The Effects of the Application of Artificial Intelligence in Material Handling – A Systematic Literature Review

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Automation;  
Smart logistics;  
Rapid Literature Review

Abstract: In this article, the authors are examining the application opportunities of artificial intelligence in the material handling industry. A structured literature review with the help of a mapping study is being conducted in the study to show how the material handling industry can benefit from the implementation of artificial intelligence. The paper will demonstrate how artificial intelligence can assist in transforming material handling processes from manual to autonomous operations impacting greatly the overall efficiency and effectiveness of different industries. The paper is using the Scopus and Science Direct databases to show what are the advantages and the constraints based on the selected articles.

1. INTRODUCTION

With the continuous development of digitalization, advanced technological improvements, such as artificial intelligence and other Industry 4.0 tools, play a more and more important role in logistical processes, making them more effective and efficient (Bartucz et al., 2021). Artificial intelligence (AI) can be interpreted as a display of intelligence by machines specifically via computer systems. AI is able to perform tasks such as visual perception, speech recognition, and decision making. As an essential part of industry 4.0, AI is having a much bigger role as it has brought about a change in the pattern of the industrial operation driven by this new form of interaction between man and machine. AI techniques such as machine learning and deep learning have very significant and positive impacts on a company and induce immense improvement in a manufacturer’s overall performance by turning the tide in the firm’s favor once it is properly implemented (Min, 2010; Klump, 2017; Ponis, Efthymiou, 2020, Yuan, 2020; Nota et al., 2021).

One field that is usually introduced by artificial intelligence is material handling. Material handling refers to the operation incorporating how materials and goods are moved, stored, protected, and controlled throughout the industrial processes, including manufacturing, warehousing, and distribution. In order to create a good flow of production processes, material handling assists in providing a smooth replenishment of input material to the production activities as well as moving the semi-finished goods within the plan or transporting the finished products into the warehouse while simultaneously ensuring the safety and timing of the moving products. Besides, it may also focus on supporting the operator while working on a task, particularly the manual one, by implementing several concepts, such as ergonomic, standardization, or lifting methods (Thamer et al., 2018; Zhang, 2019, Dhamija et al., 2020; Ammar et al., 2021).

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Material handling integrates every activity throughout the line, reflecting the importance of it for the plan. Once the processes are slow, interrupted, the other system will be affected as well. As a result, there is an emergence of either maintaining the operation level or significantly elevating the processes through artificial intelligence implementation. With the AI introduction, material handling operations are expected to work faster, safer, easier and more reliable (Kar et al., 2019; Yang et al., 2021).

The article aims to examine the application opportunities of artificial intelligence in the material handling industry. A structured literature review with the help of a mapping study is being conducted in the study to show how the material handling industry can benefit from the implementation of artificial intelligence.

The research question of the article intends to answer is: how the implementation of artificial intelligence can improve the efficiency and productivity of material handling activities and what are the advantages and constraints of the implementation?

The paper will demonstrate how artificial intelligence can assist in transforming material handling processes from manual to autonomous operations impacting greatly the overall efficiency and effectiveness of different industries.

The paper conducts a rapid systematic literature review, using the Scopus and Science Direct databases to show what are the advantages and the constraints based on the selected articles, with a narrative summary, giving an overview of the content of the selected articles and answering the research question.

2. METHODOLOGY

In this article, a rapid systematic literature review is carried out on the application opportunities of artificial intelligence in the material handling industry, following the steps of Figure 1.

![Figure 1. Literature review process steps](Author's own creation)

According to literature a systematic literature review (SLR) identifies, selects, and critically evaluates research in order to answer a clearly articulated question. SLR is a review in which a detailed search for relevant studies on a particular topic is performed, and then the ones identified are evaluated and synthesized according to a predetermined and explicit method. A systematic review attempts to gather all empirical evidence that meets predefined eligibility criteria.
to answer a specific research question. It uses explicit, systematic methods that are selected to minimize bias, giving more reliable results from which conclusions can be drawn and decisions made (Tranfield et al., 2003; Briner and Denyer, 2012; Denyer and Tranfield, 2009).

Rapid systematic review is a literature review produced using accelerated and streamlined systematic review methods, by applying a narrow search strategy, limiting the number of databases searched, narrowing the time frame for article retrieval, omitting hand searching of reference lists and relevant journals, or limiting the number of reviewers involved in inclusion/exclusion criteria formulation, data extraction and quality assessment (Reyen et al., 2017; Hamel et al., 2020).

The research aims to answer the following research question:

**RQ:** How the implementation of artificial intelligence can improve the efficiency and productivity of material handling activities and what are the advantages and constraints of the implementation?

In order to answer the research question, a systematic literature review is applied by using the Scopus and Science Direct databases to collect and categorize articles.

During keyword identification, the research also took into consideration the most common synonyms and alternatives of material handling and artificial intelligence. Based on this concept the following keywords were identified and used during the research:

Artificial Intelligence, Material Handling, Machine Learning, Automation, Smart Material Handling, Smart Manufacturing, Smart Warehousing, Productivity, Efficiency, Industry 4.0, AGV, Automated Guided Vehicle, Smart Logistics.

To organize the chosen keywords and to achieve more relevant research results during the database search the PEO (Population, Exposure, Outcome) framework was applied to organize the keywords into the three major categories, as shown in Table 1.

As a novelty, the research applies the PEO framework which is commonly used in medical literature but has fewer examples in other scientific fields. The PICO and PEO frameworks are used to help manage and break down a research question and organize relevant keywords for database searches. But while PICO is mostly used for quantitative searches PEO is used for qualitative searches, which aligns better with the focus of the research (Metzler and Metz, 2010; Bettany-Saltikov, 2012)

Three major questions help us to separate the keywords:
- Population (P): Who are you studying?
- Exposure (E): What is your population exposed to?
- Outcome (O): What is the result of the exposure on your population?

Population is the category in which the research question is generally interested, which is in this case material handling. Exposure is the category that affects the previous in any way. Outcome is the category that specifies the effects of exposure on the population. A combination of two, three, and four keywords were applied during the database searches with the help of boolean characters to generate complex keyword combinations, enhancing the effectiveness of the search for relevant literature. During the initial searches, a limitation arose as the database
of ScienceDirect has a Boolean connector limitation of eight. Because of this, during the search in the case of the ScienceDirect database, only the keyword combination of two was used while for Scopus the combination of three and four keywords was applied.

Table 1. Keywords categorized based on PEO (Population, Exposure, Outcomes)

<table>
<thead>
<tr>
<th>Population</th>
<th>Exposure</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Handling</td>
<td>Smart Warehousing</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>Smart Material Handling</td>
<td>Smart Manufacturing</td>
<td>Industry 4.0</td>
</tr>
<tr>
<td></td>
<td>Smart Logistics</td>
<td>Machine Learning</td>
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<tr>
<td></td>
<td></td>
<td>Automation</td>
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<tr>
<td></td>
<td></td>
<td>Automated Guided Vehicle</td>
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<tr>
<td></td>
<td></td>
<td>Autonomous Guided Vehicle</td>
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<td></td>
<td></td>
<td>AGV</td>
</tr>
</tbody>
</table>

*Source:* Author’s own creation

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During the preparation of the systematic literature review, the following inclusion and exclusion criteria were formulated:

1. The articles have to be related to the engineering and management science fields.
2. The articles have to be freely accessible.
3. The articles have to be written in English.
4. The articles have to be published between 2010 and 2021.
5. The articles which are present in both databases have to be eliminated to avoid duplication.
6. The articles have to be related to the research question.

3. RESULTS OF THE MAPPING STUDY

The number of collected and selected articles are presented in Table 2, where after the initial search with the different combinations of keywords, each row shows the results of inclusion and exclusion criteria application one by one.

The initial number of collected papers from the ScienceDirect database was 19,247 papers and from the Scopus database was 5,585 studies. After selecting the articles according to the three selection criteria, the paper remained 1122, accounted for 5.8% of total selected articles from the ScienceDirect database, and 813, similar to 15.7% of selected papers from the Scopus Database. Further, a detailed examination of the papers’ title and abstract based on the research questions was established, resulting in 169 articles in total from both databases. The removal of 8 duplicated studies gave a result of 161 papers to be reviewed.
Table 2. Details of Article Number Selection

<table>
<thead>
<tr>
<th></th>
<th>Keyword Queries in Science Direct</th>
<th>Keyword Queries in Scopus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Articles</strong></td>
<td>2.1 6970 12247 19247</td>
<td>363 4409 214 199 5185</td>
</tr>
<tr>
<td>SC 1. Engineering and Management Related</td>
<td>23 4910 6527 11460</td>
<td>282 3319 170 157 3928</td>
</tr>
<tr>
<td>SC 2. Free Access</td>
<td>11 547 647 1205</td>
<td>122 610 75 69 876</td>
</tr>
<tr>
<td>SC 3. Publication Year and Language</td>
<td>11 508 603 1122</td>
<td>120 549 75 69 813</td>
</tr>
<tr>
<td>Final Paper After 3 SCs.</td>
<td>1122</td>
<td>813</td>
</tr>
<tr>
<td>SC 4. Related to Research Questions</td>
<td>61</td>
<td>108</td>
</tr>
<tr>
<td>Removal of Duplication Articles</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Final Paper Number to Review</td>
<td>161</td>
<td></td>
</tr>
</tbody>
</table>

Source: Author’s own creation

The 161 selected articles were analyzed by the publication year and publication type. As Figure 2 depicts, all studies were published between 2011 and 2021. Low publication numbers were discovered between 2011 to 2015, whereas only one paper in both 2011 and 2012, and five articles from 2013 to 2015. A significant escalation trend happened afterward whilst there were 28 papers in 2019, 38 papers in 2020, and 45 papers in 2021. Figure 3 informed the publication types of reviewed articles. Journal articles were dominant with 81 files, similar to 50% of the total studies, followed by conference proceedings with 69 papers, which accounted for 43%. The remaining are nine review articles and two book chapters.

Figure 2. Number of Articles per Year
Source: Author’s own creation

Figure 3. Number of Articles per Document Types
Source: Author’s own creation
The number of collected and selected articles is presented in Figure 4. and Figure 5. The initial number of collected papers from the ScienceDirect database was 19,247 papers and from the Scopus database was 5,585 studies. After selecting the articles according to the three selection criteria, 1122 papers remained, accounting for 5.8% of the total selected articles from the ScienceDirect database, and 813, similar to 15.7% of selected papers from the Scopus Database. Further, a detailed examination of the papers’ title and abstract based on the research questions was established, resulting in 169 articles in total from both databases. The removal of 8 duplicated studies gave a result of 161 papers to be reviewed.

**Figure 4.** Application of eligibility criteria on ScienceDirect Database Articles

*Source: Author’s own creation*

**Figure 5.** Application of eligibility criteria on Scopus Database Articles

*Source: Author’s own creation*

### 4. DISCUSSION

According to the detailed analysis of the remaining 161 papers, a large proportion of the papers are focusing on autonomous guided vehicles. Van Geest et al. (2020) stated that AGV can replace human-operated forklifts by speeding up the material transportation process making it less time-consuming. Such AGV’s can be made completely autonomous through proper framework based on AI and supported by self-learning. They also showed a case study from a food industry warehouse
where multiple AGV’s are operating autonomously by communicating with each other and with the WMS for order picking and for making the work completely automated.

Toorajipour et al. (2020) talked about two computational models named ABSs (Agent-Based Systems) and MASs (Multi-Agent Systems) which have the ability to simulate the interactions of autonomous machines. These models can help the autonomous agents to perceive the surrounding environment, act autonomously in a collective or individual manner. A study by Mahmood et al. (2021) presented the A* algorithm to search the shortest path of several AGVs. Adopting the framework of Map-Reduce, the experiment proved that AGV’s task scheduling and speed control strategy resulted in a feasible and effective conflict reduction in the material handling process. Ong et al. (2020) also discussed path recognition methods, highlighting the effectiveness of flower pollination algorithm (FPA) compared to particle swarm optimization.

Gregor et al. (2017) in co-operation with CEIT have done research and developed an AGV called CEIT Aurora to implement in automotive and electronics industries in order to handle complex logistics tasks which are connected to the most important parts of value chain such as the press department, welding, painting and assembly in VW Slovakia. According to the research done by Weckenberg and Spengler (2019), an AGV system equipped with RFID technology was implemented in the automotive industry to define the direction, speed, stop or move, and activate or deactivate AGV traffic lights in transporting finished goods to the warehouse. As a result, non-value-added activities decreased to a mere 20% from 58% and accelerated the cycle time by 13%. Pedan et al. (2017) showed the implementation of an AGV in a healthcare facility where the works of the AGV were medical supplies, food and laundry transportation, heavy and dangerous medical wastage movement. This was also helping the hospital stuffs in a way where they were being able to use most of their time for patient care.

Similarly, Tai et al. (2016) showed that, with an integrated radio frequency communication system to connect different buildings, doors, and elevators, an AGV system has been implemented in a large Norwegian hospital to transport consumer goods, sterile goods, and others. However, the system faced challenges in interacting with people while using elevators or hallways, leading to the AGV failures. Thus, AGV operating hours were restricted by the operator’s attendance and surveillance.

Zhang et al. (2021) proposed a dynamic scheduling method for aircraft assembling industry so that multiple AGV’s with the same carrying capacity can combine and communicate with each other to carry out a large material handling task together. Fernandes et al. (2019) stated that it is essential to have a clear idea in the earliest stage of AGV implementation with different stakeholders’ discussion while designing the AGV system, avoiding costly and difficult changes. According to Gu et al. (2020), the scheduling of AGVs’ movements has to be carefully planned when using them in higher numbers during everyday operations, but if the scheduling optimization is successful it can significantly improve the efficiency according to Farooq et al. (2020).

Javaid et al. (2021) talked about autonomous mobile robots who can help in manufacturing for repetitive operations of high volume with speed, precision and durability and in production for optimum performance, automate routine jobs so that related people can concentrate on more profitable business areas. Alcacer and Cruz-Machado (2019) discussed about adaptive autonomous robots as they can make their own decisions and perform tasks simultaneously in a constantly changing industrial environment without operator’s interaction, and these robots can also be used to handle dirty or industrial hazards on an unstructured surrounding without any human involvement. Anastasi et al.
(2021) discussed mobile robots with embedded AI-machine learning that have the ability to calculate and find out the best route inside the plant while operating at a proper speed and can avoid people who are present and working casually in their way. Fragapane et al. (2021) discussed several AI techniques such as vision systems, machine learning, fuzzy logic, neural networks and neuro-fuzzy-genetic algorithms which help AMRs to identify, classify obstacles and reach their destination while avoiding collisions along their path.

Cyber-physical systems related research articles are also common within the remaining 161 papers. Yan et al. (2019) discussed about a cyber-physical system for intra-logistics operation which is based on AI based four-level framework to deal with critical logistics tasks and for intelligent applications to understand information, to make decision and interact. Herterich et al. (2015) discussed AI powered CPS which can bring impact on manufacturing in a good way by optimizing equipment operations, remote control & manage of equipment, predict & trigger service activities, remote diagnostics and replace & optimize of field service.

Deja et al. (2021) discussed the use of UAV in manufacturing especially for material transfers within cells and job shops and the use of UAV can be highly fruitful as they don’t occupy space on the ground and return on investment can be high due to low purchase cost of UAVs. Mourtzis et al. (2020) discussed an AI-based algorithm for that which helps human operators with physical load and production engineers to monitor the production status remotely.

Schoepflin et al. (2021) developed a smart material delivery unit for aircraft manufacturing industry that can gather information from the real process, can find out any disruptions in the process and hence can identify any kind of problem that can create structural error in the aircraft because of its ability to collect shop-floor information for long term.

Several of the selected articles are dealing with the application of robots to enhance productivity. Aaltonen and Salmi (2019) talked about cobots (collaborative robots) which can collaborate and work together with humans because of their user-friendliness and help to increase operation efficiency, innovation, improvements in physical and cognitive ergonomics, reduced monotony, and flexibility. A similar result was mentioned by Gonzalez et al. (2019) as the experiment of collaborative robot application based on an assembly task at Volvo Group Truck operations resulted in the acceleration of cycle time. However, the usage of available assist devices to perform rapid and accurate movements might pose slow, awkward, non-responsive, and hard to manipulate characteristics. Despite this Fager et al. (2020) suggested that cobots can be useful from a financial perspective in case of higher commonality order if the implementation challenges and safety issues are eliminated, and Segura et al. (2021) identified the basic components comprising human-robot collaborative systems design, allowing the selection of compatible structural components in order to respond better to manufacturing requirement.

To transport goods, a study by Fragapane et al. (2021) highlighted the experiment of conveyors application equipped with an Artificial Neural Network and vision sensor in minimizing energy consumption. The system allows the conveyor to stop, start, and define the speed automatically based on the loading characteristics, resulting in less energy consumption ranging from 87.5% to 98.5%. Another research by Frommel et al. (2019) attempted to design, integrate and test the implementation of an Autonomous Intelligent Vehicle mounted with a Telescopic Pillar Actuator (TPA) and conveyor system in the linear manufacturing circumstances to eliminate single fixed conveyors because of their high investment cost and shutting down floor space and walkways.
According to the model and simulation of material handling systems by Setiawan et al. (2021), there was evidence that automation-based tasks have significantly better performance than human-based tasks in terms of their value and human force needed. However, several factors before implementing the robot should be considered, including (1) the total cost of ownership, (2) the qualitative factors; the service and support, payment alternatives, equipment effectiveness, and (3) quantitative factors covering the operator’s wage, the cost for spare parts and cost for energy consumption, as stated by Schröder et al. (2016). Simulation and case study evidence according to Seha et al. (2017) also suggested that autonomous material handling system integration improves assembly line performance. Ng et al. (2021) also mentioned some challenges of intelligent automation implementation, such as problem dependency and expert reliance issues, cultural readiness and workforce reskilling, issues of integrating with legacy systems.

5. FUTURE RESEARCH DIRECTIONS

As the level of digitalization and the application of Industry 4.0 related technological improvements is increasing in various sectors, advanced technologies such as artificial intelligence, play a more and more important role in logistical processes. The goal of this research was to examine the implementation of artificial intelligence in the case of material handling by conducting a systematic literature review. But what we have seen so far is, the material handling operations are not completely automated yet. The future direction of this research is to extend the review based on the identified major topics and common patterns of the selected articles to conduct a further tailored wider analysis of the existing literature. Moreover, to give fellow researchers a solid ground to think and generate ideas about the complete automation of material handling operations.

6. CONCLUSION

The article aimed to examine the application opportunities of artificial intelligence in the material handling industry. A structured literature review with a mapping study was conducted to examine how the material handling industry can benefit from the implementation of artificial intelligence.

Artificial Intelligence is the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions, while material handling is the process of movement, protection, storage, and control of materials and products throughout manufacturing, warehousing, distribution, consumption, and disposal.

The PEO framework was applied to categorize identified keywords in order to enhance database search effectiveness with the help of boolean connectors in several variations. After the initial searches, 19,247 papers were identified in the ScienceDirect Database and 5,585 papers were identified in the Scopus database. After applying the previously defined inclusion and exclusion criteria 1122 (5,8%) papers remained in the case of the ScienceDirect database and 813 (15,7%) papers remained in the case of the Scopus database. Further, a detailed examination of the papers’ title and abstract based on the research questions was established, resulting in 169 articles in total from both databases. The removal of 8 duplicated studies gave a result of 161 papers to be reviewed.

From the remaining 161 articles, a large proportion focuses on the implementation, improvement, and integration of autonomous guided vehicles in various material handling and distribution systems supported by algorithms as optimization methods. Another section of the article deals with the implementation challenges and benefits of collaborative robots, or focuses on the
enhancing of the cyber-physical system for intra-logistics operation with the support of artificial intelligence-based frameworks, aiming to achieve higher performance levels.

Overall the examined papers clearly present that despite the challenges of implementation and optimization hardships, the application of artificial intelligence can assist in transforming material handling processes from manual to autonomous operations impacting greatly the overall efficiency and productivity of various industrial environments.

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REFERENCES


