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Pinquark Warehouse Management System (WMS): Moving from process-based to activity-oriented management

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Abstract

Since the release of the first warehouse management system (WMS), these systems have been systematically developed and improved to optimize warehouse operations, including inventory management, order fulfillment, receiving, picking, packing, and shipping. Among the many well-documented and well-known WMS systems, there are other systems with a similar level of maturity and comparable functionality, but not as popular, but still very appealing. Such a system is Pinquark, the flagship product of one of the leading Polish software vendors. In this sense, the aim of this article is to present its main features and discuss its further development. In particular, we introduce and outline the idea of reorienting warehouse management from a process-based to an activity-based approach. In this context, we discuss the preliminary results obtained through the study of contemporary literature, including methods addressing vehicle routing and product allocation problems.

Keywords: WMS; Warehouse Management System; Evolution; Development

1. Introduction

In a broad view, Warehouse Management System (WMS) is a set of processes, policies, measures, covering organizational, technical and economic operations related to the storage of inventory, intended to organize the work of a warehouse or distribution center to ensure that such a facility can operate effectively and achieve its objectives [20, 21]. In a narrow sense, a WMS is software that enables companies to manage and control daily warehouse operations, from the moment goods and materials enter a distribution or fulfillment center to the moment they leave [15]. For the sake of methodological clarity, the concept of WMS in our study is understood in terms of the latter definition provided above.

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According to ElevatIQ, in 2024 on a global scale, the top five WMS systems are Manhattan Associates, Blue Yonder, Korber/HighJump, SAP EWM, and Oracle WMS [9]. The size of the global warehouse management system market was valued at $ 3.94 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 19.5 percent from 2024 to 2030 [7]. In today's environment, automation is a critical component that companies across all industries are implementing [3]. Distribution centers worldwide are increasingly focused on increasing levels of automation to reduce costs, increase throughput and efficiency of an existing distribution route, and reduce labor. Obviously, a number of other factors are also impacting this global market.

While there are many more WMS systems offering similar functionality with a comparable technological maturity to the largest software vendors on the market, but with a significantly smaller market share, in this paper we aim to discuss the current stage of development of the Pinquark WMS system [14], followed by the future research agenda. Over the last five years, our system has grown from a concept to a highly efficient and reliable solution, which is gaining more and more customers every year in the European Union, especially in Poland.

By actively working with our customers during and after deployment, we have gained valuable experience and knowledge. From numerous issues encountered and observations made, we hypothesize in this study that a warehouse management system can better assign the right task to the right person at the right time, taking into account workers' skill levels, their proximity in the warehouse, their equipment, and available warehouse tasks. In other words, we are inclined to say that reorienting the WMS from process-based to activity-based will bring tangible results, including increased labor productivity.

The rest of the paper is organized as follows. In Section 2, we present the background and motivation as a foundation for our study. In Section 3, we discuss the preliminary results obtained of the qualitative research. In Section 4, we consider other related topics. In Section 5, we conclude the paper and outline future research directions.

2. Background and Motivation

2.1. Pinquark WMS

Pinquark WMS represents a state-of-the-art warehouse management system, engineered to support a wide range of warehouse operations by incorporating advanced technologies like machine learning and a low-code platform. It integrates a set of automation tools that facilitate key aspects of warehouse management, including inventory control, order processing, and logistics operations, such as order picking or receiving goods. The system's adaptability, achieved through an embedded low-code platform, allows it to be effectively applied at different operational scales, enabling streamlined management of complex warehouse operations.

In Pinquark WMS, artificial intelligence is integrated to enhance the efficiency and safety of warehouse operations. System analyze real-time data on warehouse processes, such as goods picking, efficient movement of warehouse personnel, and optimal packing strategies, to optimize performance and address operational challenges dynamically. The AI module within Pinquark WMS (WMS-AI) specifically supports functionalities such as route optimization for picking operations and collision detection using UWB localization sensors. To perform route optimization for order picking, WMS-AI calculates the most efficient paths by analyzing warehouse layouts and inventory locations. The collision detection functionality improves safety by predicting potential collisions between warehouse personnel and equipment, allowing proactive measures to avoid accidents. These capabilities demonstrate a practical application of AI in the management of complex warehouse activities and in ensuring a safer, more efficient operational environment.

One of the modules of Pinquark WMS is a simulator that allows monitoring the work of the system, during the process of order picking, on a warehouse modeled in advance. The simulator, along with the working simulation that represents the order-picking process, is shown in Figure 1. The user, using the simulator, selects picking documents (orders consisting of various articles) and agents (warehouse workers) who will collect these goods, completing the selected orders. The WMS AI system optimizes the work of agents, minimizing the distance of employees picking paths. In the figure, the agents are shown as green and red dots, the dashed line shows the optimized picking path, and the solid colored lines show the traveled path of each agent. The colored dashed lines showing in front of the agents are a prediction of their trajectories, used to find collisions and adaptively determine paths taking into account the agents' avoidance of each other. The whole is plotted on a model of a real warehouse, with an area of $2500m^2$, created in Pinquark WMS.

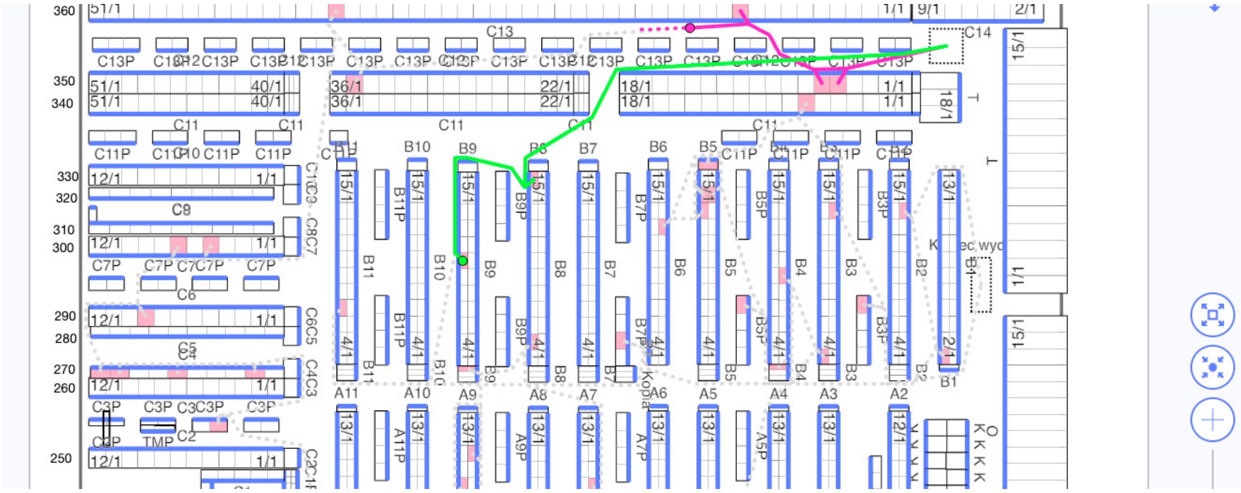

Fig. 1. Pinquark WMS Simulator on which the work of two workers moving along the picking paths optimized by the system was simulated.

Additionally, Pinquark WMS incorporates a low-code platform, called Creator, that facilitates the development of custom applications within the WMS environment without extensive technical expertise. This feature enables users to tailor the system to specific operational requirements rapidly, allowing for the implementation of customized solutions that enhance system functionality and responsiveness to changing operational dynamics. The 2 shows the interface of the Creator module in the Pinquark WMS system. The interface is divided into several sections:

1. Screen List (left panel): This panel displays a hierarchical list of screens and modules within the WMS. Each item can be expanded to show more detailed sub-options.
2. Screen Preview (middle panel): This panel provides a preview of the currently selected screen from the list. The preview includes various UI components such as text fields, buttons, and dropdowns.
3. Components (right panel): This panel lists various UI components that can be added to the screens, such as buttons, text fields, scan options, and text labels. Other components include images, navigation elements, and maps
4. Below the components list, there's a section showing currently active components on the screen, such as buttons and text fields with their associated actions and variables.

Overall, this interface allows users to design and customize screens for the WMS environment by dragging and dropping components, configuring their properties, and setting up interactions between different elements, all without requiring extensive technical expertise [10].

2.2. Activity-based approach

The current goal for Pinquark WMS is to move from traditional process-based management to a more dynamic, activity-based approach. Using the existing Pinquark.com WMS system, the new development focuses on transforming intricate warehouse processes into simple, manageable activities.

The plan involves reimagining traditional warehouse processes such as receiving and issuing (e.g., picking, multipicking, sorting), which typically require detailed planning and expert knowledge. These processes will be broken down into fundamental "fetch" and "shelve" activities. An artificial intelligence mechanism will dynamically delegate these activities based on real-time data, optimizing resource allocation, and task execution.

This shift aims to streamline warehouse operations by eliminating the need for warehouse workers to consider complex logistics processes. Instead, the system will assign simple tasks to warehouse personnel in real time, considering factors such as proximity, skill levels, and current workload. This approach ensures that tasks are distributed efficiently and that the overall workflow remains flexible and responsive to changing demands.

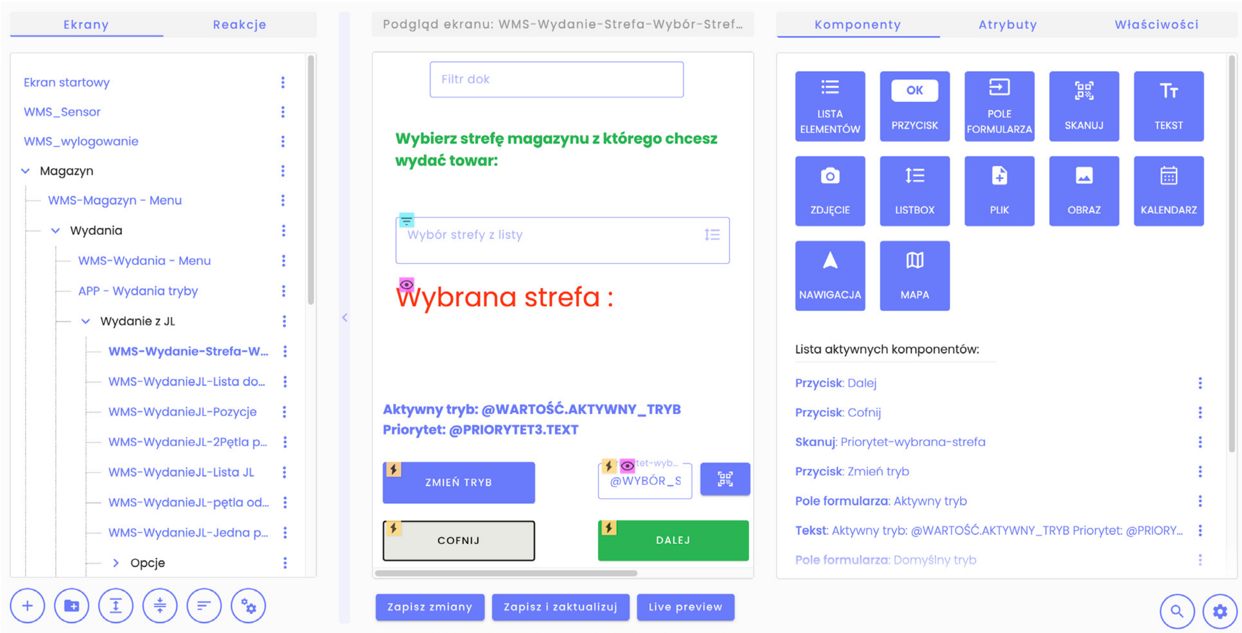

Fig. 2. Pinquark WMS Creator during edition of user application view.

This activity-based approach will seamlessly integrate with the low-code platform of Pinquark WMS. The deployment of this WMS will boil down to specifying any unusual processes and setting them up as article transfers [4]. The system will then further simplify these into basic activities. The low-code platform facilitates rapid customization and deployment, allowing users to tailor the system to their specific operational needs without requiring extensive technical expertise.

By transitioning to activity-based operations, Pinquark WMS is expected to significantly enhance operational efficiency, reduce costs, and improve productivity. This method allows for more adaptive management of warehouse activities, facilitating quicker responses to operational changes and better utilization of resources. The new system aims to set a benchmark in warehouse management by providing a more intuitive and efficient way to handle warehouse operations.

3. Preliminary findings from qualitative research on related topics

As a data source, we used the Scopus database [16], which is now considered one of the most reliable and up-to-date repositories of research papers [19]. The words used to form a search string were extracted from both the purpose of the study and the core functionality of the system. In this regard, we defined the combinations of search queries, including strings such as ”vehicle routing problem”, ”picking routing problem”, ”route planning”, each time narrowing the context by adding the logical operator AND, followed by the string ”warehouse”.

To understand the needs and requirements of the system, a thorough analysis was performed, including interviews and direct observation of warehouse operations. This study identified that the main issues affecting warehouse efficiency were the poor placement of products and the inefficient order picking path with inefficient allocation of human resources. These factors significantly disrupted the picking process, as both the order of operations and the assignment of activities to workers were not optimized.

According to the study [8], the product allocation problem (PAP) is a significant issue in warehouses that greatly influences the cost of other operations, notably order picking, which accounts for more than half of the total operational costs [6]. The efficiency of order picking is also affected by how the Warehouse Management System (WMS) assigns tasks and determines the paths employees follow when picking goods. The challenge for the WMS in determining these paths stems from its complexity as an NP-hard problem. Specifically, it resembles the Traveling Salesman

Problem (TSP) when determining paths for individual agents or the Vehicle Routing Problem (VRP) when multiple agents are involved simultaneously. Due to the inherent difficulties of these problems, WMS often relies on path determination methods that consider the warehouse's layout, such as the S-Shape or mid-point strategies. However, studies indicate that methods based on solving the VRP are significantly more effective, improving efficiency by several tens of percent [18].

To better understand the challenges associated with the Vehicle Routing Problem (VRP) and the Product Allocation Problem (PAP), and to identify state-of-the-art solutions, a comprehensive literature review was conducted. The findings of the reviewed articles are detailed in further detail in this section of the paper.

3.1. Vehicle Routing Problem

The Vehicle Routing Problem (VRP) is an optimization challenge focused on determining the most efficient routes for a fleet of vehicles. The goal is to serve a series of designated delivery points while adhering to specific constraints. Due to the variety of these constraints, VRP can be divided into several categories, each considering specific aspects such as vehicle capacity (CVRP), delivery time windows (VRPTW), or the number of available depots (MDVRP).

The Vehicle Routing Problem (VRP) is an NP-hard problem first described by Dantzig and Ramser in 1959 [5]. It is a critical aspect of warehouse operations because the time spent by workers picking orders can account for more than 50% of their total working time [6]. The techniques used to solve the vehicle routing problem (VRP) are described as follows [11, 12, 13]:

1. Exact Algorithms. This category of algorithms aims to find the optimal solution to the problem. Dynamic programming, linear programming, and branch and bound methods are widely used here. The main drawback of exact algorithms is their computational complexity, which leads to poor scalability.
2. Heuristic and Metaheuristic Algorithms. These algorithms aim to obtain a sufficiently good solution in an acceptable time frame. Examples include genetic algorithms, particle swarm optimization, and tabu search.
3. Artificial Intelligence Algorithms. These involve using AI models to generate solutions. There are two ways to use AI for solving the VRP:
   (a) Step-by-step algorithms: These improve the solution step by step. They scale better and produce better solutions than end-to-end approaches but are significantly slower.
   (b) End-to-end algorithms: In these, the AI model directly returns a result. They are very fast but highly sensitive to the quality of the data used during training and usually return lower-quality results.
4. Quantum Algorithms: These solutions use quantum computing. Current quantum algorithms are in the early stages of development. The main challenges of this method are the underdeveloped technology of quantum computers. However, they have the potential to be highly effective in solving the VRP.
5. Hybrid Approach: This mixed approach uses various algorithms to achieve the best possible results. For example: AI can be used tsuch aspport other algorithms, such as by selecting parameters, thereby improving the performance and adaptability of heuristic and metaheuristic methods.

The current state-of-the-art for solving the Vehicle Routing Problem (VRP) indicates that the most effective approaches predominantly rely on heuristic and metaheuristic methods, supplemented by AI algorithms. Exact algorithms struggle with large and complex VRP instances due to their high computational demands. Purely AI-based solutions often produce lower quality results compared to heuristic methods and are highly dependent on the quality of the training data [12].

3.2. Product Allocation Problem

The Product Allocation Problem (PAP) involves assigning products to different storage slots in a warehouse to minimize handling costs and maximize space utilization. High-demand products are typically placed closer to the I/O doors to reduce handling time. The problem considers input factors such as warehouse layout, storage slot characteristics, and product dimensions, demand, and supply times. Constraints include storage capacity, picking capacity, supply times, product compatibility, and picking policies such as FIFO and LIFO [8].

3.2.1. Classic methods to solve Product Allocation Problem

The classic methods used to solve the Product Allocation Problem (PAP) are as indicated:

1. ABC : this is the most frequently chosen classification method, which divides products into three groups according to their importance and value, where A represents high value products, B - medium value products and C - low value products. This is a one-criterion analysis, which cannot accept several parameters at the same time. The most frequently used criteria are: the sales value of the item, the frequency of picking, the size of the item, its weight and volume.
2. XYZ : this is a complementary method to ABC analysis, which allows to analyze isolated groups of products on the basis of their individual factors. The most frequently used criterion in XYZ analysis is based on the regularity of product collection. X represents the group of regularly collected items, Y represents the group of frequently collected items, and Z represents the group of rarely collected items.
3. EIQ : method related to the entry (E), the item (I) and the quantity (Q). The analysis of these three factors makes it possible to choose the appropriate picking method and, consequently, the appropriate allocation of articles. The method is based on analyses that combine individual criteria:
   (a) EQ - used to analyze order distribution and sortation planning.
   (b) EN - analysis to determine the best picking method.
   (c) IQ - determines the status of items in stock to provide a better picking method for future orders.
   (d) CI - Analysis of the frequency of item picking.
4. COI index : this is a bi-criteria analysis that takes into account the dimensions and volume of the product and its demand. This analysis makes it possible to place the items with the highest COI index closest to the loading area in order to optimize the product collection route.

Developing a model that implements the basic assumptions of classical methods for solving the PAP problem will prepare the ground for future, potential solutions that include more advanced mechanisms using artificial intelligence.

Classic methods will also have a benchmark function, thanks to which it will be possible to compare product allocations created by artificial intelligence [1, 17].

3.2.2. Solving PAP using artificial neural network

A method for solving PAP using an artificial neural network (ANN) was presented in a research paper by Lorenc in Lerher [1]. The presented model is based on the analysis of data regarding product characteristics, customer orders, and warehouse layout. It uses traditional methods of product classification lited above, and an original method of determining the relationships between them. Input data is analyzed to identify correlations between products, and the classification results are compared with product parameters and demand using statistical analysis methods. The best classification method is then used to prepare data for an artificial neural network (ANN), which is trained and used to simulate product classification and allocation. Performance analysis and modifications to the ANN structure are performed sequentially until the desired result is achieved. Once this condition is achieved, the model provides product classification values and a product allocation system.

The study by Lorenc, Kuznar and Lerher [2] also applies ANN to solve the PAP problem. However, it is also possible to divide products into clusters based on their similarity. The article compares the results only to real picking times and does not simulate them. A reduction in picking time was found only for products on a pallet unit for SNN and clustering. The reason is a short second in the tested warehouse itself and Quasi-demand.

So far, the solution design, which takes into account the use of artificial intelligence, is characterized by a 10-15% reduction in picking time, compared to classically used methods such as ABC, XYZ or COI. This approach to solving the PAP problem is not as common as the use of alternative article classification methods. Implementation using artificial intelligence for this problem indicates certain optimization of warehouse processes and, consequently, better use of resources.

3.3. Activity-based simulator

The current Pinquark simulator uses a process-oriented approach, which requires the preparation of specific processes for the execution of the task. To evaluate the impact of an activity-based approach, we designed an experiment that involves creating a second simulator to compare both methodologies. In addition, this experiment will allow the comparison of different algorithms and approaches for the Product Allocation Problem (PAP) and the Vehicle Routing Problem (VRP). The goal is to provide a unified test environment for different PAP and VRP algorithms to facilitate their comparison and evaluation.

In contrast to the process-oriented simulator, the activity-based simulator will respond to environmental changes (such as incoming and outgoing orders) by continuously optimizing the work of warehouse workers. This approach will make the simulator more reflective of a real warehouse environment. Such a system is designed to support not only warehouse workers, but also management tasks, relying on algorithmic results rather than domain-specific knowledge.

The Figure 3 shows a visualization of the operation of a simulator, divided into three main sections:

1. Warehouse visualization tab, visualizes the work of agents within a warehouse, showing their paths and current positions. Each of the workers moves along the shortest paths designated by the A* algorithm to the location where they will perform the assigned activity visible in the Activities tab. Workers execute PICK and PUT activities, taking and placing items marked on the visualization as colored circles with the quantity of the given item in the circle. The warehouse is represented in the form of a discrete grid, in this scenario sized 16x8. Each field of the simulator can occupy one location, being of the type: storage (gray), loading (red), packing (purple), unloading (green).
2. Orders tab, show the lists of generated orders with a timer next to each order, indicating the simulation step (tick) at which it will be handled by the system. The order list represents the events occurring in the warehouse, such as the arrival of new orders and new goods. These orders are processed by the system and converted into basic activities. Ultimately, orders will be generated by adapting activities occurring in companies using Pinquark low-code platform - Creator.
3. Activities tab, contains atomic activities added by the system. Each entry details the type of activity, its location, and the assigned agent. The color coding represents the status of each activity. White records are scheduled activities, green records are currently running activities and gray records are completed activities.

The simulator allows the selection of a test scenario (warehouse and corresponding orders to be fulfilled) and PAP and VRP algorithms. The performance of a given configuration is evaluated in terms of the number of simulation steps (ticks), which reflects the time required to complete the test orders.

The goal of the project, after analyzing the relevant algorithms with a simulator, is to develop a real-time warehouse management system. It focuses on several key components:

1. The efficiency of worker management. The project presents an activity-based system that introduces only two atomic tasks, namely: ”pick” and ”put”. By breaking down tasks into smaller, more manageable components, the system aims to improve productivity by making the most of workers' skills and strengths.
2. Historical data analysis. The project aims to use the wealth of data collected from past operations to inform current decisions. By analyzing performance metrics from historical data, the system introduces a tailored approach that can lead to more efficient warehouse management.
3. The Decision Support System. The project was initiated to change the distribution of knowledge and responsibilities from the manager to the AI, reduce the workload and optimize the unit's performance, allowing the manager to take on more tasks, replacing those performed by the AI-powered system.

The simulator is currently in the early stages of development. It can accept artificial data representing warehouse configuration, orders, and deliveries. The simulator uses basic implementations of PAP algorithms to translate these assigned operations into atomic operations, which the VRP module then assigns to the appropriate agents. Future work will include extending the simulator to use real-world data, implementing additional PAP and VRP algorithms, and extending these algorithms to allow the definition of more complex constraints.

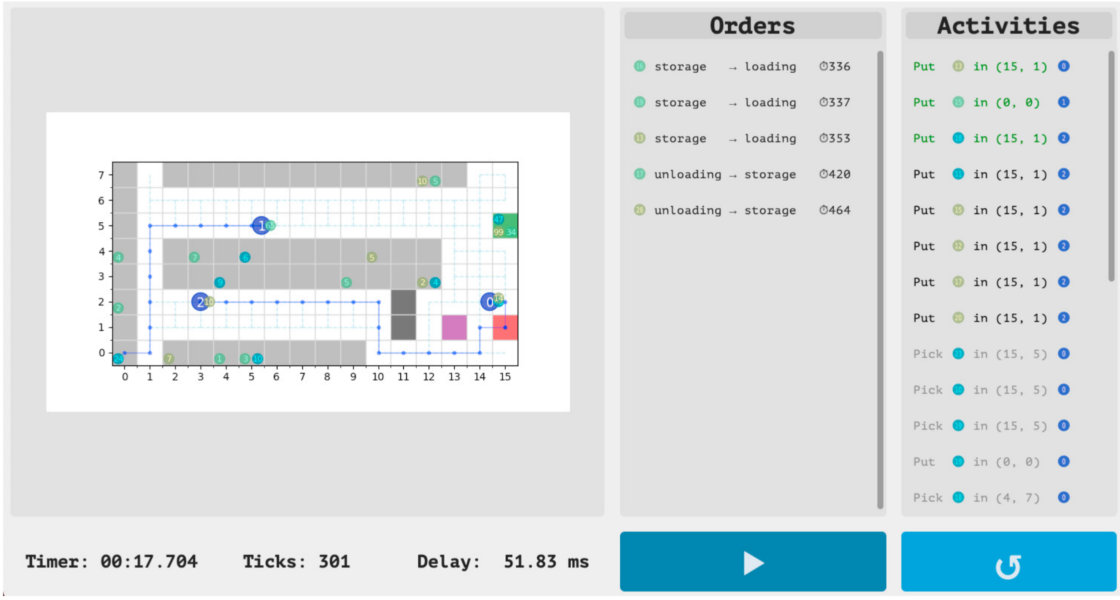

Fig. 3. Activity-based simulator in which three agents perform actions to handle orders delivered

4. Discussion

Currently, heuristic and metaheuristic solutions lead in solving VRP (Vehicle Routing Problems). On the other hand, AI algorithms are seen as contenders, still perceived to yield worse results. However, an increasing number of studies indicate that AI-based purely solutions have been able to achieve equally good, if not better, results in terms of quality. This may suggest a trend in which AI solutions will become the primary method for solving VRP [11, 12].

Hybrid algorithms, which combine the strengths of both heuristic methods and AI, are also emerging as powerful tools [22, 23]. Such solutions leverage the flexibility and efficiency of heuristics with the learning capabilities of AI to produce even better results in solving complex VRP scenarios [11].

Another emerging branch of solutions is quantum algorithms. Despite their current early stage of development, it is expected that with the further advancement of quantum computing technology, they may become one of the key branches in solving optimization problems. Quantum algorithms have shown promising preliminary results in simulations and experiments, suggesting that they could significantly accelerate VRP solutions and handle complexities that are infeasible for classical methods [13].

The process-based system relies on fixed sequences of actions needed to complete warehouse processes, which can lead to monotony and underutilization of workers' skills. In contrast, the task-based system is more dynamic and flexible, assigning tasks based on workers' skills, their location, available equipment, and task priorities.

Switching to a activity-based system can bring several benefits:

1. Better utilization of workers skills. Tasks are assigned based on specific skills, increasing their efficiency.
2. Minimization of movement. Tasks are assigned to workers closest to the location, reducing travel time.
3. Optimal equipment usage. The system monitors equipment availability and assigns tasks accordingly.
4. Dynamic task prioritization: The system can adjust task priorities based on changing conditions.

Transitioning to a task-based system requires investment in modern WMS technologies that monitor and analyze real-time data. Long-term benefits, such as operational cost reduction and increased efficiency, typically outweigh initial investment costs. Implementing a task-based system in a warehouse can lead to better resource utilization, faster response to demand changes, and overall increased operational efficiency.

5. Conclusions

This article touched on both known and emerging issues in the warehouse management environment to find inspiration for creating a new way of managing warehouses. The motivation is to transfer the existing process-based solution to a new one that takes advantage of atomic tasks, incorporating the state-of-the-art methods of solving PAP and VRP problems. Such integration, according to the preliminary results, indicates the improvement of warehousing activities. In particular, we found that the most effective approaches to solving the Vehicle Routing Problem (VRP) are based on heuristic and meta-heuristic methods supplemented by AI, while AI-driven solutions to the Product Allocation Problem (PAP) achieve a 10-15% reduction in picking time, optimizing warehouse processes more effectively than traditional methods such as ABC, XYZ, or COI.

By moving from a process-oriented to an activity-based approach, workers are empowered to perform simpler tasks and respond more quickly to changing environments and conditions. Resources, both human and material, can be used more efficiently, resulting in optimized warehouse operations. As a result, picking times can be reduced and more optimized routing paths can be provided with real-time changes by moving to more activity-based solutions. The PAP and VRP algorithms, coupled with historical data from previous orders, could play a critical role in ensuring that Artificial Neural Networks (ANNs) produce the most efficient results.

Future work will include the development of a test environment that allows the evaluation of different solutions and their benchmarking for comparison purposes. This environment should allow quick verification of different solutions and facilitate further research on different versions of VRP and PAP algorithms. Specifically, we aim to extend and improve the functionality of the current testbed with the new solutions to the PAP and VRP problems in terms of improving the efficiency and effectiveness of warehouse operations and their real-world behavior. In addition, we will explore advanced machine learning techniques and their ability to integrate with Internet of Things devices.

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