workplace because the lightest products are already situated in the lowest shelves. Putting heavier products there would make the injury risk rise.

An efficient ergonomic measure would be to reduce the time employed by the operator to perform the task, designing even more dynamic working shifts. With this measure, the workers would carry out multiple tasks during their working shift and would get even more involved in the whole process.

6. CONCLUSIONS

In this ergonomic study carried out, where three different mechanical tasks have been analysed in depth the final conclusions are different depending on the task.

In the first task, the Picking Process, the analysis done after the ergonomic measures were quite positive. It must be mentioned that due to the fact that it was a very simple task with an ergonomic problem easily detectable (the posture adopted when leaving the products on the pallet), the difficulty to improve the results wasn't as high as in other tasks. However, if the operators of the company become aware of the importance of the posture when performing the task, the injury rate will get down for sure.

In the second task, the Closure Process, the results obtained after introducing a table at an adequate height were very positive. The posture adopted by the operator when picking the products from the table wasn't natural and required too much bending for the backbone. In addition, this task implies a lot of repetitions which in consequence, requires bending too much time so the changes introduced were necessary.

Finally, the Particular Order Process is the most difficult task redesign. Some easy measures to be taken would be to introduce devices to get the products from the shelves without having to squat but this measure requires a further economic study. However, the measure mentioned before of reducing the task shift is also possible and the injury rate would go down, but not disappear so this requires a wider and more in depth study with economic factors and viability.

7. REFERENCES

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