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Review

Interaction between a Human and an AGV System in a Shared Workspace—A Literature Review Identifying Research Areas

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Abstract: Background: This article presents the results of a literature review from 2018 to 2023, which focused on research related to human and AGV system cooperation in a shared workspace. This study defines AGV systems as systems using Automated Guided Vehicles or Autonomous Guided Vehicles. An Automated Guided Vehicle is a cart that follows a guided path, while an Autonomous Guided Vehicle is an Automated Guided Vehicle that is autonomously controlled. The analyses conducted answered two research questions: (RQ1) In what aspects are the human factor examined in publications on the implementation and operation of AGV systems? (RQ2) Has the human-AGV collaboration aspect been analyzed in the context of a sustainable work environment? Methods: The literature review was conducted following the systematic literature review method, using the PRISMA approach. Results: Based on the search of two journal databases, according to the indicated keywords, 1219 documents pertaining to the analyzed issues were identified. The selection and elimination of documents that did not meet the defined criteria made it possible to limit the number of publications to 117 articles and proceedings papers. On this basis, the authors defined a classification framework comprising five basic research categories and nine subcategories. The analyzed documents were classified, and each distinguished group was characterized by describing the results. Conclusions: The development of a two-level classification framework for research from the analyzed area according to the assumptions of the concept map and the identification of research gaps in the area of human-AGV interaction.

Keywords: human factor; AGV; risk; cooperation; sustainable workspace; work environment

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1. Introduction

Humans are crucial elements in any operating system, a feature that is challenging to recreate in contrast to technology [1]. For this reason, a whole area of research on the human factor exists. From the point of view of technical systems, the human factor is often analyzed due to the possibility of errors made by it, which may interfere with the system's proper functioning [2]. Numerous studies have also mentioned human error as being the cause of most recorded accidents [3]. Instances in the literature have distinguished between two approaches with regard to human failure [4]: (1) It relates to the mistakes of individuals and focuses on issues related to their behavior (forgetfulness, inattention, moral weakness, etc.); (2) It relates to the conditions in which people work and focuses on building defense mechanisms to avoid or mitigate the effects of mistakes that occur. Concept (1) is a personal approach, while (2) is a systems approach. The concept of human error and blame has been prevalent in society throughout history. In contrast, the engineering perspective has only just begun using formal safety approaches, such as accident investigation, completed by systems theory and complexity science within ergonomics and human factors (EHM) [5]. According to the guidelines of the Human Factors and Ergonomics Society [6], the assumption for the purposes of research is the systematic use of the knowledge concerning relevant human characteristics to achieve compatibility in the design of interactive systems of people, machines, environments, and devices of all kinds to ensure specific goals. However, the human factor is often primarily identified with ergonomics, which results in the strong focus of the research being on safety issues, with no analysis of the impact on productivity [7]. However, efficiency is an important parameter for assessing the effectiveness of human work in terms of its replacement by automatic and autonomous systems [8].

The human factor has increasingly become the subject of research in production engineering [9,10] and transport [11,12]. As part of these studies, the mental and physical requirements for operators operating a given system are often determined. The effects of these requirements may relate to employees' required training, knowledge, and competencies, but also pertains to their fatigue, discomfort, and injuries [1]. At the same time, the failure to consider these requirements may translate into operator errors, a decrease in the efficiency of the entire process, and a loss in terms of achieving goals. Such an approach aligns with socio-technical systems theory, in which the proper alignment of system technology with human operators is critical in achieving a common goal [1].

In addition to the requirements for operators, an important factor affecting their safety and productivity is the workplace created for them, including its equipment, organization, and working conditions. Therefore, the creation of sustainable workplaces has become an important issue. In numerous publications, this concept is referred to as reducing environmental impact and waste, but also improving employee health and creating a friendlier and more productive environment [13]. Therefore, research on social sustainability in manufacturing plants focuses on workers' rights, preventive occupational health and safety, a human-centered design of work, workers' empowerment, individual and collective learning, employee participation, and work-life balance [14]. As Papetti et al. highlighted, in most of these studies, the authors have demonstrated that improvements in workplace conditions beyond the requirements of current laws result in greater employee engagement and increased job satisfaction [14].

Many authors have emphasized that in complex sociotechnical systems, outcomes (e.g., behaviors, accidents, successes) emerge from the interactions between multiple system components [15]. These interactions are dynamic, non-linear, and non-deterministic. Complex sociotechnical systems are open to the environment, which makes it necessary to react and flexibly adapt to the environment. People operating in these systems often do not have full knowledge of the system as a whole, which is why they act locally, and the decisions made refer to different perspectives and worldviews. Additionally, Ottino pointed out that complex systems are inseparable, so the unit of analysis must be the whole system [16]. For this reason, current research on the human factor in operating systems should be dominated by systemic thinking, emphasizing interactions and relationships, multiple perspectives, and patterns of cause and effect. A key consequence of systems thinking is also that the behavior of a component is only considered in the context of the whole [15]. In addition, Salehi et al. emphasized that the behavior of a complex socio-technical system does not necessarily depend on the behavior of its individual components [17]. This means that occurrent disturbances and accidents cannot be solely attributed to the behavior of selected components, and their analysis should be carried out in relation to the entire system. An example of modern complex social engineering systems is Industry 4.0 (I4.0) systems, in which human and machine cooperate on entirely new principles. Many publications have pointed to the significant changes introduced by I4.0, which relate to the rules of competition, prevailing socio-environmental norms, the functioning of the labor market, and new guidelines for educational processes [18,19]. In a literature review on the role of I4.0 in sustainable supply chains, Naseem and Yang identified five dominant I4.0 technologies: Automated Guided Vehicles (AGV), the Internet of Things, cyber-physical systems, drones, and Smart Factory [20]. This study defines AGV systems as systems using Automated Guided Vehicles or Autonomous Guided Vehicles. An Automated Guided Vehicle "is an automated guided cart that follows a guided path" [21]. However, an Autonomous Guided

Vehicle is an Automated Guided Vehicle that has been "upgraded into autonomously controlled" [22]. Although AGV systems have been known about for several decades, only the development of the Industry 4.0 concept made companies interested in their large-scale implementation in their logistics processes. The most important benefits related to the implementation of AGV are presented, among others, in [23]. From the point of view of the research presented in this article, improving human safety should be considered the most important benefit of implementing the AGV system, primarily by reducing the number of accidents in warehouse processes involving employees [24]. However, as Telukdarie et al. [25] noted, the implemented solutions of Industry 4.0 provide companies with tremendous opportunities but also involve many challenges for organizations. These challenges include not only adapting processes to changing technologies but also a new approach to managing the people involved [26]. Therefore, in line with our previous research in [27], implementing AGVs in complex cyber-physical-human systems also generates other risks, not only those related to employee accidents. Therefore, the issue of creating sustainable workplaces, including collaborative shared spaces between humans and automated and autonomous systems, becomes critical. Therefore, it becomes crucial to analyze the research areas in human-AGV system interaction and identify the current research gaps.

This article presents the results of a literature review from 2018 to 2023, which focused on research related to human and AGV system cooperation in a shared workspace. The literature review was conducted following the systematic literature review method, using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach. The following research questions were defined for the conducted research:

RQ1: *In what aspects is the human factor examined in publications on the implementation and operation of AGV systems?*

RQ2: *Is the human-AGV collaboration aspect being analyzed in the context of a sustainable work environment?*

Following this, the main contributions of this paper include:

- Review of the literature on the cooperation of humans and AGV systems from the last five years;
- Identification of the main research trends for the analyzed area based on the concept of mind map;
- Grouping and preparing the characteristics of 117 documents according to the adopted division criteria based on the results of literature research;
- Identification of research gaps in the area of human-AGV interaction.

The outline of this review paper is as follows: Section 2 presents the research method based on the PRISMA concept. The identification of publications accepted for further analysis resulted from the search for thematically related articles. Section 3 describes the main results of the conducted bibliometric analysis. Section 4 presents the detailed results of the conducted analytical procedure, including a map of concepts, the division into categories and subcategories, the results of the classification procedure, and the characteristics of articles assigned to individual categories. Section 5 will deliver the discussion results and identify the research gaps in the analyzed area. Section 6 describes the theoretical and practical contributions of the presented research, the identified limitations of the conducted classification, and further research directions.

2. Research Design

Due to the research questions posed, was decided to conduct a systematic literature review. The conducted research process aims to identify and critically evaluate research on the cooperation between humans and AGVs in contemporary socio-technical systems. Following the guidelines for this literature analysis method [28], the conducted procedure identifies all empirical evidence that fits the prespecified inclusion criteria to answer a particular research question.

Preparing a review article begins by finding the appropriate literature, and which collection could explore the chosen topic. The PRISMA method was chosen to realize the subject in which topics about humans and AGV are connected. PRISMA enables the creation of a systematic and explicit review with established methods of identification, selection, and evaluation [29]. Figure 1 contains a diagram that illustrates the used PRISMA method.

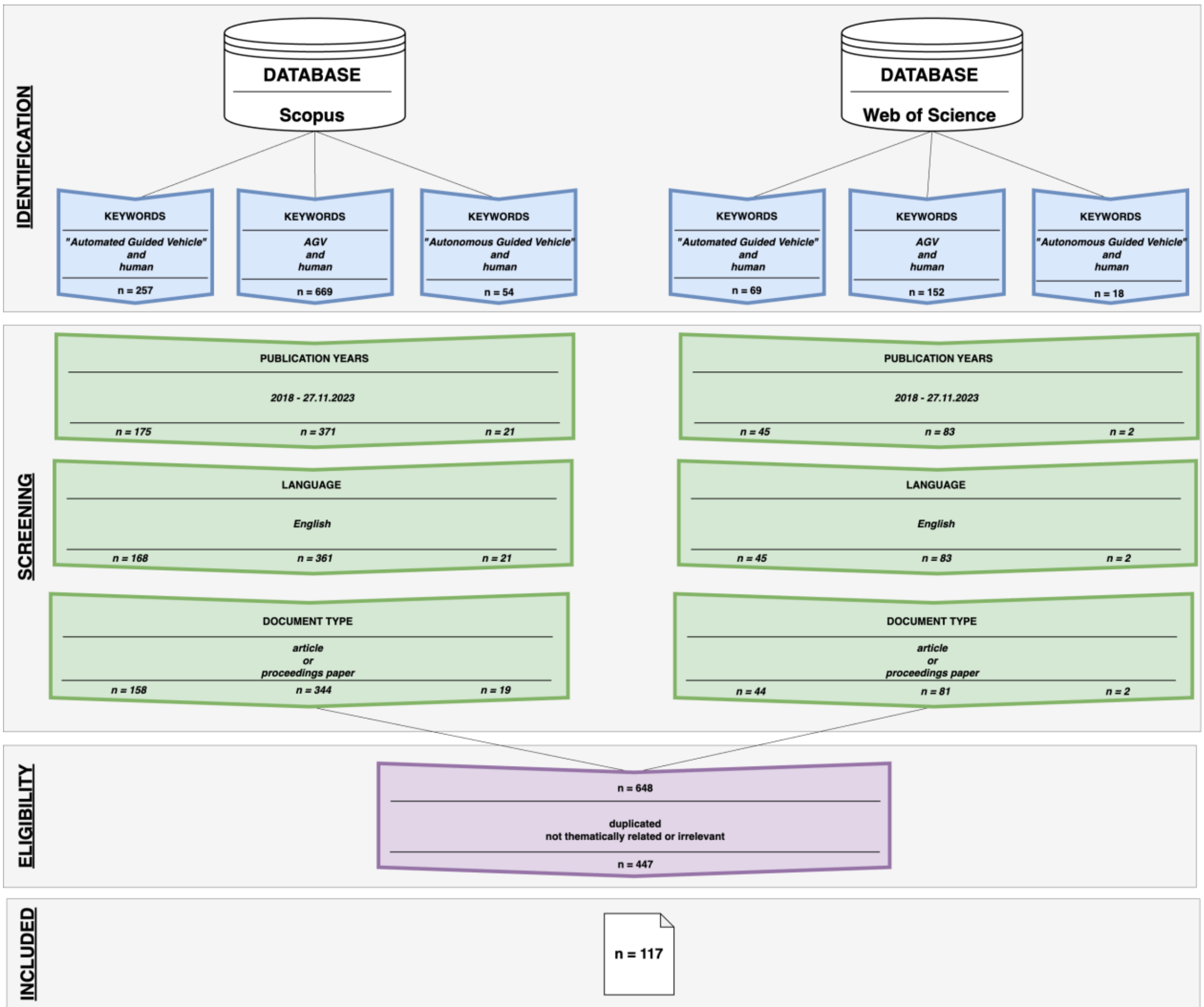

Figure 1. Methodology.

2.1. Identification

For the identification step, two databases were chosen: Scopus and Web of Science (WoS). These databases were selected as they have some of the largest business and technical research repositories and are typically used in literature reviews, e.g., [30].

For each database, three searches were conducted with the following keywords:

- 'Automated guided vehicle' and 'human',
- 'AGV' and 'human',
- 'Autonomous guided vehicle' and 'human'.

The research subject was AGVs appearing in the literature under their full name or abbreviation. The occurrence of these two forms resulted in a search for documents divided into these two entries. The AGV abbreviation was also used for autonomous guided vehicles, whose human-vehicle interactions are similar, so it was appropriate to include them as a keyword for the third search. The second search element was limited to the word human, as the research focuses on sociotechnical systems in which the human element is referred to as the human factor. The word human refers to people representing different roles in the system. Keywords were searched for among document titles, abstracts, and keywords assigned to documents. After this first stage of the PRISMA method, 1219 documents were selected for the screening stage.

2.2. Screening

In the second step, searched documents were limited with clarified criteria. Exclusion criteria were established based on discussion by the authors. The selection considered the current trends and development of Industry 4.0, the dominant role of AGVs in it, and the role of humans, which is increasingly noticed by researchers. The primary publishing dates were set to the period from 2018 to 27 November 2023 (the day of the searching in databases). This period was selected because, since 2017, the concept of Industry 4.0 has been developing, which changed the role of humans in the sociotechnical system and, at the same time, caused the development and increased interest in AGV as one of the leading tools in cyber-physical systems. Second, the literature written in English was selected—it is an international language that allows specialists worldwide to hold a scientific debate. Lastly, research was determined for articles and proceedings papers, which consist of practical information and case studies related to the subject of AGVs and humans in industries. The analysis was limited to publications reflecting the latest scientific research results and, at the same time, meeting the requirements of peer-reviewed publications, proving the quality of the presented results. These constraints made it possible to obtain a set of 648 documents, where some of them were duplicated from both WoS and Scopus databases. Searching in two databases and using three sets of keywords resulted in significant overlapping of search results, proving the search's consistency. Removing duplicated articles or proceedings papers allowed for the preparation of 447 documents in the last stage of the PRISMA method.

2.3. Eligibility

The last stage required checking whether the documents found thematically corresponded and were valuable for the analyzed issue. Decisions and exclusion conditions were based on the contents of the whole article and were subject to discussion before final removal. The criteria for excluding documents were as follows:

- medical documents, in which the abbreviation "AGV" was found, which stands for Ahmed glaucoma valve or apple geminivirus;
- human was mentioned as a subject in the AGV work environment but was not a main subject in the actual study;
- the abbreviation "AGV" also appeared for "autonomous ground vehicles".

After eliminating documents that met the above criteria, 117 articles or proceedings papers were selected for further analysis.

2.4. Identifying Research Trends

The next step in the analysis was to determine the main directions of the research work described in the identified set of 117 documents. The Mind Map method was used to carry out the qualification procedure. The different categories were defined based on a preliminary analysis of the documents, which primarily focused on the abstracts and keywords used in the publication. On this basis, the identification of the main research trends was carried out. Then, based on an analysis of the full texts of the publications, individual documents were assigned to the highlighted thematic groups. Articles not classified in any identified collections were placed under "Other".

3. Bibliometric Analysis

The created collection of articles related to AGV and humans included 81 proceeding papers and 36 articles. Figure 2 shows an increase in the number of publications in the researched area. The analysis of publications grouped by year shows that, in 2019, there was an almost threefold increase in their number compared to 2018. The dominance of conference publications can also be observed. The reason for such proportions may be that the issue of human cooperation with automatic and autonomous systems is a new issue, still under development. The large number of proceedings in 2020 may result from the pandemic period, during which the availability of many prestigious conferences increased due to their implementation in virtual mode. The decrease in the number of articles in 2023 is due to a search conducted before the end of the year.

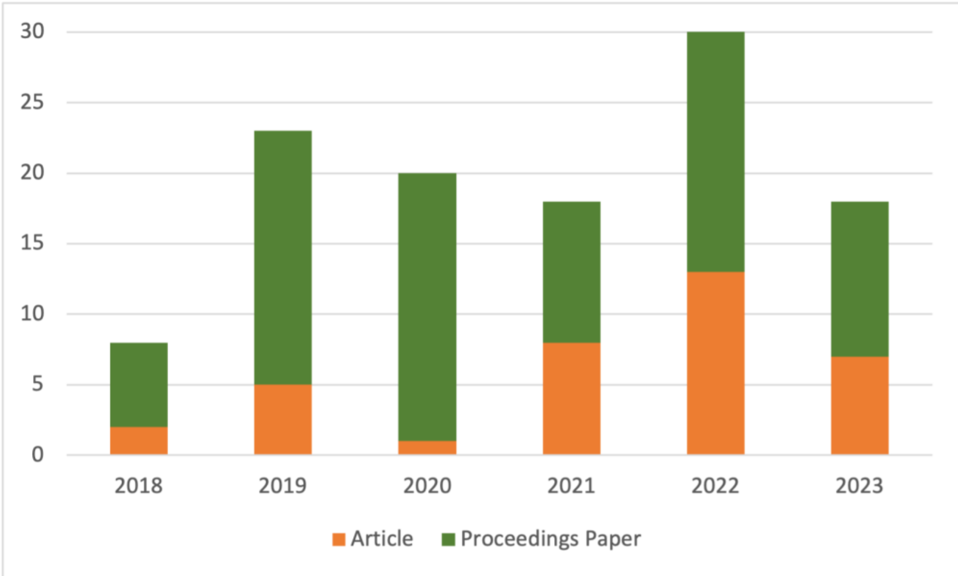

Figure 2. The number of publications.

IEEE is the publishing house with the most significant number of published materials. This publishing house is a co-organizer of numerous conferences in the field of computer and science engineering. Therefore, it mainly publishes proceedings papers. The distinguished publishers with many publications also include Springer and Elsevier. In these two cases, proceedings papers dominate; however, this disproportion is less spectacular than in the case of IEEE. Within the analyzed publications was a large variety of journals; therefore, the remaining 42 documents were combined into one group—Other publishers. The results of the analysis are presented in Table 1.

Table 1. The number of publications.

Publisher	Document Type	Number of Documents	Total Number	%
IEEE	Article Proceedings Paper	8 41	49	42%
Springer	Article Proceedings Paper	3 15	18	15%
Elsevier	Article Proceedings Paper	2 6	8	7%
Other	Article Proceedings Paper	23 19	42	36%

The articles were also analyzed for the number of citations in the WoS and Scopus databases. Articles with the highest number of citations, according to Table 2, presented a high level of research and analysis.

Table 2. The most cited publications.

Authors/Article Title	Scopus	WoS
Goli A., Tirkolaee E.B., Aydin N.S.: Fuzzy Integrated Cell Formation and Production Scheduling Considering Automated Guided Vehicles and Human Factors	61	50
Sabattini L., Aikio M., Beinschob P., Boehning M., Cardarelli E., Digani V., Krengel A., Magnani M., Mandici S., Oleari F., Reinke C., Ronzoni D., Stimming C., Varga R., Vatavu A., Castells Lopez S., Fantuzzi C., Mayra A., Nedevschi S., Secchi C., Fuerstenberg K.: The PAN-robots project: Advanced automated guided vehicle systems for industrial logistics	40	
Gebser M., Obermeier P., Schaub T., Ratsch-Heitmann M., Runge M.: Routing Driverless Transport Vehicles in Car Assembly with Answer Set Programming	18	10
Indri M., Lachello L., Lazzero I., Sibona F., Trapani S.: Smart sensors applications for a new paradigm of a production line	28	
Prati E., Peruzzini M., Pellicciari M., Raffaeli R.: How to include User experience in the design of Human-Robot Interaction	21	

Research teams prepared all of the most cited articles. At the same time, it was not possible to identify one outstanding author among the most cited articles.

Keywords indicated by the authors of the publication were also analyzed. The authors used the abbreviation AGV in keywords with a much greater frequency (36 cases) than the system's full name (19 cases). The "Human" keyword was often considered a stand-alone term (22 cases). This expression appeared seven times in the combination "human-robot". It is also worth noting that in nine publications, the authors included "Interaction" among the keywords, which referred to the cooperation of a human and the AGV system.

4. Results

Based on the Mind Map investigation, four basic research trends and an additional "Other" group were identified. Then, based on a detailed analysis of the full content of the studied articles, additional subcategories were distinguished for the three basic categories. The distinguished subcategories made it possible to detail the scope of the described research. The results of the final classification of research trends at both levels of detail are shown in Figure 3 and characterized in Table 3.

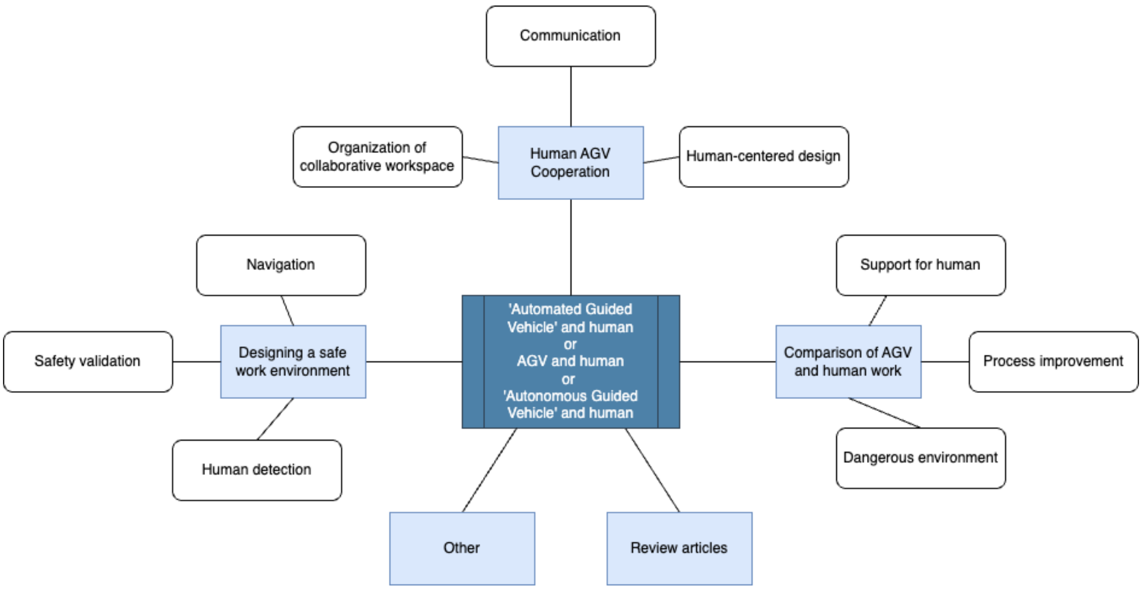

Figure 3. Categories and subcategories.

Table 3. Documents assigned to categories and subcategories.

Category	Subcategory	Articles
Review articles		[31–38]
Comparison of AGV and human work	Process improvement	[8,34,39–52]
	Dangerous environment	[53–55]
	Support for human	[45,56–60]
Human AGV cooperation	Human-centered design	[58,61–65]
	Communication	[55,58,66–81]
	Organization of collaborative workspace	[45,59,60,70,74,82–86]
Designing a safe work environment	Human detection	[75,87–112]
	Navigation	[70,108,110,113–136]
	Safety validation	[85,109,133,137–143]
Other		[144–146]

4.1. Review Articles

Only two of the seven review publications directly concerned the analysis of articles relating to the cooperation of humans and the AGV system. These were the studies reported by [31], and this publication is the most consistent with the direction of the analysis. Its authors presented the evolution of the literature focused on AGV systems, emphasizing the latest research trends and the emerging gaps, also including the ones related to the shared presence of humans and AGVs within the same environment, which can affect the overall performances and the implementation phases. The second literature review was prepared by [32] and included 50 publications selected from a group of 282 articles. Among other things, the authors of this publication focused their attention on the ethical concerns associated with the deployment of AGVs. This is because these systems can collect information about people's behavior without their consent or knowledge. The extensive sensing capabilities used in AGV solutions are now becoming a challenge to respecting the privacy of people interacting with the vehicles. In other literature reviews, the human only appears as a reference point. In the analysis presented in [33], the publications focus on using artificial intelligence (AI) in autonomous and automated guided vehicles. The task of these vehicles is to support human work, but the authors do not analyze the interactions between the vehicle and the person. In addition to human support, AGV systems are implemented to replace human work. A literature review in this area is presented by [34]. The researchers presented the results of comparing AGVs and human work in the order-picking process. The point of reference was to compare the results achieved by humans or AGVs without analyzing their interaction. Another publication compares solutions regarding the local position system, which is used in research on human tracking, object tracking, animal tracking, and AGV tracking [35]. In their review, the authors of this publication analyzed articles on popular Local Position System (LPS) technologies. Also, in this case, the research primarily focused on technology, not the human's role in the technical system. A similar situation occurred in a review prepared by [38]. The authors of this publication studied the application of autonomous vehicles in flexible manufacturing systems to improve the processes implemented in them. The human in this research appeared as an object that would be relieved by the implemented autonomous solutions. In the literature review presented in [36], publications on the possibility of using Monte Carlo Tree Search (MCTS) in improving automatic solutions implemented in smart factories were analyzed. Senington proved that MCTS can support the cooperation of automatic systems with a human and allows for the optimization of the movement of AGV systems in a designated area (including improving path planning). The last review concerned self-organizing production systems cooperating with a human [37]. The authors presented a literature review on two views of such a design: a technical and a human-machine system. The limits and advantages of both views were presented, followed by the merged view, based on the use of the cognitive work analysis (CWA) approach.

4.2. Comparison of AGV and Human Work

A large number of the articles concerned the analysis of the legitimacy of implementing automated solutions in processes and operations previously carried out by humans. For this reason, the first research category we distinguished was comparing the operation of an AGV system and a human in a specific operating environment. In most cases, such a comparison is intended to gather arguments in favor of replacing human work with automated systems. Therefore, some researchers have focused on comparing human work's effects and AGVs [8,34,39]. This comparison applies to selected processes that are usually labor-intensive and time-consuming, but repeatable. Human labor is costly today, so employing it to implement simple, repetitive operations is economically unprofitable [52]. An example of such a process may be order picking, which is often the arena of implementation for AGV systems. This is confirmed by the literature review prepared by [34].

In the analyzed articles, the implementation of AGVs is a solution that improves and streamlines the current implementation of selected processes and operations. The main attention of researchers is focused on analyzing the impact of replacing humans with AGVs through the prism of such aspects as:

- productivity [8,42,43,57],
- efficiency [8,40–49],
- cost reduction [49],
- time reduction [45,48–50,57],
- increase available working time [51],
- reduction of human errors [41,42,47],
- congestion [43],
- improvement of safety [40,42–44].

It should also be noted that most of the articles in this group referred to the comparison of human and AGV work in connection with the implementation of Industry 4.0 solutions and the potential benefits of automating and digitizing repetitive operational activities.

AGVs are also used to support or replace a human in a dangerous work environment. The COVID-19 pandemic became a testing ground for implementing automated solutions, the use of which was to protect hospital staff against infection. AGVs were intended to replace people in contaminated areas for delivery logistics, patient care, and disinfection [53–55]. Thanks to this, it was possible to implement solutions that limited the danger of human exposure to extreme infections and fatal illnesses.

AGVs also support operations that cause excessive physical strain on the employee. An example here may be the transport of people in a hospital between rooms, which can be supported by AGV systems [56]. Restaurants are another example where an AGV can assist staff. To reduce the burden on the waiting staff, AGVs can transport dishes to customers and bring dirty dishes [57]. Automatic systems can also cooperate with humans and support them in jointly implementing selected operations related to assembly [58] or order picking [45,59,60].

4.3. Human—AGV Cooperation

The growing requirements in the internal transport sector, seen as achieving the highest possible effectiveness or efficiency, means that researchers are looking for new ways to improve AGV systems. One of the possibilities is to focus on cooperation between AGVs and humans, which is settled in a dynamic environment and changes over time [64,70,72,84,85,92]. Human experience [56,58–63,65,80,82] is considered in these cases. To describe this cooperation, the authors used the following:

- HRC—human-robot collaboration [58,74],
- HRI—human-robot interaction [58,70,81],

- HMI—human-machine interference [66,73].

In a system with a human-centered design, where workers cooperate with AGV, it is important to use information about people's ways of acting. In [61], the work of the AGV was based on human behavior and was analogous to nature, so the AGV work was more predictable and understandable for workers. A similar approach was presented in the research prepared by [108], where AGVs could anticipate human behaviors and predict their trajectory because human movements are usually directly motivated by their tasks. In [62], a controller was proposed, which mimics the standards of human vehicle control, for example, "situation-aware speed adjustment on curved paths". Prati et al. adopted a human-centered approach to prepare a set of guidelines with details on information exchange between humans and robots. These investigations highlighted that using these methods could improve system performance [58]. Equally important is how to introduce the AGV system into the enterprise. Challenges and measures to support communication between AGVs and employees were mentioned in [63]. In [65], a survey of employees who had interacted with AGVs was presented. The survey tested employees' opinions on success factors and acceptance, as well as on their satisfaction with the implementation of AGVs. The results revealed significant differences in the perception of AGVs by high-level managers, project leaders, and operational staff.

To prepare the system described above, designers need proper information and the database, so there must be complete communication between AGV and humans. Vlachos foregrounded that AGV information should be used to raise awareness and improve the interaction between humans and AGV. For this reason, to ensure the possibility of data exchange between the AGV and a human, the prepared interface should be straightforward and convenient for the operator [66]. David et al. proposed an architectural approach for AGVs, which was interoperable and accessible and could be used with any type of AGV. In this approach, every piece of information could be helpful and used for future research or system updates [67]. Ballal et al. [68] proposed a wireless data acquisition and communication system between the user and the AGV. The data acquisition from the AGV was accomplished with the help of sensors mounted on the vehicle. The sensors could continuously collect the incoming signals along the path, which were transmitted via Wi-Fi, and the information was displayed to the user on a laptop [68]. Some researchers highlighted that communication with AGV must be bidirectional [58,69,70]. In the wireless communication systems described in [71], the important feature was the communication between sensors located on AGVs with Access Points (APs), based on which the truck's position in space could be determined. Other researchers assigned to this group prepared systems that enabled real-time co-working with AGV. Correct communication can be accomplished in the following ways:

- call system [72,73],
- follow-me system [73–78],
- guide-me system [55],
- control system [69,79–81], mainly performed by hand gestures [79–81].

Mohsin analyzed the appropriate settings of the AGV user panel (parameters such as height, angle, and distance to the operator) and its impact on working conditions for a human to design an ergonomic workplace with all required applications [82]. In the case of human-AGV cooperation in special applications, such as automobile assembly lines, parameters related to the speed of the AGV cart along with the human positioned on it are important [83]. Coelho points to an equilibrium between human resources and AGVs to project a collaborative workspace with an optimal number of workers and AGVs [84]. The examination of AGV and human cooperation could also be used in the order-picking process, where humans and AGVs cooperate and need to be scheduled in the most appropriate way [45,59,60,85,86]. Papcun proposed an Augmented Reality environment where planned AGV paths can be checked, and users have the possibility to determine areas for humans, AGVs, or where both cooperate [70]. In addition, AGV-human cooperation can be checked by simulations [84], numerical simulations [85], or Virtual Reality [74].

4.4. Designing a Safe Work Environment

One of the main categories is "Designing a safe work environment". Safety plays a key role in designing communication paths and navigating AGVs because AGVs move in a shared space with people, as shown in Figure 4. Sharing space creates dangerous situations that may threaten the life and health of employees and also damage AGVs.

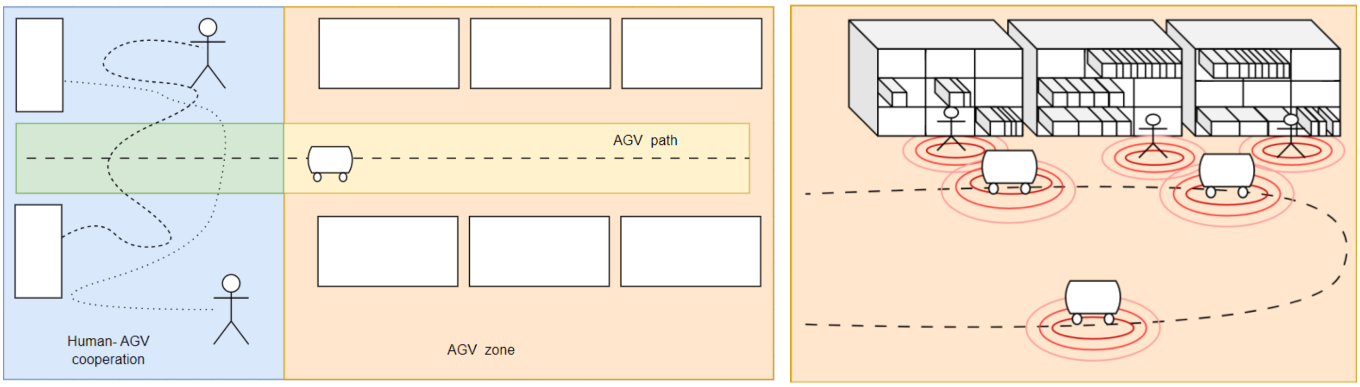

Figure 4. Examples of sharing space between humans and AGVs.

The first subcategory refers to detecting environmental obstacles, including fixed obstacles and people. During operation, technical systems should obtain the required information about the position of obstacles in the space they move [75,87–94]. Therefore, articles in this group focused on technologies and methods for collecting real-time data on elements on the AGV route. In the analyzed publications, this data was directly collected by the transport device [95–98], by using cameras [96,98–102], laser sensors [95,99–101,103–105], and ultrasound [95], as well as indirectly, using sensors located on a human (Ultra-wideband system—UWB) [99,104,106–108]. In some articles, hybrid solutions were presented [101,103,104,109,110,112]. Hybrid solutions are most often a response to the limitations of traditional detection systems. For this reason, some authors focused their research on developing advanced detection systems that would make it possible to make high-level decisions in dynamic environments. An example of such a solution is the PAN-ROBOTS project described in [111].

The critical aspect is the navigation system, which allows the AGV to smoothly move along the designated route. For this purpose, appropriate programs, algorithms, and systems are created, responsible for the correct movement of AGVs along fixed routes [108,113–124]. Regarding navigation, it is also crucial that the AGV continues the task in the event of a disturbance (e.g., an obstacle). For this reason, a large portion of the publications concern [70,110,125–133]: (1) the reaction of the vehicle to the occurrence of a disturbance during the task; and (2) the method of determining a new, optimal route to achieving a goal for a given mission. The aspect of path optimization becomes crucial in this case, as it allows for more efficient use of the available infrastructure. This is possible by appropriately using software adapted to the place of application based on VLC (Visible Light Communication) [134], a heuristic model [128], color Petri nets [136], and FSD (Free Space Detection) algorithms [135].

The third subcategory is safety validation. This validation has been divided into three research areas. The first refers to the possibility of using risk analysis to validate the safety of the AGV system. Such analyses were presented in [137,138]. Thanks to the analyses carried out in [137], it was possible to identify the wrong places in the system and consider the risk of situations threatening its functioning. On the other hand, in [138], the authors' attention was primarily focused on the risks of human-machine interaction. Some authors used various simulation tools and test programs to identify dangerous situations and determine the level of risk. These articles constituted the second research area in this subcategory and included research related to verifying simulation methods [85,139–141] and systems and testing available solutions [109]. The last area of research in this subcategory is safety assessment publications to prevent future accidents. An example of such solutions is the research presented in [133], which describes a system for preventing accidents between a human and a machine. In [142], the authors presented a disturbance management support system based on the CBR (Case-Based Reasoning) system, which assigns disturbances to appropriate classes. On the other hand, [143] presented CSMA/CA-based Random Access Control Suitable for Delay-Constrained Packet Transfer, designed to prevent collisions in smart factory environments.

4.5. Other

The "Other" group included articles that were inconsistent with any of the distinguished categories. In these articles, human-AGV interactions were studied in approaches other than those discussed above. In [144], the authors studied the role of AGVs and human factors as indispensable components of automation systems in the cell formation and scheduling of parts under fuzzy processing time. In [145], the authors described cooperative autonomous product tracking and maintenance systems using automated guided vehicles to minimize human interaction inside a smart factory. Noteworthy is the project experiences related to implementing automated solutions described by [146]. In their publication, the authors pointed out that only some recipes for introducing automation in the factory exist. However, cooperation between humans and machines is crucial to reduce production costs by automating simple and repetitive logistics operations.

5. Discussion

The analysis of the articles selected by the systematic literature review indicated an increasing interest in the subject of challenges related to human-AGV interaction in complex sociotechnical systems. The upward trend has primarily been observed since 2019, which two phenomena may have caused: (1) the development of the Industry 4.0 concept and the growing interest in the automation of simple and repetitive logistics and production operations; and (2) the COVID-19 pandemic demonstrated the limitations on the work of teams exposed to virus infection and absenteeism caused by numerous illnesses.

Therefore, it is worth noting that the links regarding human-AGV interactions related to the development of Industry 4.0 are clearly indicated and emphasized in the published studies. In contrast, references to the impact of the COVID-19 pandemic are only indicated in a few publications. However, this trend may change due to research currently being conducted in the post-pandemic period.

The research issue's importance is also evidenced by the fact that the search returned four review articles in this area in the last three years [31,33,34,36]. This means that the topic of human-AGV interaction appears more and more often in publications and allows for identifying new related research areas. This is justified by the growing popularity of implementing Industry 4.0 tools (including AGV systems) and the growing importance of human security in cyber-physical systems. Digital technologies, which are the basis of Industry 4.0, provide significant opportunities but also carry new forms of risk [147]. It is also worth noting that the heterogeneous nature of the Industry 4.0 network causes significantly more degrees of freedom in the social-technical relationship that was not conceivable in the context of conventional technologies [148], which translates into new levels of human-AGV cooperation.

When answering the research questions, it should be emphasized that mainstream research focuses on safety-related aspects. Safety issues are analyzed in publications included in the "Designing a safe work environment" category, but also in selected documents classified in the "Comparison of AGV and human work" and the "Organization of collaborative workspace". In the "Designing a safe work environment" category, the described research focuses on the risks associated with sharing the working environment and the possibility of potential human-vehicle collisions. To eliminate the potential threat, the selected documents describe possible simulation and testing tools that can reduce the occurrence of potentially dangerous situations at the system design stage ("Safety validation"). In the case of the "Process improvement" subcategory, only four documents concerned the improvement of safety in the implementation of AGVs. However, articles classified in the other subcategories of the "Comparison of AGV and human work" research focused on improving human safety and health protection through implementing the AGV system.

Regarding safety, it is worth referring to earlier research published in [27]. In those studies, a literature review was conducted to identify the risk associated with the functioning of the AGV system in logistics processes. The conducted analysis showed that the human factor as a source of risk related to the functioning of AGVs was only the subject of research in a few publications. This could suggest that this factor is not perceived as a significant risk source in the AGV systems' operation. However, this approach seems unjustified, considering the analysis presented in this article. A human is a source of risk in AGV systems not only due to a potential collision with a moving vehicle but also due to errors made in cooperation with the technical system.

This research has proven that communication between the operator and the system turned out to be an equally important issue. This was confirmed by numerous publications classified in the "Human—AGV cooperation" category, which addressed the issue of improving systems for exchanging messages between a human and a vehicle in real time. This improvement concerned communication methods and specific guidelines for the design of the AGV user panel. Many publications on human-AGV interaction also referred to the benefits of replacing human work with an automated solution. Documents included in the "Process improvement" category allowed for distinguishing as many as six areas of impact of replacing humans with AGVs. The increase in efficiency and productivity recorded in these studies will contribute to their further development and implementation in production and logistics systems, particularly in smart factories.

The analyzed publications indicate that Industry 4.0 has caused significant changes in current social engineering systems. People and AGVs share the work environment in these systems and perform everyday tasks [31]. This generates new challenges in the design, implementation, and operation of AGV systems. This is confirmed by studies included in the "Human—AGV cooperation" category, particularly those publications relating to the requirements for communication between a human and the AGV system. At the same time, as noted by [147], to take advantage of the potential benefits of implementing Industry 4.0, it is necessary to ensure compliance not only with the technical architecture but also to formulate Industry 4.0 as a socio-technical system. Meanwhile, as the same authors note, the principles of Industry 4.0 currently primarily focus on technical implementation. This causes the socio-technical aspects of this implementation to be still overlooked [147]. The results of the analyses presented in this article emphasize the critical role of social aspects that should accompany technology development. It should be remembered that the tools of Industry 4.0 are primarily intended to serve people. Hence, it is essential to study the relationship between human and machine to be able to define the principles of cooperation better and strive for a situation where Industry 4.0 is not only a technological tool but also an element of the organizational culture of the company, considering the needs of a wide range of stakeholders [147].

The analysis of publications allowed us to propose a classification framework for documents describing the human-AGV interaction. However, it is worth noting that the topics in the selected documents covered issues belonging to several categories, which have been included in Table 3 and a description of each category is presented. This shows the complex relationship between a human and a vehicle sharing a working environment and, in which, must interact with each other.

The proposed research framework for the area of cooperation between humans and AGV systems, as well as the conducted classification of the analyzed publications, made it possible to assess the degree of completion of individual groups. Analyzing the distinguished thematic groups also made it possible to identify the current research gaps. The first gap is the lack of research on the methods of assessing interdisciplinary risk related to the functioning of humans and AGVs in a common work environment. Risk assessment was the subject of the research described in publications belonging to the "Safety validation" subcategory (among others in [137,138]) and was only concerned with safety aspects. As has been proven in the reasoning presented above, safety issues are critical, but this is not the only area of potential risk associated with human-AGV cooperation. The risk may also occur in the form of errors that may reduce performance indicators or threaten the achievement of operational goals. For this reason, research is needed to identify risk factors and methods for their analysis and assessment, which will allow for the preparation of appropriate risk management procedures at the design stage of the AGV system, but also in the process of its operation and maintenance, and the implementation of commissioned operational tasks. This is confirmed by research on other complex socio-technical systems [17]. AGV systems implemented as support for logistics processes in smart factories are an example of complex socio-technical systems. They comprise numerous cooperating elements, including technology, people, and organizations [149]. Interactions between these three sets of elements can be non-linear and dynamic [150], which may intensify undesirable consequences found in complex systems [151]. In addition, according to Hollnagel, this fact makes it necessary to consider the transition from "human error" to "human performance variability" [149] in the risk analysis, which means that conventional tools are unable to understand the risk associated with the variability of results [152]. For this reason, research is needed to identify risk factors and methods of their analysis and assessment, which will allow the preparation of appropriate risk management procedures at the design stage of the AGV system, but also in the process of its operation and maintenance, and the implementation of commissioned operational tasks.

The second significant research gap is the lack of research focused on the requirements for creating sustainable workplaces that include the shared space and working environment of humans and AGVs. Publications categorized under "Human-AGV cooperation" primarily focused on the safety of interaction and mutual communication between humans and automated vehicles. However, none of the analyzed articles included research results directly aimed at aspects of sustainable planning and the design of the shared environment and work organization. In our opinion, the critical issue in this case is using the results of interdisciplinary risk assessment in creating sustainable workplaces. Based on the analysis and evaluation of potential adverse events, it is possible to create a work environment that is more friendly and productive for all participants in material handling processes while making efficient use of the resources consumed.

6. Conclusions

The systematic review presented here identified 117 publications on human-AGV system interactions. This study has important implications for practitioners and researchers. The proposed classification framework shows the dominant directions of research over the last five years. This allowed us to identify the current research gap that can be filled by people researching the design and operation of AGV systems. This is important from the point of view of Industry 4.0, the further development of which depends on reducing the risk associated with the cooperation of automatic and autonomous systems with people. At the same time, classifying the analyzed documents has a practical dimension. It groups publications relating to individual aspects related to the implementation and operation of AGV systems in such a way that the classification framework guides those seeking good practice in this area. The presented characteristics of individual articles allow one to quickly find documents providing information on guidelines for implementing automatic systems, the benefits of AGV systems, and tools for testing their effectiveness.

The research procedure can be considered comprehensive. The two most crucial journal databases were included. However, the focus of attention only on articles and proceedings papers and the lack of non-reviewed documents in the analysis, which often appear in magazines and on industry websites, is a limitation. However, such action was justified by the care for the quality of the documents accepted for analysis. It is also worth noting that the work patterns and interactions between different types of AGVs and humans may vary depending on specific application scenarios and system designs. In the analysis presented here, this aspect concerning specific examples was omitted. The rationale for this was the adopted goal of the conducted analyses, which focused on generalizing research trends concerning the cooperation between humans and the AGV system. For this reason, specific solutions relating to various cooperation schemes appeared in the described publications but were not highlighted as a separate research issue. The limitation of the research is also the lack of consideration of the prestige of the journal publishing the paper and its citability. This is because it is understandable that prominent publications may be more important for the research trends created, which should also be reflected in the analytical procedure. However, this restriction was declined due to the limited number of publications identified in the initial search.

The identified research gap indicates the direction of future research. For this reason, the subject of further research will be to seek answers to the following questions:

- In what areas of functioning of cyber-physical-human systems should hazards to human-AGV cooperation be sought?
- What methods of identifying adverse events should be used in the risk analysis of the human-AGV interaction?
- How to assess the risks of human-AGV interaction in Industry 4.0 systems?
- How to use risk assessment results to design sustainable workplaces where humans interact with AGVs?

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