AUTONOMOUS MOBILE ROBOTS (AMRS) IMPLEMENTATION TOOL BASED ON SIMULATION MODEL IN THE CONTEXT OF LOGISTICS 4.0

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Abstract

Increasing global competition drives the need to meet new customer demands, which leads to significant changes in modern industry. In this context, the rapid development of Industry 4.0 over recent years has been observed. The pillars of the new revolution have become technologies based on the Internet of things, cyber-physical systems, Big Data, cloud computing, robotics and simulation.

Many companies are choosing to automate their internal transport in order to eliminate human factors and reduce storage costs globally. Autonomous mobile robots (AMRs) have become a common solution. In addition to a number of problems related to their design (localization, navigation, routing, obstacle detection) widely discussed in the literature, there is also the problem of their implementation. This is influenced by many factors related to the characteristics of the system.

This publication describes a tool developed to implement AMRs in a warehouse with given characteristics such as layout, size and type of storage. Tool fits into the concept of Logistics 4.0. It allows to determine the number of robots, to determine the location of picking stations, their number and the necessary number of charging stations. In addition, it makes it possible to take into account the different intensities of the order stream.

Keywords: Autonomous mobile robot, simulation modelling, AMR implementation, Logistics 4.0, fleet size determination

1. INTRODUCTION

Technologies of a physical-digital interface, network, data processing and digital/physical process are indicated as key elements of a rapidly growing industry 4.0 [1]. There are multiple solutions considered in reference to them, such as Internet of Things, cloud computing, Big data analytics, cyber physical systems, augmented reality, and advanced robotics [2]. The indicated technologies of Industry 4.0 formulate new research problems in many scientific fields. Consequently, it is observed that new terminology is being introduced in the literature to clearly indicate the relationship of the proposed solutions with Industry 4.0. In the field of logistics, the term Logistics 4.0 is increasingly used as an answer to and support for Industry 4.0 in the form of digitalization of logistics processes [3]. This involves changes in logistics systems towards cooperation, connectivity, adaptiveness, integration, autonomous control and cognition [4]. The last two development directions are reflected in the use of artificial intelligence (AI), robots and drones in material handling operations. By introducing such solutions, the aim is to improve efficiency, lower labor costs and cover labor shortages. All of this to meet the growing demands of customers [5].

Our paper considers one of the key solutions identified in Logistics 4.0. We have addressed the topic of autonomous mobile robots (AMRs). Their operation is characterized by autonomy, allowing for work without human involvement and adjusting the performed tasks to the changing conditions of the environment. Autonomous operation determines the number of problems considered as part of research in the context of robotics, electronics, management, maintenance and many other fields of science. These numerous research studies can be placed within the life cycle phases of a technical object (**Figure 1**).

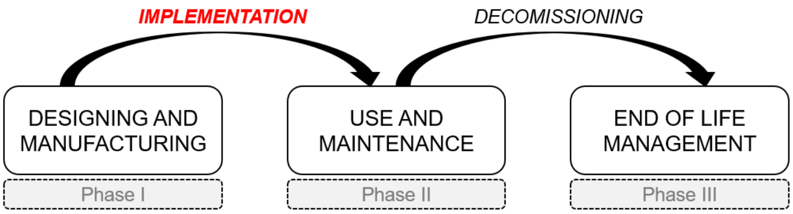

Figure 1 Life cycle of technical object [6]

Three phases can be identified in the life cycle of a technical object: designing and manufacturing, use and maintenance, end of life management [6]. Most AMR studies fall into phase I. In this phase, solutions for proper AMR operation in the context of perception, cognition, localization, navigation, obstacle avoidance and path planning are developed [7,8]. Phase II focuses on AMR management in terms of its operation (completing the assigned tasks) and maintenance. AMR maintenance is mostly referred to a battery management issues [9]. Besides this, task allocation problems, including parking and charging processes [10] can be found. In the context of AMR operation, the digital twin approach was also considered [11]. In phase three, one should consider AMR end of life management through waste from electrical and electronic equipment issues.

The literature indicates a number of studies on AMR issues that can be assigned to the life phases of any technical object. However, it was noted that the transition between phase one and phase two, namely implementation, is rarely considered. The designed and manufactured object can only be in the use and maintenance phase after its proper implementation. This is a crucial AMR aspect yet often omitted in the literature. One can find works focused on determining the number of robots or designing zones and service points introduced by mathematical modelling, simulation and queuing network modeling [12]. In [13], the number of robots is determined based on task lists and the time required to fulfill each task. Other papers include assigning robots to warehouse zones [14], or three different layouts with from 1 to 15 robots in terms of throughput [15]. The most extensive solution includes a number of AMR and pickers determination under different throughput rates, pick cycle, picking area size, and storage policy scenarios [16]. It presents analytical models for Last-Mile-Delivery and Meet-in-Aisle mobile solutions. However, a comprehensive solution that considers all relevant aspects of implementation is lacking. Only selected aspects of the implementation are analyzed. Due to the complexity of AMR processes, it is necessary to consider those aspects simultaneously.

The conducted literature review indicates that there are many solutions dedicated to AMR design both from the software development side (new algorithms) as well as on the construction side (e.g., selection and placement of sensors, determination of dimensions, selection of construction materials). However, completing the design and manufacturing phase as intended does not guarantee the expected benefits. It is because the implementation aspects of AMR are crucial. From the point of view of the AMR end user, it is necessary to determine the number of robots, the arrangement of their service and delivery points with regard to the system's required performance and the parameters of the storage area. From the AMR producer's point of view, there is in contrast the need to match their product to customer expectations and to price it correctly. An improper implementation may generate additional costs and fail to meet the system's requirements. The literature review demonstrates the lack of a comprehensive solution that addresses the identified implementation problems.

This paper aims to present AMRs implementation tool through a simulation model. It is organized as follows. In Chapter 2 we have described the proposed autonomous mobile robots implementation tool in the form of a simulation model. We have also provided a sample model application. Chapter 3 shows the results of the applied tool with regard to the selected application scenario. Chapter 4 summarizes the entire paper and provides directions for future work.

2. SIMULATION MODEL DEVELOPMENT

AMR implementation can be considered in two ways. On the one hand, it is possible to consider the real system, and on the other, the system yet to be designed. In the case of the real system, the problem of implementation will be reduced to the arrangement of robots and determining the appropriate number of them, considering the required efficiency that must be achieved. The lower number of variables to consider in this case is determined by the limitations of the existing infrastructure in the system. In a system yet to be designed, the number of variables to consider will increase significantly. This is because there is additionally the option of considering different storage area sizes, different aisle widths or different types of storage. However, regardless of the system type (real/designed), the AMR implementation tool determines the need to consider two groups of variables. The first group will refer to the parameters of the warehouse system and the second to the parameters of the implemented AMRs (**Figure 2**).

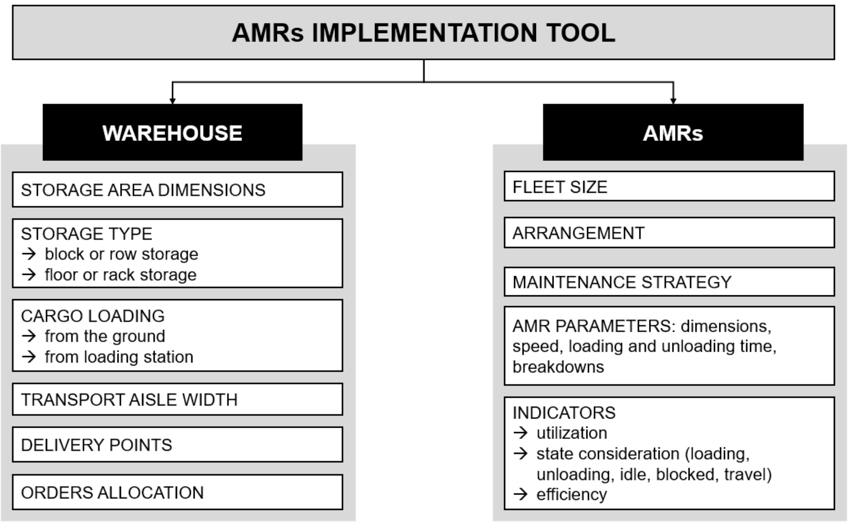

Figure 2 Variables classification of the proposed implementation tool

The proposed AMR implementation tool is developed in the form of a simulation model. The input variables to the model are:

- warehouse system parameters (length and width of storage area, type of storage in the context of the presence or absence of racks and in the context of cargo stacking, type of cargo loading, aisle width, number of delivery points and their arrangement, orders allocation),
- AMR fleet parameters (fleet size, arrangement, maintenance strategy, parameters of each AMR in the form of their speed, breakdowns occurrence frequency, dimensions, loading and unloading time).

Among the output variables, the following were identified:

- AMR utilization,
- distribution of times in AMRs' states,
- system efficiency (number of orders delivered per unit of time).

The use of a simulation model in the context of AMR implementation is justified primarily by the presence of stochastic processes and the occurrence of interference between robots. These interferences translate into potential path blocking situations and should definitely not be ignored.

2.1. Model application

The application of the designed AMR implementation tool is presented in the example of a simplified warehouse system with the parameters listed in **Table 1**.

Table 1 Sample system's parameters

Variable name	Value
storage area dimensions (width x length)	15 x 15 m
storage type	floor and row storage
cargo loading	from the ground
transport aisle width	2.4 m
number of delivery points	5
orders allocation	uniform distribution
fleet size	5
AMR arrangement	south

Due to the limited length of the paper, we didn't consider maintenance-related matters. A simplified system scheme characterized by the parameters in **Table 1**, is shown in **Figure 3**.

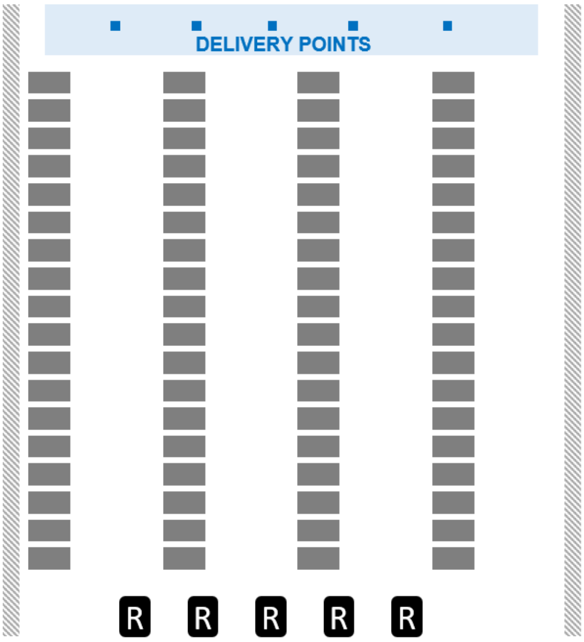

Figure 3 Scheme of the sample system

3. RESULTS AND DISCUSSION

The model does not return the optimal number of robots with respect to the adopted optimization criterion. However, it is possible to change the assumed number of robots and observe the effect of these actions on the output variables. In addition to the performance achieved, it is necessary to also look at the times the robots stay in each state. For a sample system with five robots, an efficiency of 71 fulfilled orders per hour of scheduled work time was achieved. **Figure 4** shows the distribution of times the robots stay in each state. A balanced utilization of the robots implemented in the system can be observed. A blocked state is also noticeable due to interference between the robots resulting in no possibility of executing the given route.

Additionally, the proposed tool can generate a heat map based on traversals per time (**Figure 5**). The maximum heat values represented by red color indicate the most frequently used roads. In contrast, those least traveled are indicated by the blue color. Identifying these types of zones is especially important when sharing workspace between robots and humans.

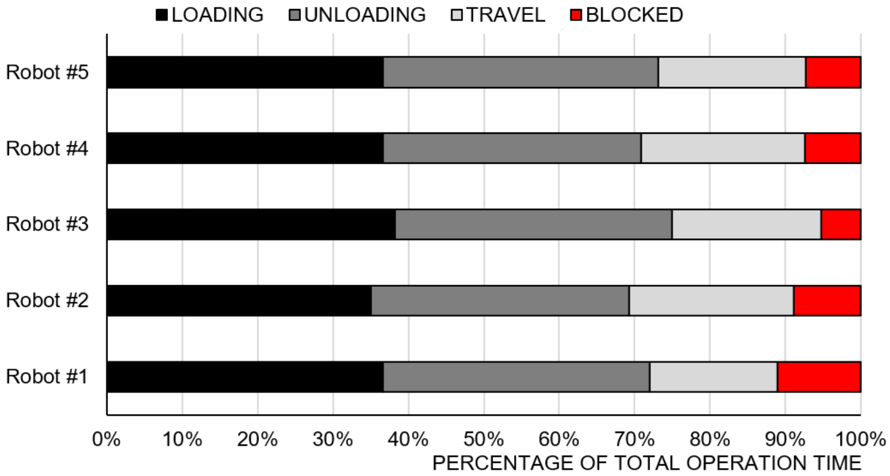

Figure 4 Scheme of the sample system

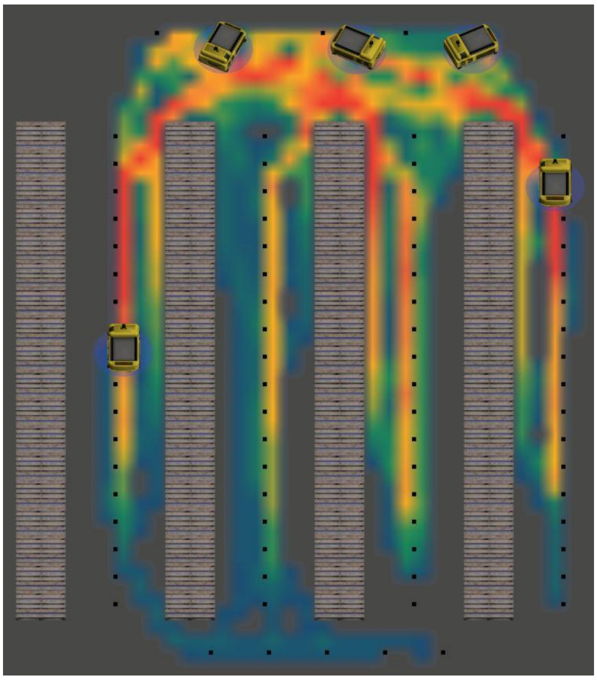

Figure 5 Heat map for the considered sample system

4. CONCLUSION

The paper considers the issue of AMR implementation, which is a transition from the AMR's design and manufacturing phase to the AMR's use and maintenance phase. The solutions available in the literature in this context do not comprehensively consider all implementation aspects. Meanwhile, testing only selected factors, as it is currently done, may significantly overestimate expected results. An AMR implementation tool in the form of a simulation model is presented to fill the identified research gap. Accordingly, two groups of variables were identified related to storage system parameters and AMRs fleet parameters, respectively.

The developed tool can be used when implementing AMRs into an existing system, where it is crucial to address a number of its limitations. It can also be used when designing a storage system with the intent of using AMR. It is then possible to consider many scenarios involving different concepts for the use of available storage areas. Future steps within the considered topic include the development of the presented case under another pillar of Industry 4.0 - digital twins.

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