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ADVANCED APPROACHES FOR OPTIMIZING LOGISTICS AND WAREHOUSE PROCESSES: FROM PLANNING TO DELIVERY

ZAAWANSOWANE PODEJŚCIA DO OPTYMALIZACJI PROCESÓW LOGISTYCZNYCH I MAGAZYNOWYCH: OD PLANOWANIA DO DOSTAWY

Abstract

The article discusses critical aspects of managing logistics and warehousing processes in today's business environment. The authors present modern approaches and strategies to help companies manage their supply chains efficiently and optimally. The first emphasis is on understanding logistics's role in a company's operations. The article presents an application developed to help analyze key elements of logistics management, such as transport, warehousing, and inventory management. Modern technology in logistics and warehouse management has been designed and used. The authors highlight the role of information systems, process automation, and data analytics in improving efficiency and reducing operating costs. The conclusions of the article point to the need for continuous improvement of logistics and warehouse management strategies so that companies can meet growing market demands and remain competitive in a dynamic business environment.

Streszczenie

Artykuł omawia kluczowe aspekty zarządzania procesami logistycznymi i magazynowymi w dzisiejszym środowisku biznesowym. Autorzy przedstawiają nowoczesne podejścia oraz strategie, które mogą pomóc firmom w efektywnym i optymalnym zarządzaniu swoimi łańcuchami dostaw. Pierwszy akcent kładziony jest na zrozumienie roli, jaką odgrywa logistyka w ramach działalności przedsiębiorstwa. Artykuł przedstawia opracowaną aplikację, która pomaga analizować kluczowe elementy zarządzania logistyką, takie jak transport, magazynowanie, zarządzanie zapasami. Zostało opracowane i wykorzystane nowoczesne technologie w zarządzaniu logistyką i magazynem. Autorzy podkreślają rolę systemów informatycznych, automatyzacji procesów oraz analizy danych w poprawie wydajności i redukcji kosztów operacyjnych. Wnioski płynące z artykułu wskazują na konieczność ciągłego doskonalenia strategii zarządzania logistyką i magazynem, aby firmy mogły sprostać rosnącym wymaganiom rynkowym i utrzymać konkurencyjność w dynamicznym środowisku biznesowym.

Keywords: *management warehouse, management of logistics, routing, the traveling salesperson problem, planning and design of logistics systems*

Słowa kluczowe: *zarządzanie magazynem, zarządzanie logistyką, wyznaczania trasy, problem komiwojażera, planowanie i projektowanie systemów logistycznych*

Introduction

The planning and design of logistics systems – both at the supply chain and intralogistics level – is often supported by simulation studies, used to compare design alternatives, assess their feasibility, and estimate KPIs such as lead time or throughput. Regarding the implementation phase of logistics systems, the main challenges relate to the development of controls and operational information systems. Given that the testing, integration, and commissioning (and bug fixing) of these systems usually consume a significant part of the realization phase, it becomes clear that testing the developed system as early as possible is beneficial. The article (Lechler, 2019) describes testing software against a digital equivalent of a natural system, using simulation models to emulate real-world interactions. The approach described here (Hofmann, 2020) will show an example of what integrating simulation-based testing with agile software development processes can look like, exploring a case study on order management and delivery optimization.

Idea of system operation

In the example presented here, we assume that we are involved in the logistical planning of deliveries to a selection of ten Biedronka shops in the Lublin area. After evaluating various options for scaling the business model with the help of an innovative open-source approach to simulating an urban delivery network, the growing network becomes increasingly difficult to manage, requiring increased software-based support for the daily logistics operations of the listed shops (Dmowski, Wołowiec, Laskowski, Laskowska, 2023).

To be able to focus on its core tasks (instead of fighting with opaque spreadsheet data), our chain of shops decided to develop a web-based logistics planning application. The basic processes to be supported in it are:

- Registration of customers and tracking of their orders.
- Management of warehouse locations to plan the best possible deliveries.
- Tracking of trucks delivering goods according to planned routes.

Below are screenshots of the application, including the BPMN diagram created to implement the business process described.

Figure 1. *BPMN diagram of the described process*

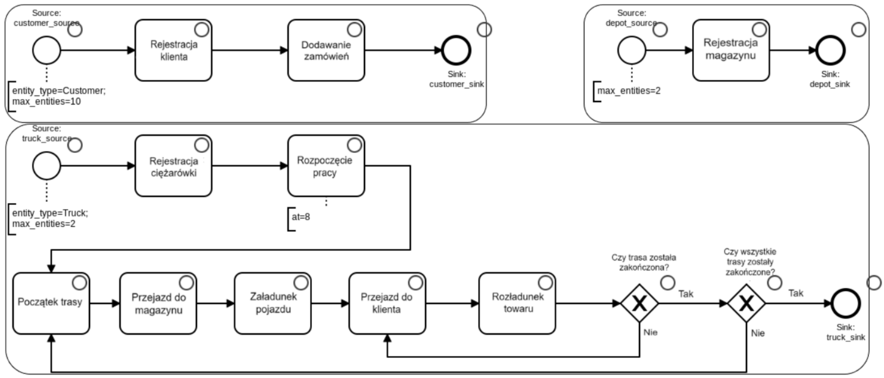


Figure 2. *Diagram showing when customers place orders and when a supplier starts*

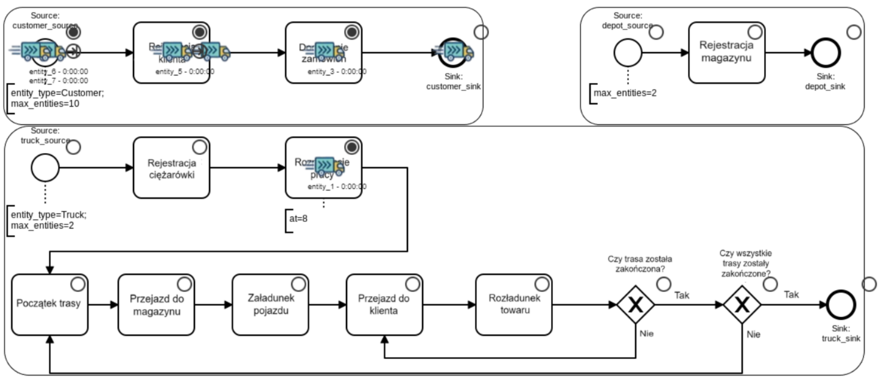
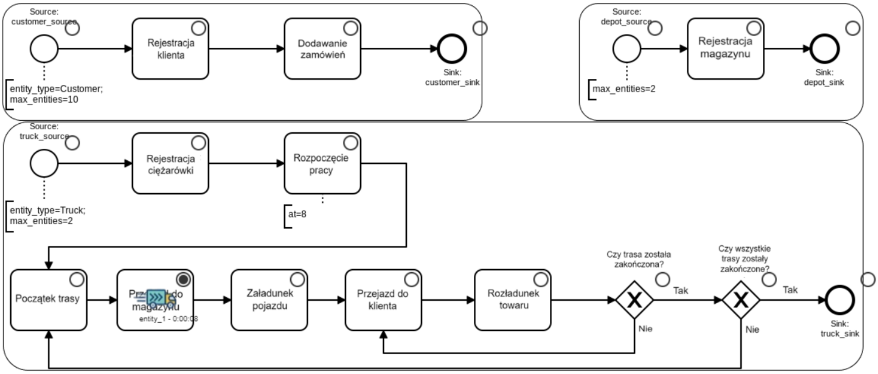


Figure 3. *Diagram showing when the supplier drives to the warehouse*



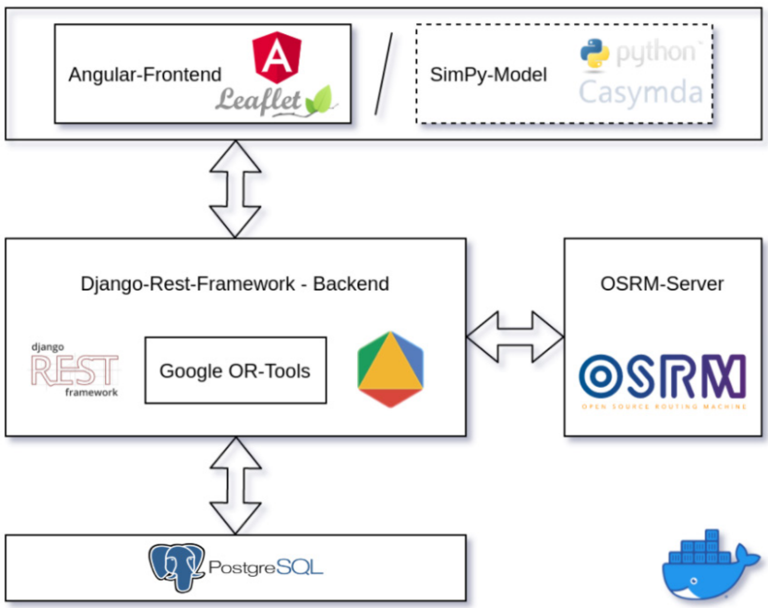
The figures above show that the business process is divided into three parts: customers, warehouses, and suppliers. The process starts with customers' registration and the addition of their order quantities. At the same time, available warehouses are added from which goods can be taken. Once all orders have been registered, the work of suppliers begins – vehicles are registered, and then routes are started. They drive to the warehouses to load the goods (taking into account the payload, of course) and set off to the following customers on the route. Of course, everything works in a loop, and the process is completed when all orders have been delivered. To ensure that all the required processes are adequately supported by the software being developed, the software development department of our network opted for a test-driven approach supported by a suitably created pipeline that automatically checks all the code pushed out to the repository.

Based on a defined business process, a Casymda simulation model is generated, ready to emulate the actual system with which the software under development is to interact. As the processes and scope of the application change, the simulation model is agilely evolved. The proposed solution (Gitea, 2022, Drone, 2022) forms the basis of the continuous integration infrastructure. Within the virtual runtime, the pipeline runs the application in a service container against which the simulation model runs a test scenario, emulating the interaction and verifying the expected behavior of the software. It is worth noting that the pipeline can be improved in various ways, e.g., by appropriately waiting for the application (service) to be available for the simulation stage.

Application diagram and implementation

The application for our example shop chain deals with the data management of customers, orders, warehouses, routes, and trucks. In addition, support is required in planning the delivery process by calculating efficient routes and assigning them to available trucks. This assumes a basic 3-tier structure consisting of a browser-based user interface, a backend containing business logic and optimization algorithms, and a POSTGRESQL database. The graphic below summarises the configuration, including a simulation model that acts as a client in an automated build pipeline:

Figure 4. *Diagram of the application structure and operation*

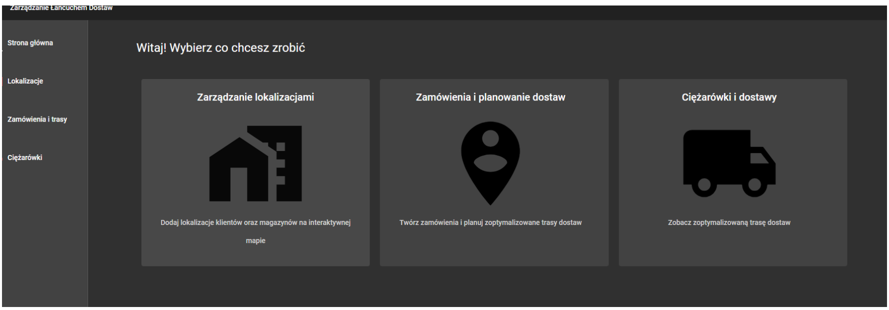


The backend uses Django + Django-Rest-Framework and relies on Google-OR-Tools for optimization tasks. Trip planning is modeled as a vehicle routing problem with multiple warehouses. To optimally assign pending routes to available trucks, OR-Tools provides a minimum flow cost solution used on the corresponding bipartite graph. We can use the Open Source Routing Machine to create the required distance matrices, supplied as a ready-to-use Docker image (OSRM-in-a-box). OSRM offers a convenient, synchronous API when creating a new client or depot. Open-Street-Map data can be downloaded, e.g., from https://download.geofabrik.de.The basic front is built with Angular, Material, and Leaflet.js (easy to integrate thanks to ngx-leaflet).

Visualization of operations

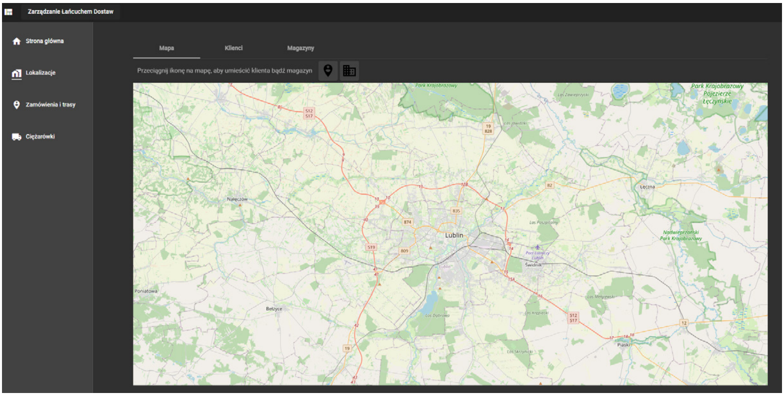
The following briefly outlines the subsequent elements of the application, which connects to a PostgreSQL database to visualize deliveries. As mentioned, routes are determined using a map of the Lublin region processed by OSRM. Delivery times and number of orders are chosen by default only to show the idea of the system. The load capacity of the trucks was assumed to be 1,000 units of product. Figure 6 shows the main screen after launching the application. Here, we have access to three places from both the sidebar and the tiles in the middle of the screen – location management, orders and delivery planning, and the deliveries themselves handled by the trucks.

Figure 5. *Start screen*



The following figure shows a map of the delivery locations. Based on the previously mentioned idea, we have here a map of the Lublin Voivodeship, with the center located in Lublin.

Figure 6. *Location tab*



From this level, a customer or store can be added by dragging icons to the appropriate place on the map and specifying their name (Figure 7). When using the BPMN process presented earlier, points are automatically plotted on the map according to the shop locations defined in the application.

Figure 7. *Adding a customer*

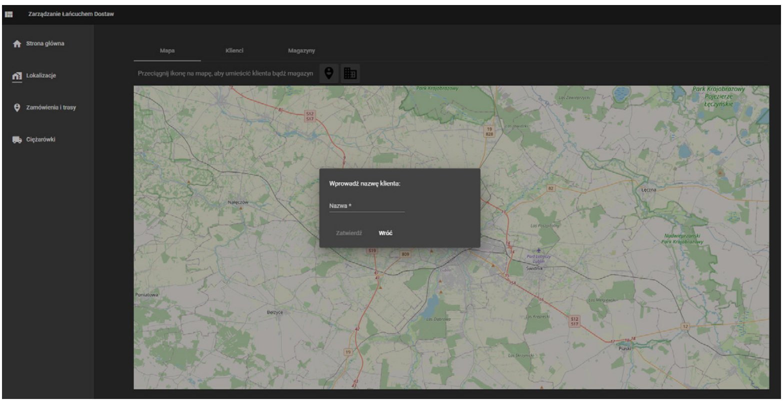
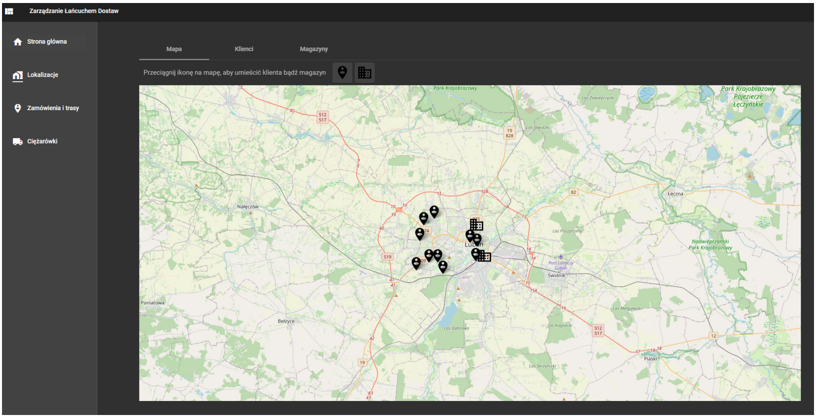
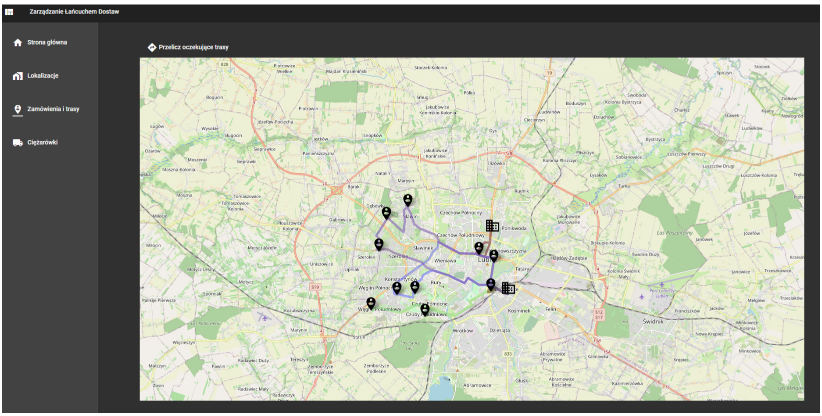


Figure 8. *Locations of stores and warehouses plotted on the map*



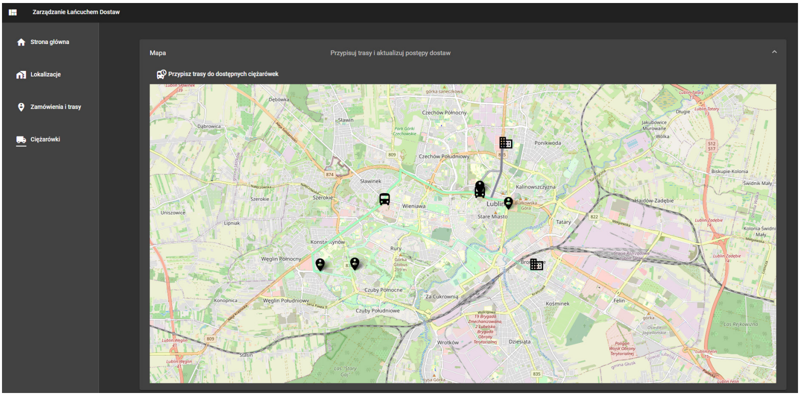
The next tab already deals with orders to created customers and displays the current lightly coloured delivery routes between points (Figure 9). Here, we also have the option of viewing the volume of orders relating to a particular customer and their status—if they are pending—while if the demand has already been fulfilled, they disappear from the shop's order list and only exist in the historical database.

Figure 9. *Routes between points*



The last figures show the delivery tab and, more specifically, the trucks handling these deliveries. During the simulation, the suppliers' consecutive routes and locations are visualized on the map according to what is happening. Taking this into account, in Figure 10, one of the suppliers is at one customer (stage *Unloading of goods*), and the other is in the process of driving after loading the products on the truck to the next customer (stage *Drive to the customer*).

Rysunek 10. *Wizualizacja dostawy z wykorzystaniem dwóch ciężarówek*



Management of warehouse processes

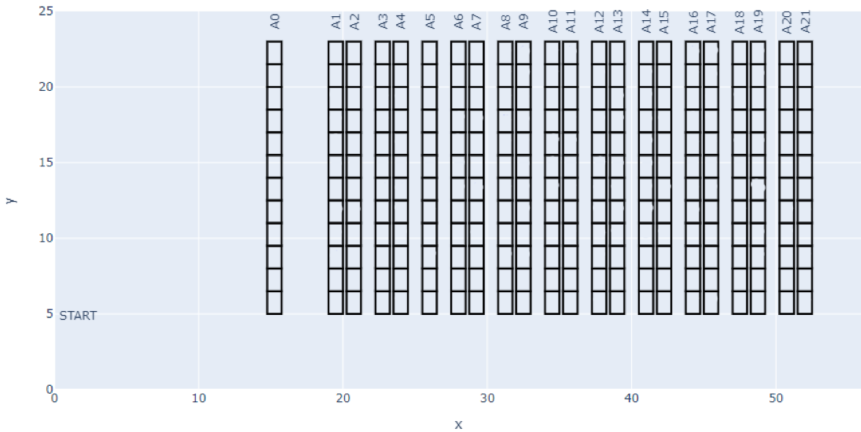
In the approach presented here, a simulation model is designed to estimate the impact of different order-picking strategies on the warehouse. The problem posed here is that the transition time between the locations of the products comprising an order represents a significant proportion of the operator's working time. The solution presented here is to show ways to reduce movement time for order picking, which translates directly into increased warehouse productivity. More specifically, this solves the Single-Picker Routing Problem (Scholz, 2016). The algorithm aims to determine the order in which the locations of items in the distribution warehouse should be visited and to identify the appropriate routes that the operators (order pickers) must take to collect the products the customers require. This is a particular case of the well-known Traveling Salesman Problem (TSP) (Flood, 1956), whose standard formulations ignore the fact that article locations are arranged in a specifically structured way in distribution warehouses.

Items arranged according to a block layout are located in parallel picking aisles, and order pickers can only move to another aisle at specific positions using so-called cross aisles (or without them). In the presented solution, we additionally consider picking order waves (Wave, Picking, 2022), i.e., picking multiple orders simultaneously during one route to minimize the distances covered. We make the following assumptions:

- We consider a 2D approach to the warehouse.
- We have 22 racks on which products are placed in multiple boxes
- We assume that the racks are low and that we do not need special equipment or consider the third dimension of the warehouse (height)
- The products are small and light
- The trolley that collects the orders during the route has a capacity of 20 orders
- The picking route starts and ends at the same place (START).

The figure below shows a pictorial representation of the warehouse model with the product racks marked on it and the start of the operator's route marked. The values shown on the axes are expressed in meters.

Figure 11. *Warehouse model*



In the following discussion, models of different strategies will be presented to simulate their impact on the total distance an operator travels for a given order wave size. The entire solution will be offered as an application created with (Streamlit, 2022).

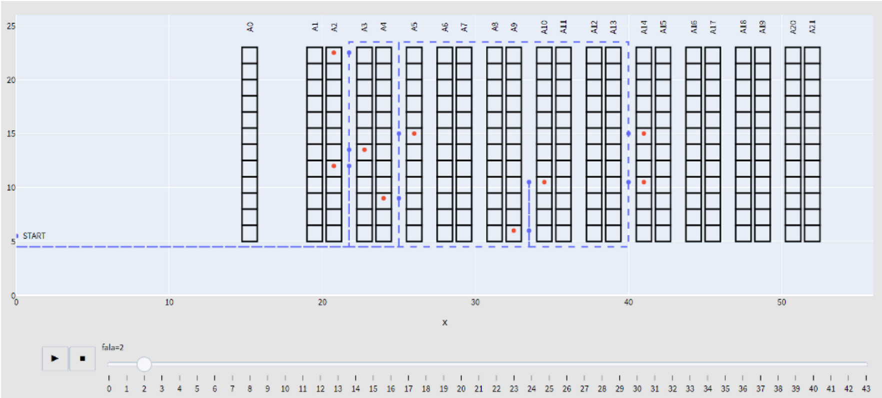
Calculation of the total distance without order grouping

This approach will only rely on the distance calculated between consecutive store points and the corresponding wave size. So, the first thing to calculate is the distance between successive products. As this is a warehouse, a measure that would not be very good would be Euclidean distances, etc. We pre-determine the distance on the X-axis and then choose the shorter two possible distances on the Y-axis (going to the alleys down or up). Next, an essential element is determining the following product location to move to. The smallest one is selected based on all the distances between the point under consideration and the others. These are two essential functions that will allow us to determine the length of the route depending on the distribution of products and the size of the waves. Then, based on a list of the locations of all orders, we can determine the following route points and the total distance to be covered. In addition, we can take the number of orders per wave, as previously defined, to see how this affects the distance covered. In line with this idea, an interface was created that allows the user to select the number of orders per wave and determine the results.

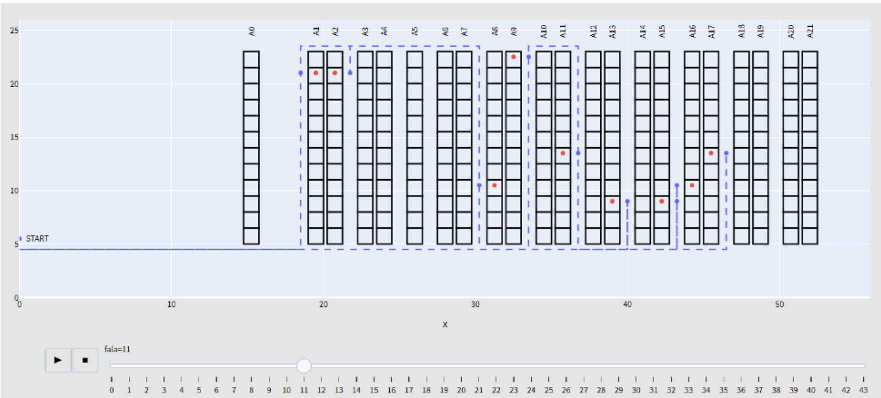
The user selects the number of orders to be simulated (in hundreds) and a range of the number of orders collected during one tour. Five hundred orders have been selected, and the wave size is in the range [1,10]. After using the Start Simulation button, we obtain a graph of route lengths as a function of wave size and a simulation of the worker's passage through the warehouse in successive waves for a wave size equal to the selected maximum. As the number of orders collected during one route increases, the distance required decreases – from almost 39 km to 10 km. Therefore, this significantly differs when optimizing the operator's working time.

The following figures show how an operator would move to complete the orders for a wave size of 10. Thus, 43 such routes came out of all orders. In the diagram, the dotted lines indicate the routes, the blue points the stops at the items that need to be taken, and which are marked by the orange points on the shelves.

Rysunek 12. *Route visualisation for wave 2*



Rysunek 13. *Route visualisation for wave 11*



Rysunek 14. *Route visualisation for wave 38*

Calculation of total distance with order grouping

In the second approach, it is still worth exploring what happens when we further group the orders. This approach is divided into two ways of grouping:

- Single-line – we consider grouping products within a single alley (Figure 12).
- Multi-linear – grouping products from multiple aisles (Figure 13).

Figure 15. *Example of single-line grouping*

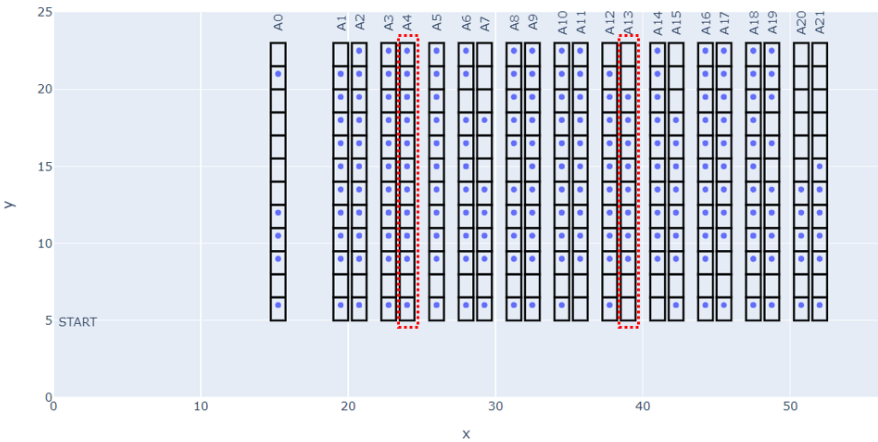
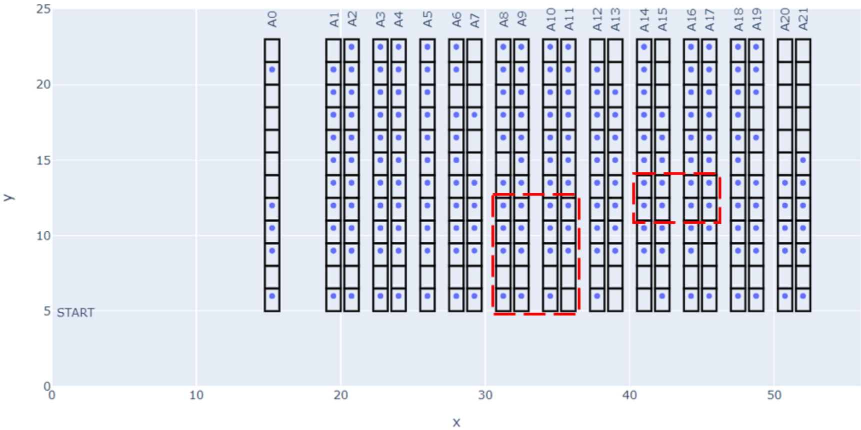
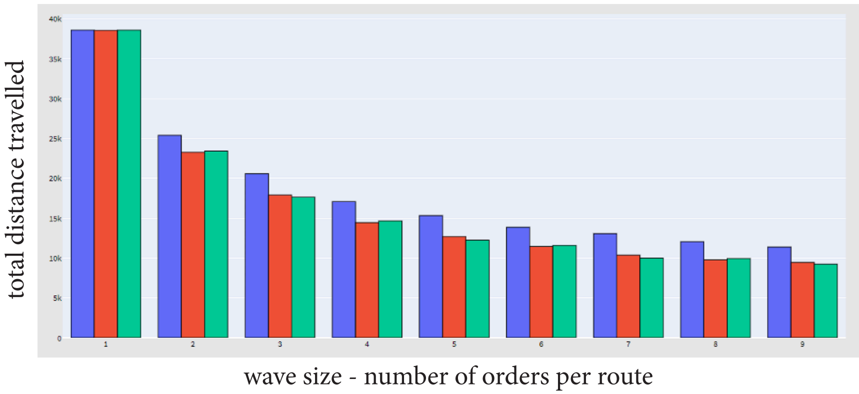


Figure 16. *Example of multi-line grouping*



In both solutions, it is essential to indicate the maximum distance that indicates which elements can be in a cluster. In other words, spatial clustering involves grouping a set of points so that objects in the same cluster are more similar than objects in different clusters. In line with the previous words, the similarity metric, in this case, will be the distance between locations calculated according to the function presented in the last approach. As for multilinear clustering, a centroid is determined, which defines the cluster's center. A simulation is performed, which is also posted in the application. The figure below shows the results of such a simulation for the 500 orders also taken previously.

Figure 17. *Results with product grouping (blue – no grouping, red one-line grouping, green multi-line grouping)*



As can be seen, grouping products further reduces the distance needed to travel. Based on the example presented, multi-line grouping seems to be the best solution.

Conclusions

This paper discusses advanced approaches to optimizing logistics and warehouse processes, focusing on efficient planning and delivery. The authors highlight the importance of implementing simulation models to improve logistics systems from design to execution. They describe a practical example of managing deliveries to Biedronka stores using a web-based logistics planning application. The application features route management, customer registration, and tracking of delivery trucks in real-time. The article further explores warehouse management strategies, particularly the challenge of minimizing order-picking time. Simulation models help evaluate the efficiency of different methods, including wave picking and clustering algorithms, which reduce travel distances and improve productivity.

The article demonstrates that simulation-based testing and agile software development can significantly enhance logistics planning, leading to more efficient delivery processes. By implementing strategies like wave picking and single – and multi-line clustering, warehouses can dramatically reduce order picking times, enhancing overall productivity. An intelligent logistics system helps optimize delivery routes, making it possible to assign available trucks to the most efficient paths. Applying simulation models and analytics in logistics management provides actionable insights that can drive better decision-making and operational efficiency. The study emphasizes the need for continuous optimization of logistics strategies to meet the evolving demands of the market and remain competitive. Adopting advanced logistics systems that integrate simulation models, route optimization, and clustering algorithms is crucial for businesses aiming to streamline their supply chain and warehouse operations efficiently.

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