**Proceedings of the ASME 2023**
**International Mechanical Engineering Congress and Exposition**
**IMECE2023**
**October 29-November 2, 2023, New Orleans, Louisiana**

**IMECE2023-113495**

# WAREHOUSE AND LOGISTICS ERGONOMICS OPTIMIZATION THROUGH REAL-TIME EVALUATION OF THE NIOSH INDEX

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## ABSTRACT

*Logistic activities can cause long-term musculoskeletal problems due to repetitive and incorrect movements, heavy loads, and uncomfortable positions. Ergonomic evaluations are conducted to prevent these risks, optimize workstations, and work processes. Some studies use automatic evaluation of ergonomic indices or frameworks for optimizing workstations and logistics reorganization. However, optimization is often disconnected from real-world case studies. This research work validates a new approach that integrates an automatic ergonomic evaluation and optimization in real-world scenarios, comparing this analysis with traditional manual evaluation method. Our approach is applied to a real logistics case study using a wearable motion capture system and an interactive interface that displays the Digital Twin of the analyzed task. Results show that our approach provides a more accurate evaluation of the ergonomics and an evident time-saving.*

Keywords: Ergonomics, Optimization, Warehouse Logistic

## NOMENCLATURE

| | |
|---|---|
| *NIOSH* | National Institute for Occupational Safety and Health |
| *MSD* | Musculoskeletal Disorder |
| *MOCAP* | Motion Capture System |
| *DHM* | Digital Human Modelling |
| *DT* | Digital Twin |
| *FIRWL* | Frequency Independent Recommended Weight Limit |
| *FILI* | Frequency Independent Lifting Index |
| *STRWL* | Single Task Recommended Weight Limit |
| *STILI* | Single Task Lifting Index |
| *CLI* | Composite Lifting Index |

## 1. INTRODUCTION

Despite the digitalization of Industry 4.0 and the increasing use of cyber-physical systems to support operators, logistics tasks are still largely carried out manually. This practice poses various challenges, including complex sorting procedures, low efficiency, high cost, and especially worker fatigue [1]. This type of activity, such as order picking, carries a high risk of developing musculoskeletal disorders (MSDs) and lower back injuries [2]. In particular, some factors have been identified that increase the risk of musculoskeletal problems or even directly cause occupational injuries among operators. Some of these risk factors include high physical workload, awkward positions, repetitive movements [3][4] and there is evidence that also the work environment plays a crucial role in the health of operators [5]. Hence, there is the need for a clear understanding of the tasks performed by the operators and the work environments in which they operate. In this regard, the European Union introduced a standard (Directive No. 90/269 [6]) to regulate the use of manual force in load handling work operations, as the associated risks are prevalent, and prevent musculoskeletal problems and occupational injuries. By adopting measures that consider human and ergonomic factors, positive results can also be achieved in terms of process quality and performance [7]. Currently, ergonomists base their assessments mainly on observational methods [8], resulting in time-consuming and subjective monitoring. There are evaluation techniques based on direct measurements of ergonomic exposures, such as digital goniometers [9] and Motion Capture (MOCAP) systems, to increase measurement accuracy and speed (e.g., inertial measurement units [10] or optical systems [11][12]). Both observational and direct measurement methods can be approached for proactive or reactive ergonomics programs. A proactive approach involves identifying and addressing potential ergonomic issues during the design and planning phases of the production system, usually using Digital Human Modeling (DHM) tools. For instance, several studies [13][14][15] use

 

DHM tools such as Siemens Jack, IPS IMMA, and DELMIA to simulate the interaction with a workstation and identify design mistakes before actual implementation. However, these solutions do not accurately replicate the actual work environment or the abilities and limitations of the operator, since they are typically based on empirical data obtained from observations [16]. The reactive approach, instead, involves ergonomic evaluation after the implementation of the workstation. For example, Battini et al. [17][18] propose two studies for ergonomic evaluation of different indicators using MOCAP tools in industrial and logistics tasks, without subsequent improvement of the analyzed workstations.

In this context, our research proposes a framework for both the proactive and reactive approach that exploits objective data from MOCAP solutions. In particular, the application has the following functionalities:

- Real-time evaluation of the NIOSH index [20] during the logistics tasks starting from the data provided by the MOCAP devices. This evaluation can be conducted on-site or remotely.
- Simulation of tasks in virtual reality (for proactive approach) or with a Digital Twin (DT) (for reactive approach) and an integrated MOCAP system for monitoring the performed tasks.
- Recording the data obtained from the MOCAP system and the DT the evaluation can be conducted after the task has been completed.
- Automatic report for optimizing the workstation based on the previous ergonomic evaluation.

Based on the features illustrated, this study presents an innovative tool for the two evaluation approaches illustrated above, exploiting objective data from the acquisitions made during the performance of the tasks to be evaluated. Furthermore, the solution itself offers valuable improvement suggestions for potential future workstation redesigns.

In the previous research work [21], we presented a semi-immersive VR system to simulate a logistics task with subsequent redesign of the workstation to obtain a better solution in terms of operator's working condition. After assessing the effectiveness of the proposed solution, the present research work applies the framework to a real case study, evaluating the reactive approach. The case study was conducted at JOiiNT LAB, which is a combined laboratory between IIT and Consorzio Intellimech, located in Kilometro Rosso (BG), dedicated to applied research and technological transfer. The work involves a logistics task that recreates the environment of a real industrial site [22].

In the following sections the description of the use case, the task performed, and the framework used for the evaluation is presented. Finally, testing performed on an actual use case confirmed the evaluation methodologies, and future developments of the framework have been proposed.

## 2. TASK DESCRIPTION

The case study refers to an industrial site, where production is organized in about 50 workstations each requiring 2 or more types of components supplied in standard boxes. The plant logistics are currently performed by workers who manage the boxes flow over the time shifts from the warehouse to the production lines (Figure 1). The process of recognizing the box, removing it from the shelf, and placing it on a trolley are typical manual procedures in the warehouse. Similarly in the production area, the operator is required to pick the box from the support and load it on the machine. Boxes are characterized by a set of sizes (Odette standard) and different weights, between 1Kg and 12kg.

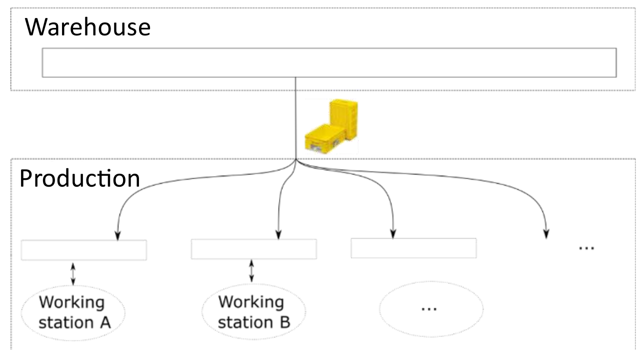


**FIGURE 1:** DESCRIPTION OF THE INDUSTRIAL SETUP

To this aim, we set-up a laboratory experiment to evaluate the ergonomics of the logistic operations. The task involves 10 different types of components, each stored in different boxes (2 large and 8 small) placed on a cart (Figure 2a). Table 1 provides a summary of the different box types and their respective weights.

| Name | Size | Weight [Kg] | Name | Size | Weight [Kg] |
|---|---|---|---|---|---|
| **A** | Big | 7.9 | **F** | Small | 6.0 |
| **B** | Big | 11.6 | **G** | Small | 5.0 |
| **C** | Small | 2.5 | **H** | Small | 5.4 |
| **D** | Small | 3.8 | **I** | Small | 5.7 |
| **E** | Small | 6.5 | **L** | Small | 6.1 |

**TABLE 1:** INFORMATION FOR EACH BOX TYPE

Moreover, two different types of shelves are considered, that are respectively representative of the warehouse (Figure 2B) and production line configurations (Figure 2 c). This approach allows a comparison among several shelf arrangements and assess their impact on a person's ergonomics during operation. Finally, two tests were carried out for each configuration, with the cart positioned at different distances from the shelf (Figure 3).

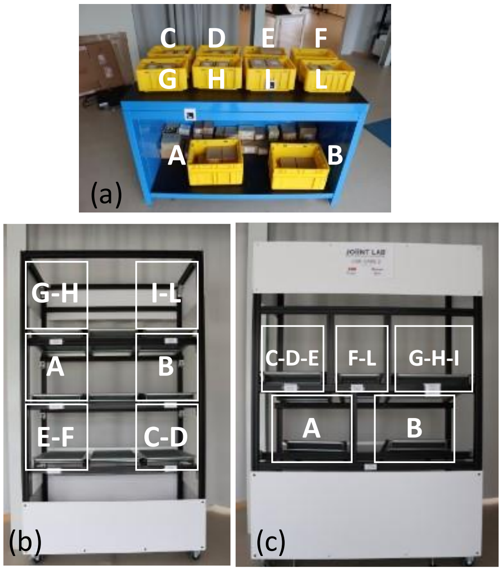


**FIGURE 2:** (a) CART CONFIGURATION AND SUPPLY SHELVES USED FOR THE TASKS: CONFIGURATION (b) IS USED IN THE WAREHOUSE (W) AND CONFIGURATIOIN (c) IN PRODUCTION LINE (P). THE LETTERS IN (b) AND (c) ARE RELATIVE TO THE LOCATION OF EACH BOX (a) INTO THE SHELVES

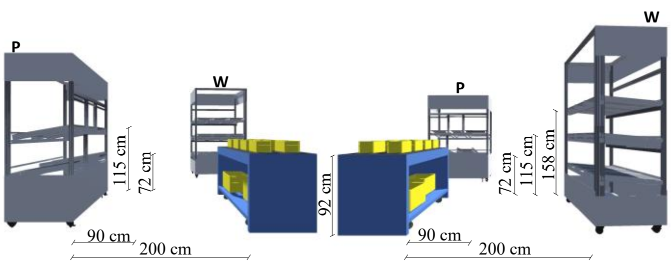


**FIGURE 3:** TASKS CONFIGURATION

## 3. ERGONOMICS FRAMEWORK

Figure 4 illustrates the framework used to evaluate the ergonomics of logistic operations. The core parts are the MOCAP system used to monitor the movements and the Evaluation Module developed to automatically assess the ergonomics: the two parts are respectively highlighted in yellow and green. Since the priority is to validate the Evaluation Module, the wearable IMU MOCAP Xsens [23] system has been chosen. The use of a wearable inertial system avoids the drawbacks of the optical marker-less one, such as partial self-occlusion and lack of accuracy in tracking movement [24][25]. To obtain the correct information from the wearable device, it is necessary to measure user's size according to Xsens protocol [23] and perform a calibration of the system. In this way, the information about the position, velocity, and rotation of each body joint is provided to the evaluation module.

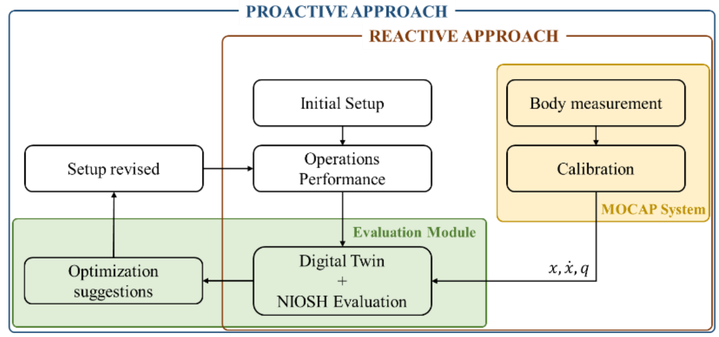


**FIGURE 4:** EVALUATION FRAMEWORK

In the evaluation module, the NIOSH index is chosen as a specific method for the assessment of the lifting task. As described in the ISO TR 12295 [19], the manual lifting activities can be classified in different types of lifting tasks: mono task, composite task, variable task, and sequential task. Since our case study consists of several distinct actions to move the boxes to/from shelves at different heights and/or distances, the composite task lifting analysis is performed.

Before starting the evaluation, the ergonomist must manually insert the information regarding the operator (gender and age) and about the task to be performed, such as the frequency of box movement, the weight of each box, and the quality of the hand grip on the object (handle, cut-out, or grip). The quality of the grip is classified by the NIOSH index as good, acceptable, or poor; it is important for the evaluation because the nature of the grip method can affect the maximum force that a worker can or should exert on the object and the vertical position of the hands during lifting.

Starting from this information and the data acquired through the MOCAP system, the analysis is conducted in three steps. Firstly, the frequency-independent Recommended Weight Limit (FIRWL) and frequency-independent lifting index (FILI) for each sub-task are computed. These parameters reflect the compressive force and muscle strength demands for a single repetition of the task. Then, the Single-Task Recommended Weight Limit (STRWL) and Single-Task Lifting Index (STILI) are calculated, which indicate the overall demands of the task if it was the only task being performed. Finally, the tasks are renumbered in order of decreasing physical stress determined from the STILI value, and the Composite Lifting Index (CLI) for the overall job is computed. The detailed method can be found in the Waters et al. [20] manual.

This evaluation can be performed in different way exploiting the DT developed (Figure 5):

- Offline: all operator's movements can be recorded over time and evaluated at a later time through the developed software.
- Real-time: the ergonomist can perform an on-site or remote evaluation through the developed DT, which allows real-time visualization of the operator's activity.

 

The DT is generated by creating the 3D virtual elements in the scene, including the 3D models of the shelves, using Unity software. Through the user interface, the ergonomist is able to view the operator's movement and performs the ergonomics evaluation. Additionally, a report with recommendations for improving the workstation is generated. This tool provides important information for improving the shelves (e.g., of dimension, position, boxes allocation etc.) and allowing the operator to perform the task in a more ergonomic way.

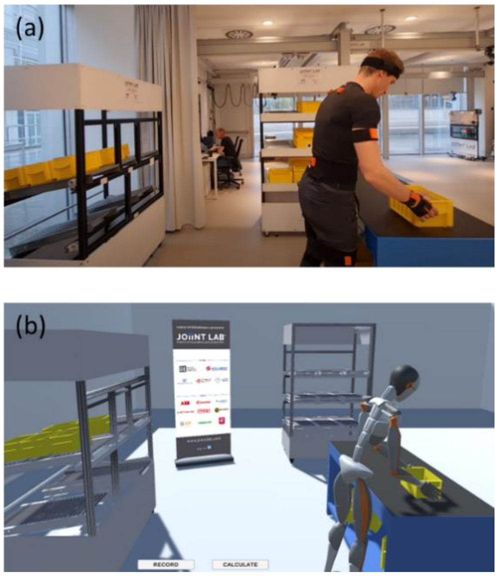


**FIGURE 5:** THE OPERATOR PERFORMS THE TASK (a) AND THE ERGONOMIST CAN ASSESS THE MANUAL OPERATION BY THE DIGITAL TWIN (b)

## 4. RESULTS AND DISCUSSION

Four tests have been conducted by each of the five volunteers. In particular, two tests are performed for each of the two shelves considered. As shown in Figure 3, the following scenarios are obtained:

- Warehouse's shelves with the cart positioned at a distance of 90cm (WN) and 200cm (WF), respectively.
- Production line's shelves with the cart near (PN) and far away (PF) using the same distances as in the previous point.

The frequency of picking and placing boxes is estimated to be about the same as the one carried out in the real production plant. The current study aims to assess the validity of the reactive approach analysis framework outlined in the introduction. Following an examination of optimization performance in a previous study, the current focus shifts on analyzing the results and evaluating the time required for conducting the analysis. Subsequently, the values obtained using the framework are compared to those of a manual analysis performed using the tables proposed by Waters et al. in the NIOSH manual [20]. This analysis requires unique measurements for each shelf by including their dimensions, box weights and estimated values, such as operator-shelf distance and trunk rotation at the moment of load placement.

The assessment is conducted for two different task duration ranges, moderate (from 1 to 2 hours) and long (from 2 to 8 hours). The results of the automatic approach are computed as the average values of the test results of each volunteer (i.e., with the cart near and far from the shelf). Table 2 presents a comparison between manual and automatic values for each shelf by considering both task durations.

In general, the composite lifting index computed with the automatic approach is higher than the manual one. In particular, the automatic approach highlights a worsening of the exposure level from "Low" to "Moderate" ($\Delta_{a-m}$ = 0.3) for 3 shelves scenario, 1-2h time range. The $\Delta_{a-m}$ score increases ($\Delta_{a-m}$ = 0.6) by considering 2-8h time range in the "High" exposure level for the 3 Shelves scenario. The differences highlighted by the scores confirms that the introduction of MOCAP solution may have an important impact of the final evaluation of physical ergonomics score as the NIOSH index.

| CLI | | | | |
|---|---|---|---|---|
| Shelves Scenario | Task Duration | Manual | Automatic | $\Delta_{a-m}$ |
| Production line | 1-2h | 1.1 | 1.2 | 0.1 |
| | 2-8h | 1.6 | 1.7 | 0.1 |
| Warehouse | 1-2h | 1.4 | 1.7 | 0.3 |
| | 2-8h | 2.1 | 2.7 | 0.6 |

| CLI | Exposure Level |
|---|---|
| CLI ≤ 0.85 | Acceptable |
| 0.86 < CLI ≤ 1 | Borderline |
| 1.0 < CLI ≤ 1.5 | Low |
| 1.5 < CLI ≤ 2.0 | Moderate |
| 2.0 < CLI ≤ 3.0 | High |
| CLI > 3.0 | Very High |

**TABLE 2:** CLI OBTAINED FROM THE MANUAL AND THE AUTOMATIC EVALUATION AS WELL AS THE CLI RANGES CORRELATED TO EXPOSURE LEVELS

Figure 6 depicts the graphs relative to the CLI obtained by each volunteer in the range of 1-2h. In contrast to the previous considerations, the analysis of these graphs allows us to assess how the position of the cart affects the ergonomics of the task. In particular, results of PF and PN scenarios show a slight deviation from the theoretical value, while the WN test results are consistently higher than the WF values. The wider disparities between the WF and WN scenarios are mainly correlated to the distance between the operator and the shelf: when the cart is near the shelf, participants maintain a static position and, therefore, the parameters related to arms extension and trunk rotation are more realistic than the constant values defined in the theoretical approach.

Another result concerns the comparison between the times required for the analysis in both manual and automatic evaluation (Figure 7). Taking into account the time required for testing, using the framework saves at least 30% compared to the manual approach. It is important to note that this rough calculation is based on tasks involving two or three components, similar to those analyzed in this research. In scenarios with more tasks, the time saved could be even greater. As discussed in section 3, a wearable system was chosen as a more accurate MOCAP solution than a marker-less optical system. In this way, the data obtained from the assessment can be exploited to validate the system.

According to studies presented in the literature, such as [26], the wearable system employed is comfortable for industrial work and provides the flexibility to perform any task. However, it is important to note that the tests were conducted in a controlled environment for less than an hour. It is plausible to assume that these systems may cause discomfort to operators when used for prolonged periods or in harsh environmental conditions, such as extremely hot warehouses or during physically demanding activities. In this regard, future developments will consider the use of optical marker-less systems, such as RGB-D cameras. The use of these systems will further reduce time related to the calibration (estimated time savings of about 70%). In a warehouse, optical systems may also be more affordable and easier to use. In addition, these systems can compete in terms of cost, as they are generally much less expensive than wearable devices, with price differences of at least two orders of magnitude.

However, future work will consider a comparative evaluation between marker-less and wearable systems in order to assess whether and how the accuracy of the evaluation is worsened.

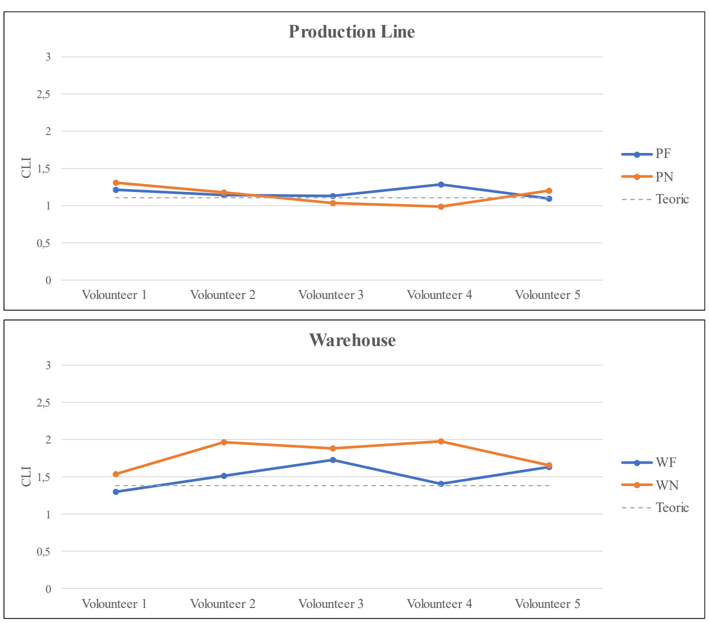


**FIGURE 6:** CLI OBTAINED FOR THE SUPPLY SHELVES IN MODERATE DURATION RANGE (1-2h) COMPARED WITH THE THEORETICAL VALUE

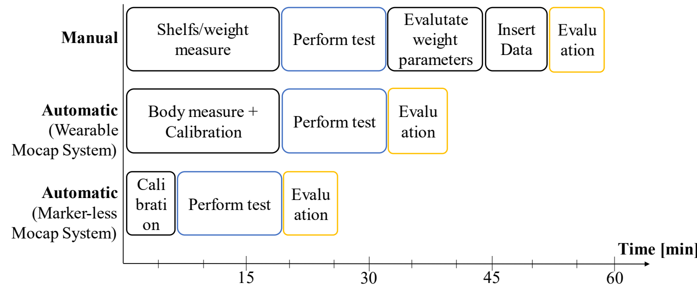


**FIGURE 7:** GRAPHICAL REPRESENTATION OF THE EVALUATION APPROXIMATE TIME FOR BOTH MANUAL AND AUTOMATIC PROCEDURES

## 5. CONCLUSIONS

Logistic operations can pose a significant threat to an operator's health due to the physically demanding nature of the work, including the repetition of incorrect movements, the handling of heavy loads, and the need to maintain uncomfortable postures while moving objects. To avoid long-term MSDs, it is crucial to observe operator's ergonomic practices at various stages of work and rectify any issues. This involves identifying and correcting inappropriate movements, limiting lifting loads to a reasonable level, and avoiding inappropriate static postures. Also, others crucial factors are the design of the workstation and the sequence of tasks.

In such context, the aim of this work has been to validate a framework for the reactive ergonomic assessment in real use case. By using an inertial MOCAP system and a DT, it is possible to automatically, real-time, and remotely evaluate physical ergonomics through the NIOSH index.

From the comparison between experimental data obtained from the tests carried out and theoretical data obtained from manual calculations, it can be concluded that the developed framework allows for a correct evaluation with a significant timesaving. The difference between the CLI evaluate from the experimental and theoretical data is mainly due to two factors. Firstly, automatic calculation allows evaluating the real operator’s movements, leading to a more precise assessment. Secondly, in order to save time, in manual evaluation the parameters used in the NIOSH equations are estimated using the tables from the manual. These parameters are evaluated more accurately using the dedicated formulas in the automatic procedure.

The outcomes of the ergonomic study recommend some modifications for scenarios involving three or two shelves and shifts of no more than two hours in order to improve the quality of the operator's work. In any case, automating the process and eliminating the operator from handling loads may be the best option for operations that require the processing of large quantities of products. In this regard, the JOiiNT LAB team is developing a robotic system to assist humans in logistic operations.

Future developments will include the evaluation of different MOCAP tools, such as optical systems, in order to further reduce evaluation times and facilitate any on-site monitoring in the company.


## ACKNOWLEDGEMENT

This activity was developed at the JOiiNT LAB in collaboration with the University of Bergamo. We would like to thank Intellimech, Confindustria Bergamo, and Kilometro Rosso that supported the initiative and the professionals that contributed to the definition of the use case. We want to express our gratitude to all the volunteers who participated in the experiments conducted.


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