

Assessing operators' workload in collaborative logistics 5.0: a case application with AMR

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Abstract: In recent decades, technologies such as Automated Guided Vehicles (AGV) and Autonomous Mobile Robots (AMR) have emerged as promising solutions to assist or replace humans in physically demanding and risky tasks in logistics, improving worker safety and wellbeing. However, the integration of these advanced technologies with human activities poses challenges related to system design and task management, particularly in the context of Industry 5.0, which promotes human-centricity, advocating for sustainable systems that consider human needs and characteristics in smart manufacturing and logistics environments. This paper contributes to the Logistics 5.0 research stream by presenting an experimental study on the use of AMRs to assist operators in material handling tasks. The study, conducted in the SLIM laboratory at the University of Bergamo, evaluates operators' workloads during material handling activities with and without AMR assistance. The NASA-TLX questionnaire is employed to measure the perceived workload in the collaborative tasks. The results offer valuable insights into designing effective, human-centred logistics systems, enhancing operator efficiency and wellbeing.

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Keywords: Logistics 5.0, AMR, Human factors, Workload, Human-robot collaboration.

1. INTRODUCTION

Material handling has been a key topic throughout the history of industrial logistics: ergonomics, operability, safety and flexibility have been always under the focus of researchers and practitioners to increase its efficiency. In the last decades, several technologies have been introduced to help operators manage logistics activities in the factories, paving the way to the concept of Logistics 4.0 and Logistics Operator 4.0 (Cimini et al., 2020; Winkelhaus & Grosse, 2019). Some technologies proved to be significantly useful to fully replace or assist humans in the execution of risky and physically demanding tasks, with the potential of substantially improving the operators' safety and wellbeing. Indeed, in manufacturing environments, and specifically in material handling tasks, physical demand and fatigue can be critical, resulting in negative outcomes, such as discomfort, lower work quality, and increased number of accidents or errors (Sedighi Maman et al., 2017). For this reason, currently, several assisting devices are widespread in industry to support manual material handling aiming at reducing the physical workload (Glock et al., 2021). Among the most promising technologies, that have been increasingly adopted by industrial companies, there are Automated Guided Vehicles (AGV) and Autonomous Mobile Robots (AMR), whose deployment is growing up thanks to their robustness and reliability (Löcklin et al., 2022). These systems are extremely significant to increase material handling efficiency (Faccio & Granata, 2024), but their integration with human work is crucial.

Indeed, the adoption of advanced technologies in logistics activities requires an increasing integration and interaction with humans, posing new challenges for the logistics environment, both in the design of user-friendly systems and for the management of tasks between operators and technologies.

The new imperative of focusing on human centricity, promoted by the Industry 5.0 paradigm (European Commission. Directorate General for Research and Innovation, 2021) aims to raise awareness about a more accurate design of smart manufacturing and logistics systems, considering the humans' characteristics and needs. In this context, Logistics 5.0 aims to provide sustainable systems taking care of human roles and their interaction with all the other elements, including machines, equipment and other humans (Trstenjak et al., 2022).

This paper aims to support the Logistics 5.0 research stream by presenting an application of an AMR used to support operators in material handling tasks. The paper describes a test developed in the SLIM laboratory of the University of Bergamo, in which material handling of products and components of an assembly line has been performed by a sample of operators with and without the help of the AMR. The aim of the experiments is to assess the workload of the operators in performing the material handling assisted by the robot. NASA-TLX questionnaire is used for the assessment. The novelty of the current study consists in the investigation of the factors impacting the execution of fruitful collaborative tasks between humans and robots in material handling, which is a topic that has been scarcely researched with an empirical approach. The test finally provides interesting insight for designing an effective and human-centred smart logistics environment.

The paper is structured as follows. Section 2 presents the literature background about Logistics 5.0, in particular focusing on AMR, and human factors analysis. Section 3 explains the methodology of the study. Section 4 describes in detail the test performed and its results. Section 5 discusses some evidence from the laboratory experiments, while Section 6 points out limitations and further developments.

2. BACKGROUND

2.1 Logistics 5.0 and Autonomous Mobile Robots

The evolution from Logistics 4.0 to Logistics 5.0 has the potential to mark a significant shift in modern supply chain management. If Logistics 4.0 focuses on smart technologies, automation, and data-driven processes, Logistics 5.0 aims to integrate advanced technologies while emphasizing human-centric approaches and sustainability (Trstenjak et al., 2022). Among the most challenging aspects of the transition towards Logistics 5.0 (and Industry 5.0 at large), the design and management of human-machine and human-robot cooperation is one of the crucial ones, requiring efforts in accommodating a trade-off between automation and human integration (Jafari et al., 2022).

From a technological perspective, Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs) stand as key components of the Logistics 5.0 adoption in warehouse and logistics operations. In particular, overcoming some of the AGV limitations, AMRs are capable of moving autonomously within a dynamic environment, thanks to sensor technology that allows them to perceive their surroundings and adapt to changes, also exploiting artificial intelligence that controls the movement (Fragapane et al., 2021). Thanks to sophisticated navigation systems, AMRs can perform tasks such as material handling, inventory management, and goods transportation autonomously, depending on the technology they are equipped with and the environment in which they must operate. Some AMRs have robotic arms to move objects from shelves to the loading surface of the trolley and vice versa (Lackner et al., 2024).

If the AMR has the advantages of streamlining operations and enhancing productivity based on their flexibility, Niermann et al. (2023) discuss that they are still far from human adaptability. Therefore, the collaboration between human and robots is the way to exploit at best their strengths. The interaction of humans with the robot varies according to technology and environment, and the available interfaces range from screens, to buttons, to voice commands, according to the data that robots have to output or receive as input.

2.2 Human-robot collaboration and workload assessment

The interaction between robots and operators is crucial in order to ensure workers' well-being, maintain safety, and achieve operational balance between humans and machines. The main characteristic of human-machine collaboration is ergonomics, which aims to achieve an optimal adaptation of the human-machine-work environment system to the psycho-physiological capacities and limitations of humans. The physiological aspects that are dealt with during the ergonomics analysis include postures, material handling, repetitiveness of movements, and workstation layout, as well as reactivity and time pressure. Other relevant human factors to be evaluated cover the psychic and cognitive sphere, such as memory, decision-making, complexity of reasoning, experience, or stress (Cimini et al., 2021).

The introduction of automation and AMRs can influence the cognitive and physical workload of human operators.

Evaluating workload is essential to identify areas of task overload, inefficiency, or underutilization of human capabilities. One of the main commonly adopted methods to evaluate the physical and mental effort an operator has to make while performing tasks, also in collaboration with a technology, is the 'NASA - Task Load Index'. The NASA Task Load Index (NASA-TLX) is a widely used, validated tool for assessing perceived workload (Braarud, 2021). It evaluates six dimensions of workload:

- Mental Demand, i.e., the cognitive effort required to complete a task;
- Physical Demand, i.e., the level of physical effort exerted;
- Temporal Demand, i.e., the pressure caused by task time constraints.
- Performance, i.e., the perceived success in task completion.
- Effort, i.e., the amount of work required to achieve the desired performance.
- Frustration, i.e., the emotional state, including stress or dissatisfaction, experienced during task execution.

This tool provides a structured and quantifiable approach to workload evaluation, enabling researchers and practitioners to optimize task distribution, improve worker satisfaction, and minimize stress levels in logistics environments where humans interact with AMRs and automated systems. For this reason, the NASA-TLX approach is used in this study to evaluate the collaboration of humans with an AMR in material handling tasks.

3. METHOD

To reach the objective of this study, a laboratory test has been chosen as the most suitable method to provide preliminary insights about the potential benefits and challenges in performing collaborative material handling between humans and AMR in a smart logistics environment. Although in the past, several scholars have shown considerable skepticism in the use of laboratory tests in the field of logistics and supply chain, in the work of Deck & Smith (2013) these criticisms are overcome and the valuable contribution laboratory tests can bring to logistics research is highlighted. Moreover, recently, several studies have analyzed the issues of human-robot interaction in production and logistics environments in laboratory settings (Zhang et al., 2024). In this regard, Hoffman & Zhao (2021) propose a 4-step methodology to conduct empirical research on human-robot interaction, namely i) planning, ii) execution, iii) analysis and iv) reporting. Following this approach, our experiment was defined as follows.

Planning. The experiment was planned to take place in the Smart Living in Manufacturing (SLIM) laboratory of the University of Bergamo. In the lab, an SMC SIF-400 automatic assembly line is present, which is connected to an AMR (Figure 1). The robot can withstand loads of up to 60kg and the maximum speed it can reach is 1.8m/s. The kinematic system consists of four corner support wheels, to maintain stability, and two larger central drive wheels, which are located

in the innermost part of the robot. These two wheels are equipped with a gyroscope and accelerometer to adjust the rotation and speed of the robot. The operating system developed by SMC to manage the device is SetNetGo and allows the ARAM (Advanced Robotics Automation Management) software installed in the automaton to run. This software performs all design-level robotic functions using the data the sensors detect: navigation, localization, protection from crashes and obstacles, and path planning. Currently, the robot is connected to the assembly line, which has a “call” function in the human-machine interface of each station to ask the robot to approach the specific line station.



Figure 1. SLIM Laboratory – experiment's setting.

During the planning phase, the process to be carried out, in which the differences between manual handling of loads and handling using a robot could be observed, was identified. The choice had to ensure a high level of collaboration between operators and robot, and for this reason a task of disassembly, components handling and reloading on the production line was defined. It consists in i) taking finished products from the last station on the assembly line, ii) disassembling the components and iii) reloading the components into the previous stations. The choice of the number of finished products was made by experimenting with a number of samples that would allow for a repetitive series of operations for the movements and, at the same time, would not be too burdensome for the timing of the experiments. The chosen quantity, therefore, is 6 finished products at a time. A detailed description of the procedure is presented in Section 4.1.

Execution. The experiment involved a sample of 16 people, students or researchers from the University of Bergamo, whose ages vary between 20 and 40 years, 5 males and 9 females. Each participant was required to perform the designed procedure two times, once performing manual material handling and once with the AMR collaboration. Before the execution of the procedures, each participant was instructed in the operation of the line and the robot by means of an instruction manual. The manual consisted of an explanation of the two procedures, not strictly regulated, but deliberately left not detailed in order to understand how each person would behave. Each experiment was observed by two researchers, in order to record execution times, individual behaviors and problems occurred during the test. After each test, the

participants were asked to fill a questionnaire composed of 25 questions:

- 20 close-ended questions (answers on a scale from 1 to 10), classified according to the NASA-TLX assessment (Hart, 2006) to evaluate physical demand, cognitive demand, temporal demand, performance, effort and frustration level. For each category, 3 or 4 detailed questions have been asked in order to analyze the multifaceted perspectives about the human-robot interaction.
- 5 open questions about strengths and weaknesses of the process, challenges and preferences in using the AMR.

Analysis. The data were collected by using a Google Form and were analyzed with Microsoft Excel. The most common descriptive statistics have been calculated to derive preliminary insights. Further, the correlation matrix has been used to highlight the relationships between participants' perspectives about the collaboration with AMR and their self-assessed workload. The data analysis has been performed by two members of the research team and the results have been discussed by all the team members to provide a multi-perspective interpretation, combining the members' expertise in logistics, human factors and digitalization. All the results are reported in the Section 4.

Reporting. The reporting phase consisted in the development of a series of graphical representations, plots and tables containing the most relevant elaboration of the results of the tests. Some of them are reported in the next sections.

4. RESULTS

4.1 Experiment description

According to the experiments' planning, the procedure executed by the participants involved the disassembly and handling of manufacturing components among different stations of the production line.



Figure 2. Products used in the experiment.

In particular, Figure 2 depicts the finished product that is stored on the line, in the warehouse at Station 4, and its main components: the pallet equipped with an RFID sensor (which is assembled in Station 1), the plastic container (assembled in Station 1) with the small colored balls (assembled in Station 2) and the cap (assembled in Station 3). The steps of the

procedures executed by the participants are described in Table 1.

Table 1. Experiment's procedures

Without AMR	With AMR
1. Pick 6 products from St. 4	1. Call the robot to St. 4
2. Handle the products to the disassembly workbench	2. Pick 6 products and load them on the robot
3. Disassemble the products	3. Call the robot at the disassembly workbench
4. Handle the components to St. 1, 2 or 3.	4. Pick the products from the robot and disassemble them
5. Reload the components in their feeders in St 1, 2 and 3	5. Load the components on the robot
	6. Call the robot to St.1, 2 and 3 to handle components.
	7. Reload the components in their feeders in St 1, 2 and 3

The main difference in the procedures consists in the replacement of manual material handling with the robot handling, whose activity is triggered by the human request. This collaboration mode was dependent on the current programming of the AMR and entailed doubling the execution time. Nevertheless, due to the intrinsic limitations of the AMR configuration, the time was not considered as a relevant feature to make a comparison, since the objective of the test was primarily to assess the operators' workload in collaborative work.

4.2 Questionnaire's results

The results are presented according to the different categories of the NASA-TLX assessment and the scoring is from 1 (low) to 10 (high).

The physical demand was assessed asking the participants to evaluate: the number of repetitive movements, the occurrence of uncomfortable positions in performing the procedure (e.g., twisting, bending), and the efficiency of the layout. The AMR procedure was rated better concerning repetitive movement (average (avg.) score = 4.5 vs 5.44) but rated about 1.5 points worse than manual handling with regard to discomfort and layout. Indeed, the use of the AMR reduces repetitive movements due to the possibility of placing all the products to handle on the loading table. The height of the loading table, however, plays against the robot, as it is necessary to bend the torso to move the parts; equally, the layout is more inappropriate as the volumetric dimensions of the trolley are limiting for the work area.

The cognitive demand was linked to the complexity of the procedure to manage the transportation with or without the robots, including the number of steps to remember to correctly perform the task and the need for supplementary reading of the instructions' manual. Generally, the two procedures did not have a marked difference in the scores obtained, showing a low level of cognitive demands. The participants evaluated both

the procedures as sufficiently clear and exhaustive to perform the tasks, even if the AMR procedure resulted slightly more complex (avg. score = 4.38 vs 3.5).

Concerning the temporal demand, the participants were asked if the activity could be performed more efficiently (with less time) and if the task duration was primarily affected by repetitive movements, instructions clearness or experience level. Most of the participants highlighted the high potential of speeding up the tasks and performing the procedure in less time, especially with the AMR (avg. score = 8.31 vs 7.25) while no relevant differences in task duration were assessed concerning the mentioned factors. Also asking the participants general feedback about their performance, and in particular, about their satisfaction in performing the procedures, we observed that the satisfaction level is similar with or without the AMR (avg. score= 7.19 vs 7.13).

In the assessment of the effort, the physical effort perceived by the participants in performing all the procedures was almost the same with or without the AMR (avg. score= 2.44 vs 2.25). The overall physical effort is rather low due to the nature of the products and organization; the products are light and small in size and in order to be able to perform all the tests in a short time, it was decided to move only six samples at a time. Nevertheless, in terms of difficulties in managing the handling, the AMR was rated better (avg. score = 2.63 vs 4.00). Generally, the participants picked up two finished products at a time, performing a total of three sets of repetitive movements between the warehouse and the disassembly area to carry out the movement during the manual handling procedure. This solution allows a higher amount of physical energy to be used but provides less mental effort to manage coordination because it allows one product to be moved with one hand. A small part of the volunteers (4/16) decided to carry out the movements by picking up three finished products at a time, in order to make only two trips; also in this case there is a trade-off between the physical effort, as one trip is saved, and the mental effort, because the coordination must be greater as the nature of the goods does not allow to place two products on one hand, but it is necessary to use the forearm. The AMR overcame this problem allowing the simultaneous handling of the six products, thus reducing the general effort.

Finally, the frustration level was assessed by asking the participants to rate if they encountered stress, high level of coordination required or insecurities and doubts in carrying out activities. The only significant difference between the two procedures consisted in a lower level of coordination required by the AMR collaboration compared with the manual handling (avg. score= 3.5 vs 5.63). This is explained by the fact that the AMR reduces the worries that arise during the displacement of the products for the handling due to loading surface, which allows the user to place the products on a safe and stable surface during handling and reloading. In general, no increase in participants' stress or insecurity due to working with the robot was observed.

4.3 Results' analysis

Further analyses have been performed on the questionnaire results, in order to get useful insights.

First, we classified the participants according to their age in three classes (20-25 – 5 participants, 26-30 – 7 participants, 31-40 – 4 participants) and we looked for significant differences in the questionnaire's results according to this classification. The classes were defined in order to balance three groups considering that the participants' age range was limited to 20 years and only few participants were over 30. It was observed that in the test performed with the AMR, the people aged 31-40 perceived an increased difficulty in understanding the procedures. They also suffered a lot the discomfort in moving the products on the robot as well as the inadequate layout space in the collaboration with the AMR (Figure 3). Also, the cognitive demand and the stress levels were perceived higher in the AMR-assisted procedure.



Figure 3. Age effect.

As a second analysis, we looked for correlations between the answers to the questionnaires. We built a correlation matrix for the answers of each test (with and without AMR) and we calculated the Pearson's coefficient to measure the linear correlation between two variables (two questions of the NASA-TLX assessment), quantifying the degree to which a relationship between these variables can be described using a straight line. The Pearson's coefficient (r) is calculated as the covariance of the two variables divided by the product of their standard deviations. From the correlation matrix of the AMR-assisted procedure, two links emerged:

1. A strong positive correlation ($r=0,82$) between the number of instructions to be remembered and the potential of improving the task efficiency with the experience. This result suggests that, since one of the main barriers to low completion time (time efficiency) was the need to remember the exact procedure to communicate with the robot, i.e. calling it to the stations for performing the handling, the participants consider that this aspect could be overcome with the experience.
2. A moderate positive correlation ($r=0,72$) between the physical effort and the mental effort perceived. This suggests that actually, the potential of reducing the physical demand to the operators, using the AMR could benefit accordingly also the cognitive workload. This is probably due to a more standardized way of conducting the activities.

In the results of the manual handling procedure, we observed these correlations:

1. A strong positive correlation ($r=0,86$) between the number of instructions to be remembered and the difficulties in managing the handling of the products. This result suggests that the main problem with manual handling consisted in the need to engage in a decision-making process for defining the most efficient way of transporting the products.
2. A positive correlation ($r=0,89$) between the complexity in understanding the procedure and the number of situations in which uncertainty about how to proceed was perceived by the participants. This correlation is in line with the previous one.

5. DISCUSSION

Together with the quantitative analysis based on the questionnaire results, interesting insights were derived from the qualitative evaluation of the test provided by the participants according to five questions: i) In your opinion, are there any critical aspects in the process? ii) Which aspects of the activity would you improve? iii) Did you encounter any difficulties while carrying out the activity? iv) Which test did you prefer to carry out and why? v) In your opinion, in what situation would the robot be preferable?

The most critical aspect cited by the participants is the need to share the space with the AMR. It is considered to slow the tasks due to the low velocity, which is even lower when dealing with narrow passageways. Some participants suggest optimizing the stop positions of the robot next to the stations, in order to minimize the risk of obstruction. As shown also by the correlation matrix, this study supports the idea that experience can play a key role in making the interaction between humans and robots more efficient by increasing mutual understanding. In fact, if the robot merely perceives the presence of man in real time thanks to the embedded sensors, humans have the more advanced ability to predict the robot's behavior, having observed it a good number of times and in multiple situations. This, in the long run, through a learning principle, would allow the operator to minimize the chances of getting in the way of the robot in its path, but on the contrary to position himself in space in order to streamline collaborative task execution.

Other problems in using the AMR concerned the ergonomics, which forced operators to bend their backs to load and unload products. This suggests that when dealing with human-robot collaboration, the design of the robot should take into account the physical interface, also considering a trade-off between the needs of different categories of operators (e.g. female-male, young-elder).

When asked to express a preference between the two procedures, 8 participants expressed a preference for the AMR, 6 for the manual test and 2 were undecided. This suggests that there is as yet no one solution that can be called the absolute best. However, although there are several limitations due to the contingent application, technology and available space for the test, this preliminary study shows that

the solution of assisting the operators with robots can be a winning strategy, as the work is perceived as more interactive and fun. One of the risks, mentioned by only one participant, was the possibility of seeing their work ‘debased’ by the use of the robot, whereas performing a manual task made the participant more fulfilled. However, the same participant acknowledges that in cases where the effort required is greater (e.g. handling many products and heavy), the AMR would become far preferable.

6. CONCLUSIONS

This study offers an empirical perspective on the use of AMR in collaborative material handling. In particular, the tests performed in the UNIBG laboratory assessed the perception of operators in carrying out a simple procedure including material handling with the help of the AMR. The workload assessment through NASA-TLX, revealed that the AMR could require increased attention to the layout and the sequence of steps to be carried out, but the experience is expected to mitigate these problems in the long term, finally providing positive predictions for a fruitful use of collaboration in Logistics 5.0 environment. The practical implications of the study concern the identification of the most relevant aspects to consider when designing human-robot collaboration for material handling, specifically the training needs, the layout issues and the experience level. The main limitations of this study lie in the low number of participants who took part to the test and the technological limitations of the devices involved, for which an ad-hoc procedure was assumed, probably not optimized for industrial use. However, the test was aimed at gathering preliminary impressions from a group of non-expert users regarding the execution of robot-assisted collaborative work. For this reason, although the test presented several limitations in terms of task duration efficiency, it provided interesting insights for future research. In particular, the learning effect could be studied through multiple executions of procedures. Different layout configurations could also be tested in order to overcome the problems raised in this study and provide a substantial boost to the adoption of AMRs in industrial logistics. Also, economic aspects coming from the advantage in human-robot collaboration could be researched, in order to provide evident benefits to the industrial companies.

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REFERENCES

- Braarud, P. Ø. (2021). Investigating the validity of subjective workload rating (NASA TLX) and subjective situation awareness rating (SART) for cognitively complex human-machine work. *International Journal of Industrial Ergonomics*, 86, 103233.
- Cimini, C., Lagorio, A., Pirola, F., & Pinto, R. (2021). How human factors affect operators’ task evolution in Logistics 4.0. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 31(1), 98–117.
- Cimini, C., Lagorio, A., Romero, D., Cavalieri, S., & Stahre, J. (2020). Smart Logistics and The Logistics Operator 4.0. *IFAC-PapersOnLine*, 53(2), 10615–10620.
- Deck, C., & Smith, V. (2013). Using Laboratory Experiments in Logistics and Supply Chain Research. *Journal of Business Logistics*, 34(1), 6–14.
- European Commission. Directorate General for Research and Innovation. (2021). *Industry 5.0: Towards a sustainable, human centric and resilient European industry*. Publications Office. <https://data.europa.eu/doi/10.2777/308407>
- Faccio, M., & Granata, I. (2024). Proper Integration of AGV/AMR Systems: A Design Model for the Loading/Unloading Points. In M. Freitag, A. Kinra, H. Kotzab, & N. Megow (Eds.), *Dynamics in Logistics* (pp. 282–292). Springer Nature Switzerland.
- Fragapane, G., De Koster, R., Sgarbossa, F., & Strandhagen, J. O. (2021). Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda. *European Journal of Operational Research*, 294(2), 405–426.
- Glock, C. H., Grosse, E. H., Neumann, W. P., & Feldman, A. (2021). Assistive devices for manual materials handling in warehouses: A systematic literature review. *International Journal of Production Research*, 59(11), 3446–3469.
- Hart, S. G. (2006). Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 50(9), 904–908.
- Hoffman, G., & Zhao, X. (2021). A Primer for Conducting Experiments in Human-Robot Interaction. *ACM Transactions on Human-Robot Interaction*, 10(1), 1–31.
- Jafari, N., Azarian, M., & Yu, H. (2022). Moving from Industry 4.0 to Industry 5.0: What Are the Implications for Smart Logistics? *Logistics*, 6(2), Article 2.
- Lackner, T., Hermann, J., Kuhn, C., & Palm, D. (2024). Review of autonomous mobile robots in intralogistics: State-of-the-art, limitations and research gaps. *Procedia CIRP*, 130, 930–935.
- Löcklin, A., Dettinger, F., Artelt, M., Jazdi, N., & Weyrich, M. (2022). Trajectory Prediction of Workers to Improve AGV and AMR Operation based on the Manufacturing Schedule. *Procedia CIRP*, 107, 283–288.
- Niermann, D., Petzoldt, C., & Freitag, M. (2023). Intuitive and Flexible Process Control for Autonomous Mobile Robots: A Case Study in a Large Logistics Enterprise. *Procedia CIRP*, 120, 153–158.
- Sedighi Maman, Z., Alamdar Yazdi, M. A., Cavuoto, L. A., & Megahed, F. M. (2017). A data-driven approach to modeling physical fatigue in the workplace using wearable sensors. *Applied Ergonomics*, 65, 515–529.
- Trstenjak, M., Opetuk, T., Đukić, G., & Cajner, H. (2022). Logistics 5.0 Implementation Model Based on Decision Support Systems. *Sustainability*, 14(11), 6514.
- Winkelhaus, S., & Grosse, E. H. (2019). Logistics 4.0: A systematic review towards a new logistics system. *International Journal of Production Research*, 0(0), 1–26.
- Zhang, M., Marolt, J., Bencak, P., Grosse, E. H., & Lerher, T. (2024). Ergonomic Evaluation of Human-Robot Collaborative Order Picking: A Combined Laboratory and Simulation Study. *IFAC-PapersOnLine*, 58(19), 1042–1047.