Automated Guided Vehicles (AGVs) in Warehousing Industry: A Literature Review

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Abstract

There is no doubt that during the last decade businesses adopt Automated Guided Vehicles (AGVs) technology in their entire supply chain network. In order to operate the AGVs inside warehouses and provide high accuracy, efficiency, and sustainable solutions, it is necessary to decide on the essential current key insights and elements of AGVs, which can give a clear direction for the warehousing and supply chain managers. Hence this study aims to explore and analyse the current trends, developments and impacts of the AGVs on the warehousing design and day-to-day operations and discuss whether these key insights have received sufficient research studies and whether this can lead to new opportunities in the future. The study conducts a systematic literature review to demonstrate the whole process in a structured way of how the author identified the key journal papers for further analysis. The findings revealed that the current trends of AGVs are mainly about flexible/smart manufacturing processes, the human-machine collaboration in dynamic environments, the scheduling and routing algorithms of the AGVs and the integration between RFID technology and AGVs in warehouses. Additionally, the findings also showed that the main impacts of AGVs in warehousing design are mostly about sustainability, employment, and reshoring-nearshoring decisions.

Keywords:

Automated Guided Vehicles, AGVs, Warehousing Management Systems, AGV, Supply Chain Management, Structured Literature Review.

1. Introduction

Over the last three decades, Automated Guided Vehicles (AGVs) have been operating within warehouses and distribution systems for material handling and transportation providing a competitive advantage to increase manufacturing efficiency and productivity (Ullrich and Kachur 2015; Vlachos et al. 2021). Recent developments in Industry 4.0 transform the manufacturing space and allow for new uses and applications of AGVs (Kumbhar et al. 2018). However, the literature on AGVs on the recent warehouses and distribution systems in the context of Industry 4.0 has not previously reviewed (Polten and Emde 2021). This is the aim of this study; to review current trends and developments and critically evaluate them in the context of Industry 4.0.

The first AGV system was introduced and invented in 1953. The inventor developed a modified towing tractor by embedding an overhead wire in the factory floor in order for vehicles to follow (Corréa et al. 2007). During that decade, towing AGVs were used in many different factories and distribution centres. The arrival of solid state controls enabled the systems to augment in capabilities and flexibility. All those years AGVs have emerged into intricate material handling vehicles with a broad range of capabilities. For instance, their range varies from simple mail handling to highly automated trailer loading vehicles embedded with laser navigation technologies.

By the end of the 1970s, there have been only three AGV models produced by US manufacturers. By 1990s, product standardization was the reason why AGVs increase their number worldwide to 15 (Dissanayake, Newman, Clark, Durrant- Whyte, & Csorba, 2001), while the number of manufacturers increased sevenfold. More and more AGVs are being used because of the evolution of technology and science; therefore, more investments are made into AGVs research and development. AGV market is one of the oldest in the mobile robot sector (Bechtsis et al. 2017).
There are three main types of AGVs today:

- The Tug or Tractor – it is used to pull passive cargo located on platforms behind them
- The Unit Load – it is used to carry a single load placed in front of the vehicle on the platform
- The Forked – they are using fork implements to lift a single load

The historical progress of these vehicles reveals that they have been used mostly in strategically structured dynamic environments, based on some assumptions, such as flat doors, provided vehicle guidance etc. They are designed to reduce speed for safety measures, centralizing moving authority, and designed to follow specific guide paths, without being disrupted by other obstacles. However, risk reduction has an impact on performance and adaptability (Lin and Vlachos 2018; Mangina et al. 2020).
AGVs are entirely relied on a specifically installed infrastructure to dictate their position inside the warehouse, which is obviously quite extravagant to install and modify. AGVs have become more sophisticated and currently, they are mainly laser navigated (LGVs).

Moreover, AGVs have a great impact on the design of the warehouses and their day-to-day activities. Automated guided vehicles can contribute to the improvement of the logistics companies and help them to overcome various challenges. Nevertheless, the adoption of AGVs could reshape the competitive landscape, thus some advantages controlled by logistic companies might lose their pertinence in the future. Consequently, companies need to implement them to retain a strong market position (Mangina and Vlachos 2005; Vlachos 2016).

2. Research Methodology

This study applied a Systematic Literature Review (SLR) to identify available studies and documents (Purssell and Mccrae 2020). The SLR process has the advantage to be assessed and replicated in future studies, which makes it suitable for the study's context (AGV/Industry 4.0), which is highly dynamic (Liao et al. 2017; Vlachos 2021).

Figure 1 presents the three literature bodies the research area that were searched. The essential step in SLR process is to formulate a strategy. In this phase, the most suitable data sources and keyword search strings are located. Moreover, a considerable number of relevant articles will be added in the upcoming analysis. The primary information source for this study was journal databases. Additionally, Google Scholar contributed with other articles via snowballing to enhance the research. The reasons for selecting these first two search engines are to decrease the scope and number of articles to a manageable size and in order to create the basic sample in which supplementary journals from Google Scholar will be added after, to make it more robust.

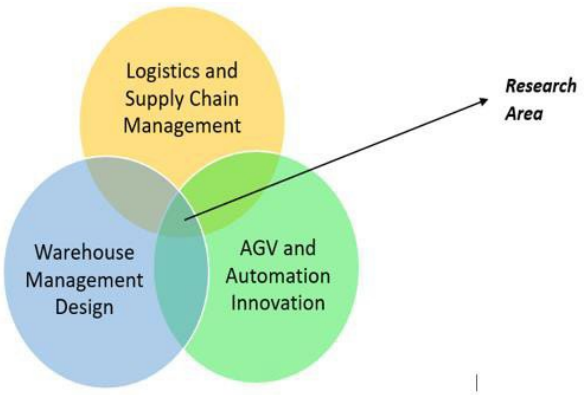

Figure 1 Research Scope - Mind Mapping

Figure 2 presents the keyword strings. The keyword search strings are divided into four main categories that contribute to the efficient search of the articles related to the objectives of this study. After running a considerable amount of trial-and-error testing, the keyword search strings where completed. Then, the identified articles were assessed related the title and abstract screening criteria.

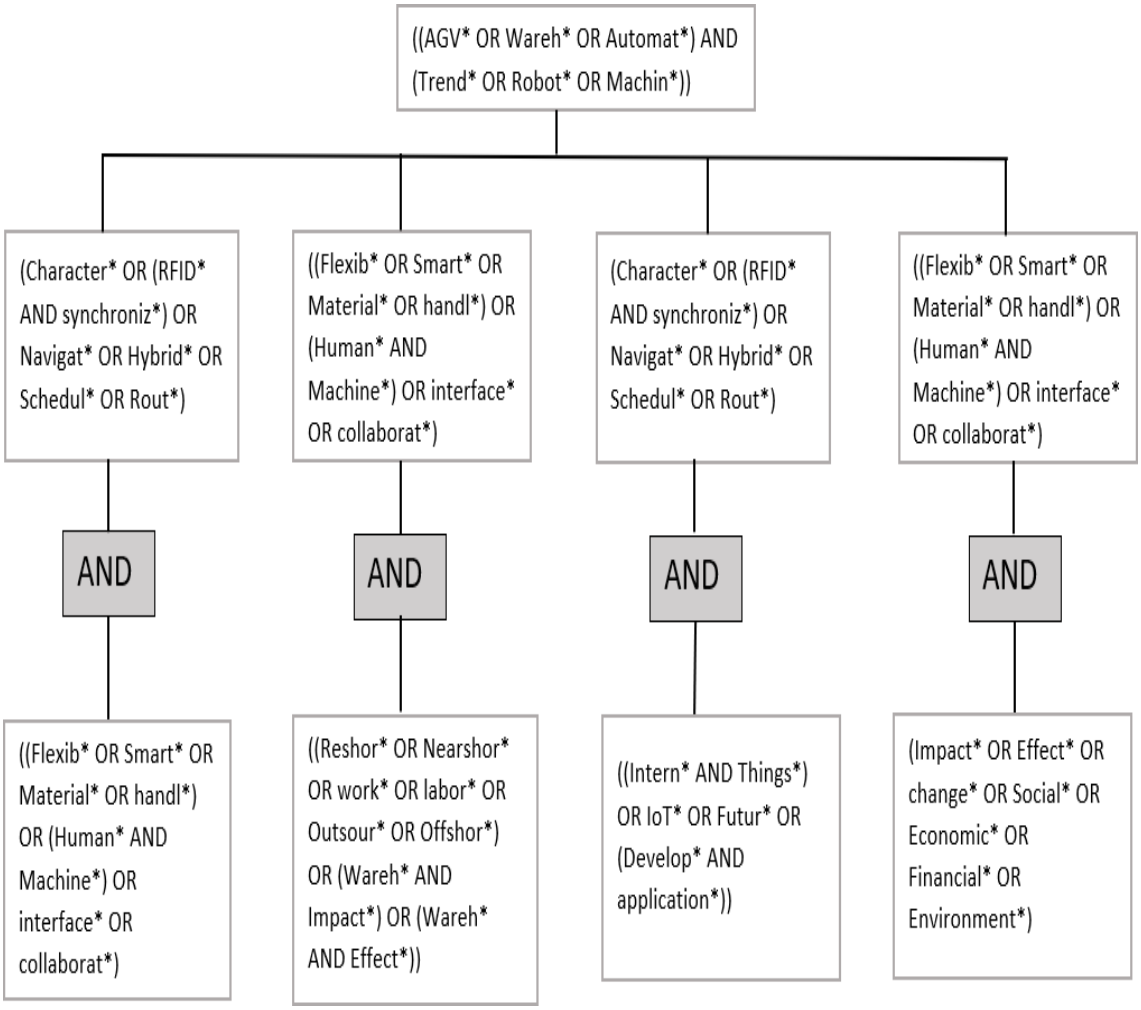

Figure 2 Keyword Search Strings

3. Findings

During the process, 1066 articles were found in the three databases. EBSCO (452 articles) reveals 68 articles less than ABI (520 articles), while in Google Scholar 34 out of 94 articles were selected. The purpose of using mostly journal articles for the descriptive and thematic analysis and not grey literature is due to the fact that books, magazines, and unpublished papers may add subjective information, which might lead to biased data. Few reports were also used from Google Scholar but its use was clearly supplementary. Moreover, after further filtering, a sample of 41 major journals was used to achieve the objectives of this research. Finally, by adding cross-references (Google Scholar papers), the total number of relevant papers were created (75 papers). Table 1 presents the articles included in the review.

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Table 1. Articles included in the study

Key Themes	**Categories**	**Study**	**Study**
Trends and Developments of AGVs	Smart and Flexible Manufacturing Systems	Seo and Egbelu (1999)) Buyurgan et al. (2007) Abdelmaguid et al. (2007) Mahadevan and Narendran (1993) Maughan and Lewis (2010)	Maughan and Lewis (2010) Farling et al. (2010) Ali and Khan (2017) Lee et al. (1996)
	Scheduling and Routing of AGVs	Co and Tanchoco (1991) Koff (1987) Narasimhan (1999)	Qiu et al. (2002) Rubrico et al. (2008) Draganjac et al. (2016)
	Synchronizing RFID with AGVs	Akerlof (1970) Cho and Cho (2013) Park and Lee (2013)	Lu et al. (2016) Zhou et al. (2017) Zecca et al. (2009)
	Human-Machine Interface	Pan et al. (2012) Michalos et al. (2016)	Villani et al. (2018) Cardarelli et al. (2015)
Impact of AGVs on warehousing design and day-to-day operations	Economic, Environmental, Social and Employment Impacts of AGVs	Montealegre and Cascio (2017) Ifr (2017)	Carter and Rogers (2008) Bechtsis et al. (2017) Sabattini et al. (2013)
	Reshoring – Nearshoring phenomenon	Dunning (1980) Kvedaravičienė (2008) Carmel and Abbott (2007)	Presley et al. (2016) Gray et al. (2013)
Future developments	Internet of Things (IoT)	Haddud et al. (2017) Al-Fuqaha et al. (2015)	Reaidy et al. (2015) Yan et al. (2014) Lee et al. (2002)

3.1 Journal Publications

The 75 journals are derived from 25 academic journals, the highest contributing journals being: Computation and Economic Cybernetics (5), International Journal of Production Research (9), Industrial Robotics (4), International Journal of Production Economics (5), and Manufacturing Technology Management (5). The research disciplines are shown in Figure 3.

3.2 Chronological Distribution.

The studies in the context of AGVs began in America in 1953, with Europe following a few years later, while the first AGV was successfully installed in 1954. However, the current research focuses on the "third era" of AGVs from 1991 to 2010, which was using mostly AGVs for Intralogistics and then the "modern era" from 2010 to 2018. Before the 2000s the journal articles were limited due to the small growth of AGVs to certain years. During the third era, academics and managers started to change their views because new technological standards were set and new markets were established (Ullrich, 2015).

3.3 Geographic distribution.

The majority of the journals come from the UK (23%) and the USA (23%) while most of the remaining journals come from Switzerland (8%) (Figure 4). The AGVs applications in warehouses have been widely studied in different regions around the globe. Europe and North America comprise a major part since both of these parts of the world have flourishing industries, highly developed and expanded economies with balanced business environments and considered to be global business leaders. India, South Korea, Italy, and Poland contribute to the research with a small number of articles, which indicates that this field is in its infancy in these countries and is about to increase in the near future.

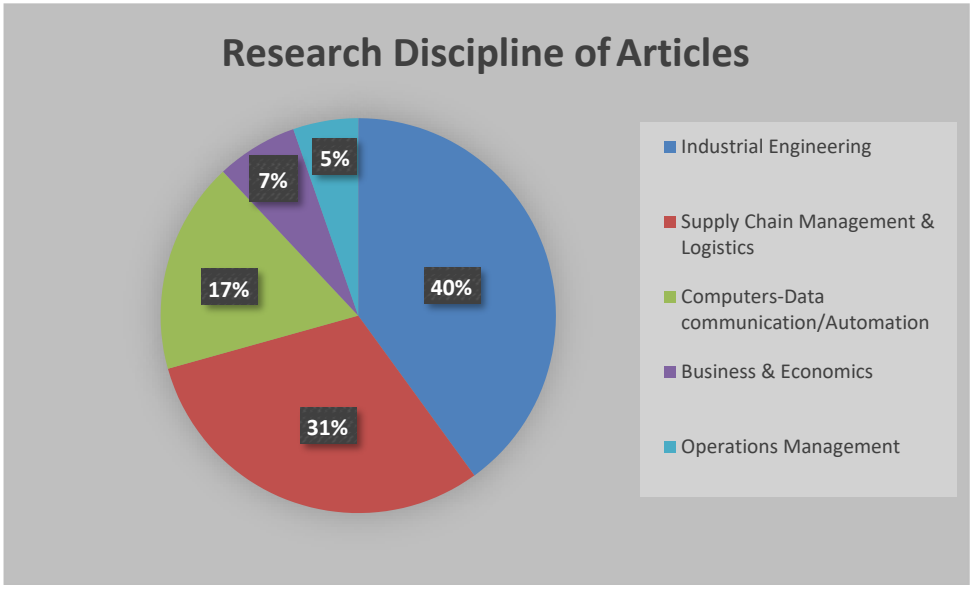

Figure 3 Research disciplines

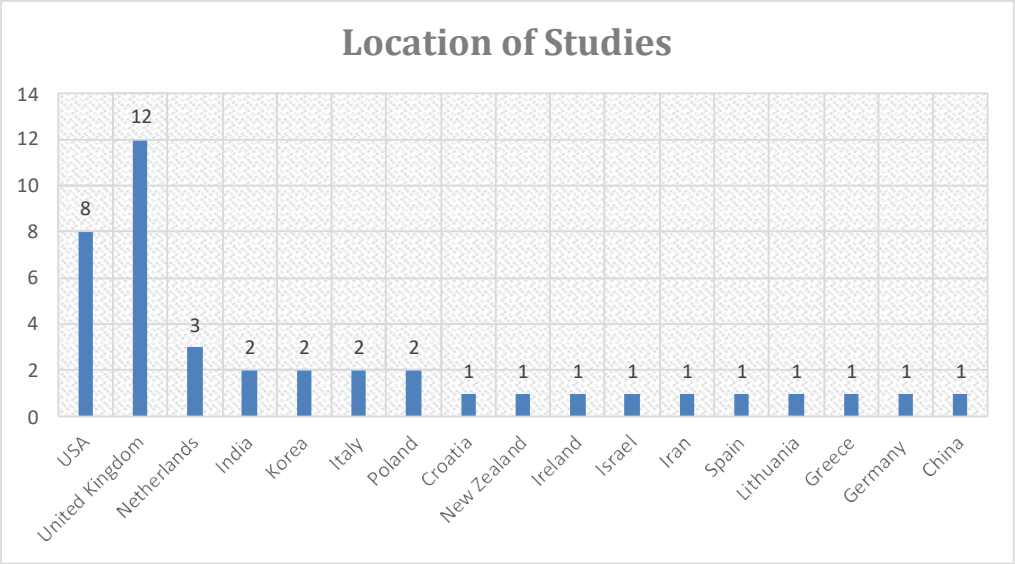

Figure 4 Location of studies

3.4 Industries and Sectors

Studies in the manufacturing sector comprises the highest percentage (55%), followed by wholesalers/retailers (21%).The sectors that captivate the most interest from the bibliography include: Industrial Machinery, Computer & Communication, and Electronics.

3.5 Research Design Models

In this section, the selected literature is analyzed further and categorized into the theoretical and empirical approaches related to the nature of the research methods. Empirical studies are the research that lay on observations and measurements of events. For instance, organized surveys, interviews, analyzed case studies, literature reviews, and practical studies. On the other hand, theoretical studies concentrate on making more explicit the academic concepts and framework of the study. For example, it could be modeling which is relied on a particular theory. Therefore, in this analysis, the two research approaches are implemented into compiling the essential data for a further all-inclusive thematic analysis.

Most of the articles (53) are empirical studies, while the remaining articles (22) are theoretically-based. Most of the selected journals have used diversified research methods in their research, reflecting the potential intricacy in this field.

Industrial research papers were found to be the main method in this paper (24%), following by literature reviews (21%) and Statistical & Mathematical Modelling Analysis (20%). In addition, the remaining papers used meta-analysis, simulation, field study, case studies and surveys as a tool to obtain primary and secondary data for further analysis (Figure 5).

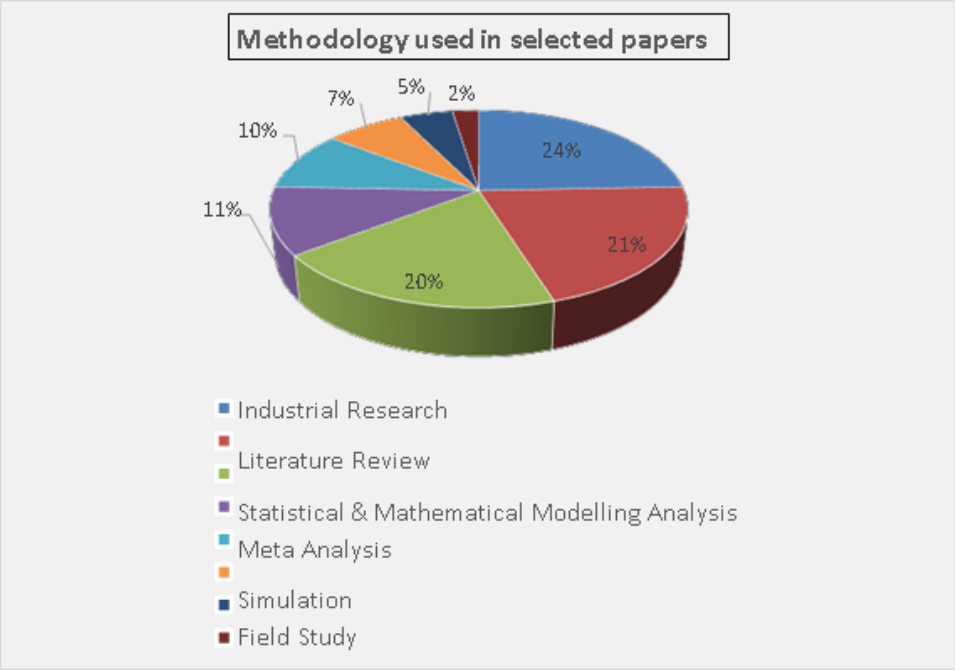

Figure 5 Methods Used

4. Discussion

The results revealed that the selected journals are derived from diverse research fields adopting multiple research methodologies. Thus, the selected academic journals are sufficient and qualified to deliver a thorough analysis from different perspectives.

Although the thesis has fulfilled its objectives, still there are certain inevitable limitations. Firstly, despite the adoption of an extended systematic literature review the data collection process was accomplished depended on three databases, namely ABI, EBSCO and Google Scholar, which restricted the author to a specific sample of journal articles. Secondly, AGVs adoption in warehousing is considered a newly emerging practice, thus the academic literature is relatively limited compared to other sectors, such as the shipping industry. Lastly, in the field of the AGVs' engineering parts, the literature is still evolving, and it does not specify to particular technical AGV system implementations.

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