МАТЕМАТИЧНІ МЕТОДИ, МОДЕЛІ ТА ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ В ЕКОНОМІЦІ

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DELIVERY ROUTES OPTIMIZATION USING MACHINE LEARNING ALGORITHMS

ОПТИМІЗАЦІЯ МАРШРУТІВ ДОСТАВКИ ЗА ДОПОМОГОЮ АЛГОРИТМІВ МАШИННОГО НАВЧАННЯ

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Delivery route optimization is a crucial concern in the logistics industry, affecting delivery times, costs, and customer satisfaction. The conventional methods for optimizing delivery routes are time-consuming and require substantial manual efforts. To address these limitations, they have increasingly used machine learning algorithms for more efficient and effective optimization. This paper reviews modern techniques for delivery route optimization using machine learning algorithms, including the key challenges faced by delivery companies. Metaheuristic methods, reinforcement learning, and machine learning are discussed, along with their advantages and limitations. In developing a delivery route optimization system, factors such as the number of vehicles, their capacity, delivery time windows, road networks, and customer demand are considered. Different optimization objectives, such as minimizing delivery time, reducing transportation costs, and maximizing customer satisfaction, are presented. Finally, the paper highlights future research directions, including multi-agent systems, swarm intelligence, and hybrid algorithms. This paper provides a comprehensive review of delivery route optimization using machine learning algorithms and can be useful for practitioners and researchers in the logistics industry.

Keywords: *Logistics, Machine learning, Real-time monitoring, Traffic patterns, Metaheuristics*
JEL classification: *C44, C61, C63, D24*

Оптимізація маршрутів доставки є критично важливим питанням у логістичній галузі, оскільки вона впливає на час доставки, витрати та задоволеність клієнтів. Традиційні методи, що використовувалися в минулому для оптимізації маршрутів доставки, займають багато часу і вимагають значних зусиль. Для подолання цих обмежень все частіше застосовуються алгоритми стохастичної оптимізації і машинного навчання, які дозволяють вирішувати проблему оптимізації більш ефективно. У цій статті представлено огляд класичних методів, таких як моніторинг трафіку в режимі реального часу, використання часових вікон та методи групових доставок. Також приділено увагу сучасним методів оптимізації маршрутів доставки за допомогою алгоритмів машинного навчання. У статті розглядається концепція оптимізації маршрутів доставки та її важливість в логістичній галузі. Представлені ключові виклики, з якими стикаються компанії, що здійснюють доставку при оптимізації своїх маршрутів доставки. Розглядаються різні типи алгоритмів машинного навчання, які зазвичай використовуються для оптимізації маршрутів доставки, включаючи алгоритми метаевристики, навчання з підкріпленням і глибокого навчання. Увагу приділено різниці між алгоритмами Обговорюються переваги та обмеження кожного типу алгоритмів. В статті обговорюються різні цілі оптимізації, які можна розглянути, такі як мінімізація часу доставки, мінімізація транспортних витрат і максимізація задоволеності клієнтів. Стаття завершується обговоренням майбутніх напрямків досліджень в області оптимізації маршрутів доставки з використанням алгоритмів машинного навчання. Це включає використання передових методів, таких як ройовий інтелект та гібридні алгоритми. Таким чином, дана робота містить комплексний огляд останніх розробок в області оптимізації маршрутів доставки з використанням стохастичних методів. Висновки цієї статті можуть бути корисними для дослідників та практиків у логістичній галузі, щоб краще зрозуміти виклики та можливості використання алгоритмів машинного навчання для оптимізації маршрутів доставки.

Ключові слова: *Логістика, Машинне навчання, Моніторинг в реальному часі, Патерни трафіку, Метаевристика.*

Problem formulation. Delivery route optimization is a critical problem in logistics because it has a significant impact on the overall performance of delivery companies. Optimized delivery routes can result in improved operational efficiency, reduced costs, faster delivery times, and enhanced customer satisfaction. One of the primary challenges in optimizing delivery routes is the unpredictable nature of demand. Delivery companies must be able to predict demand accurately to optimize their routes effectively. Another challenge in optimizing delivery routes is the need to consider various factors, such as traffic patterns, road conditions, and delivery windows. The paper will review the existing literature on these factors and the different methods that have been proposed to optimize delivery routes.

Analysis of recent research and publications. Logistics problems have always been a priority for economic researchers. One of the main tasks of planning in trade logistics is to achieve the desired level of service and quality of supply at the lowest possible price level [1, p. 15]. Transportation planning is one of the main challenges in logistics. S. Nily, A. Federgruen, conducted a fundamental study of optimization methods for cost reduction in transportation. The paper provides a method for minimizing transportation and inventory costs for a distribution system with a depot and many geographically dispersed retailers [2]. Ferrier found that real-time traffic monitoring is beneficial because it is fast and accurate [3]. An approach of minimization of transportation risks based on determining the shortest path presented by Ukrainian researchers O. Yashkina and D. Yashkin [4] method gives all possible routes for cargo transportation with a corresponding projected number of road accidents. Then finding the route that has a minimal projected number of road accidents at each stage. A later study of optimization problems was integrally connected with the development of computer technology.

In particular, machine learning algorithms. Nemoto and Rothengatter [5] suggest using the milk run method that involves multiple suppliers and one route. It helps to minimize the total cost spent in delivering goods by finding an optimal combination of routes within the capacity of the trucks' total volume. Last-Mile logistics should be mentioned too. Last-mile logistics is the process of delivering goods from a transportation hub to their final destination. It typically involves multiple steps, such as picking up orders at warehouses or distribution centers and then transporting them to customers' homes or businesses [6]. All of these methods could potentially be effective ways to optimize delivery routes.

Previously unsolved parts of the problem. The main research gaps and limitations of the current literature identified in this paper are the lack of studies that consider multiple objectives, such as cost, time window constraints, environmental impact, etc. when optimizing last-mile delivery routes. Limited use of machine learning algorithms for real-world applications due to lack of data availability or difficulty in obtaining accurate predictions from existing models. Insufficient attention is given to sustainability aspects like energy consumption during the transportation process, which can have a significant effect on overall efficiency and performance metrics associated with last-mile logistics optimization techniques.

Formulation of the aims of the article. This paper aims to summarize delivery route optimization, highlighting the importance of this problem in logistics and identifying the gaps in existing research. The paper will be useful for researchers and practitioners in the logistics industry who are interested in optimizing delivery routes to improve operational efficiency, reduce costs, and enhance customer satisfaction**.**

The main research material. Optimizing delivery routes is a complex problem that has many different approaches. There are classical methods such as real-time traffic monitoring, group deliveries, delivery utilization, vehicle load optimization, etc. Real-time traffic monitoring is a technique that enables delivery companies to receive live updates on the current traffic conditions. By leveraging this information, they can reroute their vehicles to avoid congestion and reduce delivery times. This can have a significant impact on the overall performance of the delivery network, as it helps to reduce delays and ensure that deliveries are made on time [7]. Real-time traffic monitoring can help drivers avoid congestion and optimize their routes to reduce delivery times.

Group deliveries are another strategy that can be used to optimize delivery routes. By combining multiple deliveries into a single trip, delivery companies can reduce the number of vehicles on the road and save on fuel costs. Group deliveries also help to reduce the overall delivery time, as drivers can make multiple stops along their route. This approach is particularly effective in urban areas, where traffic congestion can be a major issue. Grouping deliveries to specific locations can help reduce the distance traveled and the number of stops required, thereby improving the efficiency of the delivery route.

Using delivery time windows is another way to optimize delivery routes. Many customers have specific time windows during which they would like their deliveries to be made. By taking these preferences into account and planning deliveries, delivery companies can reduce the number of trips and vehicles required to complete their deliveries. This helps to reduce delivery costs and improve customer satisfaction by ensuring that deliveries are made within the specified periods. Setting delivery time windows can help drivers plan their

routes more efficiently and reduce wait times at delivery locations.

Stochastic algorithms can be used to optimize routes by finding the most efficient path between two points. It works by randomly selecting and evaluating different combinations or parameters until it finds an optimal combination that maximizes (or minimizes) some objective function. These algorithms use random sampling techniques such as genetic programming to explore different possible paths, evaluate them based on certain criteria (such as distance or time) and then select the best route that meets those criteria. This approach is often more effective than traditional optimization methods since it takes into account all of the variables involved in a given problem instead of just one or two at a time. Stochastic optimization can be applied in many areas, such as Machine Learning, where there are multiple variables with complex interactions between them, which need to be optimized for maximum performance [8].

The most effective and modern way for delivery route optimization is Machine Learning (ML). Machine learning algorithms have become increasingly popular for optimizing delivery routes because of their ability to overcome the limitations of classical methods like real-time traffic monitoring. Machine learning algorithms can optimize routes by using data from past trips and applying predictive models that learn patterns in the data. These models can then suggest more efficient paths for future journeys, considering factors such as traffic conditions or weather forecasts [9]. Machine Learning focuses on the development of algorithms and models and making predictions or decisions without being explicitly programmed to do so. It uses techniques such as supervised learning (where labeled training datasets are used for model building) and unsupervised learning (where unlabeled datasets are used). ML algorithms can optimize delivery routes by predicting accidents and analyzing the combination of high-frequency risk factors throughout the entire process. ML algorithms for delivery route optimization typically require data, such as customer locations, delivery times, and distances between customers. They may also need information about the type of goods being delivered (e.g., weight or size), traffic conditions in certain areas, road restrictions because of construction work, etc. All this data is used by ML algorithms to calculate optimal delivery routes that minimize cost while maximizing efficiency and customer satisfaction. There are a lot of modern algorithms which can be useful for routes optimization. Machine learning algorithms, such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Genetic Algorithms (GA).

These algorithms are inspired by natural phenomena and are designed to solve complex optimization problems more efficiently than traditional methods.

Particle Swarm Optimization (PSO) is an optimization technique that uses a swarm of particles to search for the optimal solution in complex problems. It works by having each particle represent a potential solution and then using its current position, velocity, and personal best-known positions as inputs into equations that determine how it moves around the problem space. The goal is to find solutions with higher fitness values than those found previously until eventually converging on an optimum value or set of parameters. PSO can be used for route optimization by having each particle represent an individual solution and then using its position in space as well as information from other nearby particles to update itself towards better solutions over time. This allows the algorithm to identify more efficient paths based on data about past trips or traffic conditions, helping optimize routes with ML algorithms.

Ant Colony Optimization (ACO) is a metaheuristic algorithm inspired by the behavior of ants. It works by having each ant represent a potential solution and then using its current position left behind by other ants as inputs into equations that determine how it moves around the problem space. The goal is to find solutions with higher fitness values than those found previously until eventually converging on an optimum value or set of parameters. This allows the algorithm to identify more efficient paths based on data about past trips or traffic conditions, helping optimize routes with ML algorithms. ACO can consider factors such as distance traveled and the number of stops when optimizing a delivery route, which makes it particularly useful for this type of problem.

Large Neighborhood Search (LNS) is a metaheuristic algorithm used to solve complex optimization problems. It works by breaking down the problem into smaller sub-problems and then using local search techniques such as hill climbing, simulated annealing or tabu search to find solutions for each of these sub-problems. The goal is to identify good quality solutions quickly while also being able to escape from any local optima that may be encountered during the process.

Genetic Algorithms (GAs) can be used for delivery route optimization by using a population of potential solutions and then applying evolutionary principles such as selection, crossover, and mutation to the population to find an optimal solution. This allows GAs to identify more efficient paths based on data about past trips or traffic conditions while also considering factors such as distance traveled and the number of stops when optimizing a delivery route.

Metaheuristic algorithms have several advantages when it comes to route optimization. Firstly, they are able to find approximate solutions quickly and efficiently which makes them suitable for

real-time applications such as delivery routing. Secondly, metaheuristics can take into account factors such as distance traveled and number of stops when optimizing a delivery route which helps make the solution more efficient overall. Finally, these algorithms also require less computational resources than traditional methods making them ideal for large scale problems with many possible solutions.

The main disadvantage of using metaheuristic algorithms for route optimization is that they can be computationally expensive and time consuming. Additionally, metaheuristic algorithms may not always find the optimal solution as there are many possible solutions to a given problem, which makes it difficult to identify the best one. Finally, GAs require careful tuning in order to get good results so this could also add extra complexity when trying to optimize routes with reinforcement learning algorithms.

We can use reinforcement learning for delivery route optimization as it helps in finding the best path between two points while avoiding congested areas or roads with heavy traffic. This algorithm uses rewards and punishments to guide their decisions on which action should be taken next, based on previous experiences. This makes them suitable for solving complex problems such as optimizing routes since they can consider multiple factors like time constraints, fuel consumption, etc. when deciding what paths should be chosen during navigation through a network of streets/roads [10].

Deep Learning is a type of Artificial Intelligence (AI) that uses algorithms to learn from data and make decisions. It can be used for delivery route optimization by using the collected data about customer pick-up points, traffic conditions, etc., in order to determine an optimal path or sequence of actions. The deep neural network will analyze this information and use it as input into its algorithm which then produces output such as optimized routes with maximum profitability for taxi drivers [11]. The difference between Deep Learning and Reinforcement Learning lies in the field that deep learning is used to learn patterns and relationships in large amounts of data, while reinforcement learning is used to learn from feedback in the form of rewards and penalties. Both approaches can be applied to route optimization, but they have different strengths and weaknesses depending on the specific problem and requirements.

Hybrid approaches combining traditional methods of machine learning have also been proposed for variants of vehicle routing problems, which involve synthetic case studies. They work by combining the strengths of different algorithms to find better solutions than any single algorithm could provide on its own. For example, one approach might combine genetic algorithms with particle swarm optimization (PSO) and large neighborhood search (LNS). This would allow for faster convergence towards an optimal solution while also providing robustness against local optima that may be encountered during the process [12].

Efficient delivery routes not only benefit delivery companies but also their customers. Faster delivery times and lower costs can lead to increased customer satisfaction, which is critical in the highly competitive logistics industry. Additionally, optimizing delivery routes can reduce the carbon footprint of delivery companies, leading to environmental benefits.

Despite the potential benefits of using machine learning algorithms to optimize delivery routes, many delivery companies are still struggling to implement these solutions effectively. There are several factors contributing to this, including a lack of expertise in data analysis and machine learning, a lack of data infrastructure, and the need for significant investments in technology and training.

Last mile logistics is crucial for delivery routes optimization because it has a direct impact on the customer experience. By optimizing last-mile deliveries, companies can ensure that their customers receive their orders in an efficient and timely manner while also reducing costs associated with transportation. Additionally, by minimizing traffic congestion and environmental pollution caused by urban logistics operations, public administrations are able to guarantee better quality of life for citizens living in cities [13].

Conclusion. Delivery route optimization is a critical problem in logistics that affects the overall performance of delivery companies. By using machine learning algorithms, considering various factors, and implementing strategies to optimize delivery routes, delivery companies can improve their operational efficiency, reduce costs, enhance customer satisfaction, and contribute to a more sustainable future.

To address these issues, delivery companies have turned to machine learning algorithms to optimize delivery routes and predict demand. By analyzing data on past deliveries and customer behavior, these algorithms can help companies develop more accurate demand forecasts, which can optimize delivery schedules and allocate resources more effectively. Machine learning algorithms can identify the most efficient delivery routes, considering factors such as traffic patterns, road conditions, and delivery windows.

To overcome these challenges, delivery companies need to take a comprehensive approach to implement machine learning algorithms. This includes developing a robust data infrastructure, investing in technology and training, and partnering with experts in data analysis and machine learning. With these steps in place, delivery companies can unlock the full potential of machine learning algorithms to optimize delivery routes and improve the customer experience.

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