Goods-to-Person Picking Strategies Human Factor Simulation and Validation

Fatma Almazrouei
Student of College of Engineering
Khalifa University of Science and Technology
Abu Dhabi, UAE
100049440@ku.ac.ae

Alreem Almansoori
Student of College of Engineering
Khalifa University of Science and Technology
Abu Dhabi, UAE
100049632@ku.ac.ae

Maryam Aldhamani
Student of College of Engineering
Khalifa University of Science and Technology
Abu Dhabi, UAE
100049622@ku.ac.ae

Sara Alhosani
Student of College of Engineering
Khalifa University of Science and Technology
Abu Dhabi, UAE
100049537@ku.ac.ae

Saed T. Amer
Faculty of College of Engineering
Khalifa University of Science and Technology
Abu Dhabi, UAE
Saed.amer@ku.ac.ae

Abstract

Typical actions performed by order pickers in e-commerce warehouses include retrieving, scanning, grabbing, lifting, etc. making the human order-picker the spine of such warehouse operation. For an order picking system based on a Goods-to-person (GtP) strategy, the repetitive motions raise many concerns. This increased frequency of actions may lead to the development of musculoskeletal diseases in the order picker's body. Many methodologies, like human factors simulation, are available and can be utilized to assess the impact of the working environment on the human body. However, the evaluation of human factors in a simulated environment might differ from the actual case in real life since the interpretations of fatigue and discomfort can be subjective. Therefore, the objective of this paper is to validate the results obtained from the human factors simulation, by constructing a physical order picking environment and comparing the output through evaluating responses from volunteers who are subjected to similar to the simulated order picking environments and tasks. Three matrices of human factors were evaluated in this study. The study concludes that the results obtained from human factors simulation are in line with the subjective interpretation of the discomfort and fatigue experienced by the volunteers. As well as RULA ratings are similar in both cases.

Keywords
Goods-to-person, Order Pickers, HF Simulation, Anthropometry, Ergonomics, e-commerce warehouse.

1. Introduction
Order picking is the assignment of the worker to obtain, grab, lift, scan, and box items in a retail warehouse in order to fulfill the customer demands (van Gils et al. 2018). Human factors and anthropometry in warehouses are studied to assess the safety and health of the humans who are assigned to keep up with the fast-growing demand for items sold through e-commerce venues (Boysen et al. 2019, Winkelhaus and Grosse 2020). Goods to Person strategy is one solution that addresses the problem of waste caused by traveling which can be blamed for wasting half of the time needed to achieve one pick (Tompkins et al. 2010). Typically, in a warehouse, workers are expected to search, scan, grab and place items within seconds, repeatedly, leading to physical and psychological strains (Battini et al. 2015). Hence, the human factors and ergonomics analyses would help in enhancing the work environment and ensure the safety and health of the workers. The primary purpose of the research is to validate the similarity of the pain points of volunteers to the results obtained from the human factors simulation (HF) software. A validated HF simulation will be considered a great tool to monitor, analyze and recommend healthier and safer operations in the warehouse. Combined with a motion capture ability, the HF stimulation helps to enhance the work environment to best fit the workers and their task requirements, reducing unnecessary motion, increasing worker safety, and meeting elevated levels of efficiency and production that can be used in further studies

1.1 Objectives
As established in the previous paragraph, in a warehouse, GtP pickers workers are expected to perform picks in seconds, repeatedly, leading to health and safety concerns. HF Simulation is considered a valuable tool that can provide continuous and fast services to detect, analyze and mend the human inappropriate postures. Thus, the main goal of the project is to employ a simulation tool to provide fast assessments of the worker's ergonomics and well-being in the workplace. One of the objectives is to absorb the NOISH and OSHA guidelines and promptly detect and identify the human's non-conformance while performing repetitive tasks. Another objective is to collect and compare the output of the HF simulation tool with experiential, real-life scenarios to validate and calibrate the system. The study also aims to detect and eliminate unnecessary movements to increase the safety of the workers and fulfill a high level of efficiency and productivity. The final objective is to recommend workplace enhancements to best fit the workers to the task based on the human's anthropometry and physical capabilities.

2. Literature Review
The GtP system consists of a picker, a picking area, a storage area, and a material handling system to replenish the picking area. Picking areas have picking bays that are filled with products from the stocking area based on the order's list. The picker obtains items and fills orders from various picking bays. Technically, two technologies are employed to convey a container of items to a picker: The Kiva automated storage and retrieval (AR/S) system and the Miniload automated storage and retrieval (AR/S) system. In the study conducted by (Bozer & Aldarondo 2018), the two retrieval techniques were compared. Both systems were simulated using ProModel (Bozer, Y. A., & Aldarondo, F. J. 2018). After receiving the order's list of items to be collected, the picker moves to the picking area and locates the items. Technologies such as pick-to-light and pick-to-voice are used to help the pickers locate the items quickly.

Order picking is an activity in which a limited quantity of goods is retrieved from a warehouse to meet many separate client requests. Another purpose of order picking is to raise service levels while keeping different restrictions in mind, such as cost, setup, pickup, searching, traveling, and other order picking actions that have been recognized (Goetschalckx & Ashayeri 1989). It was discovered that travel accounted for the bulk of overall time and cost in an order-choosing strategy employing a basic picker-to-parts technique (Tompkins et al. 2010). Because traveling wastes the worker's time while providing little value to order picking, it is considered a waste of resources. It is directly related to the amount of time spent traveling and the amount of distance traveled. A significant amount of study on order picking optimization is focused on lowering trip distance. According to (Rouwenhorst et al. 2000) companies select their order-picking techniques at both the operational and tactical levels.

3. Methods

When it comes to collecting data from a lab experiment, the data must be dependable, and uncontrollable random errors can be minimized by designing the experiment with authenticity, and precision in mind from the beginning. Furthermore, ensure that the movements required to experiment are safe and do not expose the volunteers to any musculoskeletal disorders (MSDs) risks by calculating the acceptable range of lifted weights and conducting the Recommended Weight Limit assessment. The Recommended Weight Limit (RWL) assessment score, on the other hand, Rapid Upper Limb Assessment (RULA) can be used to determine how severe the movements are, which helps to determine the MSD risk level.

3.1 Standards and Regulations

When describing the accuracy of a measuring procedure, the International Organization for Standardization (ISO) 5725 utilizes two terms: "trueness" and "precision." The term "trueness" refers to the degree to which the arithmetic mean of a large number of test findings is consistent with the actual or acceptable reference value. The term "precision" refers to the degree to which test findings agree with one another. When a test result differs from some defined value due to inevitable random errors, it is not possible to determine if an actual deviation from a given value has occurred. In this scenario, the difference between the test result and some specified value cannot be determined. The operator, equipment utilized, calibration of the instrument, environment (temperature, humidity, air pollution, etc.), and time elapsed between measurements can all contribute to the variation of measurement findings. Precision refers to the degree to which a measurement differs from the previous one. A measuring method's variability may be described by two precision criteria, referred to as "repeatability" and "reproducibility conditions," which have been proven to be essential in many practical situations (1994).

As the design of the experiment is suggests, the OSHA (Occupational Safety and Health Act) standards guide the team through the process of identifying and eliminating potential safety hazards. Consequently, it assists in keeping volunteers safe from harm and any potential diseases associated with heavy containers, inadequate handholds, plastic wrapping, wooden pallets, pallet wrapping, and box opening (*United States Department of Labor.* n.d.). Lastly, to determine the weights for the experiment that would not cause any harm for the volunteers, the team had conducted a Recommended Weight Limit (RWL) calculation as shown in Appendix C and found that the maximum accepted weight is 2.10 kg. Originally the maximum allowed weight based on NOISH is 23 kg, but it went down to 2 kg because in the calculations done in RWL the frequency multiplier was down to 0.13 because the time between lifts was 6 seconds on average (Middlesworth 2022).

Results variations in the experiment were minimized in two ways to make sure that the data collected is reliable and the inevitable random errors are limited. At first, the same items were picked and the order picking activity steps were standardized when the volunteers experimented on the same testbed to limit the variation. Meanwhile, the volunteers were assigned to pick the items differently in different grip and posture positions and they varied in anthropometric measurements in height, weight, and gender. Secondly, to limit the deviation between the simulated experiment and the lab experiment all the dimensions of the testbed were measured and used to build the simulation model. Moreover, the simulated picker was programmed to follow the same standardized order picking process that was formed by the volunteers, and the items picked were simulated to bear the same weights as the ones in the testbed. To ensure the safety of the volunteers, the weights are assigned following the Recommended Weight Limit (RWL) as calculated and the potential stress caused by order picking as determined by OSHA (Occupational Safety and Health Administration). Heavy containers are avoided by calculating RWL, small items are stable, and the heavier items have a handle cut to avoid having inadequate handholds. Furthermore, none of the items have been packaged in plastic, nor have they performed the activity of wrapping items in plastic.

3.2 Details of the theoretical model

3.2.1 Mathematical model

To avoid putting the volunteers at risk of MSD, the experiment was designed around the Recommended Weight Limit (RWL). It was used to determine the weighted average for the objects picked, which defined the maximum allowed weight (load) that almost all healthy personnel could lift over the course of an 8-hour shift without raising the musculoskeletal disorders (MSDs) risk on the lower back. A Lifting Index (LI) is generated to quantify the level of physical stress and MSD risk associated with the manual lifting operations that are examined. If a lifting index value of 1.0 or below is recorded, the risk to healthy employees is minimal. An index greater than 1.0 indicates that the task

poses a danger to a specific subset of the general population. The greater the LI, the greater the danger of damage. Therefore, lifting jobs should be designed to achieve a LI of 1.0 or less (Middlesworth 2022).
The order picker's movements must be evaluated to determine the severity of the movement. Thus, the RULA assessment is performed for each volunteer while picking from different shelf heights and various item weights. Upper extremity work-related musculoskeletal disorders (MSDs) in the workers' upper limbs can be quickly assessed using the Rapid Upper Limb Assessment (RULA). Biomechanical and postural load requirements for neck, trunk, and upper limb tasks are considered by RULA ergonomic assessment tool. It utilizes a structured approach to determine the amount of force, repetition, and body posture required to perform the job being evaluated. The frequency of muscle use, as well as the forcefulness of the exertion, can all be assessed on a single page of a worksheet. The RULA assessment tool produces the final RULA Score. The score represents the level of musculoskeletal disorders (MSD) risk for the job task under consideration. The minimum and maximum RULA scores are 1 and 7, respectively (Middlesworth 2022).

3.2.2 Discrete or other approximations

Every experiment is subject to variations; in our case, the main source of variation is human error. The sequence of picking items from the shelves is standardized to reduce variation, so the volunteer would follow the same steps, picking the same item. The only uncontrollable factor is the total time required by each volunteer to complete the activity since it depends on the volunteer's speed, strength, and ability to lift the objects. Time plays an important role in the experiment. Thus, to ensure that the means of the lab experiment and the simulation means do not differ, the two-sample t-test (also known as the independent samples t-test) is used to determine whether the unknown population means of the two groups are equal or not (*JMP Statistical Discovery* 2022). The Minitab software is used to run a two-sample t-test to test the hypothesis.

3.2.3 Limitations and assumptions

Both RWL and RULA assessments have some limitations, whereas NOISH RWL only applies to two-handed manual lifting tasks performed from a standing posture. Additionally, the calculations assume that other manual material handling activities are minimal and do not consider unforeseeable conditions such as unusual heavy applied loads, unstable loads, slips, falls, traumatic incidents, or unpleasant environmental conditions (*University of Cape Town.* n.d.). A study entitled "Evaluation of the NIOSH Lifting Equation" demonstrates that the revised NIOSH lifting equation has limited applicability in a variety of realistic manual lifting situations. While it takes twisting into account, it does not consider modeling lifting tasks performed at restricted ceiling heights. Additionally, it recommends that is significantly less than the mean weight accepted by all participants (Elfeituri & Taboun 2002). However, there are several limitations to the RULA assessment, including the fact that it does not consider the duration of the task, available recovery time, or hand-arm vibration. This method also requires separate assessments for the right and left sides of the body, although in most cases it is easy to determine which side of the body is most exposed to MSD risk fairly quickly. Additionally, this method only allows the evaluator to assess one employee's worst-case posture at a time, necessitating the use of representative postures (Middlesworth 2022).

3.3 Alternative designs

Three different alternative designs were proposed to detect and measure repetitive motion in order-picking. As showing in Figure 1, one is the use of an ordinary RGB camera for Ergonomic posture recognition supplemented with image recognition software and classification capability. The second is the self-monitoring surveys, and finally, the team considered the HF simulation.

When contrasted to wearable sensors, an RGB camera is employed to collect skeletal movements. It is also sturdy and commonly utilized at an outdoor construction site, due to the varying light conditions and diverse working regions. View-invariant characteristics were gathered as classifier inputs from collected 2D skeleton motion samples throughout the test run to guarantee the learned classifier was not adaptable to various camera perspectives and labor distances. Three-position detectors for the human back, arms, and legs were used to ensure that three postures were detected at the same time in a single video frame (Yan et al . 2017).

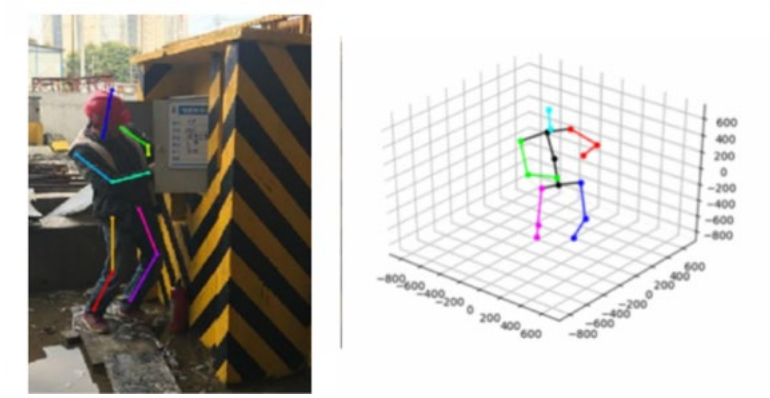


Figure 1. Ordinary RGB Camera.

As Figure 2 shows, the surveys are conducted by laborers after performing the task for a long time. They aim to scale and identify the level of discomfort caused by repetitive movements, leaving them fatigued, such as Comfort Analysis, Fatigue Analysis, and RULA.

Figure 2. Self-monitoring Surveys.

The human factors simulation tool employed for this study is Jack® by Siemens which is recognized for improving the ergonomics of industrial processes (Figure 3). Jack® and its supplementary toolkits provide human-centered modeling software for conducting ergonomic evaluations of digital products and digital workplaces. There is the option to set the size of human models to match worker demographics and evaluate designs for a variety of criteria such as injury issues, worker comfort, arms reach, sightlines, energy consumption, tiredness limitations, and other critical human characteristics (*Siemens* 1992).

Figure 3. Simulation Modeling Tool JACK®.

After looking deeper into those approaches, the HF simulation modeling tool is the appropriate methodology to apply, due to the features it provides. Through the HF simulation software, the emulation of real experiments with workers of different heights and genders is possible. The developed working environment using JACK® involves realistic digital pickers, where it has a similar layout to the actual warehouse components. The HF simulation will provide results of various human factors assessments that will be compared with the real-life experiment and used for validation.

As illustrated in Figure 4, a Motion Capture Suit can detect and gather the person's movements in real-time by using a technology of sensors spread across the suit. It captures a person's real-life motion and translates it into a 3D simulated character, which mimics the exact movements performed by the person. Using motion capture technology and replaying the playback of the workers, the level of ergonomic comfort can be determined by recording the intensity of the workload subjugated on a worker during a specific period. The factors that might affect ergonomic comfort are the product's weight, shift length, and workstation design (Feldmann et al. 2019).

A computer vision system can recognize objects based on a visual learning method (*Photonics Media* 2022). It might become advanced by implementing artificial intelligence (AI) systems that make decisions based on intuitive reasoning and interact in a way similar to humans. However, contemporary computer vision systems are not capable of learning alone; they need to be trained on how to analyze the knowledge obtained. Mostly, computer vision systems learn by checking a huge number of images that have labeled objects which they have to try to identify. They follow a three-step approach that could be described as follows:

1. Break down the image into small blocks that are called "viewlets" by the researcher
2. Learn how the object in question is formed from the fitted together viewlets
3. Check the surrounding area for objects that are relevant to identifying and describing the primary objects.

Consequently, developing a computer vision mimic for human posture is perhaps a reasonable way to make a model for Goods-to-Person picking. Converting it to simulation could make a model that is accurate as it reflects thousands of postures' information (*Mount CG.* n.d).

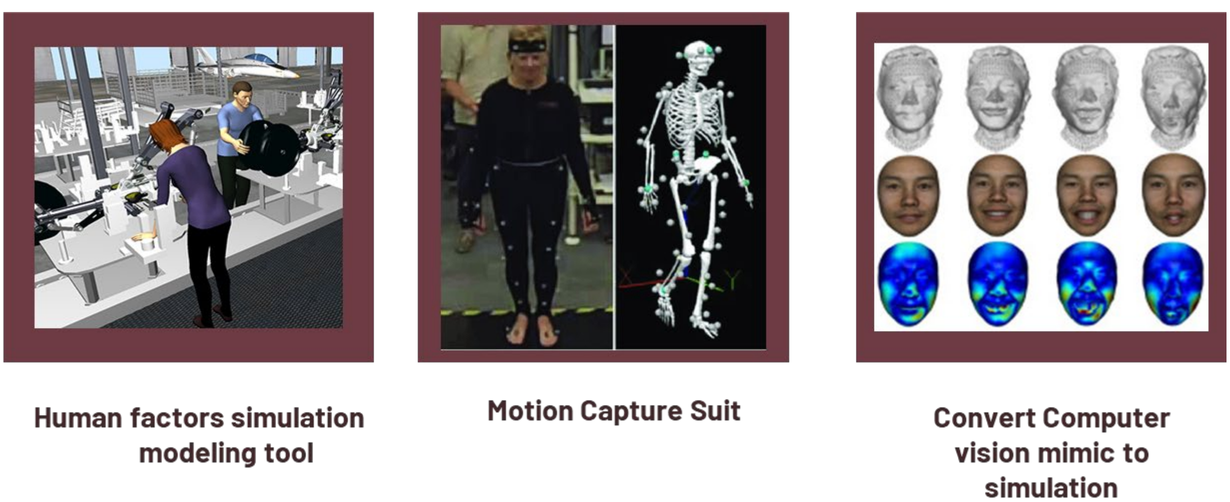


Figure 4. Proposed Tool Capabilities

3.4 Key design constraints

Self-monitoring surveys have been used widely, yet they have many drawbacks. The respondents would provide inaccurate data since they may not feel motivated to give precise answers. Their responses may be biased and could not have enough knowledge and information on the surveys. The simulation tool is not user-friendly where the user has to go through the user manual provided for each step. The program is also not intuitive nor easy to use as the user would need guidance to fully use the features of the software. It is very slow and keeps lagging resulting in files suddenly not working and it deletes them. The software does not allow the copy and pasting of objects and there is no option of backtracking the work done. Another constraint is that the files cannot be imported easily and not any files can be imported into the program. The program is way too complex and has many features that require training. Furthermore, finding volunteers that fit the height and weight requirements is time-consuming. The volunteers may be busy at suitable test times and have time conflicts with volunteers. Preparing the testing environment takes time, so it is better to test the volunteers. Training all the volunteers on the specific steps to follow and having them memorize them is a tedious task. The volunteers sometimes forget tasks and have to redo the whole process.

3.5 Modeling Simulation

To visualize our tests and results, the team chose HF simulation software. The software was chosen because it was the most appropriate and acceptable to the situation at hand, as it involves multiple attributes and features that would fulfill the project scope. As showing in Figure 5, the software program allows the user to import 3D CAD models and alter them to better match the requirements (*Siemens.* 1992).

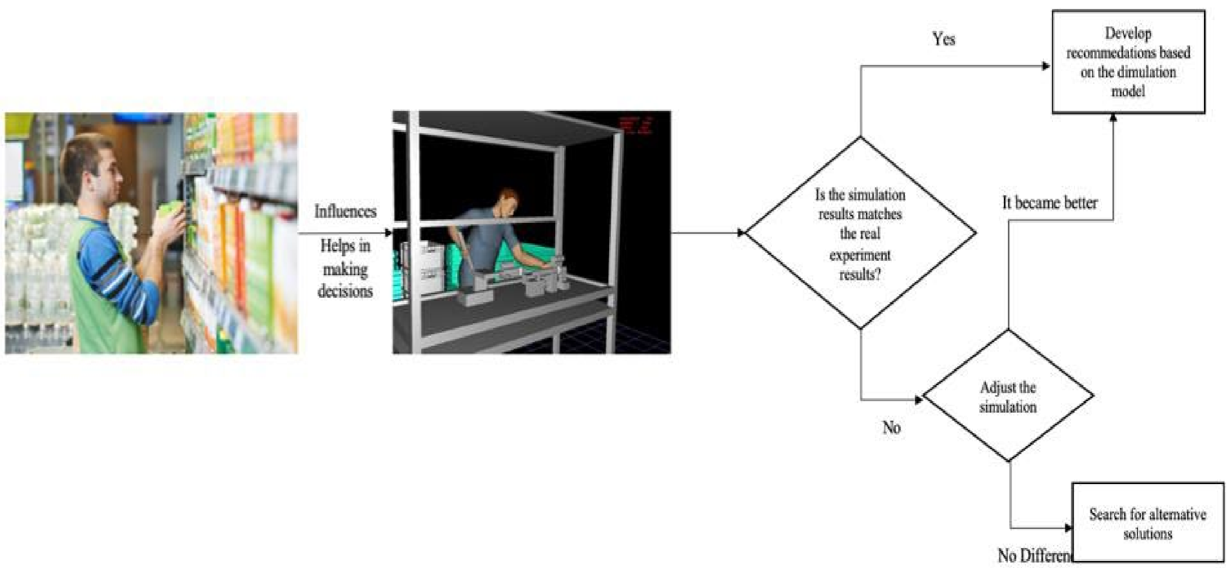


Figure 5. Model Description.

The software allows the human in the simulation to carry various things while allowing the user to adjust its posture and behavior (*Siemens.* 1992).

The software has a function called "Task Analysis Toolkit (TAT)," which allows the user to evaluate and analyze how relaxed the person in the simulation is, depending on their posture and the forces operating on it (*Siemens.* 1992). Lower back analysis, fatigue analysis, metabolic energy expenditure, force solver, and OVAKO working posture analysis are some of the techniques accessible in TAT (*Siemens.* 1992). The software will reflect the real-life experiment that will be conducted.

3.6 Assessment of Design

Workstation designs have been assessed using various human factors approaches and human modeling software such as human factors simulation software, to verify that our simulation indeed reflects the situation of real-life workers. Anthropometric dummies are used in the software where they can act as live subjects and show how certain movements and work conditions affect workers. Simulating real-life designs allows the development of the design process and enhances the human experience and accommodation in the work environment. The design will be assessed through the evaluation of how the human reaches all the products as well as the repetitive motion. Also, having test subjects with various anthropometric measures will ensure the variation in the results and provide sufficient data regarding the extreme members. Along with the software, different human factor tools will be used to assess the validity of the design.

4. Data Collection

The experiment will be conducted in the manufacturing lab where eight volunteers, 4 males, and 4 females, will be performing various tasks of retrieving items from the shelf, which will demonstrate the Goods-to-Person methodology. The testbed will include a table, shelf, and items which will represent the warehouse employee's workplace. The weights of the items chosen are based on the calculations done in the RWL and they varied from 0.14770 kg to 2.01923 kg, and they are ten different items, as shown in Figure 6. They will first be trained on the order of the retrieval and placement of the various items from the shelf repetitively for the ten items. They will pick the item from its designated location which differs from one item to the other, then place it on the table and scan the item, and set the item on the conveyor belt.

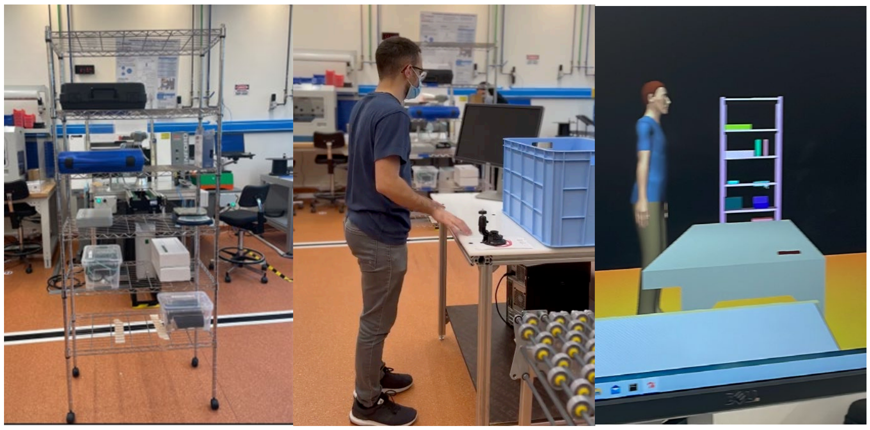


Figure 6. Items arrangement on the shelf.

The volunteers will then fill out Comfort Analysis and Fatigue Analysis questionnaires, after doing the experiment. Their postures will be assessed according to the results of the questionnaires. Also, RULA will be used to analyze their postures in different picking positions. Figure 7 illustrates the assessments will show the pain points of the volunteers due to the repetitive motion and various tasks.

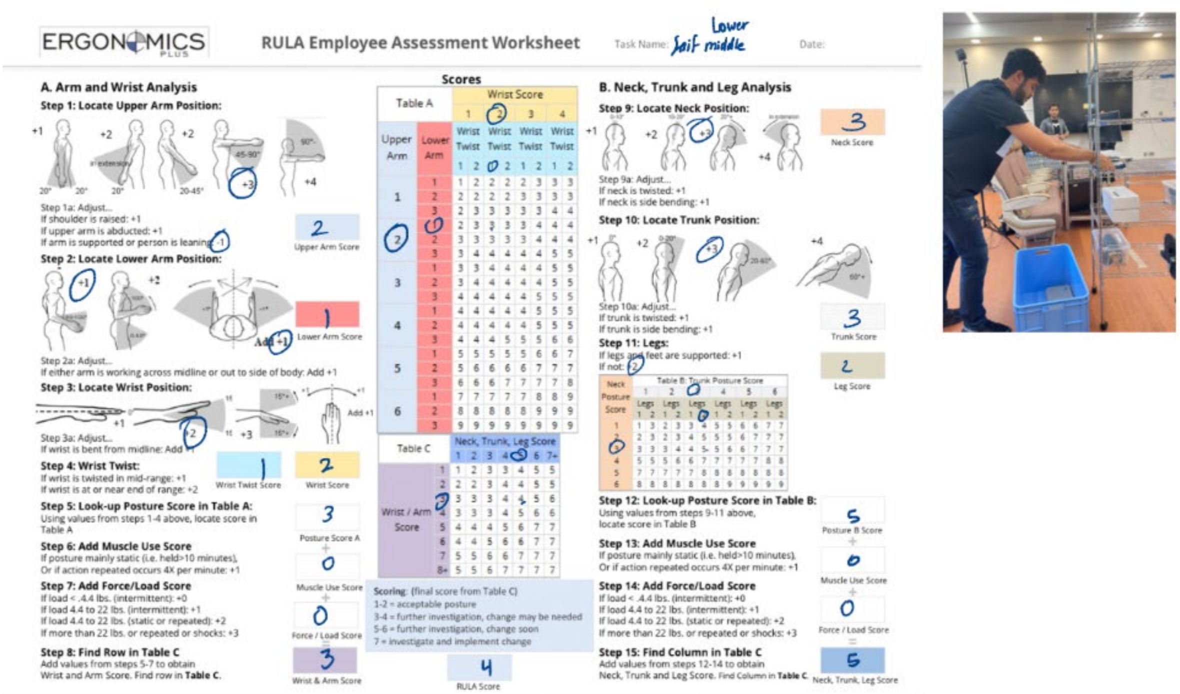


Figure 7. Survey and Volunteer Feedback

5. Results and Discussion

To validate our project, attempts are made to replicate as many of the worker's conditions in warehouses as possible in both the testbed environment and in the simulation. Several products are displayed on the shelf, along with a table, a computer, and a conveyor belt. Weight and size are factors that are considered when specifying the product's specifications. This process is validated under circumstances that are similar to those of the actual picking system. The system of the testbed experiment is similar to the real-life systems of warehouses with slightly minor differences. It is simpler and does not require automated systems to retrieve the shelf to the worker's workstation (table and conveyer belt). Several assessment tools are used to evaluate the performance of the system's accuracy and to validate whether or not the picker experiences fatigue.

The human in the simulation software is simulated four times, according to the 50th and 95th percentile of men and women. It corresponds to the Asian/Indian population in the database installed in the software. The database is somewhat similar to the 50th and 95th percentile measurements gathered from the volunteers. The environment created in the program reflects the real environment of the experiment that is conducted. The measurements of the table, conveyer belt, shelf, and items are all adjusted according to the measurement of the actual objects. The weight of the items is also considered and specified in the software. The simulation in the software mimics the exact sequence of steps that the volunteers follow, as well as the same position and location of the items on the shelf. Also, some of the postures of the human in the software are altered to demonstrate the retrieving positions of the volunteers. One of the differences between the simulation program and the experiment is the squatting down posture while retrieving items from the lower shelves. The volunteers' exact measurements are not used in the simulation, but instead generalized Asian/Indian measurements are chosen. All the system requirements that are set are followed by the use of the human factors simulation software.

The qualitative tools that are used are the comfort and fatigue analysis tools. The comfort analysis included questions about picking items from the upper shelf, shoulder level shelf, lower shelf, motion from shelf to table, and the table work done as shown in Appendix D. The volunteers are asked to fill in questionnaires based on what they felt during the experiment and rate their level of pain and discomfort from 1 to 10, the least being 1. For the fatigue analysis, they had to answer questions with 'yes' or 'no' for the three parts and they are the weak activities, weak motivations, and physical fatigue. Meanwhile, a fatigue report will be generated from the software.

5.1 Numerical Results

Rapid Upper Limb Analysis (RULA) was calculated for both the volunteers and extracted from the simulation through the HF simulation as shown in Appendix B. Since, RULA is used to rate the level of musculoskeletal disorder risks (MSD) from 1 to 7, the higher the score higher the risk. The results obtained from both the volunteer experiment and the simulation from the HF simulation are shown in Tables 1 and 2. For the sake of comparison, the averages of the RULA scores of both the males and females from the volunteers and the simulation were calculated at each shelf level. Both the lower and upper shelves in the volunteers and simulation have high scores of 7 and 6 which indicates that investigation and change are required immediately. Whereas in the lower middle shelf, the results obtained were identical for the females but it does not for the males, yet both scores seek investigation and changes are required soon. For the upper-middle shelf, the results were quite different for both the males and females in the volunteers and simulation, which indicates that a possible human error could have occurred while assessing the volunteers. As a result, it can be stated that the HF simulation results of RULA are validated through the calculations done.

Table 1. RULA Scores.

	Simulation			
Shelf	95th male	50th male	95th female	50th female
Upper shelf	7	7	7	7
Upper middle shelf	4	6	4	4
Lower middle shelf	5	7	7	5
Lower shelf	6	7	6	7

	Volunteers							
Shelf	Male 1	Male 2	Male 3	Male 4	Female 1	Female 2	Female 3	Female 4
Upper shelf	7	7	5	7	6	7	6	7
Upper middle shelf	6	3	3	3	6	6	6	3
Lower middle shelf	6	4	4	4	7	6	7	4
Lower shelf	7	7	7	6	6	5	6	7

Table 2: RULA results from averages for different genders and shelves.

	Simulation		Volunteers	
Shelf	Male	Female	Male	Feamle
Upper shelf	7	7	6.5	6.5
Upper middle shelf	5	4	3.75	5.25
Lower middle shelf	6	6	4.5	6
Lower shelf	6.5	6.5	6.75	6

5.2 Graphical Results

The quantitative assessment tools that are used for evaluating the simulation tool are RULA (Rapid Upper Limb Assessment) and LBA (Lower Back Analysis). RULA is done based on the volunteers' retrieving positions from the upper, middle, and lower shelves and scoring them based on specific criteria in RULA. Lowest Back Analysis measures the lower back pain the workers will face from the weight of the items being lifted.

The performance metrics will be based on how similar the qualitative and quantitative data from the experiment are to the simulation's results. The HF simulation software generates a fatigue report that will be compared with the comfort and fatigue analysis done on the volunteers. In the fatigue report seen in Figures 8 – 10 the obtained results showed that the subjects faced pain in the right and left ankle for 8 hours shift and that was also confirmed in the assessment done by the volunteers through the comfort and fatigue analysis. The volunteers in the lab experiment did face pain points in different areas of their body, mostly in their arms, shoulders, and back. There is shared data from both the volunteer's assessment and the ones generated from the software, thus it can be confirmed that the software detects the physical stress that workers in warehouses are exposed to.

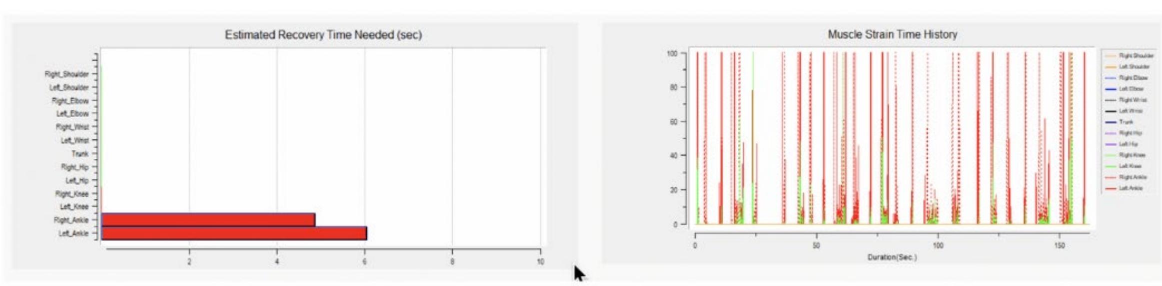


Figure 8. the HF Simulation Fatigue Report set 1.

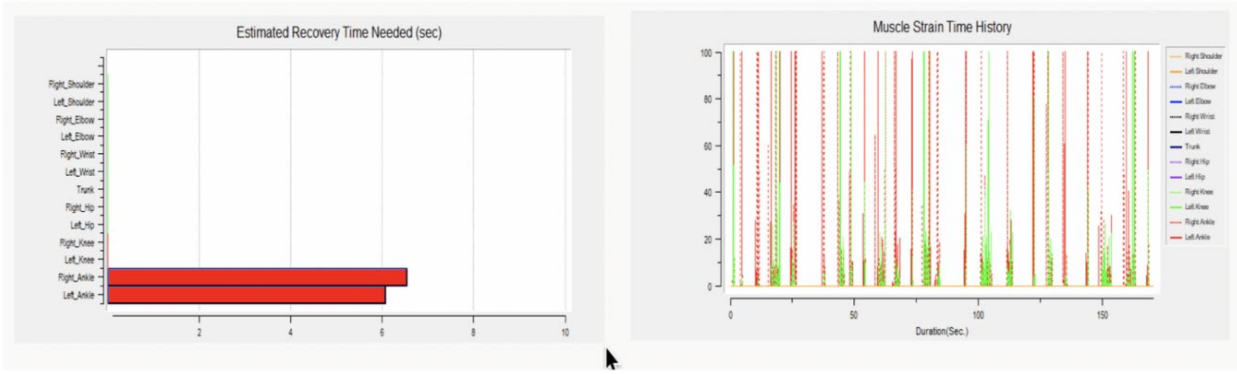


Figure 9. the HF Simulation Fatigue Report set 2.

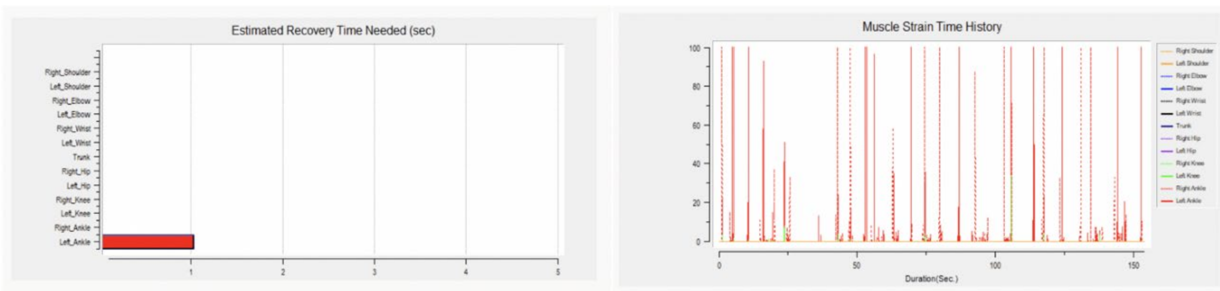
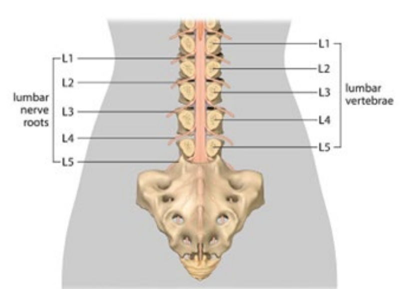


Figure 10. the HF Simulation Fatigue Report set 3.

The data that is acquired from the simulation software regarding the LBA (Lower Back Analysis), shows the tasks done by the human and simplified in different actions, which then measures specific forces in Newton. The L4/L5 Moments and L4/L5 are the Muscle Tensions and L4/L5 are the two lowest vertebrae of the lumbar spine as shown in Figure 11 (Ramadhan, A. A., Ahmad, A., Alotaibi, S., & Kasap, S. 2017). They carry the upper body and permit it to twist in different directions and most of the weight is applied to them which makes the area prone to injuries. Volunteers also had lower back pain in the peak moments of the LBA according to the results obtained from the fatigue and comfort analysis. The LBA simulation results confirm that they are exposed to tension in their lower back due to the picking movements. However, since the lower back compression forces as shown in Figure 12 that apply to 95^{h} women were all chosen percentiles for both women and men are less than 3400 N, they are still on the safe side and have nominal risk according to the NIOSH back compression action limits (Ramadhan, A. A., Ahmad, A., Alotaibi, S., & Kasap, S. 2017). In this assertion, the LBA L4/L5 force applied was compared with the volunteer's rating, where pain faced by the volunteers and indicating it by yes/no and rating it from 1 to 10 was compared with the force in LBA. Thus, the more pain the person is feeling the more the force is applied to their back. The outcomes compared the results from LBA at specific time intervals in seconds indicating where the subject faced the highest pain due to the force.



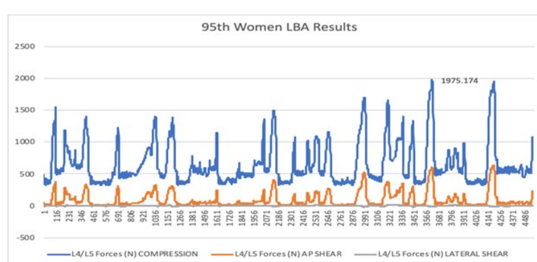


Figure 11. Vertebra of human spine L1 to L5.

Figure 12. Vertebra of human spine L1 to L5.

5.3 Proposed Improvements

To conclude, the team recommends using the simulation to analyze and generate data about the health and well-being of the warehouse workers. The team also suggests using cameras and artificially intelligent devices such as the Motion Capture Suit and the Connect smart monitor to continuously observe and monitor the worker's status during the picking operation. The devices will monitor and generate reports about the worker. Also, it will notify the worker when a possible danger could occur to him so he stops and takes a break. In fact, this technique is not only exclusive to picking workers, but also for all other workers in manufacturing processes like assembly lines. Moreover, using the Electromyography (EMG) machine which measures muscle reaction in response to nerve stimulation (*HospitalsStore.com.* 2022). Thus, experts will be capable of accurately measuring the amount of strain or fatigue the worker gets while doing his job. Additionally, implementing engineering controls might be helpful such as providing the workers with tools and gadgets that facilitate their reach for products. Examples of the tools are belts, hangers, and slides. These tools will help the workers avoid doing hazardous postures that could lead to an injury. Administrative control is a valid approach to mitigate any future risks by assigning only employees who could reach the shelves without the need for severe effort. Additionally, administrative control includes training which has a huge impact on the workers. The team suggests continuous breaks throughout the shifts to allow for muscle recovery. Lastly, the team highly recommends using Personal Protective Equipment (PPE) such as Webbing Sling Lifting Belt which facilitates lifting heavy products.

5.4 Validation

Minitab is used to perform a two-sample t-test on the lab experiment and the simulation's means to ensure that both means are within a 95 percent confidence interval, regarding the time of the volunteers and the simulation. The results obtained from the hypothesis testing failed to reject the null hypothesis meaning that the two means of the volunteers and the simulation were similar, which means that the data obtained is valid, as shown in Figure 13.

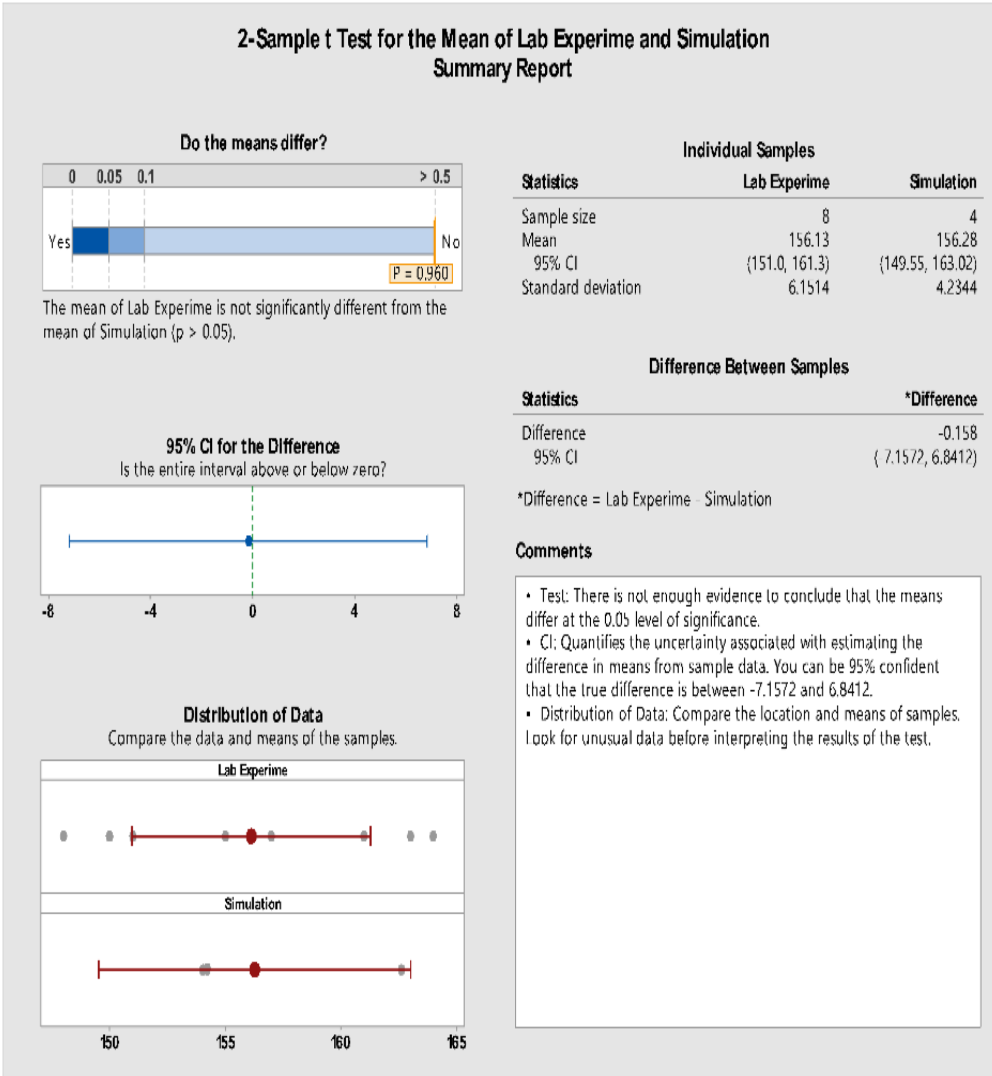


Figure 13. Minitab Two-sample T-test Results.

6. Conclusion

After collecting the data and analyzing it, the team developed conclusions that summarize the findings of this project. The simulation software results were pretty accurate. As a result, using simulation to study the human factors of workers in warehouses is advisable. It will optimize the cost of studying the worker's human factors as well as finding the best mitigations to avoid fatigue and injury risk. On the other hand, the simulation software has some limitations as it is very time-consuming, not user-friendly, and requires a high amount of accuracy to get good results. Furthermore, some postures are not supported in the simulation software. For instance, the volunteers used a squatting position to reach the lower shelf items, but the team couldn't simulate it as the software does not support the squatting position. Additionally, training is essential for volunteers to make them understand the task accurately. The number of volunteers was based on their availability when the experiment was conducted, and it was not mathematically calculated since the team did not have enough expertise and knowledge to calculate it.

7. References

Aramex. About Aramex. https://www.aramex.com/ae/en/about/about-aramex, accessed on June 1st, 2022.

Battini, D., Delorme, X. Dolgui, A., Sgarbossa, F., Assembly line balancing with ergonomics paradigms: two alternative methods IFAC-PapersOnLine, 48 (3), pp. 586-591, 2015

Blanchonette, P., Jack human modelling tool: A review. Dtic.mil. https://apps.dtic.mil/sti/pdfs/ADA518132.pdf. 2010.

Boysen, N., de Koster, R., Weidinger, F., Warehousing in the e-commerce era: A survey European Journal of Operational Research, 277 (2), pp. 396-411, 2019

Bozer, Y. A., & Aldarondo, F. J., A simulation-based comparison of two goods-to-person order picking systems in an online retail setting. International Journal of Production Research, 56(11), 3838-3858, 2018.

Charalambos, B., Height percentile calculator, by age or country. Tall.Life. https://tall.life/height-percentile-calculator-age-country, accessed on June 1st, 2022.

Elfeituri F. E., & Taboun, S. M., An evaluation of the NIOSH Lifting Equation: A psychophysical and biomechanical investigation. Int. J. Occup. Saf. Ergon., 8(2), 243–258, 2002.

Feldmann, F., Seitz, R., Kretschmer, V., Bednorz, N., & Ten Hompel, M., Ergonomic evaluation of body postures in order picking systems using Motion Capturing. 2019 Prognostics and System Health Management Conference, 2019.

Fox, R. R., Lu, M. L., Occhipinti, E., & Jaeger, M., Understanding outcome metrics of the revised NIOSH lifting equation. Applied Ergonomics, 81, 2019.

Goetschalckx, M., & Ashayeri, J., Classification and design of order picking. Logistics World, 2(2), 99-106, 1989.

JMP Statistical Discovery, Two-sample t-test. https://www.jmp.com/en_ch/statistics-knowledge-portal/t-test/two-sample-t-test.html, accessed on June 1st, 2022.

Middlesworth, M., A step-by-step guide to using the NIOSH Lifting Equation for single tasks. ErgoPlus. https://ergo-plus.com/niosh-lifting-equation-single-task/. accessed on June 1st, 2022.

Mount CG., Suit up! The art and magic of MoCap suit. https://mountcg.com/how-do-mocap-suits-work/#:~:text=How%20do%20mocap%20suits%20work,were%20captured%20from%20the%20suit. accessed on June 1st, 2022.

Photonics Media, Computer vision system mimics human visualization. https://www.photonics.com/Articles/Computer_Vision_System_Mimics_Human_Visualization/a64264, accessed on May 3rd, 2022

Ramadhan, A. A., Ahmad, A., Alotaibi, S., & Kasap, S. (). Ergonomic weightlifting' competition by using JACK. Proceedings of the International Conference on Industrial Engineering and Operations Management, 2474-2479, 2017.

Rouwenhorst, B., Reuter, B., Stockrahm, V., Van Houtum, G. J., Mantel, R. J., & Zijm, W. H., Warehouse design and control: Framework and literature review. European Journal of Operational Research, 122(3), 515-533, 2000

Siemens, Jack A premier human simulation tool for populating your designs with virtual people and performing human factors and ergonomic analysis. 1992.

Simister, N., & James, D., Quantitative and qualitative methods - INTRAC. Intrac for Civil Society, 1-6, 2020

Tompkins, J.A., White, J.A., Bozer, Y.A., Tanchoco, J.M.A., Facilities Planning, (4th ed.), John Wiley & Sons, Hoboken, 2010

United States Department of Labor. Grocery warehousing eTool. https://www.osha.gov/etools/grocery-warehousing/packaging, accessed on May 20th, 2022

University of Cape Town, Introduction to ergonomics. https://vula.uct.ac.za/access/content/group/9c29ba04-b1ee-49b9-8c85-9a468b556ce2/DOH/Module%201%20(OH)/Ergonomics/Ergo-8.htm, accessed on June 5th, 2022.

Winkelhaus, S., Grosse, E.H., Logistics 4.0: A systematic review towards a new logistics system international Journal of Production Research, 58 (1), pp. 18-43, 2020.

Yan, X., Li, H., Wang, C., Seo, J., Zhang, H., & Wang, H., Development of ergonomic posture recognition technique based on 2D ordinary camera for construction hazard prevention through view-invariant features in 2D skeleton motion. Advanced Engineering Informatics, 34, 152–163. 10.1016/j.aei.2017.11.001, 2017

Zhang, C., Grandits, T., Härenstam, K. P., Hauge, J. B., & Meijer, S., A systematic literature review of simulation models for non-technical skill training in healthcare logistics. Advances in Simulation, 3(15). 2018.