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ORIGINAL PAPER

CHALLENGES IN THE IMPLEMENTATION OF AUTONOMOUS ROBOTS IN THE PROCESS OF FEEDING MATERIALS ON THE PRODUCTION LINE AS PART OF LOGISTICS 4.0

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ABSTRACT. **Background:** Along with the development of Industry 4.0, the concept of Logistics 4.0 is also developing in parallel. Some researchers emphasize that the fourth industrial revolution in the area of logistics concerns in particular warehouse services. New technologies related to automatic data identification and autonomous vehicles are increasingly appearing in warehouse processes. In particular, the implementation of autonomous vehicles in processes carried out so far by people generates significant challenges related to the proper preparation of the entire system, but also its coordination with processes carried out in the enterprise. The aim of the article is to present the results of the analysis of disturbances occurring in the first stage of the implementation of autonomous vehicles in the process of feeding material production lines in a surveyed company from the automotive industry.

Methods: The article presents the implementation assumptions for the use of autonomous robots in the process of materials feeding. The scope of the required safety analyzes was presented as well as the time measurements carried out regarding the implementation of the process of servicing power supplies for assembly lines. The research used direct observations in the assessed enterprise and unstructured interviews with persons responsible for the implementation.

Results: The results show the deviations from the adopted assumptions, both in the area of vehicle safety and the deviations in the time of material supply operations. It is worth noting that both positive and negative deviations from the adopted standard were recorded in the measurements. Based on the analyzes of the causes and effects of the deviations, guidelines have been developed for the changes to the functioning of autonomous vehicles.

Conclusions: The results of the presented research allowed to identify potential adverse events that may occur in the process of implementing autonomous solutions in logistics service processes. The basic rules for the implementation of autonomous solutions in logistic operations, which are carried out in anthropotechnical systems, were also indicated.

Key words: autonomous vehicles, logistics 4.0, disruptions.

INTRODUCTION

In recent years, a very intensive development of the concept of Industry 4.0 has been observed, which is referred to as the Fourth Industrial Revolution [Kagermann 2013]. This development is visible both in the practical sphere (more and more widespread implementation of solutions based on cyber-physical systems) and in the area of scientific research, which has been reviewed, among others in [Kosacka-Olejnik and Pitakaso 2019, Gajdzik et al. 2021]. In its original form, Industry 4.0 mainly concerned production processes and the creation of the so-called Smart Factory, which is equated with a smooth flow of information, ease of adaptation to a changing market environment, as well as a high level of data security [Odważny et al. 2018b]. Gajdzik et al. [2021] emphasize that Industry 4.0 is a strong combination of operational technology (OT) and information technology (IT) in production. However, the growing popularity of this concept caused the fourth revolution also in processes supporting

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production processes, such as logistics and maintenance. For this reason, the simultaneous development of Logistics 4.0 can be observed, which is now considered an integral part of Industry 4.0 [Kostrzewski et al. 2020]. The Logistics 4.0 is linked to such notations as Smart Services and Smart Products [Cyplik et al. 2019]. For this reason, as emphasized by Wawrla et al. [2019], the fourth industrial revolution in the area of logistics concerns in particular warehouse services. For this reason, new technologies related to automatic data identification and autonomous vehicles are increasingly appearing in warehouse processes.

The potential for the implementation of new technologies in the area of warehouse services is large due to the fact that these are routine operations, based on a certain pattern of conduct, which in the traditional system generates a high demand for man-hours of the staff. At the same time, in many cases these activities are simple, repetitive and do not require high competences. For this reason, in the face of the current demographic decline and the growing employee market, companies are looking for solutions that will allow them to eliminate the human factor in some operations. This is especially true for enterprises in the phase of intensive development. The planned increase in warehouse turnover and an increase in employee salary make the implementation of automatic solutions in logistics processes attractive. This is confirmed by the research presented, among others in [Čámská and Klečka 2020], in which the authors proved that enterprises can achieve higher profitability through the human labor replacement by machines (robots) and other new technologies.

However, the implementation of autonomous vehicles in processes carried out so far by people generates significant challenges related to the proper preparation of the entire system, but also its coordination with processes carried out in the enterprise. For this reason, the aim of the article is to present the results of the analysis of disruptions occurring in the first stage of the implementation of autonomous vehicles in the process of production line material feeding on the example of a project carried out in a selected company from the automotive industry. The structure of the article includes a literature review on Logistics 4.0 and the implementation of autonomous vehicles. Then the methodology and scope of the conducted research were discussed and the obtained results were presented. Based on the achieved results, final conclusions were formulated regarding the challenges of preparing the organization to implement solutions in the area of Logistics 4.0.

LOGISTICS 4.0. – LITERATURE REVIEW

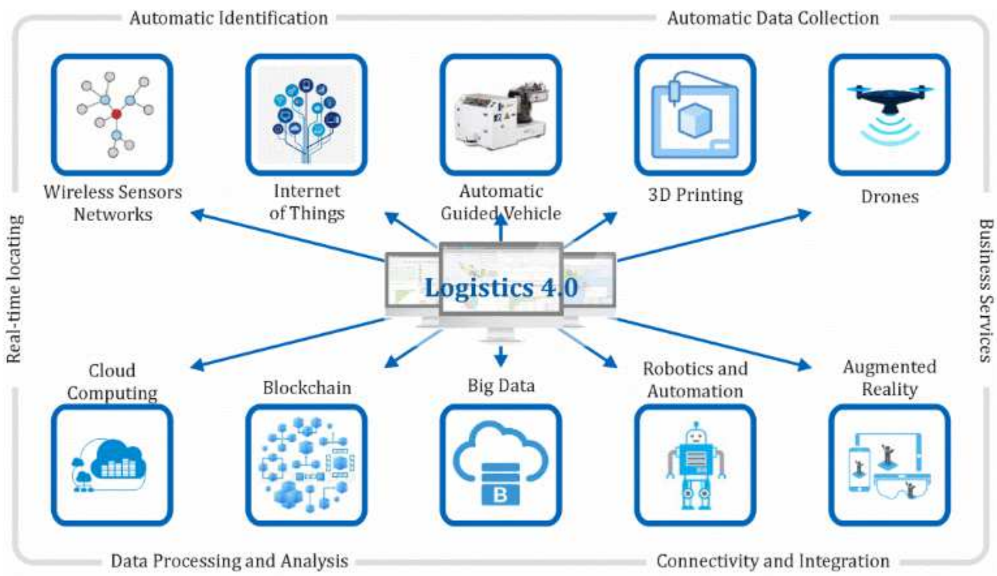
Internet access and the development of mobile devices and intelligent sensor technology enabled the intensive development of the Industry 4.0 concept [Gotz 2017]. Industry 4.0 is an overall term for technical innovations and value change organization concepts that revolutionize industrial production [Gracel et al. 2017]. One of its primary goals is enabling the communication and cooperation of people and machines with the systems of information and communication technology in real-time [Odważny et al. 2018a].

Industry 4.0 is based on an innovative technology system, called Technology 4.0. The key innovations of this system include [Gajdzik et al. 2021]:

1. a new communication system that connects the digital world with the real world and enables direct communication between devices, devices and people (through human-machine interfaces);
2. intelligent sensors with built-in systems of individual identification, data processing, and communication;
3. data processing in the cloud and simulation techniques for the operation of real objects in their virtual representations, based on data provided and processed in real-time;
4. a new generation of robots that enable active interaction with the environment and adaptation to changing conditions and requirements.

Digitization of production in the concept of Industry 4.0 requires the interconnectivity and integration of the adjoining internal and external procedural landscape in order to ensure efficient value creation. For this reason, it is also necessary to digitize the processes supporting the 4.0 production system. As noted by Schmidtke et al. [2018] it requires integration of existing logistic processes into the virtual level and linking them with internal and external production facilities and partners. This makes Logistics 4.0 an integral part of the Industry 4.0 concept [Kostrzewski et al. 2020]

Many authors define Logistics 4.0 as a collective term for technologies and concepts of value chain organization. The key element of this concept is the creation of a cyber-physical system supporting logistic processes. The term cyber-physical systems (CPS) refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities [Baheti & Gill 2011]. Wang [Wang 2016] notes that within the logistics, CPS monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions and thanks to IoT, CPS communicate and cooperate with each other and humans in real-time. According to [Barreto et al. 2017] Logistics 4.0 can be seen as a supply network where all processes can communicate with each other, as well as with humans for enhancing their analytical potentialities throughout the supply chain. Optimization carried out within this network must be supported by intelligent systems, embedded in software and databases from which relevant information is provided and shared through the Internet of Things (IoT) systems, in order to achieve a major automation degree [Barreto et al.2017]. For this reason, Logistics 4.0 combines two aspects of material flows [Szymańska et al. 2017]: processual (supply chain processes are a subject of the Logistics 4.0 actions) and technical (tools and technologies that support internal processes in the supply chains). Therefore, an efficient Logistics 4.0 system must use the following technological applications [Baretto et al. 2017]: (1) Resource Planning, (2) Warehouse Management Systems, (3) Transportation Management Systems, (4) Intelligent Transportation Systems and (5) Information Security. The most important technological components used in Logistics 4.0 are shown in Figure 1.



Source: AtiGA 2020

Fig. 1. Components and technologies of Logistics 4.0

The development of Logistics 4.0 in production and logistics companies has caused changes in the current material flows in supply chains. The most important development trends in this area include [Glistau & Coello-Machado 2019]: (1) Cloud software, (2) Edge Computing, (3) Artificial Intelligence, (4) Big Data Analysis, (5) Blockchain technology, (6) Decentral organization and self-organization, (7) Networking, (8) Autonomous driving, (9) New professions and activities in logistics, (10) Infrastructure and smart infrastructure. The subject of the research presented in this article is the use of autonomous vehicles in logistics 4.0 systems. The studies described in [Wen et al. 2018] presented several areas in logistics that could be supported by autonomous swarm robotics, e.g. efficient transportation or green Logistics. These systems are also of particular importance in warehouse operations, and their implementation results primarily from economic benefits, which include [Bechtsis & Tsolakis 2018]:

- a capability to function on a 24/7 basis;
- a minimization of labor cost;
- a low maintenance cost;
- an enhanced accuracy in daily activities, and
- an improved safety at industrial facilities.

The most frequently used autonomous vehicles in Logistics 4.0 systems include Unmanned Aerial Systems (UAS) and Automatic Guided Vehicles (AGV). This article focuses on the use of Automatic Guided Vehicles in logistics processes. AGVs are unmanned vehicles based on sensor and video detection technologies, artificial intelligence, and other information and communication technologies. AGV vehicles that are used in logistic processes may be [Radivojević & Milosavljević 2019]: tractors for towing trailers, vehicles for unit loads, pallet trolleys, trolleys with additional forks, light load vehicles, assembly line vehicles, special vehicles, etc. These vehicles are used for traditionally demanding tasks; they enable automatic handling of freight and equipment. The application of AGVs in logistic processes decreases expenses and labor, increases reliability, productivity, safety and quality of work, reduces the risks of human errors and damaged, etc. [Kückelhaus & Chung 2018]. Some authors, however, also pay attention to the limitations associated with the use of AGVs. [Zhang et al. 2018] highlight three main problems with the use of AGV:

- The urgent tasks are unable to be dealt with because of the low flexibility of the AGVs.
- AGVs have to stop to avoid collisions due to the limited detecting distance.
- The workspace is seldom optimized in order to increase the number of vehicles operating in the limited area.

However, the currently identified limitations will be removed through intensive development, e.g. towards increasing vehicle intelligence [Zhang et al. 2018]. Thanks to this, according to the research [Kostrzewski et al. 2020], the use of AGV in Logistics 4.0 will represent future trends in less than the next 5 years. However, according to the consulting company ABI Research, the robots will become the so-called warehouse standard until 2025 [Kulikowska-Wielgus 2019]. Currently, it can be noted that in some systems, AGVs are used as basic devices, while in some logistic systems they supplement the existing cargo manipulation system [Jurczak 2019].

METHODOLOGY AND SCOPE OF RESEARCH

The aim of the research is to analyze the potential and risk associated with the use of AGV robots in logistics systems. According to the research presented in [Automatyka B2B 2019], AGV vehicles are most often used in warehouse logistics, as well as in production and intralogistics. From the point of view of the coordination of internal processes, the case of the use of robots in intralogistics is particularly interesting. Moving loads between the warehouse and the production area is exposed to more disruptions because delivery processes are carried out at the junction of two areas of the company's activity. For this reason, the material supply process on assembly lines in the intralogistics system of a manufacturer from the automotive sector was selected for the study.

The material supply system for the assembly stations concerned the operation of two assembly lines shown in Figure 2. Loop 1 is 420 m long, and loop 2 is 300 m long.

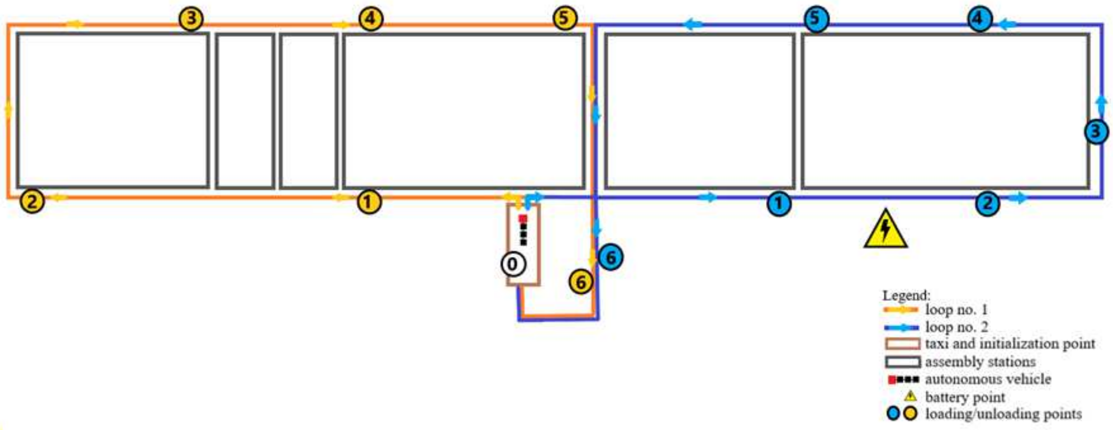


Fig. 2. Presentation of the assembly lines supported by the AGV system

The implementation of the system was carried out in accordance with the procedure described in [Poturaj & Lewandowski 2020]. This procedure includes 7 steps of the procedure presented in Figure 3. From the point of view of the conducted research, the "Implementation" stage is particularly important.

It is also worth noting that the research presented in [Automatyka B2B 2019] indicates that for AGV users, safety and reliability are of significant importance when implementing this solution (see Figure 4). Both of these elements are subject to specific monitoring during the implementation phase. For this reason, the results of these analyzes are presented in this article.

Research on the safety of use of AGV devices was carried out in cooperation with the Health and Safety Department. As part of the evaluation carried out, it was checked:

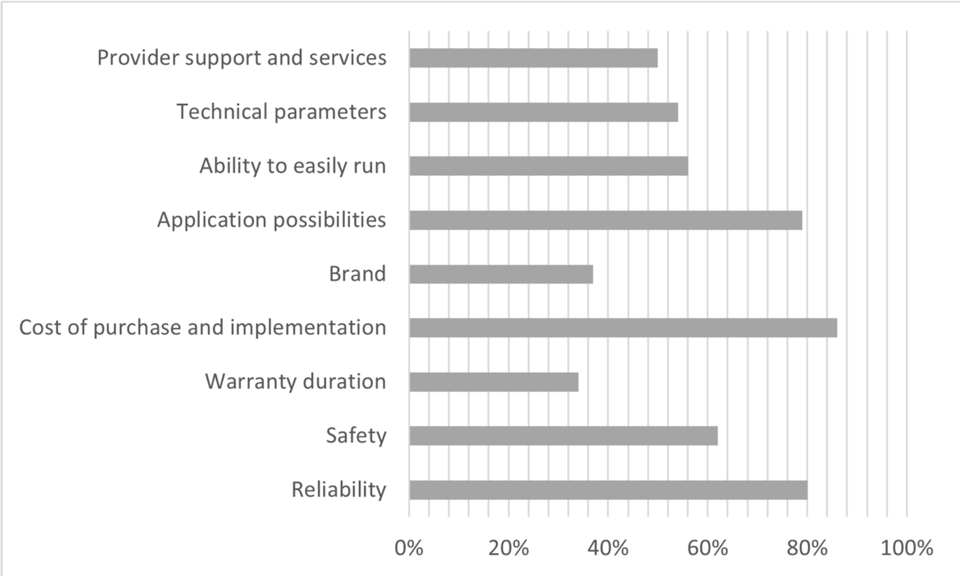
1. Vehicle equipment, including: warning lights related to the operating mode of the device; emergency stop system; laser curtain scanner for obstacle detection, LED light informing pedestrians about the approaching work
2. The applicable fields for dynamic deceleration and stopping of the device.
3. Functioning of the device in the event of loss of reference to the mapped path (the vehicle goes into error mode when the navigation laser is not able to measure a sufficient number of points).

The parameters of the device offered by the manufacturer were compared with the safety standards required by the organization and on this basis, the possibility of approving the vehicle for use was determined.

Reliability can be understood as the lack of failure of the device, but also as failure-free (correct) execution of the process. For this reason, as part of the research carried out in the first phase of implementation, the correctness of the mission of delivering components to the assembly stations was assessed. At the stage of testing the system, the failure rate of vehicles was assessed primarily from the safety point of view, as described above. With regard to the reliability assessment, the measurement concerned the time of vehicle travels and the completeness of the mission (delivery of materials to all planned assembly stations). The reliability analysis method is shown in the Figure 5.

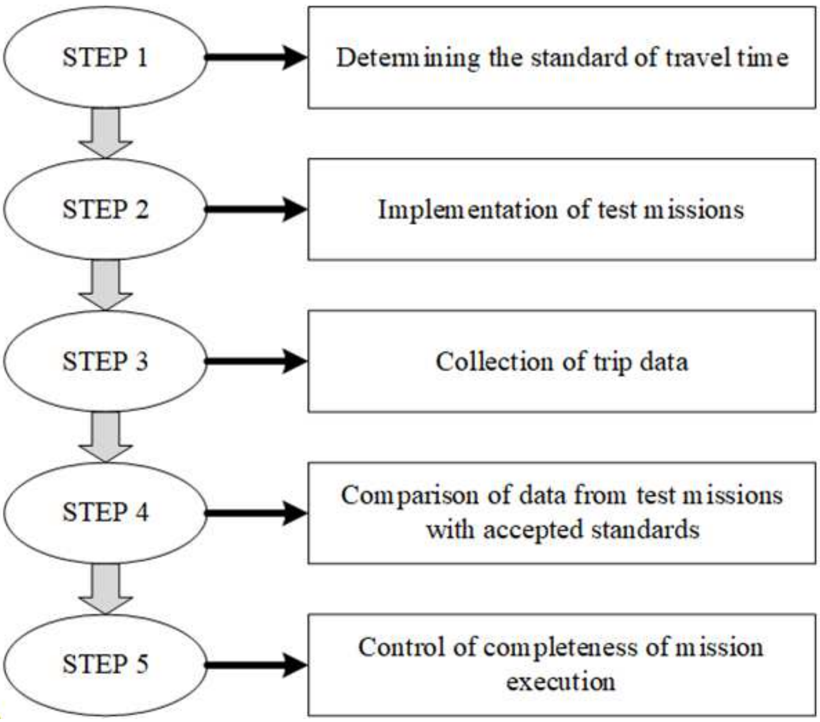
Source: Poturaj & Lewandowski 2020

Fig. 3. Implementation scheme



Source: Automatyka B2B 2019

Fig. 4. Criteria for the selection of AGV solutions by future users



Source: Automatyka B2B 2019

Fig. 5. Reliability analysis method

In the first step, the standard travel times of the device along each assembly line were determined. These standards were defined by the implementation team based on the adopted assumptions regarding the speed of vehicle movement and the average time of loading and unloading materials at the assembly station. The following times were assumed for both lines:

- Correct travel time - 15 - 20 minutes.
- Too short travel time - less than 15 minutes - means that the vehicle did not stop in all designated service zones.
- Too long travel time - more than 20 minutes - signals that the route was disturbed or the vehicle waited too long to be loaded or unloaded by assembly line workers.

The tests were carried out in two stages in accordance with the procedure presented in Figure 3. The first stage: "The vehicle moves under the supervision of the operator" was carried out in the period October 28 - October 30. The second stage: "The vehicle moves independently" was carried out in the period October 31 - November 3.

The data on travel times for each mission was collected from the Robot Manager system recorder that each vehicle is equipped with. The data collected in this way was analyzed in terms of meeting the standards adopted in step 1. Then, the completeness of the missions was checked.

For a detailed analysis of the time deviations recorded during the measurement, the following were used: (1) cause and effect analysis, (2) direct interviews with selected representatives of the warehouse zone and the assembly line, (3) the Ishikawa diagram.

RESULTS

In Logistics 4.0 systems, special emphasis is placed on security issues that must be guaranteed in connection with the cooperation of people and automated systems. Before starting the tests of the AGV vehicle in the real system, it was necessary to obtain the approval of the Health and Safety Department in the scope of including it in the processes carried out in the storage area and the assembly line. The Health and Safety Department actively participated in the 2nd stage of the implementation process – “System Planning". As a result, the selected device to be implemented in the enterprise complied with the approval conditions that were specified from the point of view of process implementation security. The vehicle is equipped with:

- Stack controller module - two warning lights (green and blue) controlled by the original truck system and two warning lights (orange and red) controlled by the automatic control system.
- Emergency stop button.
- Laser curtain scanner.

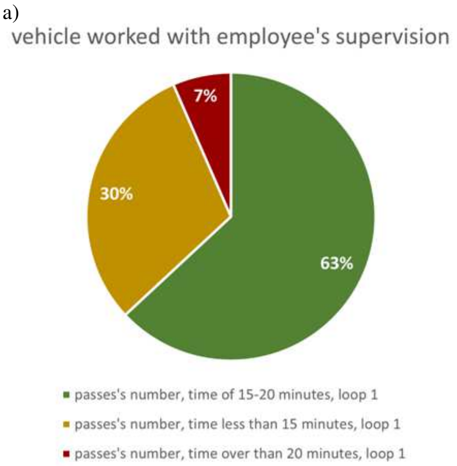
However, the standard equipment offered by the manufacturer did not meet the internal health and safety requirements regarding the visibility of the vehicle and reporting irregularities during the implementation of the mission, i.e. when moving in the storage and assembly area. For this reason, it was necessary to place additional signaling, located on each wagon. It has two colors - green and red. When the green part of the siren is on, it means that all elements are properly connected. Turning on the red lamp means that there are irregularities in the group consisting of a tractor and wagons.

The second area of research was the assessment of the reliability of delivery missions. To analyze the correctness of the missions performed, time measurements were taken in two stages, which are described in the Methodology section:

1. „The vehicle moves under the supervision of the operator "- the total number of test runs was: loop 1 - 46 missions, loop 2 - 30 missions.
2. „The vehicle moves independently "- the total number of test runs was: loop 1 - 70 missions, loop 2 - 47 missions.

Measurements were carried out separately for each of the serviced assembly lines. Therefore, Figures 6 (a) and 6 (b) show the share of individual travel times achieved in stage 1 - moving under the supervision of the operator, while in Figures 7 (a) and 7 (b) - in stage 2 during independent movement of the vehicle.

a)



b)

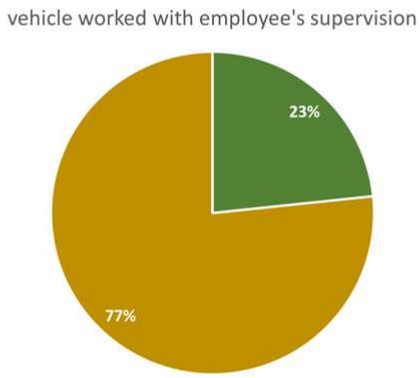
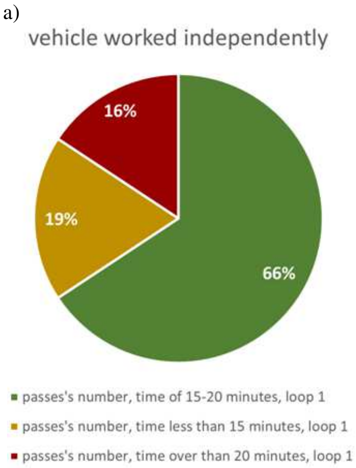


Fig. 6. The share of the individual times of vehicle movement under the supervision of the operator (a) on line 1 and (b) on line 2.

Measurement of the operation of the device under the supervision of a warehouse employee showed that for Loop 2, most of the completed runs were completed below the target of 15 minutes. Only 23% of the journeys were made in accordance with the assumption. At the same time, on the basis of observation carried out by the person supervising the operation of vehicles, it was found that only in part of the journeys there was a skipping of selected service zones. A detailed analysis has shown that the required travel times on loop 2 should be shorter than in the case of loop 1 (shorter route and fewer service zones).

a)



b)

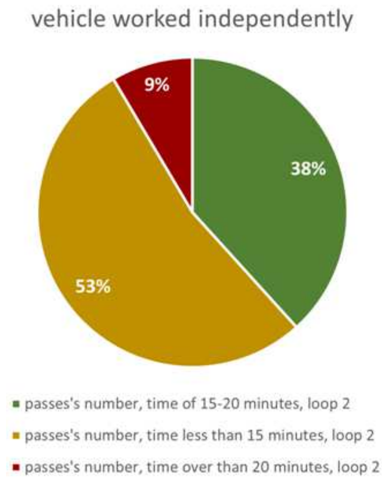
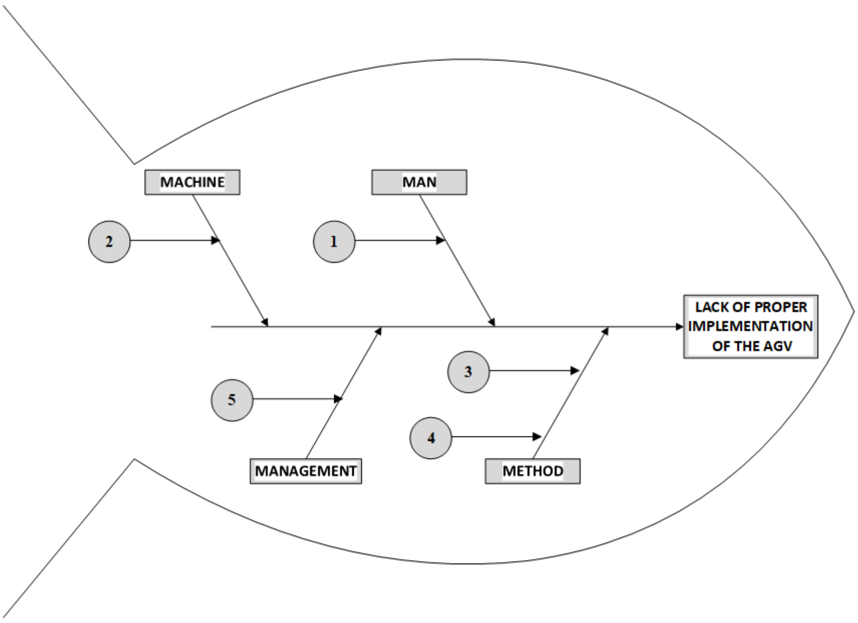


Fig. 7. The share of the individual times when the vehicle was traveling alone (a) on line 1 and (b) on line 2.

The independent implementation of the mission by the vehicle increased the share of journeys exceeding 20 minutes. The cause-and-effect analysis proved that the source of the occurring delays is the prolonged stay of the vehicle in the service zones. The main cause of this situation is the duration of the unloading and loading operations of the vehicle by the assembly line operators. The conducted direct interviews proved that many employees, due to the use of personal protective equipment (e.g. ear muffs, glasses), do not always see the vehicle waiting for unloading. One of the reasons given was the lack of regularity of the train run (no fixed service hours). At the same time, the analysis of the vehicle departure times for each line showed that the train was leaving on line 2 more frequently than it was expected from the schedule. In-depth interviews with delivery operators revealed that the initially adopted delivery schedule for this line is insufficient. This makes it necessary to carry out additional deliveries beyond the designated tact.

The obtained results of the mission analysis should be considered statistically significant. For this reason, it was necessary to conduct additional analyzes that identified the reasons for the deviations from the adopted standard. All indicated disturbances recorded during the implementation phase were classified according to the Ishikawa diagram presented in Figure 8.



1 – Longtime of loading and unloading the vehicle by an assembly line worker
2 – Limited visibility of the vehicle
3 – Standard travel time incorrectly specified
4 – Incorrectly specified frequency of travel
5 – No fixed hours of service

Fig. 8. Ishikawa diagram for recorded adverse events during the implementation phase.

A well-conducted implementation phase allowed to identify significant disruptions in the implementation of the AGV system in the material supply process for the selected two assembly lines. Thanks to this, it was possible to supplement the vehicle's equipment with additional lighting elements and to change the schedule of journeys on both lines. In this way, the risks associated with the functioning of the anthropotechnical system in which autonomous vehicles must cooperate with people were limited.

CONCLUSIVE REMARKS

The implementation of automated solutions in logistics processes is playing an increasingly important role. This is the result of the development of the Logistics 4.0 concept, an increase in employee salary costs, and the progressive development of new technologies for this area. Autonomous vehicles that support warehouse operations and material supply systems in production are currently particularly popular.

The concept of Logistics 4.0 is a new trend that is currently developing as part of improving the functioning of individual cells as well as entire supply chains. On the basis of an increasing number of implementations, good practices are formulated that allow implementation companies and their clients to prepare better and better for this process. In this area, publications on potential adverse events and methods of risk assessment related to implementation are of particular importance. For this reason, the aim of the article was to analyze the potential disruptions occurring in the first phase of the implementation of autonomous vehicles. The significant contributions of the presented research include:

- Identification of adverse events related to the AGV implementation phase.
- Including in the analyzes not only the assessment of the functioning of the vehicle itself, but also its functioning in cooperation with the environment.

At the stage of choosing the right solution, the particular attention of decision-makers is focused on the costs of purchasing and implementing such a system. However, in the operation phase of autonomous devices, decision-makers focus their attention primarily on the safety and reliability of these vehicles in the anthropotechnical system. For this reason, the testing phase should include at least 2 stages of the assessment of the operation of these devices: (1) work with human supervision and (2) independent operation of the vehicle. Particular emphasis should be placed on the first stage of device performance evaluation. The operator's supervision over the device should concern not only the correctness of the delivery mission carried out by it, but also its functioning in the anthropotechnical system. Thanks to the operator's report on the completed mission, it is possible to assess the correct functioning of the vehicle and delivery reliability in the logistics process, as well as its cooperation with the operating environment.

Simulation tests can provide better preparation for the testing phase by eliminating potential hazards related to the operation of the device in an anthropotechnical system. By mapping the real system in the simulation model, various decision-making variants regarding future material supply and AGV operation can be analyzed. At the same time, the analysis of simulated flows will allow to identify potential undesirable events still in the virtual model phase. Thanks to this, it is possible to limit their occurrence in the real system before the start of the test phase.

The article presents the results of the test phase of a selected power supply system of assembly lines. The conducted analyzes indicate that even proper preparation of the system for operation, taking into account the safety and reliability aspects at an early stage of system design, does not guarantee success. Only the tests of the device's operation in real conditions show the potential threats that may occur in connection with the integration of the elements of the anthropotechnical system. For this reason, in the testing phase, not only the failure-free operation of the device itself should be assessed, but it is also necessary to observe its cooperation with the environment. It should also be remembered that introducing improvements / corrections after the test phase should not end the process of monitoring the functioning of the device. Due to the changing environmental conditions, wear of the AGV system components and human-vehicle cooperation, it is recommended to perform further systematic evaluation aimed at identifying potential hazards in the activities performed.

The research presented in the article is an introduction to the development of detailed risk analysis for adverse events related to the implementation of solutions in the Logistics 4.0 system. The analysis of adverse events was focused primarily on the process aspects related to the correctness of achieving the assumed goal for the delivery mission. However, in the next stages of research it is justified to carry out a risk analysis in accordance with the ISO 12100:2012 standard, which will allow for a comprehensive assessment of the risk posed by AGV machines in the logistics service environment.

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REFERENCES

Advanced Logistics or Logistics 4.0, 2020. AtiGA International Technological Alliance of Galicia. Available on the Internet: https://www.atiga.es/en/advanced-logistics-or-logistics-4-0/ (15/04/20210)

AutomatykaB2B, 2019. Roboty współpracujące i mobilne roboty AGV. Raport z rynku [Collaborative robots and mobile AGV robots. Report form market], Available on the Internet: https://automatykab2b.pl/raporty/51097-roboty-wspolpracujace-coboty-agv-raport-rynek (10/02/2021)

Baheti R., Gill H., 2011. Cyberphysical Systems, The Impact of Control Technology, 161-166. http://doi.org/10.1109/ICMECH.2019.8722929

Barreto L., Amaral A., Pereira T., 2017. Industry 4.0 implications in logistics: an overview, Procedia Manufacturing 13, 1245-1252. http://doi.org/10.1016/j.promfg.2017.09.045

Bechtsis D., Tsolakis N., 2018. Trends in Industrial Informatics and Supply Chain Management, International Journal of New Technology and Research, 4(10), 91-93. http://doi.org/10.31871/IJNTR.4.10.44

Čámská D., Klečka J., 2020. Cost development in logistics due to Industry 4.0, LogForum 16 (2), 219-227. http://doi.org/10.17270/J.LOG.2020.415

Cyplik P., Oleskow-Szlapka J., Tobola A., Adamczak M., 2019. Building a Model For Assessing The Maturity Of Polish Enterprises In Terms Of Logistics 4.0 Assumption, Business Logistics in Modern Management, Josip Juraj Strossmayer University of Osijek, Faculty of Economics, Croatia, 19, 105-120.

Gajdzik B., Grabowska S., Saniuk S., 2021. A Theoretical Framework for Industry 4.0 and Its Implementation with Selected Practical Schedules. http://doi.org/10.3390/en14040940

Glistau E., Coello-Machado N.I., 2019. Solutions and Trends in Logistics 4.0., Acta Technica Corviniensis, XII (4), 129 – 132.

Götz M., Gracel J., 2017. The Fourth-Generation Industry (Industry 4.0) – Challenges to Research in the International Context, Kwartalnik Naukowy Uczelni Vistula, 1(51), 217-235.

Gracel J., Stoch M., Biegańska A., 2017. Inżynierowie Przemysłu 4.0, Kraków – ASTOR Publishing.

Jurczak M., 2019. Logistyka 4.0 w praktyce. Jak wózki autonomiczne sprawdzają się w transporcie wewnętrznym? [Logistics 4.0 in practice. How can autonomous vehicles work in internal transport?], Trans.info. Available on the Internet: https://trans.info/pl/wozki-autonomiczne-w-transporcie-wewnetrznym-131662 (20/03/2021)

Kagermann H., Helbig J., Hellinger A., Wahlster W., 2013. Recommendations for implementing the strategic initiative Industrie 4.0: Securing the future of German manufacturing industry. Final report of the Industrie 4.0 Working Group, Forschungsunion. Available on the Internet: https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-forimplementing-industry-4-0-data.pdf (20/02/2021)

Kosacka-Olejnik M., Pitakaso R., 2019. Industry 4.0: State of the art and research implications, LogForum 15 (4), 475-485. http://doi.org/10.17270/J.LOG.2019.363

Kostrzewski M., Varjan P., Gnap J., 2020. Solutions Dedicated to Internal Logistics 4.0. In: Grzybowska K., Awasthi A., Sawhney R. (eds), Sustainable Logistics and Production in Industry 4.0. Eco-Production (Environmental Issues in Logistics and Manufacturing), Springer, Cham, 243-262. http://doi.org/10.1007/978-3-030-33369-0_14

Kückelhaus M., Chung G., 2018. Logistics Trend Radar, DHL Customer Solutions & Innovation, Germany. Available on the Internet: www.dhl.com (23/12/2018)

Kulikowska-Wielgus A., 2019. Do 2025 r. miliony robotów będą obsługiwać magazyny na całym świecie [By 2025, millions of robots will operate warehouses around the world], Trans.info. Available on the Internet: https://trans.info/pl/do-2025-r-miliony-robotow-beda-obslugiwac-magazyny-na-calym-swiecie-139138, (20/03/2021)

Odważny F., Szymańska O., Cyplik P., 2018. Smart Factory: The requirements for implementation of the Industry 4.0 Solutions in FMCG Environment – Case Study, LogForum 14 (2), 257-267. http://doi.org/10.17270/J.LOG.2018.253

Odważny F., Wojtkowiak D., Cyplik P., Adamczak M., 2018. Smart Factory within sustainable development and green growth concepts, LogForum 14 (4), 467-477. http://doi.org/10.17270/J.LOG.2018.301

Poturaj H., Lewandowski T., 2020. Procedura identyfikacji otoczenia w fazie projektowania systemu transportu wewnętrznego z wykorzystaniem pojazdów AGV [Guidelines which are used in environment identification during design phase of AGV system project in internal transport], Journal of Translogistics, 6(1), 201-210.

Radivojević G., Milosavljević L, 2019. The Concept of Logistics 4.0, 4th Logistics International Conference, Belgrade, Serbia, 283-292.

Schmidtke N., Behrendt F., Thater L., Meixner S., 2018. Technical Potentials and Challenges within Internal Logistics 4.0, 4th IEEE International Conference on Logistics Operations Management (GOL), 1-10. http://doi.org/10.1109/GOL.2018.8378072.

Szymańska O., Cyplik P., Adamczak M., 2017. Logistics 4.0 A new paradigm or a set of solutions, Research in logistics and production, Poznan University of Technology Publishing House, 7(4), 299–310. http://doi.org/10.21008/j.2083-4950.2017.7.4.2

Wang K., Logistics 4.0 Solution. New Challenges and Opportunities, 2016. International Workshop of Advanced Manufacturing and Automation (IWAMA), 68 – 74. http://doi.org/10.2991/iwama-16.2016.13

Wen J., He L., Zhu F., 2018. Swarm Robotics Control and Communications: Imminent Challenges for Next Generation Smart Logistics, IEEE Communications Magazine, 56(7), 102-107, http://doi.org/10.1109/MCOM.2018.1700544.

Zhang Y., Zhu Z., Lv. J., 2018. CPS-based Smart Control Model for Shopfloor Material Handling, IEEE Transactions on Industrial Informatics 14 (4), 1764–1775. http://doi.org/10.1109/tii.2017.2759319.

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